Foliar Nutrient, Root Chemistry, Growth and Carbon Allocation Patterns of Douglas-fir Seedlings Grown Under Different Nitrogen and Potassium Treatments

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AUTHORIZATION TO SUBMIT

THESIS

This thesis of Terry Mac Shaw, submitted for the degree of Master of Science with a major in Forest Resources and titled "Foliar Nutrient, Root Chemistry, Growth and Carbon Allocation Patterns of Douglas-fir Seedlings Grown Under Different Nitrogen and Potassium Treatments," has been reviewed in final form, as indicated by the signatures and dates given below. Permission is now granted to submit final copies to the College of Graduate Studies for approval.

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ABSTRACT

This research was designed to investigate Douglas-fir seedling nutrition as influenced by four nitrogen and potassium treatments. The results of this study are presented in two sections with these main objectives: 1) to determine the effects of N and K nutrition on Douglas-fir foliar nutrient concentrations, plant growth and carbon allocation patterns; and 2) to determine the effects of nitrogen and potassium nutrition on Douglas-fir root storage and chemical composition.

Experimental design and statistical analysis for this experiment were common for both sections of this paper. Results in both sections are based on data taken at the end of a three-year treatment period. Douglas-fir seedlings were randomly assigned to four nitrogen and potassium treatments within two blocks. Treatment effects on growth and plant chemical parameters were estimated by analysis of variance. General linear contrasts and differences between means by treatment for foliar nutrient data, root chemistry and growth parameters were determined by using least-squares means.

Results from this study have shown that the N treatments significantly altered foliar nitrogen levels, growth rates and carbon allocation patterns in Douglas-fir seedlings. As expected, total biomass, measured as total dry weight, was threefold higher for seedlings receiving the high nitrogen treatments than for seedlings receiving the low nitrogen treatments. Seedling allocation to needles was the same between the high and low nitrogen treatments, but allocation to roots increased while allocation to stem decreased under low nitrogen supply. Potassium supply had little if any significant effect on growth rates or carbon allocation to stems, roots or needles. This study has shown that the Douglas-fir seedlings adjusted to different nitrogen and potassium treatments by changing carbon allocation patterns.

The effects of the nitrogen and potassium treatments on Douglas-fir seedling root production of soluble sugar, starch, phenolic and protein-precipitable tannin were observed in this study. Root storage compounds such as starch were reduced in Douglas-fir seedlings receiving the high nitrogen treatments, whereas secondary defensive compounds like phenolics and tannins were reduced in plants receiving low K treatments. Relationships between nitrogen and potassium nutrition lead to storage and secondary compound imbalances.

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INTRODUCTION

INTRODUCTION

Overview

Mineral nutrients are essential for plant growth and development (Marschner 1986). Mineral nutrient availability is commonly a limiting factor in forest growth. Nitrogen is the most common limiting nutrient for the growth of trees (Tamm 1964, Gessel et al. 1973, Mahendrappa et al. 1986, Chapin et al. 1987, Luxmoore et. al. 1993). Evidence shows that potassium can also be limiting in a natural forest environment (Heiberg and White 1950, Holopainen and Nygren 1989, Moore and Mika 1991, van den Driessche and Ponsford 1995). However, a single nutrient limitation cannot always be perceived and there is evidence that N and K interact in conifer nutrition (Hüttl 1990, Moore and Mika 1991, Flaig and Mohr 1992).

Nitrogen is a main constituent of proteins vital to plant growth. In light of this, the significance of nitrogen nutrition in tree growth research is well known (Gessel 1973, Lavender and Walker 1979, Brix 1983, Linder and Rook 1984, Waring and Schlesinger 1985, Chapin et al. 1987, van den Driessche 1991). In fact, Ingestad's Wallenberg prize (Zobel 1991) winning work on steady-state mineral nutrition of deciduous and conifer seedlings (1967, 1979, 1988) was fundamentally based on stressed and supra-optimum rates of nitrogen. Ingestad recognized that nitrogen and other nutrients need to be in balance and available for uptake at a rate conducive to optimal growth. Specifically, Douglas-fir has been the focus of a great deal of nitrogen nutrition research. (Anderson and Gessel 1966, Harington and Miller 1979, van den Driessche 1980, 1982, 1988, Brix 1981,1983, Heilman et al. 1982, Margolis and Waring 1986).

Potassium's role in plant growth and development is primarily in production of enzymes that influence physiological and biochemical processes and not as a structural component (Marschner 1986). Although potassium research in tree growth has not been as extensive as nitrogen, there has been research devoted to specific roles of potassium nutrition in tree growth and development (Christersson 1973, 1976, Ingestad 1979, McDonald et al. 1991, Ericsson and Kähr 1993). Much of the potassium nutrition work has been focused on seedlings grown at steady-state nutrition, that is, plants whose internal nutrient concentrations remain constant with time. For example, in a steady-state potassium study of birch seedlings, Ericsson and Kähr (1993) found it questionable whether a balance between potassium uptake and growth could be established under growth limiting potassium conditions. Instead, Ericsson and Kähr's investigation reflects the fact that the role of potassium in regulating growth is more indirect when compared with other nutrients like nitrogen and phosphorus. In another steady-state nutrition study, McDonald et al. (1991) found that plants limited in potassium supply did not show any large shift in dry matter allocation between shoots and roots or leaves and roots. Apparently, poor rates of potassium supply limits carbon uptake but does not involve the same shift in dry matter allocation in preference for roots as found with most other nutrients (McDonald et al. 1991).

In general, few studies, if any, have been conducted that have specifically addressed Douglas-fir seedling growth and development under high (luxury) and low (stressed) nitrogen and potassium treatments. Most Douglas-fir studies have focused on nitrogen alone and have failed to examine effects on carbon allocation (van den Driessche 1980, 1982, Margolis and Waring 1986). However, one Douglas-fir fertilization study (Mika and Moore 1991), conducted in the Inland Northwest of the United States, did show evidence that low potassium levels, either naturally occurring or induced by additions of nitrogen, were related to poor nitrogen fertilization response.

A number of studies have demonstrated that deficiencies in nutrients result in reduced tree vigor and increased susceptibility to disease (Stakman and Harrar 1957, Matson and Waring 1984, Entry et al. 1991) as well as to some insects (Mattson 1980, Joseph et al. 1993, Mika and Moore 1994). Plants growing in suboptimal nutrient conditions become stressed and may alter the production of chemical defenses (White 1984, Bryant et al. 1983, Waring and Pitman 1985). Nitrogen nutrition has been a main focus in many nutrient stress/defense chemical studies (Larsson et al. 1986, Bryant et al. 1987, Entry 1986, 1991a 1991b). With the exception of Moore et al. (1994), very few have addressed the role of nitrogen and potassium nutrition in relation to defense chemistry.

Problem Statement

Nearly all forest sites in the Inland Northwest are nutrient deficient, usually for nitrogen but sometimes for potassium as well (Moore et al. 1994). It follows that if nutrient deficiencies are severe enough to cause physiological stress, then growth and survival can be compromised in forest trees. A significant improvement in quality, measured in terms of survival and increased growth, can be achieved through fertilization (van den Driessche 1983). The objective of this study was to determine the influence of optimal and deficient nitrogen and potassium nutrition on the physiological condition of Douglas-fir seedlings. Monitoring the effects of the nutrient treatments through growth, carbon allocation and tree chemistry will allow us to interpret the physiological status of Douglas-fir seedlings.

Therefore, understanding the relationships between nitrogen and potassium nutrition should improve forest productivity and survival.

Background

In 1980, a group of forestry organizations formed the Intermountain Forest Tree Nutrition Cooperative (IFTNC) to study forest tree nutrition in the Inland Northwest region of the United States. Initial efforts were concentrated on studying the effects of nitrogen fertilization on growth and survival of Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Mirb.) Franco). Initial results showed that nitrogen fertilization increased tree growth (Moore et al. 1989). However, the initial results also indicated that other factors might limit tree response to nitrogen fertilization. Upon investigation of all macro and micro foliar nutrient concentrations only K was present in levels thought to limit tree growth (Mika and Moore 1991). Furthermore, evidence showed that low K levels, either naturally occurring or induced by additions of nitrogen, were related to poor N fertilizer response (Mika and Moore 1991).

In 1987, Entry et al. conducted a nutrition/root disease study in thinned and/or fertilized second-growth stands of Rocky Mountain Douglas-fir located in the Inland Northwest (1991). Entry's investigation involved some of the same stands studied by the IFTNC cooperative. Entry's objectives were twofold: 1) to determine whether thinning or thinning combined with nitrogen fertilization would improve the physiological status of second-growth Douglas-fir and thereby, increase resistance to infection by the root disease *Armillaria ostoyae.* 2) to determine the role of tree defense mechanisms in resistance of Rocky Mountain Douglas-fir to infection by *Armillaria ostoyae*. Results from Entry's study found significant changes in growth, root bark chemistry and incidence of infection of *Armillaria ostoyae* associated with nitrogen fertilizer amendment. Results from Entry's study were similar to those of other plant nutrient studies that analyzed plant tissue chemistry (Bryant et al. 1987, Larsson 1986).

Results from further IFTNC investigations (Moore et al. 1993) into nitrogen and potassium nutrition have consistently demonstrated that nutrient deficiencies result in reduced tree vigor and altered tree chemistry. Results from IFTNC and other studies prompted this study's investigation into the effects of nitrogen and potassium on Douglas-fir tree growth and tree chemistry.

Methodology

Douglas-fir seedlings used in this study were grown in washed sand and arranged in a systematic random block design. Seedlings were randomly assigned to different nitrogen and potassium treatments within two blocks. The solution used to supply nutrients to the Douglas-fir seedlings was adapted from Ingestad and Lund (1979) and was considered nutritionally adequate in every respect. To insure genetic variation in experimental material, two North Idaho Douglas-fir seed sources collected from different locations and elevations were distributed equally by treatment and block.

One hundred four seedlings (26 seedlings per treatment) were collected for foliar nutrient analysis, growth and carbon allocation measurements. Nitrogen, phosphorus, potassium, calcium, magnesium, manganese, iron, copper and zinc concentrations in foliage were determined for foliar chemical analysis. Needle, stem, and root weights, and stem diameters were used for growth and carbon allocation determination. Fifty-two composite samples (four seedlings per composite), half from root collar bark and half from living root tips were used for root chemistry determination. Concentrations of sugar, starch, phenolics and protein-precipitable tannins were determined in the root chemistry analysis.

Analysis of variance and differences between treatments means were determined for foliar nutrients, growth and carbon allocation and root chemistry data by using the least-squares means ($\alpha = 0.10$) procedure of the Statistical Analysis System (SAS Institute Inc. 1985).

One objective of this study was to test susceptibility of the Douglas-fir seedlings to attack from *Armillaria ostayae.* Our hypothesis was to show that deficiencies of nitrogen and potassium, either alone or in combination, will stress potted seedlings of Douglas-fir sufficiently to allow *Armillaria* to infect them. After the seedlings were allowed to adjust to the nutrient treatments (one growing season after establishment), half of the total population of Douglas-fir seedlings was inoculated with infected *Armillaria ostoyae* birch blocks. Douglas-fir seedling root systems were inoculated by removing and replacing a pre-established round plastic pipe (2 cm in diameter) with the infected birch block (10 cm in length). Each inserted birch block was completely covered by several centimeters of sand. Birch block inoculum and Douglas-fir seedlings were monitored monthly for two years with no apparent *Armillaria* root infection of Douglas-fir seedlings. In other words, our methods were unsuccessful in testing our hypothesis. Consequently, this part of our study was dropped from any further investigation and the seedlings that were inoculated were removed from the total study population.

Thesis Organization

This thesis is written in four sections. The first section is an overall introduction to the study. The next two sections contain manuscripts to be submitted for publication, each describing a separate problem, objective, methods and results. The last section sums up the study's results and its overall implications for forest silviculturists and managers. In addition, the last section includes a literature cited section for all literature cited through the thesis.

The first manuscript, "Foliar Nutrients, Growth and Carbon Allocation Patterns of Douglas-fir Seedlings Grown Under Different Nitrogen and Potassium Treatments", studies foliar nutrient, growth and carbon allocation response of Douglas-fir seedlings under luxury and deficient nitrogen and potassium treatments.

The second manuscript, "Root Chemistry of Douglas-fir Seedlings Grown Under Different Nitrogen and Potassium Treatments", examines the effects of nitrogen and potassium nutrition on Douglas-fir root chemistry and how this may relate to plant resistance against insects and disease attacks.

The results from this data expanded our understanding of the relationships between nitrogen and potassium nutrition and Douglas-fir seedling growth and growth partitioning. In addition, these results have given us insight on nitrogen and potassium nutrition as it relates to root chemistry and tree susceptibility to insects and pathogens . These data, in combination with other data now being collected, will provide information needed to improve growth and survival in the field.

In addition, there are several appendices: Appendix A includes final statistical (ANOVA) results for growth, carbon allocation and root chemistry analysis presented in sections 2 and 3; Appendix B includes analysis of data not presented but mentioned in text, including leaf weight means and sugar, starch phenol and tannin correlation coefficients; Appendix C includes summary means for foliar nutrient, growth and gas exchange measurements that were not presented in this document but were taken periodically throughout the three year duration of this study.

SECTION II

FOLIAR NUTRIENTS, GROWTH AND CARBON ALLOCATION PATTERNS OF DOUGLAS-FIR SEEDLINGS GROWN UNDER DIFFERENT NITROGEN AND POTASSIUM TREATMENTS

FOLIAR NUTRIENTS, GROWTH AND CARBON ALLOCATION PATTERNS OF DOUGLAS-FIR SEEDLINGS GROWN UNDER DIFFERENT NITROGEN AND POTASSIUM TREATMENTS

ABSTRACT

Growth and carbon allocation of Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) seedlings was investigated in relation to nitrogen (N) and potassium (K) nutrition. Douglas-fir seedlings were grown in a shadehouse environment and received four fertilizer treatment combinations in solution containing 100 or 10 mg /L of N and 65 or 6.5 mg/L of potassium; concentrations of other nutrients were constant and equally available for all seedlings. By the end of the third growing season, N and K deficient seedlings had significantly different foliar nutrient levels, biomass and carbon allocation patterns from seedlings receiving sufficient N and K. Seedlings receiving the high N treatments produced 216% more total biomass (shoot and root dry weight) and had 84% larger stem diameter compared to those receiving the low N treatments. Seedings receiving the high N treatments allocated more dry matter to their stems and less to their roots than those receiving the low N treatments. Root tip starch levels were 35% higher in the seedlings receiving the low N treatments, but sugar levels in root tips were unaffected. Needle dry matter allocation of seedlings was similar between the N treatments, however, those seedlings receiving sufficient amounts of both N and K allocated as much as 12% more carbon to the needles, demonstrating a K allocation affect. The results indicate that seedlings acclimated to the different nutrient environments by adjusting stem and root dry weight allocation patterns.

INTRODUCTION

Nutrient availability commonly limits forest growth. Nitrogen is the mineral that plants require in greatest quantity and most frequently limits growth in natural systems (Tamm 1964, Gessel et al. 1973, Lavender and Walker 1979, Chapin et al. 1987). Evidence shows that K can also be limiting in a natural forest environment (Holopainen and Nygren 1989, Mika and Moore 1991). Furthermore, forest stands that have poor (low) K status have been associated with increased tree mortality (Moore et al. 1994). Because the availability of nutrients and their interactions are a major determinant of plant growth and survival, successful management of forest trees must consider the nutritional environment.

The availability of nutrients is considered to influence biomass allocation within trees (Brix 1983, McDonald 1991, Ericsson and Kähr 1993). Morphological characteristics change with resource availability; these changes may alter the allocation of nutrients and carbon and in turn change the rate of leaf, root or stem production (Bradshaw 1965, Ingestad and Lund 1979, Ericsson 1981, Sage and Pearcy 1987, Walters and Reich 1989). Tree survival and consequent forest productivity may be improved if nutrition effects on seedling allocation patterns can be explained.

In general, few studies have been conducted that have specifically addressed foliar nutrition, growth and allocation of Douglas-fir seedlings under high (not stressed) and low (stressed) N and K treatments. Most nutrition studies (van den Dreissche 1980, 1982, Margolis and Waring 1986) with Douglas-fir seedlings have focused primarily on N nutrition alone and have failed to examine N and K nutrition effects on growth and carbon allocation. Studies (Ingestad 1967, Gleason et al. 1990, Ericsson and Kähr 1993) researching both N and K nutrition have dealt with other tree species. Experimental manipulation of foliar N and K concentrations and carbon allocation patterns can be used to examine plant response to nutrient deficiencies in a natural environment. Consequently, the primary objective of this study was to create four luxury and deficient N and K nutrient treatments to assess the effects on Douglas-fir seedling nutrition. Foliar nutrient concentrations, plant growth, and carbon allocation patterns were measured at the end of a three year period. In addition, the intent of this study was to mimic foliar N and K concentrations observed in the field so that inferences could be drawn relative to N and K levels observed in forest conditions. The results should improve our understanding of forest N and K nutrition as it affects tree growth and survival.

METHODS AND MATERIALS

Treatments

Seven hundred twenty one-year-old Douglas-fir seedlings were planted in 2900-mL plastic containers filled with quartz sand. Seedlings were randomly assigned to four different N and K treatments within two blocks. The nutrient solution used to supply nutrients to the Douglas-fir seedlings was adapted from Ingestad and Lund (1979) and was considered nutritionally adequate in every respect. The concentrations in solution for the macronutrients were: N 100, K 65, P 13.8, Ca 7, Mg 8.5 and S 15 mg L^{-1}; and the micronutrients: Fe 0.70, Mn 0.40, B 0.20, Cu 0.030, Zn 0.030, Cl 0.030, Mo 0.007 and Na 0.0030 mg L^{-1}. The nutrient solution was modified to meet the treatment regimes (Table 1). Nutrient solutions were applied to the plants through an irrigation system at a rate of 1:100, respectively. Seedlings were irrigated between fertilizer treatments as needed, and 500 mL of dilute nutrient solution was applied every four days throughout the growing season. Irrigation was reduced in late September of each year to promote the onset of dormancy. Periodic foliar sampling was used to adjust treatments so that the N and K foliar concentrations were similar to the ranges observed in Douglas-fir foliage collected in field studies. The nutrient treatments were periodically adjusted to attain target foliar nutrient concentrations. To prevent nutrient leaching from the foliage, irrigation water and solution was applied directly to the soil through 3.2 millimeter (inside diameter) polyethylene drip tubing with Roberts 180° medium flow Spot-Spitters®.

Table 1. Nutrient treatments under which Douglas-fir seedlings were grown: low N low K (nk), low N and high K (nK), high N and low K (Nk), high N and High K (NK). Numbers represent percentage of the solution optimal concentrations.

Year	Treatment	N	K
1990 & 1992	nk	10	10
	nK	10	100
	Nk	100	10
	NK	100	100
1991	nk	25	10
	nK	25	100
	Nk	100	10
	NK	100	100

Seedlings from two north Idaho Douglas-fir seed sources from different locations and elevations were distributed equally by treatment and block to insure genetic variation in experimental material. The seedlings were grown at the University of Idaho Nursery in a shadehouse covered by a clear, corrugated fiberglass roof from June to December in 1990, 1991 and 1992. In December of the first year, seedlings were enclosed in a chamber made of 5 cm thick white styro-foam sheeting, and in December of 1991 the seedlings were transferred to a greenhouse; both actions were intended to keep temperatures around 0°C to minimize root damage due to low winter temperatures. Soil moisture, temperature and atmospheric humidity were assumed to be similar for all seedlings. Daylength followed seasonal variations for Moscow, ID.

Chemical Analysis

Random sampling of seedlings by treatment and block was completed monthly from June through October in 1990, bi-monthly from June through October in 1991 and again monthly from June through October in 1992. Selected seedlings were carefully removed from the containers and put in plastic bags then stored in coolers to prevent degradation of the plant materials. The final sampling in October of 1992 comprised one hundred four seedlings (26 seedlings per treatment). Seedlings were stored at 1°C for up to 48 hours while awaiting laboratory analysis. In the laboratory, roots were separated from the shoots and both samples were oven-dried at 70°C for 24 hours. Afterward needles were stripped from the stem and continued to dry at 70°C for an additional 24 hours. A 2-gram composite sample representing all the needles was taken from each seedling. Foliage was ground in a Wiley mill in preparation for chemical analysis (IFTNC 88). Foliar nitrogen was determined using a standard mico-Kjeldahl procedure, which is a wet-oxidation method that converts organic and inorganic N to NH_4 for subsequent measurement. Phosphorus, K, Ca, Mg, Mn, Fe, Cu and Zn were determined by inductively coupled plasma (ICP) emission with digested plant tissue. Both procedures were completed by Scotts Laboratories in Allentown, PA.

Twenty-six composite samples (four seedlings per composite) from the root tips were collected from each treatment for starch and soluble sugars analysis. Composite root samples were taken from the same seedlings that were used in the foliar nutrient analysis. Root tips were temporarily stored in coolers for transport from the nursery then frozen in an ultra-cold freezer at -40°C until analyzed. In the laboratory, all samples were put in liquid nitrogen overnight and reduced to powder by grinding in mortar and pestle. The samples were analyzed for total starch by an ethanol and perchloric acid method (Hansen and Moller 1975). Glucose concentrations were determined by adding anthrone solution and measuring absorbance at 630 nm (Hansen and Moller 1975). The Hansen and Moller method has been criticized for overestimating starch levels because carbohydrates other than starch are extracted during the process (Marshall 1986, Rose et al. 1991). Perchlorate-extractable carbohydrates were, therefore, corrected to yield starch concentrations and are expressed in their corrected form throughout this paper. Starch and sugar analyses were performed by Institute of Biological Chemistry, Washington State University, in Pullman, WA.

Growth Measurements

Seedlings were taken from cold storage and brought to the laboratory where diameters were measured at the root collar. Roots were separated from the stems at the root collar and dried at 70°C for 24 hours. Foliage, stems and roots were stored and then dried at 70°C for at least two more hours before weighing.

Mean relative growth rates per annum (RGR) were calculated according to van den Driessche (1991) (Table 2). Mean relative growth rate is a measure of the efficiency of existing plant material in producing new plant material (van den Driessche 1991). Relative growth rates were calculated using the mean total dry weight from the initial measurement in June 1990 and the mean total dry weight by treatment for the last measurement in October 1992. Total dry weight, percentage needle dry weight, percentage stem dry weight, and percentage root dry weight were calculated for each seedling (Table 2).

