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Title: Fertilization of 2-0 Ponderosa Pine Seedlings in the Nursery and Field: Morphology, Physiology, and Field Response

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Abstract Approved: R. W. Rose M. L. Duryea

Two-year-old ponderosa pine (*Pinus ponderosa* Laws.) from two seed sources were grown at two nurseries. The Fremont seed source was raised at Bend and Stone Nursery; the Ochoco was grown at only the Bend Nursery. The seedlings were fertilized in late September-early October with nitrogen (N) or nitrogen plus potassium (NK).

Foliar nutrient analysis at the time of lifting indicated both the N and NK treatments increased N concentration 7-10% in two of the three nursery/seed source combinations but had no effect on the other. The added K had no effect on K concentrations.

None of the nursery treatments had any significant effect on any of the morphological characteristics measured in all three nursery/seed source combinations.

The N treated seedlings from both seed sources at the Bend nursery appeared to be less susceptible to frost

damage. In seedlings from the same nursery, there were no differences in mean days to budbreak among any of the treatments.

The seedlings were lifted from the nurseries and planted back to their respective seed source sites. One-half of the seedlings at both sites were fertilized with a slow-release fertilizer one month after planting. There were no nursery treatment or field fertilizer treatment differences in first-year survival, which ranged from 96-100%, although there were slight survival differences between nurseries at the Fremont site.

Foliar samples taken immediately before the slow-release fertilizer application indicated that the NK nursery treatment at the Fremont site was the only nursery treatment with increased N concentration. These seedlings grew 26% more than the control seedlings and 19% more than the N treated trees during their first growing season in the field.

Compared to non-field fertilized trees, the field fertilized seedlings at the Fremont site had higher foliar N concentrations and contents and heavier fascicles by the end of the first growing season although the non-field fertilized trees grew 12% more.

At the Ochoco field site, the nursery fertilizer and field fertilizer treatments had no effect on seedling N levels or first year survival and growth.

At the beginning of the growing season at the Fremont site, seedlings from the Bend nursery had heavier fascicles and greater N concentrations and contents than the Stone Nursery's seedlings. However, the Stone Nursery trees grew 44% more during the first growing season.

The seedlings responded differently depending upon the field site at which they were planted. A graphical representation of the changes in fascicle weight, nutrient concentration, and nutrient content during the first growing season assisted in the interpretation of the responses at the two sites and provided an indication of the potential for future growth. The fascicle weights