Table 2. Formulas used to calculate growth and biomass parameters in this study.

	Definition	Units
Mean Relative Growth Rate	$\frac{\ln W_2 - \ln W_1}{t_2 - t_1}$	weight weight^{-1} time^{-1}
% Needle Weight	$\frac{W_N}{W_T}$ X 100	weight weight^{-1}
% Stem Weight	$\frac{W_S}{W_T}$ X 100	weight weight^{-1}
% Root Weight	$\frac{W_R}{W_T}$ X 100	weight weight^{-1}

Note: Here t = time (June 1990 through October 1992), W_1 = previous weight, W_2 = current weight, W_T = total plant weight, W_N = total needle weight, W_S = total stem weight and W_R = total root weight.

Statistical Analysis

After three years of growth in the shadehouse, 104 seedlings were sampled in October 1992 from the four nutrient treatments and two blocks. Treatment and block effects on foliar nutrient concentrations and growth parameters were estimated by analysis of variance for a randomized complete block design. General linear contrasts and differences between means by treatment for foliar nutrient data, root chemistry and the growth parameters were determined by using least-squares means, at a significance level $p = 0.05$, of the general linear models procedure (PROC GLM) of the Statistical Analysis System (SAS Institute Inc. 1985). Ordinary least squares regression analysis was performed for total dry weight and stem diameter relationships.

RESULTS

Foliar Nutrition

By the end of the third year of growth, foliar N and K levels and the ratio of K to N were significantly different by treatment. Foliar N in seedlings receiving the low N treatments were 42% lower than those of seedlings receiving the high N treatments (Figure 1). Treatment differences were less pronounced for foliar K concentrations (Figure 2) than foliar N concentrations. However, foliar K concentrations were lower in the plants receiving the low K and high N treatment than the plants receiving the high K treatments (Figure 2). This same trend was shown for foliar K contents (content is equal to the foliar concentration x dry weight of foliage) except that the foliar K contents in the seedlings receiving the NK treatment were significantly higher than those of the seedlings receiving the low K treatment (data not shown).

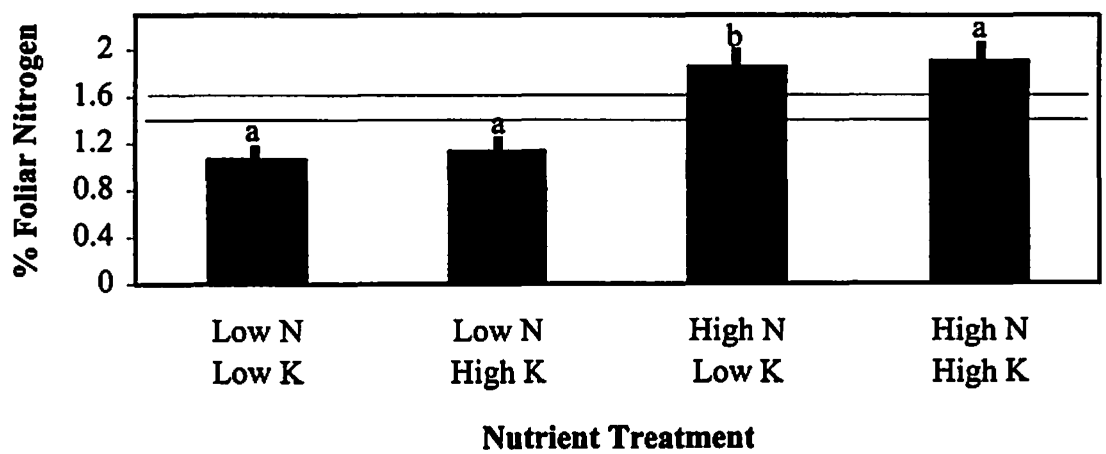

Figure 1. Foliar N concentrations of Douglas-fir seedlings in October of 1992. Horizontal bars represent critical N levels for Douglas-fir (Webster and Dobkowski 1983). Standard error was calculated for each treatment with n = 26. Bars within each treatment followed by the same letter are similar at the $p < 0.05$ level. Treatments are the same as in Table 1.

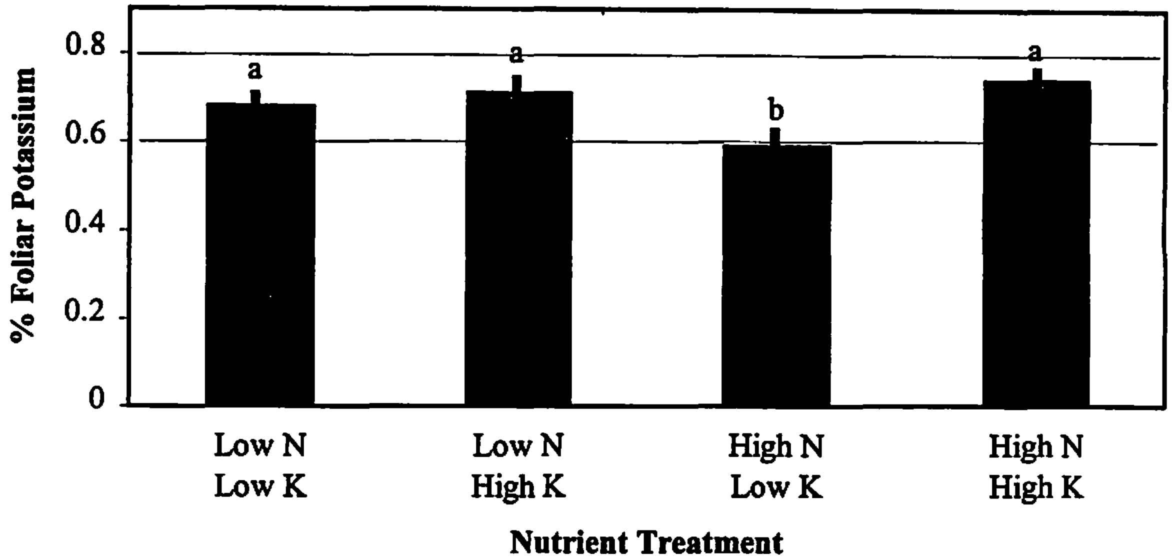

Figure 2. Foliar K concentrations of Douglas-fir seedlings in October 1992. Horizontal bars represent critical K levels for Douglas-fir (Webster and Dobkowski 1983). Standard Error was calculated for each treatment with n = 26. Bars within each treatment followed by the same letter are similar at the $p < 0.05$ level. Treatments are the same as in Table 1.

(content is equal to the foliar concentration x dry weight of foliage) except that the foliar K contents in the seedlings receiving the NK treatment was significantly higher than the seedlings receiving the low K treatment (data not shown). As expected, foliar K/N ratios of seedlings receiving the high N treatments were significantly lower than those of seedlings receiving the low N treatments (Figure 3).

All mineral nutrients were generally at or above recommended critical levels (Table 3). Even if the seedlings lacked N and K foliar deficiency symptoms, the treatments did influence foliar phosphorus concentrations. Foliar P concentrations were 56% lower in needles of seedlings receiving the low K treatments than in needles of seedlings receiving the high K treatments. Foliar Ca, Fe and Zn in seedlings also differed, but these differences were inconsistent among treatments.

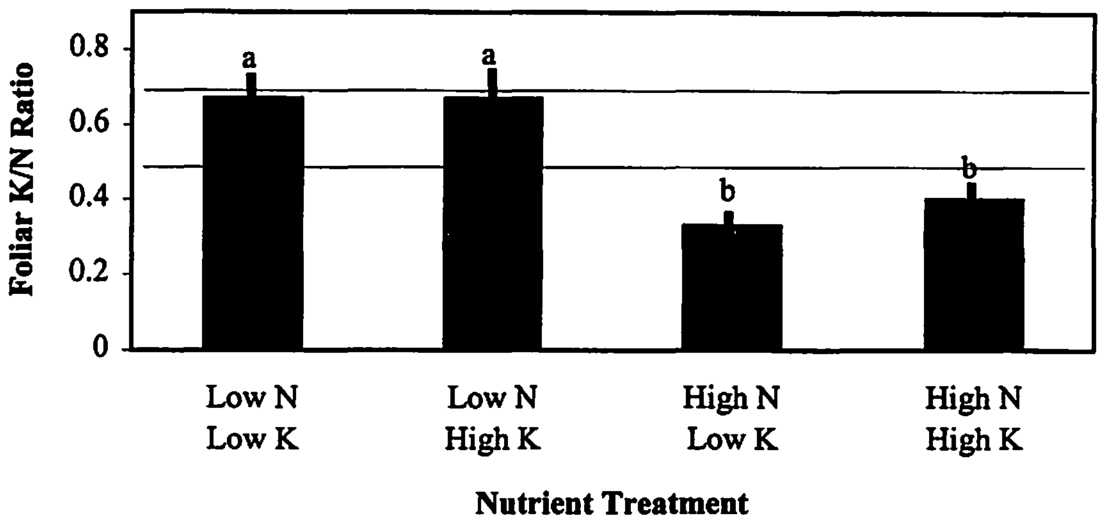

Figure 3. Potassium to nitrogen ratios for Douglas-fir seedlings in October 1992 in relation to K/N critical balances recommended by Ingestad (1967, 1979). Standard Error was calculated for each treatment with n = 26. Bars within each treatment followed by the same letter are similar at the $p < 0.05$ level. Treatments are the same as in Table 1.

Table 3. Mean foliar nutrient concentrations for four nitrogen and potassium treatments for Douglas-fir seedlings in October 1992. Treatments are the same as in Table 1.

	Elements						
	P	Ca	Mg	Fe	Zn	Cu	Mn
	%			ppm			
Critical Level[1]	0.12	0.15	0.08	25	10	2	15
Treatment							
nk	0.11 b	0.47 b	0.22 a	24 a	29 a	2 a	16 a
nK	0.23 a	0.50 ab	0.22 a	23 ac	22 b	2 a	16 a
Nk	0.09 b	0.54 a	0.23 a	19 b	26 ab	2 a	18 a
NK	0.22 a	0.51 a	0.22 a	20 bc	22 b	2 a	18 a

Note: Nutrient concentrations below the critical level of an element are normally considered to limit growth for Douglas-fir (Webster and Dobkowski 1983). Within each column, values followed by the same letter are similar at the $p < 0.05$ level (n = 26).

Root Chemistry

Root tip carbon reserves, measured in the form of starch, were 35% higher in the seedlings receiving the low N treatments than the seedlings receiving the high N treatments (Table 4). Soluble sugars were unaffected by fertilizer treatments. Starch and soluble sugar levels in the root tips were unaffected by K concentration in the fertilizer treatments (Table 4).

Table 4. Mean root tip levels of starch and soluble carbohydrates (fructose and glucose) in the root tips (% of dry weight) of Douglas-fir seedlings in October of 1992. Treatments are the same as in Table 1.

Treatment	Starch (%)	Sugars (%)
nk	12.12 a	4.04 a
nK	12.12 a	3.72 a
Nk	8.59 b	4.26 a
NK	9.32 b	4.42 a

Note: Within each column, values followed by the same letter are similar at the $p < 0.05$ level.

Growth and Carbon Allocation

Total dry weights and stem diameters of Douglas-fir seedlings were significantly affected by the treatments at the end of the third growing season (Table 5). Final measurements indicated that means of total dry weights, stem diameters, and RGR of plants receiving the high N treatments were 216%, 84% and 44% respectively, higher than those of plants receiving the low N treatments.

Seedling carbon allocation to roots, stems and needles differed substantially after three years on the specific nutrient treatments (Figure 4). Seedlings receiving the low N treatments allocated significantly ($p < 0.05$) more carbon to root dry matter than those receiving the high N treatments, with 48% and 38% of total dry weight allocated to roots, respectively (Figure 4).

Table 5. Mean total dry weights, stem diameters and relative growth rates (RGR) of Douglas-fir seedlings after three years of growth under different nutrient regimes. Treatments are the same as in Table 1.

Treatment	Total Dry Weight (g)	Stem Diameter (mm)	RGR ($g\ g^{-1}\ year^{-1}$)
nk	19.30 a	7.39 a	0.89
nK	17.78 a	6.78 a	0.86
Nk	62.22 b	13.16 b	1.28
NK	55.14 b	12.87 b	1.24

[1]Note: Within each column, values followed by the same letter are similar at the $p < 0.05$ level. RGR was calculated from mean seedling dry weights as a 3-year average, consequently, not enough degrees of freedom are present to determine statistical significance between treatments.

The higher allocation of carbon to root dry matter for seedlings receiving the low N treatments was complemented by a significant ($p < 0.05$) increase in stem dry weight of seedlings receiving the high N treatments (Figure 4). Although the proportion of total needle dry weight was similar for the high and low N treatments, needle weight per fifty needles was different between treatments. Plants receiving the low N treatments averaged 13% lower in needle weight than those receiving the high N treatments (data not shown).

To determine if the N and K treatments directly affected the stem, needle or root dry weight allocation patterns through an increase in seedling size, ten of the smallest seedlings in the high N treatments and ten of the largest seedlings (based on total dry weight) in the low N treatments were selected for additional analysis of carbon allocation patterns. Total dry weight for these selected subsets of trees was similar regardless of treatment (data not shown). Nonetheless, the dry matter stem, needle and root allocation patterns from the sub-sample matched the allocation patterns from the entire population with seedlings receiving the high N treatments having significantly ($p < 0.05$) higher (32%) stem allocation and significantly ($p < 0.05$) lower (16%) root allocation than those seedlings receiving the low N treatments. Furthermore, needle allocation of seedlings was similar regardless of treatment ($p < 0.05$).

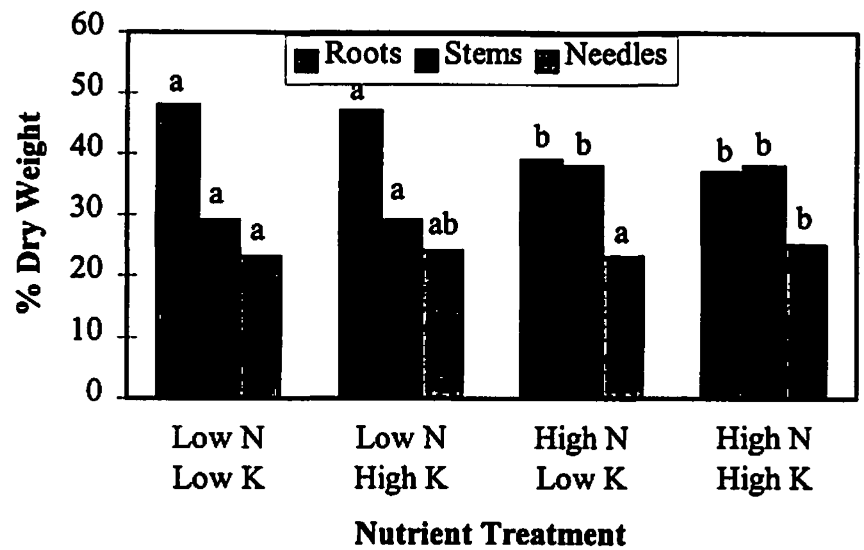

Figure 4. Percent dry weight of roots, stems and needles for Douglas-fir seedlings after three years of N and K supply regimes. Treatments are the same as in Table 1. Bars within each dry weight category that are followed by the same letter are similar at the $p < 0.05$ level.

Growth of the Douglas-fir seedlings was not significantly ($p < 0.05$) affected by the potassium treatments but was strongly affected by the level of N supplied (Table 5). However, seedlings receiving the high K treatments tended to have lower total dry weight, stem diameter and RGR than the seedlings receiving the low K treatments (Table 5). Needle dry matter allocation for plants receiving the high N and high K treatment was significantly ($p < 0.05$) higher than that of the plants grown in either of the low K treatments (Figure 4).

Needle dry matter allocation did not differ between the low K treatments (Figure 4).

DISCUSSION

After three growing seasons in a shadehouse environment, the nutrient treatments significantly affected foliar nutrient concentrations, growth and dry matter allocation among the needles, stems and roots of Douglas-fir seedlings. Seedlings receiving either high N treatment had higher foliar N concentrations, total growth and RGR. Seedling dry matter allocation to needles was the same between the high and low N treatments on a relative basis, however, dry matter allocation patterns differed significantly for roots and stems. Although not significant, the K treatments also exhibited trends in foliar K concentrations and growth. High and low K treatments caused dry matter allocation to needles to differ significantly.

Foliar nutrient concentrations of Douglas-fir seedlings were more responsive to the N treatments than for the K treatments. By design, this shadehouse study created N and K foliar concentrations similar to levels found in the field. For example, in a nitrogen fertilization study from 94 second-growth Douglas-fir stands located throughout the inland region of the Pacific Northwest, average foliar N concentrations were as low as 1.02% on untreated sites and as high as 1.87% on N treated sites (Mika and Moore 1991). Foliar K concentrations were as low as 0.61% on untreated sites and as high as 0.91% on K-treated sites (Mika and Moore 1991). In this study, average foliar N concentrations were as high as 1.90% and as low as 1.06% and foliar K levels were as high as 0.73% or as low as 0.59% for the final foliar nutrient measurement. Since foliar concentrations in the field and greenhouse are similar, results from this study should closely relate to growth and allocation patterns in the forest.

Treatment effects could also be seen by comparing foliar concentrations to reported N and K critical levels. The horizontal bars within each graph in Figures 1 and 2 represent critical N and K levels for Douglas-fir (Webster and Dobkowski 1983). Nitrogen concentrations in needles below the critical level of 1.4% are considered inadequate or deficient, 1.4 to 1.6 marginal, 1.6 to 1.8 adequate and above 1.8 are luxury accumulation. The foliage of seedlings receiving the low N treatments were below the inadequate threshold at 1.4%, whereas those of plants receiving the high N treatments were above the luxury level at 1.8% (Figure 1). Needles from the final end-of-season seedlings receiving the high K treatments were in the mid to high marginal range (0.6% to 0.8%) and those on plants in the low K regimes were near inadequate (below 0.6%).

Foliar K treatment response was less evident compared to foliar N treatment response for these Douglas-fir seedlings. This result may have been caused by nutritional imbalances with other minerals due to increases in foliar mass or seasonal variation in K levels. For instance, K uptake is closely related to the availability and uptake of other nutrients (Dibb and Thompson 1985). Nitrogen can be absorbed by plants as either a cation or an anion which presents the possibility of an anion-cation or cation-cation interaction with K^+ (Dibb and Thompson 1985). The inability to control K concentrations in this experiment despite the large K differences in the treatment solutions may have been due to the seedling's ability to maintain K concentration in response to lower K supplies (Schaedle 1991). The significantly lower K concentrations in the Nk-treated seedlings could have been in response to high seedling demands associated with the high N treatments. In general, as N is taken up in larger amounts, K is also taken up and used in larger amounts if available at adequate levels in the growth medium (Dibb and Thompson 1985). Other researchers (van den Driessche 1988, Gleason 1990, Ericsson and Kähr 1993) have had problems controlling foliar K in studies with seedlings. For example, van den Driessche (1988) found that foliar K concentration in Douglas-fir seedlings decreased late in the year even when supplying a balanced N-P-K fertilizer treatment. In a nutrient-fertilization field study with ponderosa pine, Gleason et al. (1990) had difficulties increasing foliar K. Moreover, Ericsson and Kähr (1993) in a birch (*Betula pendula* Roth.) K supply rate study, reported that increased variability among plant properties, such as foliar nutrient levels or growth, could reflect the fact that the role of K (osmoticum) is more indirect than nutrients such as N or P. In fact, McDonald et al. (1991) found that the uptake of K in plants was linked to growth requirements only when N or P were limited. Even so, the foliar K concentrations of seedlings receiving the low K treatments were generally lower than the high K treatments and significantly so in the seedlings receiving the high N and low K treatment (Figure 2).

Nutrients should be present in plant tissue in relatively constant proportions to maintain plant health and productivity at "unstressed" levels (Ingestad 1967, 1979, Dibb and Thompson 1985). Efficient use of N by plants depends on the proper level of K in the plant (Usherwood 1985). Furthermore, Ingestad (1967, 1979) suggests that the correct balance of K/N in foliage should not fall below 0.5 threshold and that the optimal K/N threshold for optimal growth should be at 0.65 (Figure 3). In this study, if N availability was high, the K/N ratio was low, regardless of K availability (Figure 3). Moreover, the K/N ratios of the Douglas-fir seedlings in the high N treatments are considered imbalanced for unimpaired growth (Figure 3, Ingestad 1967, 1979). Therefore, K/N imbalances induced in this study may have affected the efficient use of N in photosynthesis and the subsequent allocation of carbohydrates. Furthermore, K/N imbalances in the field affected seedling growth, and these imbalances may also lead to decreased tree survival through decreased resistance to pathogen attack (Moore et al. 1994).

The effects of N and K nutrition on the levels of other mineral nutrients may also be important in explaining treatment effects. The interactions between N and K and other nutrients and plant constituents are of major importance in plant nutrient uptake, assimilation and growth (Dibb and Thompson 1985, Ericsson and Kähr 1993). Results from this study show that plants receiving the high K treatments had significantly ($p < 0.05$) lower foliar P concentrations than the plants receiving the low K treatments (Table 3). Although other studies (Dibb and Thompson 1985, Schaedle 1991) have not shown any specific K-P interaction, van den Driessche (1980) found that P concentrations decreased with N fertilization in two-year-old Douglas-fir seedlings. The K-P interaction in this study may be explained by an N-K interaction which could have affected P absorption by the seedlings.

Starch stores in the root tips showed pronounced differences due to the nutrient treatments, however, soluble sugar levels were similar in roots of all plants. Several studies have shown fertilizer effects on carbohydrate levels in stems and leaves. Margolis and Waring (1986) reported higher total N, sugar and non-structural carbohydrate (starch and sugars) contents in N-fertilized Douglas-fir seedlings compared to nonfertilized plants. However, McDonald (1991) reported high leaf starch concentrations with low N supply. Starch and sugar reserves are used to provide energy for growth and maintenance in plants (Waring and Schlesinger 1985). The low root starch levels found in this study could be attributed to increased demand for carbohydrates in the leaves due to higher growth rates in the high N treatments. This study was not designed to determine the relationships between starch dynamics and plant nutrition in Douglas-fir seedlings. However, the treatment effect on root tip starch is an interesting result that should be pursued in future work.

Contrary to the N effect, root tip starch or sugar concentrations were unaffected by K treatments. Similarly, Ericsson and Kähr (1993) found that starch content was unaffected by the rate of K supply; however, in his study, sugars were higher in roots and stems at lower K rates. The contradicting results concerning the influence of K on carbohydrate reserves could be explained by K's role in plant growth and development. A primary function of K is in production of enzymes that influence physiological and biochemical processes and not as a structural component (Marschner 1986). This production role of K was supported in this study, since secondary defensive compounds (tannins and phenols) were significantly higher in the seedlings receiving the high K treatments compared to seedlings receiving the low K treatments (Shaw 1997).

The importance of nutrition for Douglas-fir seedling growth has been well documented (e.g., Anderson and Gessel 1966, van den Driessche 1980, 1982, Carlson and Preisig 1980, Margolis and Waring 1986), particularly, the response to experimental nutrient treatments or natural nutrient conditions. Nutrient deficiencies of Douglas-fir can lead to increased root proportions decreased total growth. In this study, both growth and seedling foliar nutrient concentrations differed between the N and K nutrient treatments. Seedlings in the low N treatments had substantially lower total dry weight, stem diameter and RGR than those seedlings receiving the high N treatments. These results demonstrate that deficient nutrient environments lead to decreased plant productivity. In a comparable Douglas-fir seedling shadehouse study, van den Dreissche (1984) found that after three years the seedlings receiving the high N treatments had RGR 44% higher than the low N treatments.

In the current study, higher RGR, total dry weights and stem diameters for the high N treatments may have resulted from increased net assimilation rates due to increased leaf area ratios (Margolis and Waring 1986). The higher N concentrations in the seedlings receiving the high N treatments may have influenced photosynthesis and leaf production in this study.

The K treatments had a slight effect on growth, although total dry weight, stem diameter and RGR were higher for the seedlings receiving low K treatments versus high K treatments, regardless of the amount of N being supplied (Table 4). In contrast, Ericsson and Kähr (1993) found a significant effect of K supply on growth of birch seedlings. Perhaps Douglas-fir is more efficient in using lower amounts of available K compared to birch seedlings and has adaptive mechanisms for counterbalancing a K shortage. Differences between the two studies and the absence of a strong relationship between K status and growth in this study may also result from the birch seedlings being relatively more deficient in K than the Douglas-fir in this study.

The reason for studying plant growth and allocation patterns is to determine the seedlings' response to nutrient deficiencies and stress. Carbon allocation plays an important role in plant response to stress and is a major determinant of growth and yield (Geiger and Servaite 1991). Under nutrient stress, carbon allocation patterns can change (Waring and Schlesinger 1985). Comparison of total dry weights for needles, stems and roots revealed that the Douglas-fir seedlings modified carbon allocation according to the nutrient treatments (Figure 4). Seedlings had low stem dry weights and high root proportions in response to inadequate nitrogen uptake. Low N-treated seedlings allocated more carbon to roots thus increasing N uptake. In contrast, seedlings receiving the high N treatments had adequate N uptake and allocated more carbon to stem growth (Figure 4). Although carbon allocation within plants varied substantially, depending on treatment, the percentage needle dry weights was about the same across N treatments. This result suggests that seedlings treated with high N, after three growing seasons, were able to allocate more to stems with the same proportion of needles as the low N treatments. Even though the total needle weight proportions were the same between treatments, needle weight per fifty needles was significantly different ($p <$ 0.05) by treatment. Seedlings receiving the high N treatments had higher needle weights ($\bar{y}$ = 0.14 g 50 needles^{-1}) than those receiving the low N ($\bar{y}$ = 0.12 g 50 needles^{-1}) treatment. This result is consistent with other studies, which found higher fascicle weight and increased growth response was related to N fertilization (Valentine and Allen 1989).

The proportional allocation of dry matter due to high and low K treatments was similar for stems and roots but needle dry matter was significantly higher in the seedlings receiving the NK treatment than for seedlings receiving either low K treatment (Figure 4). The increase in the dry matter allocation to needles supports the premise that abundant nutrient supply will increase allocation of dry matter to above-ground parts rather than to roots. This allocation pattern contradicts Ericsson and Kähr's (1991) findings that birch seedlings deficient in K favored dry matter allocation to the leaves. Perhaps species differences account for the contrasting responses wherein Douglas-fir seedlings have better adaptive mechanisms for K use than birch seedlings, or perhaps the three-year duration of this study simply provided time for the seedlings to adjust to the K treatments.

Dry matter allocation of conifer seedlings normally changes with increased seedling size (Ovington 1957, Cannell 1976). The results from a sub-sample of seedlings of the same size indicate that the N treatment, not ontogenetic differences, was the significant determinant in stem, needle and root dry matter allocation patterns in this Douglas-fir seedling study. However, results from other Douglas-fir seedling studies show a size effect on allocation patterns rather than a strong treatment effect (Carlson and Preisig 1981, van den Driessche 1982, Margolis and Waring 1986).

Biomass allocation to roots, stems and foliage in the entire study were significantly affected by changes in N availability. Douglas-fir seedlings in this study maintained a root-shoot balance of approximately 50-50% in the low N and 38-62% in the high N treatments. The lower shoot proportion for seedlings receiving the low N treatments was due to greater allocation of biomass to the roots and represented a direct cost to the stem rather than the needles. Seedlings receiving the high N treatments had a higher proportion of biomass allocated to the stems and generally the same proportion of biomass to the needles, compared to the low N treatments (Figure 4). This result is similar to other Douglas-fir seedling nutrition studies. Van den Driessche (1982; 1988) found that root-shoot balances decreased with increasing N amendments. However, in two different Douglas-fir seedling studies, van den Dreissche (1984, 1988) also found results that differed from those in my study on needle, stem and root dry matter allocation patterns. Needle, stem and root dry matter allocation after three years under different high and low N treatments were similar among treatments (van den Driessche 1984). However, in a second study, van den Driessche (1988) showed decreased amounts of dry matter allocated to needles and roots after two growing seasons but increased amounts allocated to stems with increasing levels of N amendment. Li et al. (1991) found that the root-shoot balance in one-year-old loblolly pine *Pinus taeda* L. was also related to N availability. Their findings were similar to this study in that the increased proportion of biomass to the roots reduced allocation to the shoots. However, in their study, reduced biomass allocation to the shoots was from the needles rather than the stem.

Although results from these various studies were broadly similar, the allocation proportions and stem-needle allocation patterns were different. These differences may be explained by the fact that my study included three growing seasons, whereas two of the other studies (Li et al., 1991, van den Driessche, 1988) spanned one or two growing seasons. Perhaps the longer time period in this study allowed treatment differences in allocation patterns to be more fully expressed. For example, the average growth (total dry weight) difference between seedlings receiving the high and low N treatments was 216% in my study versus van den Driessche at 104% (1988) and 52% in Li's study (1991). Alternatively, allocation differences between the studies could have resulted from species differences in carbon allocation under different nutrient treatments. Foliage has a high priority for carbohydrates, whereas stem wood production has a relatively low priority (Waring and Schlesinger, 1985).

CONCLUSIONS

Results from this study have shown that the N treatments significantly altered foliar N levels, growth rates and carbon allocation patterns in Douglas-fir seedlings. Carbon allocation to the roots increased but allocation to the stem decreased under low N supply. Changes in plant growth in this study were treatment induced rather than caused by seedling size differences. Potassium supply had little if any significant effect on growth rates or carbon allocation to stems, roots, or needles. Allocation to needles was unaffected by treatment except for the high N and K treatment wherein allocation to needles was as much as 12% higher than seedlings receiving the other N treatments. High K levels increased allocation to needles only when N was also adequately supplied. The Douglas-fir seedlings adjusted to different N and K treatments by changing carbon allocation patterns. Higher forest productivity and survival may be achieved if improved and balanced N and K nutrition can be used to regulate growth and biomass allocation.

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SECTION III

ROOT CHEMISTRY OF DOUGLAS-FIR SEEDLINGS GROWN UNDER DIFFERENT NITROGEN AND POTASSIUM TREATMENTS

ROOT CHEMISTRY OF DOUGLAS-FIR SEEDLINGS GROWN UNDER DIFFERENT NITROGEN AND POTASSIUM TREATMENTS

ABSTRACT

Chemical changes in roots of Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) seedlings were induced when optimal and deficient levels of nitrogen (N) and potassium (K) treatments were applied. Concentrations of sugar, starch, phenolics and protein-precipitable tannins produced in the roots of four-year-old Douglas-fir seedlings were significantly different under varied N and K addition regimes. Treatments were factorial combinations of high nitrogen (100 mg/L) or low nitrogen (10 mg/L), and high potassium (65 mg/L) or low potassium (6.5 mg/L). All other minerals in the nutrient solution were considered optimal. Root tip starch concentrations were significantly higher (35%) under the low-N treatments, whereas sugar concentrations were lower for those plants receiving the same treatments. Seedlings receiving the high N-low K treatment had significantly lower concentrations of phenolics and protein precipitable tannins and lower ratios of defensive compounds to carbohydrates than seedlings receiving the high potassium treatments. Samples taken from two locations on the root system show that storage and defensive compound levels were substantially higher in the root collar than in the root tips. These results indicate that the production of root storage and secondary compounds in Douglas-fir seedlings can be altered through N and K nutrition.

INTRODUCTION

Concentrations of storage and secondary compounds in plant tissue depend to a considerable extent on the environment in which plants grow (Waring et al. 1985; Huber and Arny 1985). In particular, plant nutrition influences production of storage compounds like sugars and starches and defensive compounds like phenolics and tannins (Bryant et al. 1987, Entry et al. 1991a, Moore et al. 1993). The concentrations of these compounds and the balance among them determine the chemical defense, or resistance of plants to herbivores and pathogens (Wargo 1972; Garraway 1975; Ostrofsky and Shigo 1984; Larsson et al 1986; Mwangi and Hubbes 1990). Therefore, the levels of specific nutrients such as nitrogen and potassium may greatly influence the resistance or susceptibility of plants to disease.

A tree's ability to resist a particular kind of stress can be assessed by evaluating how easily it can mobilize carbohydrate reserves near the points of potential need (Waring and Schlesinger 1985). Also, competition for resources may affect the levels of storage carbohydrates in various tissues (Waring and Schlesinger 1985). Limited resources may also lead to limited production of secondary compounds like phenols and tannins (Mooney 1972; Bazzaz et al. 1987). Wargo et al. (1972) found that glucose and fructose in sugar maple, *Acer saccharum* Marsh, was higher in the outermost root wood than the inner root bark. In another study with sugar maple, Parker and Houston (1971) found that levels of sugars were higher in root bark than in root collar bark. With limited nutrient and carbohydrate resources, various parts of the root system have lower concentrations of secondary defensive compounds, which may lead to higher susceptibility to disease. The levels of storage and defensive compounds have been shown to vary considerably along the gradient of stem and root bark (Kelsey and Harmon 1989). To better estimate and understand the relationship between plant nutrition, root chemistry, and plant susceptibility to disease, the effects of sampling location must be understood.

The principal objective of this study was to determine the effects of N and K nutrition on Douglas-fir root storage and defensive compound chemistry. A secondary objective was to evaluate two root sampling locations to compare distribution, trends and variation in chemical composition.

METHODS AND MATERIALS

Treatments

One hundred four one-year-old, containerized Douglas-fir *(Pseudotsuga menziesii* var. glauca (Beissn.) Franco) seedlings were planted in 2900-mL plastic containers filled with medium grade silica sand. Seedlings were grown at the University of Idaho Forest Nursery in a shade house covered by a clear, corrugated fiberglass roof from June to December in 1990, 1991 and 1992. To insure genetic variation in experimental material, seedlings from two North Idaho (Bovill, ID. and Santa, ID.) Douglas-fir seed sources, collected in different locations and elevations, were distributed equally by treatment and block. Seedlings were randomly assigned to four different N and K treatments within two blocks. The solution used to supply the Douglas-fir seedlings with nutrients was adapted from Ingestad and Lund (1979) and is considered nutritionally optimal. The levels for the macro nutrients were: N 100, K 65, P 13.8, Ca 7, Mg 8.5 and S 15 mg/L; and the micro nutrients: Fe 700, Mn 400, B 200, Cu 30, Zn 30, Cl 30, Mo 7, and Na 3 ppm. The nutrient solution was modified to meet the treatment regimes shown in Table 2. Nutrient solutions were given to the plants by adding the solution to well water through an injection system at a rate of 1:100, respectively.

Seedlings were irrigated as needed, and 500 mL of nutrient solution was applied every four days throughout the growing season. Irrigation was reduced in late September of each year to force the seedlings into dormancy. Periodic foliar sampling (data not shown) was used to adjust treatments so that the N and K foliar concentrations were similar to ranges observed from Douglas-fir in the field. Each treatment consisted of a 3-year nutrient regime periodically adjusted to attain target nutrient concentrations. To prevent nutrient leaching from the foliage, irrigation water and solution was applied directly to the soil through 3.2 millimeter (inside diameter) polyethylene drip tubing with Roberts 180° medium flow Spot-Spitters®. To avoid low winter temperatures, seedlings were transferred and stored at around 0°C. Daylength followed seasonal variations for Moscow, ID. (Latitude 46° north).

Table 1. Nutrient treatments under which Douglas-fir seedlings were grown: low nitrogen and low potassium (nk), low nitrogen and high potassium (nK), high nitrogen and low potassium (Nk), high nitrogen and high potassium (NK). Numbers are percentages of solution concentrations developed by Ingestad and Lund (1979).

Year	Treatment	Nitrogen	Potassium
1990 & 1992	nk	10	10
	nK	10	100
	Nk	100	10
	NK	100	100
1991	nk	25	10
	nK	25	100
	Nk	100	10
	NK	100	100

Foliar Nutrients

Douglas-fir seedlings were sampled in October 1992 after three years of growth under different N and K treatments. Seedlings and the sand in which they were grown were carefully removed from the containers, sand was gently removed from the root system, then the seedlings were put into plastic bags and stored in coolers to slow plant metabolism. Foliar nutrient sampling was comprised of 26 seedlings per treatment. Seedling foliage was stored at 1°C for up to 48 hours while awaiting laboratory analysis. In the laboratory, roots were separated from the shoots and both samples were oven-dried at 70°C for 24 hours. Afterward needles were stripped from the stem and continued to dry at 70°C for an additional 24 hours. A sample of 2 grams representing all the needles was taken from each seedling. Foliage was ground to a very fine consistency in a Wiley mill in preparation for chemical analysis (IFTNC 88). Foliar N was determined using a standard micro-Kjeldahl procedure, which is a wet-oxidation method that converts organic and inorganic N to NH_4, for subsequent measurement. Phosphorus, K, Ca, Mg, Mn, Fe, Cu and Zn were determined by inductively coupled plasma (ICP) emission where high temperatures (6000 to 8000°K) produce ionic emission wavelengths which were read sequentially on a spectroscope. Both procedures were performed by Scotts Laboratories in Allentown, PA.

Root Storage and Defensive Compound Chemistry

Fifty-two composite samples (four seedlings per composite), half from root collar bark and half from the root tips, were collected for analysis of starch, soluble sugar, total phenols and protein-precipitable tannins. Composite samples were taken from the same seedlings that were used in the foliar nutrient analysis. Only living root tips were included in the samples. Roots were temporarily stored for several hours in coolers while waiting for transport from the nursery then frozen in an ultra-cold freezer at -40°C until analyzed. In the laboratory, all samples (bark and root tips) were put in liquid nitrogen overnight, and then ground to a powder in a mortar. Total phenols were determined from samples by extracting with aqueous acetone (80%) and adding Folin-Ciocalteu's Reagent, and then measuring absorbances at 700 and 735 nm (Julkunen-Tiito 1985). Phenol concentrations determined using a standard curve made with phenol (Julkunen-Tiito 1985). Samples were analyzed for total soluble starch through an ethanol and perchloric acid method (Hansen and Moller 1975), and glucose was determined by adding anthrone solution for absorbance determination at 630 nm (Hansen and Moller 1975). Concentrations of glucose were measured using a standard curve established with a glucose standard (Hansen and Moller 1975). The Hansen and Moller method has been criticized for overestimating starch levels because carbohydrates other than starch are extracted during the process (Marshall 1986, Rose et al. 1991). Perchlorate-extractable carbohydrates were, therefore, corrected to yield starch concentrations and are expressed in their corrected form throughout this paper. Tannin determinations were measured by extracting with 80% aqueous acetone loaded into an agarose plate containing bovine serum albumin, diffusion rings were measured and tannin concentrations were determined using a standard curve established with tannic acid (Sigma) (Hagerman 1987). Analysis of starch, sugar (glucose), total phenols and protein-precipitable tannins analysis were performed by the Institute of Biological Chemistry, Washington State University in Pullman, WA.

Statistical Analysis

From a population of 104 seedlings, the treatment effects on foliar nutrient concentrations and root chemistry were estimated using analysis of variance for a 2 (blocks) x 2 (seed sources) x 4 (treatments) randomized complete block design. Twenty six seedlings per treatment were used for the foliar nutrient analysis while six root collar bark or root tip composite samples per treatment were used for the root chemistry analyses. Analysis of variance (PROC GLM) and differences between means by treatment for foliar nutrient and root chemistry data were determined by using the least-squares means ($\alpha = 0.10$) procedure of the Statistical Analysis System (SAS Institute Inc. 1985). Correlations between sugar, starch, phenols and tannin concentration by root sampling locations were analyzed.

RESULTS

Foliar Nutrients

Treatment differences in foliar nutrient concentrations and ratios were detected (Table 2). Foliar N concentrations were 41% higher in the seedlings receiving the high N treatments than in seedlings receiving low N treatments. Although foliar K levels were similar between treatments, those plants receiving high N and low K were 25% lower than seedlings receiving the high N and high K treatment. In addition, seedlings receiving the low K treatments showed K deficiency symptoms in the form of chlorosis and necroses along the leaf margins. The potassium treatments had a lesser effect on the K to N ratio (K:N), since highly significant differences were observed between the high N and low N treatments (Table 2).

Table 2. Nitrogen and potassium foliar nutrient concentrations collected in October 1991 from four-year-old Douglas-fir seedlings. Treatments are the same as in Table 1.

Treatment	Nitrogen (%)	Potassium (%)	Potassium/ Nitrogen
nk	1.06 a	0.68 a	0.67 a
nK	1.13 a	0.71 a	0.67 a
Nk	1.85 b	0.59 b	0.33 b
NK	1.90 b	0.74 a	0.40 b

Note: Within each column, values followed by the same letter are similar at $P \leq 0.10$.

Root Storage and Defensive Compound Chemistry

Concentrations of sugar, starch, phenolics and protein-precipitable tannins were significantly higher at the root collar sample than in the root tip area (Table 3). Soluble sugar and tannin concentrations were two to three times higher in the root collar area, whereas concentrations of phenolics were up to six times higher. These results were especially pronounced in the high N-low K treatments (Nk) with phenolic and tannin levels six and seven times lower in the root tips than in the root collar area, respectively (Table 3). Root collar phenolic to sugar ratios (P:S) were higher than in the root tips, especially in the plants receiving the Nk treatment, with the P:S ratio more than twofold lower in the root tips than the root collar. Overall, plants receiving the low K treatments had greater differences for phenolic and tannin concentrations in the root tip than the root collar.

Table 3. Root collar and root tip soluble sugar, starch, phenolics and protein precipitable tannin values collected October 1991 from four-year-old Douglas-fir seedlings. Treatments are the same as in Table 1.

Tissue/ Treatment	Sugar	Starch	Phenolics	Protein-precipitable tannins	Phenolic/ sugar ratio
			% Dry Weight		
Root Collar					
nk	9.45 a	17.81 a	10.99 c	5.94 c	1.19 b
nK	8.61 a	16.62 a	11.75 bc	6.33 c	1.39 ab
Nk	10.39 a	14.28 b	14.28 ab	9.13 b	1.35 b
NK	10.11 a	13.28 b	15.48 a	11.22 a	1.56 a
Root Tip					
nk	4.04 a	12.12 a	2.44 bc	1.72 b	0.66 ab
nK	3.72 a	12.12 a	3.15 ab	2.08 ab	0.87 a
Nk	4.26 a	8.59 b	2.34 c	1.20 c	0.57 b
NK	4.42 a	9.32 b	3.35 a	2.41 a	0.90 a

Note: Within each column, values followed by the same letter are not significantly different at $P \leq 0.10$.

Although root collar sugar, starch, phenol and tannin concentrations were substantially higher in the root collar than in the root tip, the results show similar trends by treatment. In contrast, for both sample areas, starch levels were substantially higher in the low N treatments than the high N treatments. Observations from the two sampling locations were significantly correlated with correlation coefficients for sugar of $r = 0.8476$, starch $r = 0.7872$, phenol $r = 0.9296$ and tannin $r = 0.8936$.

DISCUSSION

Douglas-fir seedlings were grown under different N and K regimes, which altered carbohydrate production and subsequent photosynthate allocation among biosynthate pathways and seedling parts. Root storage compounds such as starch were reduced in seedlings receiving the high N treatments, whereas secondary defensive compounds like phenolics and tannins were reduced in plants receiving low K treatments.

Foliar N levels for the low N treatments were well below the "adequate" threshold, whereas high N treatments were above the adequate threshold, as described by van den Driessche (1979) and Webster and Dobkowski (1983). Plants receiving high N and low K had inadequate foliar K concentrations for growth (van den Driessche 1979, Webster and Dobkowski 1983). In addition, foliar color indicated N and K deficiency symptoms in the needles. Seedlings that received the two high N treatments had K:N ratios substantially below the 0.50 inadequate level described by Ingestad (1967, 1979). These results are similar to N and K foliar concentrations in field-grown Douglas-fir trees where insufficient K was associated with optimal N levels (Mika and Moore, 1991).

The effects of excessive N on nutritional balance and plant resistance to disease have been well established. In a comparable N and K study, Ylimartimo (1990) found that scleroderris stem canker of scots pine, *Pinus sylvestris* L., seedlings was related to an imbalance of excessive N containing compounds with corresponding low levels of K. Matson and Waring (1984) and Entry et al. (1986) found that excessive N or imbalanced nutrition lead to reduced vigor and caused trees to become increasingly susceptible to disease. In this study, imbalanced nutrition led to reduced vigor, limited storage reserves and decreased production of various protective chemicals.

The rate at which stored carbohydrates or proteins may be converted into mobile forms (sugars and amino acids) and transported to sites of attack may limit plant response to attack (McLaughlin and Shriner, 1980). Furthermore, changes in the allocation of current photosynthate to remote organs such as the lower bole or roots, may be slow because of limitations in phloem transport (Waring and Schlesinger, 1985). The amount, mobilization time, and location of stored carbohydrates or proteins and defensive compounds may be important to a seedling's or tree's resistance to disease. Pronounced differences were shown in this study between concentrations of storage and defensive compound levels at the root collar and root tip (Table 3). For instance, sugar concentrations were more than two times higher and phenolic and tannin concentrations were at least three times higher in the root collar than in the root tips. This trend was especially pronounced in seedlings that received the high N low K treatment where root tip phenols were six times lower and tannins were more than seven times lower than root collar levels. Due to pronounced differences between the root collar and root tip storage and defensive compound chemistry, the root collar P:S was appreciably higher than the ratio at the root tip. This result was especially true in the Nk treatment, where the P:S ratio was more than twofold lower in the root tip than the root collar. Entry et al. (1991b) found increased concentrations of sugars may reduce or eliminate the inhibition of disease by phenols. Therefore, the low P:S ratios of the seedlings could predispose the seedlings to successful infection by pathogens.

In this study, the seedlings grown with high N regimes had significantly lower levels of starch in both the root collar and root tips than in the low N regimes. Both Wargo (1984) and Entry et al. (1991a) reported major changes among root carbohydrates associated with N levels in conifers. In this study, phenolic and tannin levels in the root collar area were significantly higher in the high N treatments. These results, however, differ from other studies that found decreased phenolic levels in leaf tissue of paper birch *Betula papyrifera* Dugle (Bryant et al. 1987) and needles of Douglas-fir with increased N (Joeseph et al. 1993). In contrast, Dudt and Shure (1994) found that leaf phenolic levels in tulip popular *Liriodendron tulipifera* and flowering dogwood *Cornus florida* were similar with different N and K fertilization regimes. Differences in root tip phenolic and tannin concentrations were strongly affected by the K treatments, with significant differences between the NK and the low K treatments. The effect of K on phenolic and tannin levels in roots was especially pronounced for seedlings receiving the Nk treatment with high N lowering the K:N ratio well below the recommended thresholds suggested by Ingestad (1967, 1979). Potassium deficiencies may have affected K controlled enzymatic activities that affect carbon allocation to the shikimic acid pathway, which produces defensive compounds such as phenols and tannins (Mooney, 1972). Furthermore, seedlings receiving the high N treatments were growing extremely rapidly and may have allocated more carbon to sugar and cellulose production and less to secondary metabolites, such as phenolics and tannins (Entry et al 1991b). Moreover, N and K imbalances resulted in imbalances between the storage compounds (sugars and starches), and defensive compounds (phenols and tannins). Wargo (1980) and Entry et al. (1991a, 1991b) reported that increased levels of glucose enable the *Armillaria* fungus to grow more rapidly, making the fungus better able to break down phenolic compounds. In addition, Entry et al. (1991a, 1991b) found that the phenol to sugar ratio was related to susceptibility to *Armillaria* infection, with low ratios (ie. low phenolics and high sugars) being bad for the trees and good for the disease. In this study, high N plus low K or just low K alone resulted in the lowest phenol to sugar ratios (Table 2).

CONCLUSIONS

The effects of high and low N and K on the production of soluble sugar, starch, phenolic and protein-precipitable tannin concentrations have been demonstrated in this study. Nutritional imbalances between these two elements led to nutritional stress and secondary product imbalances, which may decrease resistance to disease. The foliar N and K levels in this study were similar to N and K concentrations in field grown plants. Therefore, these relationships between N and K nutrition and root chemistry should provide a better understanding of the relationships between mineral nutrition and tree resistance to disease in a forest environment.

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SECTION IV

CONCLUSIONS

CONCLUSIONS

Growth and development of plants obviously depends upon the environment. Nutrient deficiencies and imbalances result in reduced tree growth and differences in carbon allocation to storage and secondary compounds. In this study, nitrogen and potassium imbalances resulted in decreased growth and changes in storage and secondary compounds. High and low nitrogen treatments caused clear growth, foliar nutrient concentration, and carbon allocation differences. In addition, nitrogen nutrition influenced levels of root storage compounds. Potassium supply had little if any effect on growth rates or carbon allocation to stems, roots or needles. Potassium shortages, however, reduced production of plant defensive compounds. The results indicate that Douglas-fir seedlings acclimated to different nutrient environments by adjusting growth, carbon allocation to stems, roots or needles and production of storage and secondary root compounds. These preliminary results indicate that it may be possible to grow plants with optimal growth and allocation patterns while controlling different root chemical properties.

Forest managers should consider the nutritional potential of a site as a significant factor in making silvicultural decisions. Deficient and imbalanced nutrition are natural and common in forest stands. However, forest practices may augment nutrient imbalances and deficiencies in forest stands by removal or redistribution of substantial amounts of biomass. Evidence has been presented that forest sites lack sufficient nitrogen and potassium to express maximum tree growth. This study has shown that imbalanced nitrogen and potassium nutrition could lead to reduced growth, carbon allocation changes and decreased production of protective chemicals. Higher tree productivity and survival may be achieved if improved and balanced nitrogen and potassium nutrition can be used to regulate growth and allocation of resources to storage and secondary compounds.

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APPENDIX A

STATISTICAL ANALYSIS DOCUMENTATION

Statistical Analysis Documentation

Variables for Growth

Variable	Units
% Root Weight (PROOTWT)	% of Total Dry Biomass
% Stem Weight (PSTEMWT)	% of Total Dry Biomass
% Needle Weight (PNEEDWT)	% of Total Dry Biomass
Stem Diameter (STEMD)	millimeters
Total Weight (TOTWT)	grams

Experimental Design Statistical Models for Growth

The SAS System

General Linear Models Procedure
Class Level Information

Class	Levels	Values
TRT	4	1 2 3 4

Number of observations in data set = 106

The SAS System

General Linear Models Procedure

Dependent Variable: PROOTWT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2625.1805621	875.0601874	23.27	0.0001
Error	102	3836.3955462	37.6117210		
Corrected Total	105	6461.5761083			

R-Square	C.V.	Root MSE	PROOTWT Mean
0.406276	14.32434	6.1328396	42.814129

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	2625.1805621	875.0601874	23.27	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	2625.1805621	875.0601874	23.27	0.0001

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		36.93428886 B	31.29	0.0001	1.18026552
TRT	1	11.56186323 B	6.93	0.0001	1.66914751
	2	10.44013621 B	6.00	0.0001	1.74020658
	3	2.44722687 B	1.49	0.1388	1.64011664
	4	0.00000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: PSTEMWT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2251.9986236	750.6662079	27.86	0.0001
Error	102	2748.5728835	26.9467930		
Corrected Total	105	5000.5715071			

R-Square	C.V.	Root MSE	PSTEMWT Mean
0.450348	15.50647	5.1910300	33.476543

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	2251.9986236	750.6662079	27.86	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	2251.9986236	750.6662079	27.86	0.0001

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		37.75941032 B	37.80	0.0001	0.99901420
TRT	1	-8.78756831 B	-6.22	0.0001	1.41281943
	2	-9.58014735 B	-6.50	0.0001	1.47296608
	3	0.12495851 B	0.09	0.9285	1.38824678
	4	0.00000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: PNEEDWT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	131.42244182	43.80748061	2.94	0.0365
Error	102	1517.59331659	14.87836585		
Corrected Total	105	1649.01575841			

R-Square	C.V.	Root MSE	PNEEDWT Mean
0.079698	16.44641	3.8572485	23.453441

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	131.42244182	43.80748061	2.94	0.0365

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	131.42244182	43.80748061	2.94	0.0365

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		25.30630082 B	34.09	0.0001	0.74232782
TRT	1	-2.77429491 B	-2.64	0.0095	1.04981007
	2	-2.03929381 B	-1.86	0.0653	1.09450265
	3	-2.57218538 B	-2.49	0.0143	1.03155111
	4	0.00000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: STEMD

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	927.71720918	309.23906973	38.93	0.0001
Error	102	810.25005497	7.94362799		
Corrected Total	105	1737.96726415			

R-Square	C.V.	Root MSE	STEMD Mean
0.533794	27.54773	2.8184442	10.231132

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	927.71720918	309.23906973	38.93	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	927.71720918	309.23906973	38.93	0.0001

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		12.86666667 B	23.72	0.0001	0.54240985
TRT	1	-5.47777778 B	-7.14	0.0001	0.76708336
	2	-6.08405797 B	-7.61	0.0001	0.79973969
	3	0.29195402 B	0.39	0.6993	0.75374177
	4	0.00000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: TOTWT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	43428.621582	14476.207194	23.14	0.0001
Error	102	63807.475480	625.563485		
Corrected Total	105	107236.097062			

R-Square	C.V.	Root MSE	TOTWT Mean
0.404981	62.77921	25.011267	39.840046

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	43428.621582	14476.207194	23.14	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	43428.621582	14476.207194	23.14	0.0001

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		55.13891852 B	11.46	0.0001	4.81342061
TRT	1	-35.84022593 B	-5.27	0.0001	6.80720471
	2	-37.36026200 B	-5.26	0.0001	7.09700151
	3	7.07902286 B	1.06	0.2924	6.68880951
	4	0.00000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

Least Squares Means for Growth

The SAS System

General Linear Models Procedure
Least Squares Means

TRT	PROOTWT LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	48.4961521	1	.	0.5206	0.0001	0.0001
2	47.3744251	2	0.5206	.	0.0001	0.0001
3	39.3815157	3	0.0001	0.0001	.	0.1388
4	36.9342889	4	0.0001	0.0001	0.1388	.

TRT	PSTEMWT LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	28.9718420	1	.	0.5917	0.0001	0.0001
2	28.1792630	2	0.5917	.	0.0001	0.0001
3	37.8843688	3	0.0001	0.0001	.	0.9285
4	37.7594103	4	0.0001	0.0001	0.9285	.

TRT	PNEEDWT LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	22.5320059	1	.	0.5034	0.8451	0.0095
2	23.2670070	2	0.5034	.	0.6218	0.0653
3	22.7341154	3	0.8451	0.6218	.	0.0143
4	25.3063008	4	0.0095	0.0653	0.0143	.

TRT	STEMD LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	7.3888889	1	.	0.4501	0.0001	0.0001
2	6.7826087	2	0.4501	.	0.0001	0.0001
3	13.1586207	3	0.0001	0.0001	.	0.6993
4	12.8666667	4	0.0001	0.0001	0.6993	.

TRT	TOTWT LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	19.2986926	1	.	0.8308	0.0001	0.0001
2	17.7786565	2	0.8308	.	0.0001	0.0001
3	62.2179414	3	0.0001	0.0001	.	0.2924
4	55.1389185	4	0.0001	0.0001	0.2924	.

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

Statistical Analysis Documentation

Variables for Foliar Nutrient Concentrations

Variable	Units
Calcium (CA)	% Concentration
Copper (CU)	ppm concentration
Iron (FE)	ppm concentration
Magnesium (MG)	% Concentration
Manganese (MN)	ppm concentration
Phosphorus (P)	% concentration
Zinc (ZN)	ppm concentration
Potassium (K)	% concentration
Nitrogen (N)	% concentration
Potassium/Nitrogen Ratio (KN)	

Experimental Design Statistical Models for Foliar Nutrient Concentrations

The SAS System

General Linear Models Procedure
Class Level Information

Class	Levels	Values
TRT	4	1 2 3 4

Number of observations in data set = 106

The SAS System

General Linear Models Procedure

Dependent Variable: CA

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.09636928	0.03212309	2.31	0.0803
Error	102	1.41558099	0.01387824		
Corrected Total	105	1.51195026			

R-Square	C.V.	Root MSE	CA Mean
0.063738	23.26099	0.1178060	0.5064528

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	0.09636928	0.03212309	2.31	0.0803

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	0.09636928	0.03212309	2.31	0.0803

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		0.5079259259 B	22.40	0.0001	0.02267177
TRT	1	-.0410370370 B	-1.28	0.2035	0.03206272
	2	-.0114259259 B	-0.34	0.7363	0.03383546
	3	0.0401074074 B	1.28	0.2023	0.03125088
	4	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: CU

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	3.83481977	1.27827326	1.10	0.3525
Error	102	118.46753872	1.16144646		
Corrected Total	105	122.30235849			

R-Square	C.V.	Root MSE	CU Mean
0.031355	63.71258	1.0777043	1.6915094

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	3.83481977	1.27827326	1.10	0.3525

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	3.83481977	1.27827326	1.10	0.3525

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		1.522222222 B	7.34	0.0001	0.20740428
TRT	1	0.414814815 B	1.41	0.1603	0.29331395
	2	-0.058585859 B	-0.19	0.8503	0.30953119
	3	0.267777778 B	0.94	0.3511	0.28588707
	4	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: FE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	391.13714872	130.37904957	5.90	0.0009
Error	102	2252.20370034	22.08042843		
Corrected Total	105	2643.34084906			

R-Square	C.V.	Root MSE	FE Mean
0.147971	21.71945	4.6989816	21.634906

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	391.13714872	130.37904957	5.90	0.0009

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	391.13714872	130.37904957	5.90	0.0009

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		20.31111111 B	22.46	0.0001	0.90431944
TRT	1	3.81481481 B	2.98	0.0036	1.27890081
	2	2.74797980 B	2.04	0.0443	1.34961086
	3	-0.77111111 B	-0.62	0.5376	1.24651832
	4	0.00000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: MG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.00227250	0.00075750	0.45	0.7205
Error	102	0.17313196	0.00169737		
Corrected Total	105	0.17540446			

R-Square	C.V.	Root MSE	MG Mean
0.012956	18.59850	0.0411992	0.2215189

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	0.00227250	0.00075750	0.45	0.7205

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	0.00227250	0.00075750	0.45	0.7205

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		0.2155925926 B	27.19	0.0001	0.00792879
TRT	1	0.0031851852 B	0.28	0.7769	0.01121300
	2	0.0090892256 B	0.77	0.4442	0.01183296
	3	0.0114074074 B	1.04	0.2991	0.01092908
	4	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: MN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	100.59472905	33.53157635	3.08	0.0308
Error	102	1110.60791246	10.88831287		
Corrected Total	105	1211.20264151			

R-Square	C.V.	Root MSE	MN Mean
0.083054	19.23520	3.2997444	17.154717

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	100.59472905	33.53157635	3.08	0.0308

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	100.59472905	33.53157635	3.08	0.0308

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		18.32222222 B	28.85	0.0001	0.63503610
TRT	1	-2.14814815 B	-2.39	0.0186	0.89807666
	2	-2.25404040 B	-2.38	0.0193	0.94773106
	3	-0.53888889 B	-0.62	0.5395	0.87533685
	4	0.00000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: P

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.40819604	0.13606535	124.31	0.0001
Error	102	0.11164223	0.00109453		
Corrected Total	105	0.51983827			

	R-Square	C.V.	Root MSE	P Mean
	0.785237	20.96033	0.0330837	0.1578396

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	0.40819604	0.13606535	124.31	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	0.40819604	0.13606535	124.31	0.0001

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		0.2212222222 B	34.75	0.0001	0.00636696
TRT	1	-.1137037037 B	-12.63	0.0001	0.00900424
	2	0.0073232323 B	0.77	0.4427	0.00950209
	3	-.1269888889 B	-14.47	0.0001	0.00877625
	4	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: ZN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	928.13054653	309.37684884	1.87	0.1389
Error	102	16848.73105724	165.18363782		
Corrected Total	105	17776.86160377			

R-Square	C.V.	Root MSE	ZN Mean
0.052210	51.73162	12.852379	24.844340

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	928.13054653	309.37684884	1.87	0.1389

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	928.13054653	309.37684884	1.87	0.1389

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		22.04814815 B	8.91	0.0001	2.47344143
TRT	1	6.76666667 B	1.93	0.0558	3.49797442
	2	-0.48451178 B	-0.13	0.8958	3.69137639
	3	4.14518519 B	1.22	0.2269	3.40940373
	4	0.00000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: K

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.33130675	0.11043558	4.21	0.0075
Error	102	2.67789898	0.02625391		
Corrected Total	105	3.00920574			

	R-Square	C.V.	Root MSE	K Mean
	0.110098	23.98375	0.1620306	0.6755849

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	0.33130675	0.11043558	4.21	0.0075

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	0.33130675	0.11043558	4.21	0.0075

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		0.7364814815 B	23.62	0.0001	0.03118280
TRT	1	-.0552962963 B	-1.25	0.2127	0.04409914
	2	-.0289814815 B	-0.62	0.5348	0.04653737
	3	-.1441481481 B	-3.35	0.0011	0.04298253
	4	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: N

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	16.19605013	5.39868338	81.93	0.0001
Error	102	6.72119138	0.06589403		
Corrected Total	105	22.91724151			

R-Square	C.V.	Root MSE	N Mean
0.706719	16.94695	0.2566983	1.5147170

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	16.19605013	5.39868338	81.93	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	16.19605013	5.39868338	81.93	0.0001

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		1.904074074 B	38.54	0.0001	0.04940162
TRT	1	-0.842222222 B	-12.06	0.0001	0.06986444
	2	-0.769528620 B	-10.44	0.0001	0.07372722
	3	-0.053407407 B	-0.78	0.4347	0.06809543
	4	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: KN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2.59363476	0.86454492	24.23	0.0001
Error	102	3.63925458	0.03567897		
Corrected Total	105	6.23288934			

R-Square	C.V.	Root MSE	KN Mean
0.416121	37.35246	0.1888888	0.5056930

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	2.59363476	0.86454492	24.23	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	2.59363476	0.86454492	24.23	0.0001

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		0.3991372608 B	10.98	0.0001	0.03635166
TRT	1	0.2753780229 B	5.36	0.0001	0.05140901
	2	0.2701088992 B	4.98	0.0001	0.05425140
	3	-.0694229869 B	-1.39	0.1689	0.05010731
	4	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

Least Square Means for Growth

The SAS System

General Linear Models Procedure
Least Squares Means

TRT	CA LSMEAN	i/j	1	2	3	4
1	0.46688889	1	.	0.3835	0.0108	0.2035
2	0.49650000	2	0.3835	.	0.1222	0.7363
3	0.54803333	3	0.0108	0.1222	.	0.2023
4	0.50792593	4	0.2035	0.7363	0.2023	.

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

TRT	CU LSMEAN	i/j	1	2	3	4
1	1.93703704	1	.	0.1293	0.6081	0.1603
2	1.46363636	2	0.1293	.	0.2832	0.8503
3	1.79000000	3	0.6081	0.2832	.	0.3511
4	1.52222222	4	0.1603	0.8503	0.3511	.

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

TRT	FE LSMEAN	i/j	1	2	3	4
1	24.1259259	1	.	0.4311	0.0004	0.0036
2	23.0590909	2	0.4311	.	0.0089	0.0443
3	19.5400000	3	0.0004	0.0089	.	0.5376
4	20.3111111	4	0.0036	0.0443	0.5376	.

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

TRT	MG LSMEAN	i/j	1	2	3	4
1	0.21877778	1	.	0.6189	0.4536	0.7769
2	0.22468182	2	0.6189	.	0.8415	0.4442
3	0.22700000	3	0.4536	0.8415	.	0.2991
4	0.21559259	4	0.7769	0.4442	0.2991	.

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

TRT	MN LSMEAN	i/j	1	2	3	4
1	16.1740741	1	.	0.9113	0.0689	0.0186
2	16.0681818	2	0.9113	.	0.0669	0.0193
3	17.7833333	3	0.0689	0.0669	.	0.5395
4	18.3222222	4	0.0186	0.0193	0.5395	.

The SAS System

General Linear Models Procedure
Least Squares Means

TRT	P LSMEAN	i/j	1	2	3	4
1	0.10751852	1	.	0.0001	0.1332	0.0001
2	0.22854545	2	0.0001	.	0.0001	0.4427
3	0.09423333	3	0.1332	0.0001	.	0.0001
4	0.22122222	4	0.0001	0.4427	0.0001	.

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

TRT	ZN LSMEAN	i/j	1	2	3	4
1	28.8148148	1	.	0.0522	0.4437	0.0558
2	21.5636364	2	0.0522	.	0.2023	0.8958
3	26.1933333	3	0.4437	0.2023	.	0.2269
4	22.0481481	4	0.0558	0.8958	0.2269	.

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

TRT	K LSMEAN	i/j	1	2	3	4
1	0.68118519	1	.	0.5730	0.0413	0.2127
2	0.70750000	2	0.5730	.	0.0129	0.5348
3	0.59233333	3	0.0413	0.0129	.	0.0011
4	0.73648148	4	0.2127	0.5348	0.0011	.

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

TRT	N LSMEAN	i/j	1	2	3	4
1	1.06185185	1	.	0.3265	0.0001	0.0001
2	1.13454545	2	0.3265	.	0.0001	0.0001
3	1.85066667	3	0.0001	0.0001	.	0.4347
4	1.90407407	4	0.0001	0.0001	0.4347	.

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

TRT	KN LSMEAN	i/j	1	2	3	4
1	0.67451528	1	.	0.9228	0.0001	0.0001
2	0.66924616	2	0.9228	.	0.0001	0.0001
3	0.32971427	3	0.0001	0.0001	.	0.1689
4	0.39913726	4	0.0001	0.0001	0.1689	.

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

The SAS System

General Linear Models Procedure

Dependent Variable: FECONTEN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1.64136489	0.54712163	0.70	0.5518
Error	102	79.28045061	0.77725932		
Corrected Total	105	80.92181550			

R-Square	C.V.	Root MSE	FECONTEN Mean
0.020283	31.08968	0.8816231	2.8357422

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	1.64136489	0.54712163	0.70	0.5518

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	1.64136489	0.54712163	0.70	0.5518

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		2.918676667 B	17.20	0.0001	0.16966845
TRT	1	-0.065834444 B	-0.27	0.7844	0.23994742
	2	0.050291515 B	0.20	0.8430	0.25321404
	3	-0.270664667 B	-1.16	0.2498	0.23387182
	4	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: MGCONTEN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.00047149	0.00015716	2.67	0.0513
Error	102	0.00599777	0.00005880		
Corrected Total	105	0.00646926			

R-Square	C.V.	Root MSE	MGCONTEN Mean
0.072881	26.37714	0.0076682	0.0290715

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	0.00047149	0.00015716	2.67	0.0513

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	0.00047149	0.00015716	2.67	0.0513

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		0.0305438852 B	20.70	0.0001	0.00147575
TRT	1	-.0047787519 B	-2.29	0.0241	0.00208703
	2	-.0018812125 B	-0.85	0.3950	0.00220242
	3	0.0004779215 B	0.23	0.8147	0.00203418
	4	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: MNCONTEN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	8.60108772	2.86702924	7.01	0.0002
Error	102	41.69475607	0.40877212		
Corrected Total	105	50.29584380			

R-Square	C.V.	Root MSE	MNCONTEN Mean
0.171010	28.27732	0.6393529	2.2610093

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	8.60108772	2.86702924	7.01	0.0002

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	8.60108772	2.86702924	7.01	0.0002

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		2.605530000 B	21.18	0.0001	0.12304352
TRT	1	-0.697610741 B	-4.01	0.0001	0.17400982
	2	-0.570748182 B	-3.11	0.0024	0.18363077
	3	-0.170908000 B	-1.01	0.3160	0.16960379
	4	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: PCONTEN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.00856344	0.00285448	76.22	0.0001
Error	102	0.00382012	0.00003745		
Corrected Total	105	0.01238356			

R-Square	C.V.	Root MSE	PCONTEN Mean
0.691517	29.29956	0.0061198	0.0208871

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	0.00856344	0.00285448	76.22	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	0.00856344	0.00285448	76.22	0.0001

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		0.0313909370 B	26.65	0.0001	0.00117776
TRT	1	-.0189241519 B	-11.36	0.0001	0.00166560
	2	-.0018569461 B	-1.06	0.2933	0.00175769
	3	-.0187201970 B	-11.53	0.0001	0.00162343
	4	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: ZNCONTEN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	9.37138462	3.12379487	0.91	0.4406
Error	102	351.37609533	3.44486368		
Corrected Total	105	360.74747995			

R-Square	C.V.	Root MSE	ZNCONTEN Mean
0.025978	56.99442	1.8560344	3.2565195

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	9.37138462	3.12379487	0.91	0.4406

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	9.37138462	3.12379487	0.91	0.4406

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		3.101015185 B	8.68	0.0001	0.35719399
TRT	1	0.293596667 B	0.58	0.5624	0.50514858
	2	-0.299155185 B	-0.56	0.5759	0.53307810
	3	0.504592148 B	1.02	0.3079	0.49235793
	4	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: KCONTEN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.01242565	0.00414188	4.86	0.0034
Error	102	0.08696632	0.00085261		
Corrected Total	105	0.09939196			

R-Square	C.V.	Root MSE	KCONTEN Mean
0.125017	32.77099	0.0291995	0.0891017

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	0.01242565	0.00414188	4.86	0.0034

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	0.01242565	0.00414188	4.86	0.0034

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		0.1057283667 B	18.81	0.0001	0.00561945
TRT	1	-.0254560926 B	-3.20	0.0018	0.00794710
	2	-.0134253394 B	-1.60	0.1125	0.00838649
	3	-.0259919400 B	-3.36	0.0011	0.00774587
	4	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: NCONTEN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.44728923	0.14909641	50.83	0.0001
Error	102	0.29920732	0.00293341		
Corrected Total	105	0.74649656			

R-Square	C.V.	Root MSE	NCONTEN Mean
0.599185	26.84103	0.0541609	0.2017840

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	0.44728923	0.14909641	50.83	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	0.44728923	0.14909641	50.83	0.0001

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		0.2704745556 B	25.95	0.0001	0.01042327
TRT	1	-.1471041111 B	-9.98	0.0001	0.01474073
	2	-.1268915556 B	-8.16	0.0001	0.01555575
	3	-.0172589556 B	-1.20	0.2324	0.01436749
	4	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

Least Square Means for Foliar Nutrient Contents

The SAS System

General Linear Models Procedure
Least Squares Means

TRT	CACONTEN LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	0.05544311	1	.	0.2244	0.0012	0.0095
2	0.06359949	2	0.2244	.	0.0597	0.2025
3	0.07601717	3	0.0012	0.0597	.	0.5326
4	0.07215815	4	0.0095	0.2025	0.5326	.

TRT	CUCONTEN LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	0.22833630	1	.	0.3042	0.6744	0.5320
2	0.18952182	2	0.3042	.	0.1488	0.6620
3	0.24296067	3	0.6744	0.1488	.	0.2895
4	0.20599926	4	0.5320	0.6620	0.2895	.

TRT	FECONTEN LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	2.85284222	1	.	0.6475	0.3832	0.7844
2	2.96896818	2	0.6475	.	0.1976	0.8430
3	2.64801200	3	0.3832	0.1976	.	0.2498
4	2.91867667	4	0.7844	0.8430	0.2498	.

TRT	MGCONTEN LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	0.02576513	1	.	0.1913	0.0112	0.0241
2	0.02866267	2	0.1913	.	0.2756	0.3950
3	0.03102181	3	0.0112	0.2756	.	0.8147
4	0.03054389	4	0.0241	0.3950	0.8147	.

TRT	MNCONTEN LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	1.90791926	1	.	0.4912	0.0025	0.0001
2	2.03478182	2	0.4912	.	0.0281	0.0024
3	2.43462200	3	0.0025	0.0281	.	0.3160
4	2.60553000	4	0.0001	0.0024	0.3160	.

The SAS System

General Linear Models Procedure
Least Squares Means

TRT	PCONTEN LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	0.01246679	1	.	0.0001	0.9003	0.0001
2	0.02953399	2	0.0001	.	0.0001	0.2933
3	0.01267074	3	0.9003	0.0001	.	0.0001
4	0.03139094	4	0.0001	0.2933	0.0001	.

TRT	ZNCONTEN LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	3.39461185	1	.	0.2688	0.6692	0.5624
2	2.80186000	2	0.2688	.	0.1260	0.5759
3	3.60560733	3	0.6692	0.1260	.	0.3079
4	3.10101519	4	0.5624	0.5759	0.3079	.

TRT	KCONTEN LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	0.08027227	1	.	0.1545	0.9450	0.0018
2	0.09230303	2	0.1545	.	0.1283	0.1125
3	0.07973643	3	0.9450	0.1283	.	0.0011
4	0.10572837	4	0.0018	0.1125	0.0011	.

TRT	NCONTEN LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	0.12337044	1	.	0.1967	0.0001	0.0001
2	0.14358300	2	0.1967	.	0.0001	0.0001
3	0.25321560	3	0.0001	0.0001	.	0.2324
4	0.27047456	4	0.0001	0.0001	0.2324	.

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

Statistical Results of Data not Presented but Mentioned in Text

Variables for Root Position Model by Treatment and Root Position

Root Chemistry Variables

Phenolics (PHENOL)
Tannins (TANNIN)
Sugar (SUGAR)
Starch (STARCH)

Root Position Variables

Root Tip
Root Collar

Treatment Variables

Low N, Low K
Low N, High K
High N, Low K
High N, High K

General Linear Models Procedure by Treatment and Root Position

Class Level Information

Class	Levels	Values
TRT	4	1 2 3 4
POSITION	2	1 2

Number of observations in data set = 52

General Linear Models Procedure

Dependent Variable: PHENOL

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	1469.7360299	367.4340075	74.77	0.0001
Error	47	230.9754374	4.9143710		
Corrected Total	51	1700.7114673			

R-Square	C.V.	Root MSE	PHENOL Mean
0.864189	27.56536	2.2168381	8.0421154

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	52.7148280	17.5716093	3.58	0.0207
POSITION	1	1417.0212019	1417.0212019	288.34	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	52.7148280	17.5716093	3.58	0.0207
POSITION	1	1417.0212019	1417.0212019	288.34	0.0001

General Linear Models Procedure

Dependent Variable: TANNIN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	612.18326456	153.04581614	46.56	0.0001
Error	47	154.49326621	3.28709077		
Corrected Total	51	766.67653077			

R-Square	C.V.	Root MSE	TANNIN Mean
0.798490	35.69775	1.8130336	5.0788462

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	70.18914148	23.39638049	7.12	0.0005
POSITION	1	541.99412308	541.99412308	164.89	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	70.18914148	23.39638049	7.12	0.0005
POSITION	1	541.99412308	541.99412308	164.89	0.0001

General Linear Models Procedure

Dependent Variable: SUGAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	412.88406007	103.22101502	29.99	0.0001
Error	47	161.77261685	3.44197057		
Corrected Total	51	574.65667692			

R-Square	C.V.	Root MSE	SUGAR Mean
0.718488	26.85482	1.8552549	6.9084615

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	11.22962930	3.74320977	1.09	0.3636
POSITION	1	401.65443077	401.65443077	116.69	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	11.22962930	3.74320977	1.09	0.3636
POSITION	1	401.65443077	401.65443077	116.69	0.0001

General Linear Models Procedure

Dependent Variable: STARCH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	413.28632344	103.32158086	19.14	0.0001
Error	47	253.65490733	5.39691292		
Corrected Total	51	666.94123077			

R-Square	C.V.	Root MSE	STARCH Mean
0.619674	17.72546	2.3231257	13.106154

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	148.68459267	49.56153089	9.18	0.0001
POSITION	1	264.60173077	264.60173077	49.03	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	148.68459267	49.56153089	9.18	0.0001
POSITION	1	264.60173077	264.60173077	49.03	0.0001

APPENDIX C

SUMMARY MEANS FOR FOLIAR NUTRIENT, GROWTH AND GAS EXCHANGE MEASUREMENTS TAKEN PERIODICALLY OVER THE THREE YEAR STUDY PERIOD

Summary Means for Foliar Nutrient, Growth and Gas Exchange Measurements

Variables for Growth Parameters

Variables	**Units**
Stem Diameter (STEMD)	millimeters
Stem Weight (STEMWT)	grams
Needle Weight (NEEDWT)	grams
Root Weight (ROOTWT)	grams
Total Weight (TOTALWT)	grams

Summary Means for Growth Parameters Over the Three Year Study Period

The SAS System

YEAR=90 MONTH=7 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	2.650	0.387	2.200	3.100
STEMWT	0.364	0.131	0.221	0.481
NEEDWT	0.755	0.159	0.581	0.921
ROOTWT	0.543	0.244	0.267	0.802
TOTALWT	1.662	0.527	1.069	2.137

YEAR=90 MONTH=7 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	2.100	0.082	2.000	2.200
STEMWT	0.300	0.058	0.247	0.371
NEEDWT	0.660	0.154	0.500	0.857
ROOTWT	0.585	0.116	0.487	0.753
TOTALWT	1.545	0.192	1.284	1.745

YEAR=90 MONTH=7 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	2.325	0.403	1.900	2.800
STEMWT	0.284	0.073	0.227	0.390
NEEDWT	0.513	0.141	0.379	0.699
ROOTWT	0.530	0.093	0.393	0.590
TOTALWT	1.326	0.213	1.179	1.636

YEAR=90 MONTH=7 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	2.075	0.126	1.900	2.200
STEMWT	0.368	0.153	0.156	0.498
NEEDWT	0.755	0.268	0.354	0.911
ROOTWT	0.524	0.158	0.293	0.642
TOTALWT	1.647	0.568	0.803	2.019

The SAS System

YEAR=90 MONTH=8 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	2.625	0.419	2.000	2.900
STEMWT	0.528	0.177	0.280	0.693
NEEDWT	0.795	0.246	0.557	1.021
ROOTWT	0.970	0.187	0.775	1.220
TOTALWT	2.293	0.420	1.663	2.525

YEAR=90 MONTH=8 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	2.675	0.287	2.300	2.900
STEMWT	0.544	0.168	0.386	0.705
NEEDWT	0.942	0.234	0.659	1.211
ROOTWT	1.088	0.451	0.744	1.715
TOTALWT	2.574	0.825	1.815	3.631

YEAR=90 MONTH=8 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	2.600	0.408	2.300	3.200
STEMWT	0.496	0.159	0.349	0.715
NEEDWT	0.946	0.348	0.530	1.382
ROOTWT	0.924	0.338	0.433	1.204
TOTALWT	2.366	0.778	1.312	3.154

YEAR=90 MONTH=8 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	3.100	0.283	2.900	3.500
STEMWT	0.716	0.202	0.548	0.974
NEEDWT	1.238	0.467	0.802	1.818
ROOTWT	0.972	0.239	0.683	1.230
TOTALWT	2.926	0.845	2.034	4.021

The SAS System

YEAR=90 MONTH=9 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	3.200	0.245	2.900	3.500
STEMWT	0.718	0.294	0.361	1.080
NEEDWT	1.239	0.602	0.750	2.118
ROOTWT	1.170	0.286	0.888	1.570
TOTALWT	3.128	1.168	1.998	4.767

YEAR=90 MONTH=9 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	3.200	0.258	2.900	3.500
STEMWT	0.807	0.239	0.625	1.142
NEEDWT	1.439	0.489	0.932	2.096
ROOTWT	1.369	0.318	1.012	1.764
TOTALWT	3.616	1.034	2.588	5.001

YEAR=90 MONTH=9 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	3.650	0.545	2.900	4.100
STEMWT	0.899	0.420	0.279	1.179
NEEDWT	1.185	0.443	0.556	1.582
ROOTWT	1.278	0.346	0.849	1.681
TOTALWT	3.362	1.131	1.684	4.097

YEAR=90 MONTH=9 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	3.775	0.275	3.500	4.100
STEMWT	1.147	0.213	0.838	1.295
NEEDWT	1.657	0.316	1.239	1.917
ROOTWT	1.387	0.350	1.019	1.831
TOTALWT	4.192	0.773	3.445	5.042

The SAS System

YEAR=90 MONTH=10 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	3.300	0.316	3.000	3.700
STEMWT	1.001	0.061	0.914	1.052
NEEDWT	1.444	0.346	1.012	1.857
ROOTWT	1.752	0.521	1.039	2.280
TOTALWT	4.197	0.691	3.580	5.147

YEAR=90 MONTH=10 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	3.325	0.386	3.100	3.900
STEMWT	0.878	0.200	0.715	1.144
NEEDWT	1.405	0.216	1.198	1.681
ROOTWT	2.145	0.273	1.950	2.547
TOTALWT	4.427	0.149	4.254	4.553

YEAR=90 MONTH=10 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	4.525	0.457	4.000	5.000
STEMWT	1.772	0.523	1.395	2.538
NEEDWT	1.560	0.344	1.222	2.039
ROOTWT	2.623	0.446	2.111	3.003
TOTALWT	5.955	1.128	4.974	7.580

YEAR=90 MONTH=10 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	4.450	0.785	3.800	5.500
STEMWT	1.550	0.360	1.073	1.894
NEEDWT	1.803	0.392	1.351	2.306
ROOTWT	2.564	0.890	1.506	3.677
TOTALWT	5.917	1.499	3.930	7.385

The SAS System

YEAR=91 MONTH=6 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	3.875	0.320	3.600	4.200
STEMWT	1.155	0.221	0.925	1.345
NEEDWT	1.132	0.276	0.801	1.450
ROOTWT	2.056	0.480	1.441	2.468
TOTALWT	4.344	0.907	3.167	5.262

YEAR=91 MONTH=6 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	3.725	1.250	2.800	5.500
STEMWT	1.072	0.596	0.614	1.880
NEEDWT	1.295	0.664	0.846	2.266
ROOTWT	2.411	1.011	1.546	3.614
TOTALWT	4.777	2.233	3.062	7.760

YEAR=91 MONTH=6 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	5.450	1.100	3.800	6.000
STEMWT	2.595	0.615	1.767	3.151
NEEDWT	2.478	0.333	2.019	2.817
ROOTWT	3.653	1.344	2.007	5.132
TOTALWT	8.726	2.059	5.794	10.616

YEAR=91 MONTH=6 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	5.750	0.420	5.300	6.200
STEMWT	2.904	0.373	2.352	3.172
NEEDWT	2.231	0.226	1.938	2.433
ROOTWT	3.418	0.485	3.013	4.047
TOTALWT	8.552	0.999	7.303	9.602

The SAS System

YEAR=91 MONTH=8 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	3.475	0.340	3.200	3.900
STEMWT	1.096	0.294	0.842	1.507
NEEDWT	1.506	0.225	1.280	1.794
ROOTWT	2.273	0.469	1.661	2.787
TOTALWT	4.875	0.968	3.783	6.088

YEAR=91 MONTH=8 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	3.600	0.535	3.100	4.200
STEMWT	1.209	0.163	1.023	1.407
NEEDWT	1.788	1.062	0.923	3.261
ROOTWT	2.401	1.018	1.544	3.645
TOTALWT	5.399	2.172	3.490	8.162

YEAR=91 MONTH=8 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	5.350	0.835	4.200	6.100
STEMWT	3.238	0.711	2.185	3.746
NEEDWT	4.442	1.367	2.856	5.869
ROOTWT	4.366	0.435	3.785	4.826
TOTALWT	12.045	2.403	8.826	14.442

YEAR=91 MONTH=8 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	5.600	0.938	4.200	6.200
STEMWT	3.183	0.982	2.185	4.160
NEEDWT	4.148	1.849	2.388	6.317
ROOTWT	4.361	1.316	3.190	6.227
TOTALWT	11.693	3.755	8.085	15.140

The SAS System

YEAR=91 MONTH=10 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	4.725	0.629	3.800	5.200
STEMWT	2.256	0.837	1.123	3.113
NEEDWT	1.752	0.588	0.924	2.313
ROOTWT	4.669	1.508	2.630	6.256
TOTALWT	8.677	2.692	4.677	10.356

YEAR=91 MONTH=10 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	4.575	0.377	4.100	5.000
STEMWT	2.141	0.318	1.824	2.491
NEEDWT	1.404	0.407	1.082	2.000
ROOTWT	5.026	0.780	3.953	5.802
TOTALWT	8.571	0.834	7.523	9.554

YEAR=91 MONTH=10 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	7.350	0.436	7.100	8.000
STEMWT	6.490	1.213	5.213	7.949
NEEDWT	5.531	0.893	4.903	6.810
ROOTWT	9.705	1.872	7.827	12.217
TOTALWT	21.726	0.879	20.470	22.333

YEAR=91 MONTH=10 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	6.475	0.550	6.000	7.000
STEMWT	4.914	1.596	2.692	6.133
NEEDWT	3.410	1.052	2.604	4.920
ROOTWT	9.612	3.780	7.127	15.217
TOTALWT	17.935	5.782	12.905	26.270

The SAS System

YEAR=91 MONTH=12 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	5.113	0.797	4.000	6.500
STEMWT	1.800	0.554	1.249	3.070
NEEDWT	1.513	0.566	0.758	2.701
ROOTWT	4.772	1.433	2.627	7.737
TOTALWT	8.086	2.518	4.634	13.507

YEAR=91 MONTH=12 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	5.213	0.642	4.000	5.900
STEMWT	1.747	0.471	1.017	2.371
NEEDWT	1.393	0.430	0.713	1.833
ROOTWT	4.275	1.221	2.297	5.824
TOTALWT	7.415	2.029	4.167	9.368

YEAR=91 MONTH=12 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	9.088	0.755	8.200	10.200
STEMWT	7.193	1.464	4.488	8.729
NEEDWT	4.812	1.657	2.362	6.771
ROOTWT	12.215	4.363	4.610	17.528
TOTALWT	24.220	6.658	14.148	31.783

YEAR=91 MONTH=12 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	8.950	1.294	6.400	11.000
STEMWT	7.285	4.601	2.530	17.932
NEEDWT	3.542	0.917	1.588	4.757
ROOTWT	8.958	2.629	3.527	12.206
TOTALWT	19.784	6.088	10.098	31.780

The SAS System

YEAR=92 MONTH=6 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	6.025	0.544	5.300	6.600
STEMWT	3.645	2.015	0.802	5.489
NEEDWT	5.030	2.764	1.365	7.786
ROOTWT	4.778	2.160	1.705	6.747
TOTALWT	13.453	6.761	3.872	18.789

YEAR=92 MONTH=6 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	6.725	0.457	6.200	7.200
STEMWT	5.651	0.665	4.904	6.482
NEEDWT	9.879	1.380	8.069	11.314
ROOTWT	7.130	1.475	5.700	9.147
TOTALWT	22.659	3.386	18.673	26.944

YEAR=92 MONTH=6 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	9.625	0.275	9.300	9.900
STEMWT	16.350	2.666	13.483	19.786
NEEDWT	18.370	2.295	16.243	21.336
ROOTWT	16.038	4.972	11.499	21.291
TOTALWT	50.758	9.340	41.900	60.388

YEAR=92 MONTH=6 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	7.700	1.334	6.200	9.400
STEMWT	9.685	3.730	4.811	13.901
NEEDWT	13.175	5.105	6.245	18.496
ROOTWT	10.624	5.493	4.460	17.646
TOTALWT	33.483	14.190	15.516	50.043

The SAS System

YEAR=92 MONTH=7 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	7.700	1.192	6.300	9.000
STEMWT	5.289	2.033	3.020	7.398
NEEDWT	5.288	2.579	2.517	8.232
ROOTWT	8.099	3.394	4.448	11.826
TOTALWT	18.676	7.874	9.985	26.609

YEAR=92 MONTH=7 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	6.575	0.096	6.500	6.700
STEMWT	4.021	0.263	3.722	4.359
NEEDWT	5.006	0.578	4.304	5.719
ROOTWT	6.504	0.722	5.652	7.416
TOTALWT	15.531	1.559	13.678	17.494

YEAR=92 MONTH=7 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	14.050	2.092	11.500	16.000
STEMWT	24.332	3.139	21.583	28.229
NEEDWT	18.680	1.657	17.209	20.951
ROOTWT	21.489	3.361	18.255	25.960
TOTALWT	64.501	5.402	57.995	71.205

YEAR=92 MONTH=7 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	10.000	0.913	9.000	11.000
STEMWT	10.552	2.214	8.377	13.622
NEEDWT	8.612	1.680	7.394	11.057
ROOTWT	8.564	1.641	6.219	9.842
TOTALWT	27.727	3.913	24.238	33.338

The SAS System

YEAR=92 MONTH=8 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	7.275	1.520	5.100	8.600
STEMWT	4.132	1.850	1.688	5.676
NEEDWT	4.021	2.347	1.186	6.892
ROOTWT	6.756	4.320	2.128	12.341
TOTALWT	14.909	8.365	5.002	24.908

YEAR=92 MONTH=8 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	7.750	0.420	7.300	8.300
STEMWT	5.610	0.473	5.172	6.238
NEEDWT	5.131	0.478	4.672	5.804
ROOTWT	9.667	0.799	8.834	10.757
TOTALWT	20.408	1.732	18.678	22.799

YEAR=92 MONTH=8 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	14.075	1.539	12.800	16.300
STEMWT	23.166	1.288	21.683	24.650
NEEDWT	14.880	1.847	12.293	16.568
ROOTWT	27.770	8.624	18.519	38.128
TOTALWT	65.816	10.060	53.442	75.520

YEAR=92 MONTH=8 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	13.125	1.464	12.000	15.200
STEMWT	17.502	2.473	14.235	20.075
NEEDWT	13.816	2.361	11.407	16.782
ROOTWT	16.644	5.971	11.739	25.307
TOTALWT	47.962	9.780	39.772	62.164

The SAS System

YEAR=92 MONTH=9 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	8.200	1.042	6.800	9.300
STEMWT	5.435	2.103	3.592	8.170
NEEDWT	4.104	1.411	2.766	5.862
ROOTWT	8.228	3.377	5.146	13.044
TOTALWT	17.767	6.672	11.902	27.076

YEAR=92 MONTH=9 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	5.250	0.129	5.100	5.400
STEMWT	2.838	0.671	2.026	3.670
NEEDWT	2.026	0.801	1.110	3.060
ROOTWT	4.444	1.448	2.558	6.088
TOTALWT	9.308	2.909	5.694	12.817

YEAR=92 MONTH=9 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	11.075	1.539	9.800	13.200
STEMWT	14.760	5.677	9.353	20.427
NEEDWT	8.952	3.056	6.617	13.161
ROOTWT	15.202	5.943	10.616	23.840
TOTALWT	38.914	14.069	27.662	57.428

YEAR=92 MONTH=9 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	11.175	1.372	9.200	12.200
STEMWT	12.068	3.142	7.701	14.891
NEEDWT	9.230	2.872	4.930	10.845
ROOTWT	14.425	6.674	6.237	20.335
TOTALWT	35.722	12.350	18.868	45.937

The SAS System

YEAR=92 MONTH=10 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	7.389	1.609	5.000	12.100
STEMWT	5.659	2.910	2.060	14.131
NEEDWT	4.560	2.710	1.273	12.747
ROOTWT	9.079	3.663	4.047	17.612
TOTALWT	19.299	8.857	7.469	42.128

YEAR=92 MONTH=10 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	6.783	1.880	4.000	10.900
STEMWT	4.747	3.090	1.063	12.159
NEEDWT	4.296	2.878	0.438	10.442
ROOTWT	8.301	4.437	0.808	16.511
TOTALWT	17.779	10.207	2.478	39.112

YEAR=92 MONTH=10 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	13.159	3.493	6.000	20.000
STEMWT	23.418	11.797	4.146	46.267
NEEDWT	14.036	7.134	1.827	28.180
ROOTWT	24.763	13.926	4.605	54.485
TOTALWT	62.218	32.316	10.881	125.537

YEAR=92 MONTH=10 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
STEMD	12.867	3.527	7.400	20.500
STEMWT	20.986	13.846	3.087	67.911
NEEDWT	14.126	9.129	1.290	47.916
ROOTWT	20.027	11.659	2.427	57.592
TOTALWT	55.139	34.101	6.803	173.420

Summary Means for Foliar Nutrient, Growth and Gas Exchange Measurements

Variables for Foliar Nutrient Concentrations

Variable	Units
Calcium (CA)	% concentration
Copper (CU)	ppm concentration
Iron (FE)	ppm concentration
Magnesium (MG)	% concentration
Manganese (MN)	ppm concentration
Phosphorus (P)	% concentration
Zinc (ZN)	ppm concentration
Potassium (K)	% concentration
Nitrogen (N)	% concentration
Potassium/Nitrogen Ratio (KN)	%

Summary Means for Foliar Nutrient Parameters Over the Three Year Study Period

The SAS System

YEAR=90 MONTH=7 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.258	0.065	0.193	0.346
CU	8.375	4.694	3.100	13.500
FE	49.775	15.024	36.700	68.100
MG	0.170	0.049	0.138	0.244
MN	40.850	17.724	23.900	56.700
P	0.341	0.118	0.247	0.514
ZN	34.225	6.644	25.400	40.100
K	0.993	0.034	0.944	1.018
N	1.249	0.172	0.991	1.350
KN	80.848	13.216	70.977	100.313

YEAR=90 MONTH=7 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.319	0.041	0.283	0.363
CU	8.075	2.392	6.200	11.500
FE	61.175	22.281	32.900	85.200
MG	0.198	0.040	0.163	0.250
MN	59.100	25.619	31.000	90.100
P	0.434	0.088	0.376	0.564
ZN	51.125	4.965	43.800	54.700
K	1.059	0.038	1.017	1.108
N	1.407	0.268	1.037	1.677
KN	77.363	14.784	63.262	98.100

YEAR=90 MONTH=7 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.309	0.037	0.267	0.358
CU	8.350	2.750	5.000	11.700
FE	40.850	1.229	39.300	42.300
MG	0.168	0.005	0.163	0.174
MN	36.750	2.255	34.000	39.500
P	0.420	0.013	0.405	0.436
ZN	44.500	3.189	40.400	48.100
K	1.001	0.009	0.989	1.012
N	1.743	0.194	1.504	1.978
KN	57.907	5.995	51.148	65.751

The SAS System

YEAR=90 MONTH=7 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.270	0.036	0.223	0.307
CU	4.700	1.152	3.500	6.200
FE	50.325	15.906	38.100	72.200
MG	0.155	0.020	0.129	0.178
MN	36.800	16.721	20.500	57.400
P	0.366	0.054	0.321	0.440
ZN	40.550	2.621	38.600	44.400
K	1.069	0.077	0.954	1.110
N	1.764	0.078	1.665	1.855
KN	60.714	5.288	53.874	66.366

YEAR=90 MONTH=8 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.291	0.032	0.268	0.337
CU	2.575	1.307	1.600	4.500
FE	36.500	15.315	19.600	56.800
MG	0.151	0.011	0.139	0.164
MN	33.625	15.146	18.700	49.000
P	0.289	0.039	0.243	0.337
ZN	30.800	9.408	18.100	40.800
K	0.837	0.107	0.754	0.994
N	0.937	0.085	0.830	1.007
KN	89.652	11.216	74.906	99.232

YEAR=90 MONTH=8 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.316	0.075	0.252	0.422
CU	1.575	0.574	0.800	2.100
FE	44.000	6.793	34.900	51.300
MG	0.167	0.023	0.135	0.188
MN	52.325	16.576	40.200	76.100
P	0.368	0.075	0.305	0.454
ZN	21.500	3.929	18.400	27.100
K	0.955	0.057	0.895	1.013
N	0.936	0.113	0.784	1.050
KN	102.739	7.880	96.514	114.171

The SAS System

YEAR=90 MONTH=8 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.358	0.068	0.316	0.460
CU	3.625	1.220	2.500	5.000
FE	33.525	14.620	18.900	53.500
MG	0.150	0.021	0.124	0.175
MN	24.925	5.178	20.400	31.700
P	0.252	0.035	0.222	0.293
ZN	24.775	7.822	18.200	35.700
K	0.854	0.178	0.629	1.027
N	1.592	0.148	1.428	1.733
KN	53.374	7.908	41.704	59.244

YEAR=90 MONTH=8 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.405	0.071	0.317	0.490
CU	1.700	0.804	1.100	2.800
FE	47.175	11.043	36.600	62.100
MG	0.204	0.037	0.154	0.239
MN	61.025	18.899	43.500	83.600
P	0.358	0.072	0.252	0.415
ZN	20.775	2.825	18.800	24.900
K	1.127	0.102	1.043	1.275
N	1.790	0.188	1.526	1.971
KN	63.964	13.193	55.566	83.578

YEAR=90 MONTH=9 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.271	0.086	0.160	0.356
CU	1.350	1.308	0.300	3.000
FE	39.800	16.065	22.500	61.300
MG	0.323	0.292	0.154	0.758
MN	22.050	5.789	14.000	27.500
P	0.220	0.074	0.114	0.285
ZN	26.075	10.906	16.500	39.600
K	0.614	0.137	0.411	0.708
N	1.009	0.254	0.676	1.292
KN	66.543	29.823	31.803	104.675

The SAS System

YEAR=90 MONTH=9 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.294	0.038	0.249	0.339
CU	1.300	1.102	0.200	2.600
FE	40.725	10.892	24.900	49.500
MG	0.165	0.025	0.140	0.192
MN	43.075	19.098	17.300	63.000
P	0.282	0.038	0.228	0.311
ZN	20.250	3.792	15.800	25.000
K	0.718	0.038	0.674	0.767
N	0.864	0.038	0.818	0.911
KN	83.255	5.341	78.601	88.512

YEAR=90 MONTH=9 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.474	0.096	0.368	0.597
CU	4.475	3.686	1.300	9.800
FE	35.350	10.175	29.800	50.600
MG	0.191	0.027	0.163	0.228
MN	37.775	17.856	24.700	64.100
P	0.207	0.051	0.138	0.254
ZN	40.325	10.057	25.300	46.200
K	0.838	0.154	0.661	0.998
N	2.100	0.161	1.952	2.316
KN	40.239	8.567	28.549	46.979

YEAR=90 MONTH=9 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.414	0.046	0.374	0.462
CU	2.400	0.829	1.200	3.000
FE	38.700	5.378	32.500	43.200
MG	0.182	0.028	0.149	0.213
MN	31.025	6.436	23.400	38.700
P	0.333	0.067	0.271	0.400
ZN	27.825	9.598	13.600	33.900
K	0.977	0.099	0.856	1.098
N	1.951	0.124	1.799	2.090
KN	50.308	6.892	42.759	57.427

The SAS System

YEAR=90 MONTH=10 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.355	0.071	0.295	0.457
CU	2.150	2.639	0.600	6.100
FE	44.125	7.246	35.000	52.600
MG	0.182	0.036	0.146	0.224
MN	32.600	9.155	25.200	45.000
P	0.185	0.016	0.169	0.207
ZN	20.775	5.163	16.600	28.100
K	0.643	0.116	0.513	0.795
N	0.877	0.130	0.787	1.065
KN	74.840	19.799	58.516	100.025

YEAR=90 MONTH=10 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.346	0.057	0.282	0.408
CU	2.250	2.255	0.400	5.300
FE	54.600	16.959	31.000	70.100
MG	0.194	0.021	0.167	0.216
MN	43.350	18.123	19.300	58.500
P	0.348	0.075	0.280	0.432
ZN	23.950	1.777	21.600	25.600
K	0.833	0.125	0.729	0.980
N	0.800	0.067	0.720	0.876
KN	104.385	15.675	88.281	125.900

YEAR=90 MONTH=10 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.550	0.100	0.411	0.645
CU	3.275	1.468	1.600	5.100
FE	43.250	5.286	35.500	47.400
MG	0.212	0.032	0.169	0.247
MN	33.475	6.960	27.100	40.900
P	0.172	0.020	0.157	0.200
ZN	35.675	9.873	27.000	48.400
K	0.675	0.103	0.565	0.799
N	1.605	0.199	1.428	1.838
KN	42.048	3.931	38.814	46.943

The SAS System

YEAR=90 MONTH=10 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.532	0.024	0.496	0.550
CU	1.525	0.866	0.700	2.700
FE	49.575	9.450	35.600	55.400
MG	0.241	0.020	0.219	0.259
MN	36.950	10.439	27.500	51.000
P	0.271	0.074	0.216	0.377
ZN	23.200	4.528	19.500	29.800
K	0.842	0.131	0.724	1.030
N	1.715	0.208	1.434	1.925
KN	49.095	3.836	44.475	53.506

YEAR=91 MONTH=6 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.458	0.126	0.305	0.564
CU	7.875	6.678	3.500	17.800
FE	61.125	12.850	43.600	73.600
MG	0.236	0.043	0.195	0.286
MN	48.175	15.301	25.600	58.800
P	0.188	0.033	0.158	0.225
ZN	27.900	8.352	19.400	35.800
K	0.526	0.084	0.407	0.604
N	0.802	0.058	0.717	0.843
KN	66.114	12.685	48.280	75.955

YEAR=91 MONTH=6 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.504	0.039	0.467	0.549
CU	7.375	3.526	4.600	12.200
FE	59.500	18.652	43.600	84.800
MG	0.252	0.030	0.208	0.273
MN	40.400	13.521	28.100	59.700
P	0.359	0.094	0.243	0.468
ZN	25.450	7.400	19.200	35.600
K	0.642	0.127	0.519	0.812
N	0.797	0.034	0.763	0.844
KN	80.608	16.270	67.995	102.617

The SAS System

YEAR=91 MONTH=6 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.562	0.053	0.518	0.625
CU	2.775	2.850	0.600	6.900
FE	43.125	14.584	27.200	58.500
MG	0.201	0.023	0.171	0.227
MN	34.350	11.905	20.300	48.000
P	0.111	0.023	0.091	0.144
ZN	25.425	10.816	14.600	36.700
K	0.376	0.117	0.258	0.537
N	1.459	0.198	1.224	1.676
KN	25.619	6.501	20.513	34.534

YEAR=91 MONTH=6 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.700	0.134	0.548	0.849
CU	4.250	1.436	2.400	5.800
FE	43.225	9.523	31.900	54.300
MG	0.204	0.041	0.159	0.242
MN	35.200	7.915	28.500	44.200
P	0.223	0.015	0.206	0.239
ZN	22.175	4.146	17.600	27.500
K	0.472	0.062	0.433	0.564
N	1.808	0.178	1.576	2.001
KN	26.235	3.806	21.614	30.209

YEAR=91 MONTH=8 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.582	0.090	0.479	0.680
CU	1.200	0.440	0.700	1.700
FE	27.675	10.511	20.600	43.300
MG	0.214	0.035	0.165	0.248
MN	20.025	6.749	14.700	29.900
P	0.127	0.012	0.112	0.138
ZN	27.750	10.159	16.700	40.300
K	0.334	0.041	0.294	0.388
N	0.802	0.103	0.657	0.899
KN	41.978	5.821	36.119	47.609

The SAS System

YEAR=91 MONTH=8 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.416	0.077	0.321	0.502
CU	1.100	0.812	0.300	1.800
FE	28.550	6.465	23.800	37.900
MG	0.193	0.029	0.163	0.222
MN	30.800	14.576	19.700	50.900
P	0.198	0.033	0.164	0.243
ZN	21.400	6.767	14.800	28.800
K	0.456	0.073	0.366	0.543
N	0.941	0.274	0.577	1.200
KN	50.385	9.070	43.306	63.402

YEAR=91 MONTH=8 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.565	0.170	0.421	0.803
CU	2.575	0.932	1.600	3.800
FE	17.800	1.639	15.700	19.200
MG	0.207	0.036	0.183	0.260
MN	22.825	9.456	12.700	35.500
P	0.086	0.007	0.077	0.091
ZN	25.925	4.601	21.800	32.200
K	0.426	0.054	0.361	0.476
N	1.522	0.185	1.336	1.772
KN	28.004	1.593	26.873	30.321

YEAR=91 MONTH=8 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.485	0.159	0.308	0.683
CU	1.325	0.206	1.100	1.500
FE	16.150	2.092	13.700	18.600
MG	0.185	0.044	0.132	0.239
MN	19.450	4.871	13.200	25.100
P	0.175	0.023	0.141	0.193
ZN	16.075	4.875	11.900	22.300
K	0.562	0.040	0.514	0.612
N	1.406	0.174	1.197	1.607
KN	40.700	7.962	31.987	51.086

The SAS System

YEAR=91 MONTH=10 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.749	0.128	0.617	0.922
CU	1.425	0.369	1.000	1.900
FE	57.325	14.344	42.400	70.100
MG	0.386	0.063	0.317	0.470
MN	43.550	11.925	30.100	57.200
P	0.192	0.050	0.162	0.267
ZN	38.475	22.145	13.400	62.100
K	0.609	0.183	0.391	0.821
N	0.937	0.070	0.872	1.029
KN	64.913	17.912	41.040	79.767

YEAR=91 MONTH=10 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.784	0.050	0.715	0.834
CU	1.225	0.519	0.500	1.600
FE	63.800	40.609	35.900	124.100
MG	0.341	0.045	0.306	0.406
MN	32.400	13.435	20.000	50.400
P	0.280	0.119	0.123	0.398
ZN	24.700	4.870	17.700	29.000
K	0.533	0.247	0.172	0.720
N	1.470	0.159	1.307	1.663
KN	35.856	16.630	13.145	52.159

YEAR=91 MONTH=10 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.756	0.089	0.630	0.834
CU	1.550	1.139	0.100	2.600
FE	51.225	4.366	46.500	55.900
MG	0.288	0.049	0.238	0.350
MN	51.925	19.400	31.400	74.500
P	0.188	0.071	0.136	0.288
ZN	37.750	24.319	14.800	61.000
K	0.732	0.133	0.640	0.922
N	1.792	0.158	1.663	2.013
KN	40.587	3.639	37.763	45.807

The SAS System

YEAR=91 MONTH=10 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.851	0.243	0.624	1.138
CU	1.125	0.830	0.200	2.200
FE	47.875	9.799	35.200	57.000
MG	0.266	0.067	0.209	0.348
MN	49.700	19.564	26.300	73.700
P	0.291	0.106	0.171	0.418
ZN	28.350	22.158	14.100	61.400
K	0.732	0.167	0.563	0.959
N	1.800	0.151	1.583	1.932
KN	40.981	10.000	29.125	51.488

YEAR=91 MONTH=12 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.773	0.171	0.588	1.107
CU	21.238	26.043	7.700	85.500
FE	36.500	7.789	25.400	49.900
MG	0.311	0.059	0.232	0.414
MN	31.363	14.153	18.200	60.800
P	0.194	0.070	0.109	0.343
ZN	59.525	21.775	28.100	91.200
K	0.325	0.150	0.230	0.680
N	1.526	0.226	1.247	1.896
KN	22.284	12.459	13.395	50.251

YEAR=91 MONTH=12 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.806	0.152	0.639	1.111
CU	9.050	2.611	4.800	12.200
FE	39.988	5.418	30.800	46.400
MG	0.354	0.053	0.251	0.417
MN	45.600	21.480	17.900	85.300
P	0.374	0.093	0.220	0.519
ZN	40.150	11.281	30.700	63.500
K	0.329	0.080	0.237	0.470
N	1.537	0.118	1.382	1.709
KN	21.449	4.866	14.031	27.518

The SAS System

YEAR=91 MONTH=12 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.749	0.064	0.665	0.854
CU	13.225	2.618	9.100	16.200
FE	40.863	8.985	27.400	57.900
MG	0.301	0.053	0.248	0.390
MN	69.163	17.392	40.800	97.000
P	0.141	0.053	0.092	0.246
ZN	40.625	16.487	27.000	69.000
K	0.328	0.045	0.248	0.406
N	1.935	0.359	1.625	2.748
KN	17.387	3.762	11.750	24.414

YEAR=91 MONTH=12 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.735	0.166	0.557	1.012
CU	11.600	3.703	6.500	17.600
FE	33.463	9.484	21.700	50.700
MG	0.271	0.055	0.190	0.384
MN	42.500	11.805	24.800	54.600
P	0.287	0.085	0.185	0.471
ZN	21.725	3.909	15.300	25.700
K	0.516	0.113	0.255	0.619
N	1.711	0.201	1.351	1.901
KN	30.226	6.633	17.403	40.799

YEAR=92 MONTH=6 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.471	0.101	0.387	0.612
CU	2.450	0.342	2.100	2.900
FE	30.800	5.217	23.500	35.500
MG	0.194	0.021	0.168	0.219
MN	29.250	9.371	19.100	41.800
P	0.130	0.031	0.096	0.169
ZN	26.750	2.408	25.000	30.200
K	0.524	0.059	0.467	0.607
N	0.888	0.208	0.680	1.150
KN	60.411	8.388	52.748	68.721

The SAS System

YEAR=92 MONTH=6 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.391	0.007	0.386	0.401
CU	1.800	0.606	1.200	2.600
FE	20.050	2.899	16.100	23.000
MG	0.163	0.009	0.152	0.173
MN	16.250	1.578	14.100	17.900
P	0.160	0.003	0.156	0.163
ZN	15.300	0.821	14.500	16.400
K	0.548	0.062	0.475	0.625
N	0.835	0.013	0.820	0.850
KN	65.524	6.489	57.915	73.541

YEAR=92 MONTH=6 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.501	0.107	0.430	0.660
CU	2.425	0.250	2.100	2.700
FE	27.500	5.977	19.800	33.800
MG	0.175	0.025	0.145	0.199
MN	47.850	11.191	33.500	60.800
P	0.120	0.032	0.086	0.151
ZN	26.400	6.347	19.700	34.700
K	0.485	0.025	0.458	0.511
N	1.235	0.048	1.190	1.290
KN	39.333	2.858	35.481	42.193

YEAR=92 MONTH=6 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.438	0.045	0.389	0.482
CU	1.325	0.189	1.200	1.600
FE	26.675	7.476	19.300	34.300
MG	0.158	0.016	0.136	0.174
MN	34.200	10.778	26.300	50.100
P	0.183	0.024	0.158	0.211
ZN	15.650	1.762	13.600	17.400
K	0.616	0.088	0.516	0.706
N	1.217	0.153	1.030	1.400
KN	50.782	5.953	45.744	59.311

The SAS System

YEAR=92 MONTH=7 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.560	0.125	0.440	0.730
CU	2.275	0.457	1.800	2.900
FE	45.500	14.201	30.000	64.000
MG	0.228	0.046	0.180	0.290
MN	21.500	3.416	18.000	26.000
P	0.098	0.014	0.084	0.110
ZN	25.500	9.747	19.000	40.000
K	0.475	0.090	0.400	0.600
N	0.870	0.187	0.700	1.090
KN	56.974	18.680	41.667	82.192

YEAR=92 MONTH=7 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.645	0.013	0.630	0.660
CU	3.700	0.374	3.200	4.100
FE	61.375	8.577	51.000	72.000
MG	0.240	0.008	0.230	0.250
MN	24.625	2.869	21.000	28.000
P	0.195	0.012	0.180	0.210
ZN	23.000	2.944	20.000	27.000
K	0.533	0.049	0.470	0.590
N	0.960	0.127	0.810	1.120
KN	55.688	2.315	52.679	58.025

YEAR=92 MONTH=7 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.640	0.073	0.550	0.730
CU	2.225	0.250	1.900	2.500
FE	36.500	8.583	27.000	46.000
MG	0.203	0.022	0.180	0.230
MN	46.500	9.037	41.000	60.000
P	0.084	0.011	0.074	0.096
ZN	23.000	1.414	21.000	24.000
K	0.458	0.054	0.380	0.500
N	1.413	0.078	1.370	1.530
KN	32.379	3.368	27.737	35.766

The SAS System

YEAR=92 MONTH=7 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.600	0.045	0.540	0.640
CU	1.950	0.500	1.400	2.600
FE	45.000	4.899	39.000	49.000
MG	0.215	0.029	0.180	0.250
MN	40.250	17.212	30.000	66.000
P	0.160	0.014	0.150	0.180
ZN	26.000	16.269	15.000	50.000
K	0.510	0.070	0.450	0.600
N	1.453	0.060	1.410	1.540
KN	35.194	5.339	29.870	41.667

YEAR=92 MONTH=8 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.418	0.092	0.320	0.510
CU	2.625	1.184	1.400	4.100
FE	41.000	16.021	32.000	65.000
MG	0.218	0.031	0.190	0.260
MN	22.825	7.056	17.300	33.000
P	0.078	0.011	0.071	0.094
ZN	22.750	5.188	19.000	30.000
K	0.533	0.093	0.430	0.650
N	0.900	0.226	0.700	1.220
KN	60.719	11.846	45.082	73.864

YEAR=92 MONTH=8 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.505	0.006	0.500	0.510
CU	1.375	0.096	1.300	1.500
FE	37.500	7.767	28.000	47.000
MG	0.225	0.006	0.220	0.230
MN	23.500	5.000	17.000	29.000
P	0.171	0.008	0.160	0.180
ZN	15.250	0.500	15.000	16.000
K	0.595	0.037	0.550	0.640
N	0.853	0.049	0.790	0.910
KN	69.786	0.887	68.605	70.588

The SAS System

YEAR=92 MONTH=8 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.613	0.133	0.520	0.810
CU	2.550	0.929	1.700	3.700
FE	41.250	9.878	29.000	53.000
MG	0.240	0.034	0.220	0.290
MN	39.500	6.557	31.000	47.000
P	0.086	0.012	0.072	0.100
ZN	19.500	4.203	15.000	24.000
K	0.708	0.135	0.530	0.840
N	1.450	0.328	1.110	1.840
KN	49.106	3.532	45.652	53.968

YEAR=92 MONTH=8 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.575	0.093	0.490	0.690
CU	1.725	0.171	1.500	1.900
FE	36.000	8.756	28.000	45.000
MG	0.238	0.017	0.220	0.260
MN	41.750	10.500	33.000	54.000
P	0.183	0.026	0.160	0.210
ZN	22.750	12.764	13.000	41.000
K	0.798	0.115	0.740	0.970
N	1.513	0.173	1.360	1.760
KN	53.601	12.479	42.045	71.324

YEAR=92 MONTH=9 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.678	0.145	0.510	0.860
CU	1.650	0.473	1.300	2.300
FE	13.300	13.157	5.700	33.000
MG	0.270	0.018	0.250	0.290
MN	22.250	2.630	20.000	26.000
P	0.114	0.019	0.096	0.140
ZN	29.750	8.995	19.000	41.000
K	0.665	0.055	0.610	0.730
N	1.028	0.104	0.880	1.100
KN	65.162	7.618	55.455	71.591

The SAS System

YEAR=92 MONTH=9 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.628	0.010	0.620	0.640
CU	1.350	0.058	1.300	1.400
FE	50.000	2.160	48.000	53.000
MG	0.275	0.021	0.250	0.300
MN	31.750	4.113	27.000	37.000
P	0.215	0.013	0.200	0.230
ZN	18.500	1.291	17.000	20.000
K	0.643	0.041	0.590	0.690
N	1.123	0.112	1.050	1.290
KN	57.847	8.351	45.736	64.486

YEAR=92 MONTH=9 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.725	0.175	0.580	0.970
CU	2.075	0.550	1.600	2.600
FE	43.250	13.351	24.000	54.000
MG	0.265	0.031	0.240	0.310
MN	51.750	7.136	42.000	58.000
P	0.103	0.019	0.089	0.130
ZN	31.500	14.012	16.000	50.000
K	0.665	0.148	0.460	0.810
N	1.613	0.330	1.390	2.100
KN	43.354	14.406	21.905	52.941

YEAR=92 MONTH=9 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.750	0.095	0.660	0.870
CU	1.400	0.392	1.000	1.900
FE	38.000	2.449	35.000	41.000
MG	0.258	0.062	0.220	0.350
MN	50.250	11.871	36.000	65.000
P	0.260	0.043	0.200	0.300
ZN	19.250	4.031	16.000	25.000
K	0.838	0.207	0.620	1.100
N	1.945	0.440	1.650	2.600
KN	45.139	16.926	28.462	66.667

The SAS System

YEAR=92 MONTH=10 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.467	0.103	0.283	0.770
CU	1.937	1.325	0.600	7.200
FE	24.126	4.589	16.200	35.300
MG	0.219	0.045	0.142	0.372
MN	16.174	2.681	9.600	20.300
P	0.108	0.021	0.081	0.158
ZN	28.815	15.772	9.700	73.100
K	0.681	0.162	0.410	1.090
N	1.062	0.214	0.630	1.480
KN	67.452	23.621	31.439	119.780

YEAR=92 MONTH=10 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.497	0.127	0.338	0.841
CU	1.464	0.416	0.800	2.800
FE	23.059	3.924	14.600	31.100
MG	0.225	0.041	0.176	0.345
MN	16.068	4.019	9.500	25.300
P	0.229	0.033	0.175	0.307
ZN	21.564	6.931	9.800	38.300
K	0.708	0.175	0.380	1.080
N	1.135	0.288	0.630	1.660
KN	66.925	26.375	30.894	130.120

YEAR=92 MONTH=10 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.548	0.122	0.320	0.831
CU	1.790	0.461	0.900	2.600
FE	19.540	3.792	13.000	29.900
MG	0.227	0.037	0.160	0.305
MN	17.783	3.239	12.600	31.600
P	0.094	0.021	0.054	0.138
ZN	26.193	14.283	13.900	77.300
K	0.592	0.150	0.343	0.873
N	1.851	0.232	1.420	2.310
KN	32.971	10.731	15.498	53.841

The SAS System

YEAR=92 MONTH=10 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
CA	0.508	0.119	0.328	0.782
CU	1.522	1.557	0.700	8.900
FE	20.311	6.090	12.200	43.900
MG	0.216	0.041	0.159	0.326
MN	18.322	3.283	11.500	24.800
P	0.221	0.050	0.121	0.323
ZN	22.048	11.531	7.500	52.300
K	0.736	0.164	0.342	1.020
N	1.904	0.292	0.910	2.470
KN	39.914	12.307	19.432	73.626

Summary Means for Foliar Nutrient, Growth and Gas Exchange Measurements

Variables for Gas Exchange

Variable	**Units**
Photosynthesis (PHOTOSYN)	$\mu mol\ m^{-2}s^{-1}$
Stomatal Conductance (STOMCON)	$mmol\ m^{-2}s^{-1}$
Transpiration (TRANSPIR)	$mmol\ m^{-2}s^{-1}$
Internal CO_2 (INTERCO2)	ppm
Ambient CO_2 (AMBIECO2)	ppm
Water Use Efficiency (WUE)	$\mu mol\ CO_2/mmol\ H_2O$
Total Leaf Area (TOTLF)	m^2

Summary Means for Gas Exchange Measurement Parameters Over the Three Year Study Period

The SAS System

YEAR=90 MONTH=8 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	10.148	3.270	5.250	11.990
STOMCON	0.179	0.061	0.088	0.213
TRANSPIR	6.325	2.156	3.100	7.600
INTERCO2	249.875	20.308	232.100	277.700
AMBIECO2	365.075	22.233	346.900	395.600
WUE	1.617	0.052	1.578	1.694
TOTLF	7.558	0.000	7.558	7.558

YEAR=90 MONTH=8 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	9.315	2.759	5.390	11.730
STOMCON	0.135	0.040	0.086	0.180
TRANSPIR	5.025	1.345	3.300	6.400
INTERCO2	231.525	9.565	219.600	241.200
AMBIECO2	365.500	4.812	358.700	369.900
WUE	1.839	0.166	1.633	2.040
TOTLF	7.558	0.000	7.558	7.558

YEAR=90 MONTH=8 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	10.435	4.464	6.120	15.760
STOMCON	0.137	0.046	0.092	0.192
TRANSPIR	5.200	1.278	3.900	6.800
INTERCO2	218.975	16.651	195.600	234.700
AMBIECO2	364.000	14.456	352.000	383.800
WUE	1.966	0.575	1.569	2.814
TOTLF	7.558	0.000	7.558	7.558

The SAS System

YEAR=90 MONTH=8 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	8.141	0.592	7.635	8.990
STOMCON	0.121	0.016	0.097	0.129
TRANSPIR	4.400	0.648	3.800	5.100
INTERCO2	224.825	20.242	204.100	243.800
AMBIECO2	356.025	10.350	341.000	364.700
WUE	1.893	0.397	1.497	2.366
TOTLF	7.558	0.000	7.558	7.558

YEAR=90 MONTH=9 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	8.988	4.349	4.540	14.760
STOMCON	0.134	0.049	0.078	0.198
TRANSPIR	4.050	1.434	2.400	5.900
INTERCO2	264.300	20.656	243.600	292.800
AMBIECO2	369.975	22.145	352.600	400.100
WUE	2.150	0.337	1.833	2.502
TOTLF	14.120	5.845	8.720	22.330

YEAR=90 MONTH=9 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	8.985	4.916	3.328	14.250
STOMCON	0.128	0.048	0.068	0.179
TRANSPIR	5.450	1.634	3.500	7.200
INTERCO2	243.525	14.509	229.500	262.900
AMBIECO2	365.575	14.297	354.900	385.900
WUE	1.537	0.481	0.925	1.979
TOTLF	17.800	2.203	14.570	19.520

The SAS System

YEAR=90 MONTH=9 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	11.937	2.728	9.078	15.590
STOMCON	0.245	0.084	0.146	0.343
TRANSPIR	7.500	2.440	4.900	10.400
INTERCO2	220.650	21.057	202.100	249.600
AMBIECO2	359.025	16.773	346.600	383.500
WUE	1.651	0.304	1.299	1.942
TOTLF	21.975	3.603	18.690	26.210

R=90 MONTH=9 TRT=HIGH N HIGH K

able	Mean	Std Dev	Minimum	Maximum
IOTOSYN	9.139	6.022	3.548	16.720
OMCON	0.141	0.087	0.071	0.266
SPIR	5.500	2.185	4.100	8.700
RCO2	230.275	26.280	207.200	268.100
BIECO2	346.250	28.953	306.700	376.100
E	1.557	0.606	0.865	2.186
F	17.940	6.428	9.990	25.080

R=90 MONTH=10 TRT=LOW N LOW K

riable	Mean	Std Dev	Minimum	Maximum
OSYN	2.373	2.472	0.519	5.960
OMCON	0.133	0.086	0.063	0.252
ANSPIR	1.200	0.424	0.700	1.600
RCO2	321.450	17.641	303.000	338.000
ECO2	355.375	1.513	354.000	357.500
E	1.702	1.372	0.741	3.725
TLF	17.183	8.160	12.160	29.290

e SAS System

EAR=90 MONTH=10 TRT=LOW N HIGH K

riable	Mean	Std Dev	Minimum	Maximum
OSYN	1.995	1.623	-0.380	3.170
CON	0.111	0.041	0.069	0.159
ANSPIR	0.950	0.173	0.800	1.200
TERCO2	327.225	31.884	296.300	369.700
ECO2	362.350	6.757	355.100	369.100
E	2.127	1.838	-0.422	3.963
TLF	19.270	8.692	6.750	25.790

EAR=90 MONTH=10 TRT=HIGH N LOW K

ble	Mean	Std Dev	Minimum	Maximum
OTOSYN	13.210	5.906	5.490	19.850
ON	0.263	0.149	0.097	0.406
PIR	1.925	0.350	1.500	2.300
TERCO2	255.050	14.723	238.000	267.500
BIECO2	354.450	17.554	339.200	370.000
E	6.610	2.115	3.660	8.630
T	23.080	9.420	13.320	34.870

The SAS System

YEAR=90 MONTH=11 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	6.078	4.446	0.930	11.780
STOMCON	0.203	0.028	0.185	0.245
TRANSPIR	2.125	0.403	1.700	2.600
INTERCO2	321.875	30.400	293.000	358.700
AMBIECO2	375.850	12.951	361.800	391.300
WUE	2.846	1.741	0.404	4.531
TOTLF	25.421	3.525	21.782	30.233

YEAR=91 MONTH=2 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	1.065	1.098	-0.430	2.105
STOMCON	0.021	0.008	0.012	0.032
TRANSPIR	0.275	0.206	0.100	0.500
INTERCO2	324.750	74.923	254.000	417.400
AMBIECO2	399.700	58.739	369.500	487.800
WUE	4.507	4.030	0.000	9.805
TOTLF	13.362	2.837	10.415	17.221

YEAR=91 MONTH=2 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	0.341	0.855	-0.930	0.866
STOMCON	0.018	0.013	0.001	0.031
TRANSPIR	0.300	0.258	0.000	0.600
INTERCO2	305.925	46.742	238.800	347.200
AMBIECO2	383.900	19.364	363.300	405.100
WUE	1.634	1.272	0.000	3.039
TOTLF	11.276	3.464	8.262	16.168

The SAS System

YEAR=91 MONTH=2 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.581	1.045	1.469	3.773
STOMCON	0.055	0.011	0.045	0.071
TRANSPIR	0.950	0.289	0.600	1.300
INTERCO2	307.125	23.303	272.200	320.000
AMBIECO2	392.100	20.791	373.400	417.600
WUE	2.933	1.597	1.469	5.162
TOTLF	27.680	4.978	22.007	33.885

YEAR=91 MONTH=2 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	4.771	2.720	2.065	7.531
STOMCON	0.055	0.023	0.036	0.088
TRANSPIR	0.725	0.206	0.500	1.000
INTERCO2	238.675	25.450	208.900	268.400
AMBIECO2	384.525	40.689	357.500	445.100
WUE	7.284	5.406	2.923	15.062
TOTLF	25.421	3.525	21.782	30.233

YEAR=91 MONTH=3 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	0.045	0.095	-0.060	0.124
STOMCON	0.003	0.002	0.002	0.006
TRANSPIR	0.033	0.058	0.000	0.100
INTERCO2	347.567	75.738	268.600	419.600
AMBIECO2	373.600	8.962	366.600	383.700
WUE	0.240	0.416	0.000	0.720
TOTLF	12.076	1.465	10.415	13.181

The SAS System

YEAR=91 MONTH=3 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	0.745	0.870	-0.081	1.746
STOMCON	0.013	0.015	0.001	0.035
TRANSPIR	0.150	0.173	0.000	0.400
INTERCO2	254.250	100.597	163.700	379.100
AMBIECO2	372.050	5.338	368.500	380.000
WUE	3.866	5.824	-0.810	11.910
TOTLF	11.276	3.464	8.262	16.168

YEAR=91 MONTH=3 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	5.926	2.365	4.077	8.591
STOMCON	0.055	0.016	0.044	0.074
TRANSPIR	0.867	0.115	0.800	1.000
INTERCO2	225.333	38.647	191.400	267.400
AMBIECO2	402.800	53.579	369.400	464.600
WUE	6.692	1.767	5.096	8.591
TOTLF	25.611	3.390	22.007	28.734

YEAR=91 MONTH=3 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.208	2.413	0.157	5.698
STOMCON	0.025	0.018	0.011	0.052
TRANSPIR	0.350	0.238	0.200	0.700
INTERCO2	259.825	68.108	189.800	353.300
AMBIECO2	383.800	14.339	370.200	401.700
WUE	5.394	3.531	0.785	8.180
TOTLF	25.421	3.525	21.782	30.233

The SAS System

YEAR=91 MONTH=6 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.287	1.319	0.930	3.917
STOMCON	0.029	0.026	0.005	0.065
TRANSPIR	1.200	0.879	0.200	2.200
INTERCO2	204.900	35.063	174.500	236.600
AMBIECO2	349.175	3.452	345.700	353.700
WUE	2.524	1.420	1.708	4.648
TOTLF	3.497	1.585	2.118	4.999

YEAR=91 MONTH=6 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	4.061	0.614	3.706	4.770
STOMCON	0.041	0.009	0.031	0.048
TRANSPIR	2.000	0.529	1.400	2.400
INTERCO2	165.567	19.462	153.200	188.000
AMBIECO2	350.933	16.166	341.600	369.600
WUE	2.428	0.381	1.988	2.649
TOTLF	5.893	1.152	4.687	6.981

YEAR=91 MONTH=6 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	4.249	1.156	3.259	5.524
STOMCON	0.040	0.021	0.015	0.059
TRANSPIR	1.800	1.102	0.500	2.900
INTERCO2	204.000	95.102	150.800	346.200
AMBIECO2	298.400	85.800	169.900	345.100
WUE	3.230	2.210	1.905	6.518
TOTLF	7.066	2.646	4.060	10.171

The SAS System

YEAR=91 MONTH=6 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	5.110	2.065	2.760	6.632
STOMCON	0.054	0.025	0.031	0.081
TRANSPIR	2.200	1.300	1.400	3.700
INTERCO2	165.233	30.443	130.100	183.800
AMBIECO2	342.800	3.863	339.400	347.000
WUE	2.625	1.400	1.792	4.242
TOTLF	7.839	1.825	5.732	8.930

YEAR=91 MONTH=7 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.642	1.113	1.042	3.523
STOMCON	0.045	0.014	0.027	0.062
TRANSPIR	2.275	0.585	1.600	2.900
INTERCO2	237.175	33.398	203.200	279.600
AMBIECO2	355.875	20.985	332.800	374.400
WUE	1.133	0.396	0.651	1.609
TOTLF	3.258	0.898	2.361	4.408

YEAR=91 MONTH=7 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	3.585	0.809	2.779	4.315
STOMCON	0.059	0.016	0.049	0.082
TRANSPIR	2.875	0.695	2.400	3.900
INTERCO2	223.500	14.485	206.900	241.500
AMBIECO2	346.450	14.886	328.200	364.300
WUE	1.418	0.341	1.089	1.726
TOTLF	4.613	1.783	3.224	6.965

The SAS System

YEAR=91 MONTH=7 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	5.728	2.086	3.850	8.704
STOMCON	0.060	0.010	0.047	0.069
TRANSPIR	2.950	0.465	2.400	3.500
INTERCO2	197.575	30.347	170.300	240.900
AMBIECO2	374.875	67.325	336.200	475.700
WUE	1.858	0.464	1.429	2.487
TOTLF	5.808	1.748	3.473	7.251

YEAR=91 MONTH=7 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	5.559	1.244	3.709	6.350
STOMCON	0.080	0.020	0.064	0.105
TRANSPIR	3.800	0.883	2.800	4.900
INTERCO2	207.850	9.746	198.800	221.500
AMBIECO2	346.150	33.133	317.700	394.000
WUE	1.472	0.221	1.296	1.778
TOTLF	5.597	1.434	3.732	7.001

YEAR=91 MONTH=8 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	3.706	1.287	2.096	5.245
STOMCON	0.055	0.017	0.038	0.076
TRANSPIR	1.925	0.556	1.300	2.600
INTERCO2	220.850	15.188	206.400	238.800
AMBIECO2	346.025	11.283	334.900	361.500
WUE	1.905	0.278	1.612	2.237
TOTLF	3.598	1.521	2.361	5.770

The SAS System

YEAR=91 MONTH=8 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	4.882	1.564	3.357	6.713
STOMCON	0.069	0.023	0.050	0.101
TRANSPIR	2.450	0.759	1.800	3.500
INTERCO2	216.925	5.116	209.700	221.300
AMBIECO2	348.375	6.040	341.600	356.300
WUE	1.975	0.186	1.865	2.251
TOTLF	4.613	1.783	3.224	6.965

YEAR=91 MONTH=8 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	5.104	1.998	3.273	7.332
STOMCON	0.077	0.021	0.057	0.103
TRANSPIR	2.450	0.557	1.900	3.200
INTERCO2	219.175	27.720	191.300	254.800
AMBIECO2	339.600	14.723	321.500	356.400
WUE	2.038	0.448	1.488	2.497
TOTLF	5.230	1.395	4.053	7.251

YEAR=91 MONTH=8 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	6.033	1.388	4.609	7.719
STOMCON	0.093	0.022	0.065	0.118
TRANSPIR	3.075	0.810	2.000	3.700
INTERCO2	209.075	22.374	184.500	237.000
AMBIECO2	333.000	10.279	320.300	343.900
WUE	2.017	0.451	1.589	2.621
TOTLF	5.343	1.335	3.732	7.001

The SAS System

YEAR=91 MONTH=10 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.572	0.936	1.163	3.821
STOMCON	0.034	0.008	0.020	0.046
TRANSPIR	0.800	0.129	0.600	0.900
INTERCO2	217.843	18.415	183.800	241.000
AMBIECO2	350.171	5.940	341.300	358.900
WUE	3.032	0.999	1.938	4.957
TOTLF	3.129	0.927	1.580	4.408

YEAR=91 MONTH=10 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.665	1.112	0.585	4.096
STOMCON	0.040	0.015	0.019	0.058
TRANSPIR	0.938	0.381	0.500	1.600
INTERCO2	232.425	30.189	181.000	287.300
AMBIECO2	349.913	4.915	342.200	356.200
WUE	2.954	1.372	1.169	5.962
TOTLF	3.566	1.952	1.901	6.965

YEAR=91 MONTH=10 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	4.350	2.043	1.006	7.022
STOMCON	0.056	0.026	0.017	0.097
TRANSPIR	1.271	0.599	0.400	2.100
INTERCO2	205.743	19.544	186.300	241.800
AMBIECO2	340.829	6.858	333.900	350.800
WUE	3.377	0.660	2.515	4.438
TOTLF	4.744	1.647	3.473	7.231

The SAS System

YEAR=91 MONTH=10 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	4.459	1.663	0.733	6.167
STOMCON	0.054	0.017	0.015	0.069
TRANSPIR	1.250	0.411	0.500	1.800
INTERCO2	219.013	53.228	181.400	335.600
AMBIECO2	327.650	48.689	208.000	353.400
WUE	3.477	0.990	1.466	4.711
TOTLF	6.009	2.512	2.217	9.983

YEAR=91 MONTH=12 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	1.237	0.310	0.741	1.578
STOMCON	0.017	0.004	0.012	0.022
TRANSPIR	0.171	0.049	0.100	0.200
INTERCO2	239.571	7.208	226.300	247.700
AMBIECO2	362.171	4.285	356.800	368.500
WUE	6.747	1.584	3.705	8.868
TOTLF	3.129	0.927	1.580	4.408

YEAR=91 MONTH=12 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	0.876	0.318	0.367	1.300
STOMCON	0.017	0.004	0.012	0.023
TRANSPIR	0.163	0.052	0.100	0.200
INTERCO2	278.400	31.012	251.200	348.300
AMBIECO2	355.863	21.526	302.800	366.400
WUE	5.452	1.327	3.670	7.427
TOTLF	3.566	1.952	1.901	6.965

The SAS System

YEAR=91 MONTH=12 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	1.760	1.303	0.616	4.314
STOMCON	0.023	0.011	0.013	0.041
TRANSPIR	0.257	0.113	0.100	0.400
INTERCO2	242.629	36.006	174.500	277.300
AMBIECO2	359.729	5.904	351.200	366.700
WUE	7.673	4.028	3.544	15.283
TOTLF	4.744	1.647	3.473	7.231

YEAR=91 MONTH=12 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	1.882	0.695	0.456	2.791
STOMCON	0.026	0.008	0.014	0.038
TRANSPIR	0.275	0.104	0.100	0.400
INTERCO2	235.125	43.340	159.300	303.800
AMBIECO2	359.538	1.538	357.400	362.500
WUE	6.891	1.764	4.569	9.304
TOTLF	6.350	3.213	2.217	12.706

YEAR=92 MONTH=6 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.534	0.857	1.529	3.617
STOMCON	0.047	0.019	0.023	0.066
TRANSPIR	1.525	0.499	0.800	1.900
INTERCO2	232.150	23.528	214.100	265.000
AMBIECO2	338.575	7.599	328.500	346.200
WUE	1.688	0.255	1.434	1.911
TOTLF	7.181	2.735	3.920	10.483

The SAS System

YEAR=92 MONTH=6 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.431	0.974	1.512	3.782
STOMCON	0.045	0.026	0.027	0.083
TRANSPIR	1.500	1.071	0.900	3.100
INTERCO2	226.550	29.216	201.500	259.000
AMBIECO2	337.125	3.477	334.300	342.000
WUE	1.879	0.700	1.220	2.689
TOTLF	7.847	3.136	4.017	11.450

YEAR=92 MONTH=6 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.160	0.996	0.923	3.138
STOMCON	0.042	0.021	0.019	0.070
TRANSPIR	1.500	0.804	0.600	2.500
INTERCO2	239.675	26.490	200.200	256.100
AMBIECO2	343.350	1.902	341.400	345.700
WUE	1.541	0.546	1.065	2.307
TOTLF	6.548	3.716	2.596	11.530

YEAR=92 MONTH=6 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	1.755	0.509	1.416	2.495
STOMCON	0.033	0.006	0.025	0.040
TRANSPIR	1.175	0.287	1.000	1.600
INTERCO2	234.475	21.106	207.000	254.100
AMBIECO2	337.650	6.811	330.100	345.500
WUE	1.565	0.574	0.885	2.268
TOTLF	6.787	0.985	5.809	7.682

The SAS System

YEAR=92 MONTH=7 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.844	1.217	1.652	4.517
STOMCON	0.062	0.015	0.050	0.084
TRANSPIR	1.850	0.526	1.400	2.600
INTERCO2	233.000	17.836	216.600	251.900
AMBIECO2	319.000	3.901	313.300	322.100
WUE	1.528	0.439	1.033	2.024
TOTLF	6.178	0.914	5.373	7.245

YEAR=92 MONTH=7 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.650	0.349	2.224	2.957
STOMCON	0.057	0.006	0.050	0.063
TRANSPIR	1.900	0.115	1.800	2.000
INTERCO2	234.050	17.348	214.500	256.600
AMBIECO2	325.150	8.935	317.800	336.800
WUE	1.396	0.185	1.236	1.618
TOTLF	6.640	1.324	4.772	7.900

YEAR=92 MONTH=7 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.894	1.323	1.934	4.795
STOMCON	0.057	0.022	0.034	0.084
TRANSPIR	1.800	0.812	1.000	2.800
INTERCO2	223.400	22.276	200.800	250.200
AMBIECO2	320.500	11.544	307.600	335.200
WUE	1.646	0.314	1.330	2.054
TOTLF	6.188	0.988	5.023	7.384

The SAS System

YEAR=92 MONTH=7 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	3.332	1.407	1.335	4.404
STOMCON	0.059	0.021	0.028	0.076
TRANSPIR	1.975	0.737	0.900	2.500
INTERCO2	212.250	14.177	192.500	226.200
AMBIECO2	316.375	6.281	308.000	323.100
WUE	1.652	0.136	1.483	1.762
TOTLF	5.376	0.748	4.294	5.909

YEAR=92 MONTH=8 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	1.759	0.485	1.325	2.367
STOMCON	0.071	0.008	0.061	0.078
TRANSPIR	3.275	0.435	2.900	3.700
INTERCO2	288.400	15.182	275.200	307.800
AMBIECO2	353.000	14.699	338.700	370.400
WUE	0.550	0.193	0.358	0.816
TOTLF	5.020	0.706	3.981	5.506

YEAR=92 MONTH=8 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.341	1.084	1.124	3.566
STOMCON	0.091	0.012	0.079	0.107
TRANSPIR	4.450	1.443	2.900	6.000
INTERCO2	279.475	36.215	247.800	327.400
AMBIECO2	345.350	16.408	331.300	368.700
WUE	0.518	0.142	0.312	0.626
TOTLF	5.951	1.736	3.911	7.961

The SAS System

YEAR=92 MONTH=8 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.872	0.903	1.584	4.074
STOMCON	0.105	0.025	0.078	0.139
TRANSPIR	4.920	0.634	4.100	5.700
INTERCO2	272.040	20.204	255.200	304.300
AMBIECO2	341.180	10.922	330.300	359.000
WUE	0.579	0.154	0.386	0.754
TOTLF	7.010	1.587	4.892	8.986

YEAR=92 MONTH=8 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.301	0.930	1.249	3.013
STOMCON	0.078	0.013	0.064	0.089
TRANSPIR	3.700	1.217	2.900	5.100
INTERCO2	272.233	26.223	247.600	299.800
AMBIECO2	345.267	14.900	330.300	360.100
WUE	0.635	0.257	0.403	0.911
TOTLF	5.845	2.021	4.034	8.025

YEAR=92 MONTH=9 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.100	0.680	1.084	2.531
STOMCON	0.061	0.009	0.049	0.069
TRANSPIR	1.100	0.216	0.800	1.300
INTERCO2	256.325	24.740	229.400	288.100
AMBIECO2	322.425	5.434	316.500	329.200
WUE	2.005	0.867	0.903	3.013
TOTLF	5.909	0.977	4.765	7.076

The SAS System

YEAR=92 MONTH=9 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	1.745	0.433	1.396	2.377
STOMCON	0.041	0.008	0.037	0.053
TRANSPIR	0.725	0.126	0.600	0.900
INTERCO2	246.000	5.807	238.800	253.000
AMBIECO2	322.975	2.301	320.000	325.200
WUE	2.388	0.172	2.254	2.641
TOTLF	4.289	1.237	2.877	5.354

YEAR=92 MONTH=9 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.680	1.028	1.700	3.957
STOMCON	0.071	0.020	0.047	0.094
TRANSPIR	1.275	0.299	0.900	1.600
INTERCO2	247.775	25.563	209.500	262.700
AMBIECO2	320.250	8.595	309.700	329.800
WUE	2.132	0.806	1.439	3.298
TOTLF	7.110	0.583	6.464	7.881

YEAR=92 MONTH=9 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	1.976	0.408	1.580	2.523
STOMCON	0.054	0.012	0.039	0.065
TRANSPIR	1.025	0.222	0.700	1.200
INTERCO2	253.850	13.229	241.500	271.400
AMBIECO2	323.200	5.945	317.300	330.800
WUE	1.967	0.385	1.479	2.294
TOTLF	4.836	0.950	4.121	6.178

The SAS System

YEAR=92 MONTH=10 TRT=LOW N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.451	0.945	1.031	3.915
STOMCON	0.044	0.015	0.022	0.090
TRANSPIR	1.961	0.429	1.200	3.100
INTERCO2	233.135	23.654	190.600	305.500
AMBIECO2	340.832	20.072	268.200	393.300
WUE	1.250	0.408	0.519	2.175
TOTLF	7.358	2.160	3.282	13.197

YEAR=92 MONTH=10 TRT=LOW N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.220	0.785	1.009	4.597
STOMCON	0.044	0.012	0.024	0.078
TRANSPIR	1.822	0.471	1.100	2.700
INTERCO2	246.248	26.908	207.000	324.800
AMBIECO2	349.981	25.816	328.000	459.600
WUE	1.277	0.465	0.561	2.554
TOTLF	7.268	1.635	4.020	10.154

YEAR=92 MONTH=10 TRT=HIGH N LOW K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.665	1.002	0.878	5.275
STOMCON	0.044	0.014	0.024	0.080
TRANSPIR	1.921	0.588	0.700	3.600
INTERCO2	229.594	32.748	174.400	292.900
AMBIECO2	349.835	26.943	307.400	451.700
WUE	1.430	0.519	0.585	3.103
TOTLF	7.608	2.006	3.950	12.491

The SAS System

YEAR=92 MONTH=10 TRT=HIGH N HIGH K

Variable	Mean	Std Dev	Minimum	Maximum
PHOTOSYN	2.716	1.119	1.113	6.494
STOMCON	0.044	0.014	0.025	0.084
TRANSPIR	1.831	0.471	1.000	3.000
INTERCO2	229.110	41.021	163.600	379.300
AMBIECO2	349.345	44.102	235.000	515.400
WUE	1.570	0.540	0.557	3.051
TOTLF	7.983	2.561	3.974	14.737

Statistical Analysis Documentation

Variables for Root Collar and Root Tip Chemistry

Variable	**Units**
Phenolics (PHENOL)	% Dry Weight
Tannins (TANNIN)	% Dry Weight
Sugar (SUGAR)	% Dry Weight
Starch (STARCH)	% Dry Weight
Phenolic/Sugar Ratio (PS)	

Experimental Design Statistical Models for Root Collar Chemistry

The SAS System

General Linear Models Procedure
Class Level Information

Class	Levels	Values
TRT	4	1 2 3 4

Number of observations in data set = 52

NOTE: All dependent variable are consistent with respect to the presence or absence of missing values. However only 26 observations can be used in this analysis.

The SAS System

General Linear Models Procedure

Dependent Variable: PHENOL

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	86.33248535	28.77749512	3.57	0.0305
Error	22	177.35757619	8.06170801		
Corrected Total	25	263.69006154			

R-Square	C.V.	Root MSE	PHENOL Mean
0.327401	21.40890	2.8393147	13.262308

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	86.33248535	28.77749512	3.57	0.0305

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	86.33248535	28.77749512	3.57	0.0305

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		15.48285714 B	14.43	0.0001	1.07316009
TRT	1	-4.49119048 B	-2.84	0.0095	1.57964888
	2	-3.72785714 B	-2.36	0.0276	1.57964888
	3	-1.20285714 B	-0.79	0.4365	1.51767755
	4	0.00000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: TANNIN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	121.32999963	40.44333321	9.58	0.0003
Error	22	92.88031190	4.22183236		
Corrected Total	25	214.21031154			

R-Square	C.V.	Root MSE	TANNIN Mean
0.566406	24.73376	2.0547098	8.3073077

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	121.32999963	40.44333321	9.58	0.0003

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	121.32999963	40.44333321	9.58	0.0003

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		11.21857143 B	14.45	0.0001	0.77660731
TRT	1	-5.28190476 B	-4.62	0.0001	1.14313500
	2	-4.89357143 B	-4.28	0.0003	1.14313500
	3	-2.09142857 B	-1.90	0.0700	1.09828859
	4	0.00000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: SUGAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	12.05560678	4.01853559	0.77	0.5250
Error	22	115.34545476	5.24297522		
Corrected Total	25	127.40106154			

R-Square	C.V.	Root MSE	SUGAR Mean
0.094627	23.63571	2.2897544	9.6876923

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	12.05560678	4.01853559	0.77	0.5250

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	12.05560678	4.01853559	0.77	0.5250

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		10.11428571 B	11.69	0.0001	0.86544582
TRT	1	-0.66428571 B	-0.52	0.6073	1.27390175
	2	-1.50595238 B	-1.18	0.2498	1.27390175
	3	0.27571429 B	0.23	0.8238	1.22392521
	4	0.00000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: STARCH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	83.91943480	27.97314493	3.13	0.0463
Error	22	196.66136905	8.93915314		
Corrected Total	25	280.58080385			

R-Square	C.V.	Root MSE	STARCH Mean
0.299092	19.46268	2.9898417	15.361923

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	83.91943480	27.97314493	3.13	0.0463

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	83.91943480	27.97314493	3.13	0.0463

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		13.27714286 B	11.75	0.0001	1.13005393
TRT	1	4.52785714 B	2.72	0.0124	1.66339434
	2	3.33952381 B	2.01	0.0571	1.66339434
	3	1.00000000 B	0.63	0.5379	1.59813759
	4	0.00000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: PS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.43041343	0.14347114	2.97	0.0539
Error	22	1.06199170	0.04827235		
Corrected Total	25	1.49240513			

R-Square	C.V.	Root MSE	PS Mean
0.288403	15.93845	0.2197097	1.3784883

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	0.43041343	0.14347114	2.97	0.0539

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	0.43041343	0.14347114	2.97	0.0539

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		1.555424131 B	18.73	0.0001	0.08304246
TRT	1	-0.360773783 B	-2.95	0.0074	0.12223519
	2	-0.162156883 B	-1.33	0.1982	0.12223519
	3	-0.208963843 B	-1.78	0.0890	0.11743977
	4	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

Least Square Means for Root Collar Chemistry

The SAS System

General Linear Models Procedure
Least Squares Means

TRT	PHENOL LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	10.9916667	1	.	0.6460	0.0492	0.0095
2	11.7550000	2	0.6460	.	0.1242	0.0276
3	14.2800000	3	0.0492	0.1242	.	0.4365
4	15.4828571	4	0.0095	0.0276	0.4365	.

TRT	TANNIN LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	5.9366667	1	.	0.7465	0.0107	0.0001
2	6.3250000	2	0.7465	.	0.0226	0.0003
3	9.1271429	3	0.0107	0.0226	.	0.0700
4	11.2185714	4	0.0001	0.0003	0.0700	.

TRT	SUGAR LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	9.4500000	1	.	0.5309	0.4684	0.6073
2	8.6083333	2	0.5309	.	0.1759	0.2498
3	10.3900000	3	0.4684	0.1759	.	0.8238
4	10.1142857	4	0.6073	0.2498	0.8238	.

TRT	STARCH LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	17.8050000	1	.	0.4984	0.0454	0.0124
2	16.6166667	2	0.4984	.	0.1736	0.0571
3	14.2771429	3	0.0454	0.1736	.	0.5379
4	13.2771429	4	0.0124	0.0571	0.5379	.

TRT	PS LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	1.19465035	1	.	0.1317	0.2273	0.0074
2	1.39326725	2	0.1317	.	0.7054	0.1982
3	1.34646029	3	0.2273	0.7054	.	0.0890
4	1.55542413	4	0.0074	0.1982	0.0890	.

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

Experimental Design Statistical Models for Root Tip Chemistry

The SAS System

General Linear Models Procedure
Class Level Information

Class	Levels	Values
TRT	4	1 2 3 4

Number of observations in data set = 52

NOTE: All dependent variable are consistent with respect to the presence or absence of missing values. However only 26 observations can be used in this analysis.

The SAS System

General Linear Models Procedure

Dependent Variable: PHENOL

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	5.05443480	1.68481160	2.48	0.0878
Error	22	14.94576905	0.67935314		
Corrected Total	25	20.00020385			

R-Square	C.V.	Root MSE	PHENOL Mean
0.252719	29.20805	0.8242288	2.8219231

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	5.05443480	1.68481160	2.48	0.0878

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	5.05443480	1.68481160	2.48	0.0878

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		3.350000000 B	10.75	0.0001	0.31152921
TRT	1	-0.906666667 B	-1.98	0.0607	0.45855858
	2	-0.205000000 B	-0.45	0.6592	0.45855858
	3	-1.008571429 B	-2.29	0.0320	0.44056883
	4	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: TANNIN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	5.53800568	1.84600189	8.23	0.0007
Error	22	4.93409048	0.22427684		
Corrected Total	25	10.47209615			

	R-Square	C.V.	Root MSE	TANNIN Mean
	0.528834	25.59353	0.4735788	1.8503846

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	5.53800568	1.84600189	8.23	0.0007

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	5.53800568	1.84600189	8.23	0.0007

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		2.408571429 B	13.46	0.0001	0.17899595
TRT	1	-0.690238095 B	-2.62	0.0156	0.26347490
	2	-0.323571429 B	-1.23	0.2324	0.26347490
	3	-1.204285714 B	-4.76	0.0001	0.25313849
	4	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: SUGAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1.78313938	0.59437979	0.30	0.8261
Error	22	43.81804524	1.99172933		
Corrected Total	25	45.60118462			

R-Square	C.V.	Root MSE	SUGAR Mean
0.039103	34.17795	1.4112864	4.1292308

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	1.78313938	0.59437979	0.30	0.8261

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	1.78313938	0.59437979	0.30	0.8261

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		4.422857143 B	8.29	0.0001	0.53341612
TRT	1	-0.379523810 B	-0.48	0.6336	0.78516727
	2	-0.704523810 B	-0.90	0.3793	0.78516727
	3	-0.161428571 B	-0.21	0.8325	0.75436432
	4	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: STARCH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	72.40339377	24.13446459	10.76	0.0001
Error	22	49.35530238	2.24342284		
Corrected Total	25	121.75869615			

R-Square	C.V.	Root MSE	STARCH Mean
0.594647	13.80417	1.4978060	10.850385

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	72.40339377	24.13446459	10.76	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	72.40339377	24.13446459	10.76	0.0001

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		9.707142857 B	17.15	0.0001	0.56611746
TRT	1	2.914523810 B	3.50	0.0020	0.83330234
	2	2.926190476 B	3.51	0.0020	0.83330234
	3	-0.760000000 B	-0.95	0.3528	0.80061099
	4	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: PS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.52570309	0.17523436	2.33	0.1017
Error	22	1.65155197	0.07507054		
Corrected Total	25	2.17725506			

R-Square	C.V.	Root MSE	PS Mean
0.241452	36.51409	0.2739900	0.7503680

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	0.52570309	0.17523436	2.33	0.1017

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	0.52570309	0.17523436	2.33	0.1017

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		0.9044092347 B	8.73	0.0001	0.10355850
TRT	1	-.2459971313 B	-1.61	0.1208	0.15243399
	2	-.0339066062 B	-0.22	0.8260	0.15243399
	3	-.3322357015 B	-2.27	0.0335	0.14645384
	4	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

Least Square Means for Root Tip Chemistry

The SAS System

General Linear Models Procedure
Least Squares Means

TRT	PHENOL LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	2.44333333	1	.	0.1545	0.8262	0.0607
2	3.14500000	2	0.1545	.	0.0936	0.6592
3	2.34142857	3	0.8262	0.0936	.	0.0320
4	3.35000000	4	0.0607	0.6592	0.0320	.

TRT	TANNIN LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	1.71833333	1	.	0.1936	0.0639	0.0156
2	2.08500000	2	0.1936	.	0.0029	0.2324
3	1.20428571	3	0.0639	0.0029	.	0.0001
4	2.40857143	4	0.0156	0.2324	0.0001	.

TRT	SUGAR LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	4.04333333	1	.	0.6938	0.7838	0.6336
2	3.71833333	2	0.6938	.	0.4964	0.3793
3	4.26142857	3	0.7838	0.4964	.	0.8325
4	4.42285714	4	0.6336	0.3793	0.8325	.

TRT	STARCH LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	12.6216667	1	.	0.9894	0.0002	0.0020
2	12.6333333	2	0.9894	.	0.0002	0.0020
3	8.9471429	3	0.0002	0.0002	.	0.3528
4	9.7071429	4	0.0020	0.0020	0.3528	.

TRT	PS LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	0.65841210	1	.	0.1937	0.5773	0.1208
2	0.87050263	2	0.1937	.	0.0631	0.8260
3	0.57217353	3	0.5773	0.0631	.	0.0335
4	0.90440923	4	0.1208	0.8260	0.0335	.

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

APPENDIX B

STATISTICAL RESULTS OF DATA NOT PRESENTED BUT MENTIONED IN TEXT

Statistical Results of Data not Presented but Mentioned in Text

Variables for Foliar Nutrient Contents

Variable	Units
Calcium (CACONTEN)	(Foliar concentration) x (dry weight of foliage)
Copper (CUCONTEN)	
Iron (FECONTEN)	
Magnesium (MGCONTEN)	
Manganese (MNCONTEN)	
Phosphorus (PCONTEN)	
Zinc (ZNCONTEN)	
Potassium (KCONTEN)	
Nitrogen (NCONTEN)	

Experimental Design Statistical Models for Foliar Nutrient Contents

The SAS System
General Linear Models Procedure
Class Level Information

Class	Levels	Values
TRT	4	1 2 3 4

Number of observations in data set = 106

The SAS System

General Linear Models Procedure

Dependent Variable: CACONTEN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.00701326	0.00233775	4.33	0.0064
Error	102	0.05504601	0.00053967		
Corrected Total	105	0.06205927			

R-Square	C.V.	Root MSE	CACONTEN Mean
0.113009	34.56110	0.0232307	0.0672164

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	0.00701326	0.00233775	4.33	0.0064

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	0.00701326	0.00233775	4.33	0.0064

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		0.0721581519 B	16.14	0.0001	0.00447076
TRT	1	-.0167150407 B	-2.64	0.0095	0.00632260
	2	-.0085586609 B	-1.28	0.2025	0.00667218
	3	0.0038590215 B	0.63	0.5326	0.00616251
	4	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

The SAS System

General Linear Models Procedure

Dependent Variable: CUCONTEN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.04324987	0.01441662	0.84	0.4740
Error	102	1.74671571	0.01712466		
Corrected Total	105	1.78996558			

R-Square	C.V.	Root MSE	CUCONTEN Mean
0.024162	59.82780	0.1308612	0.2187298

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TRT	3	0.04324987	0.01441662	0.84	0.4740

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	3	0.04324987	0.01441662	0.84	0.4740

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		0.2059992593 B	8.18	0.0001	0.02518426
TRT	1	0.0223370370 B	0.63	0.5320	0.03561592
	2	-.0164774411 B	-0.44	0.6620	0.03758511
	3	0.0369614074 B	1.06	0.2895	0.03471410
	4	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.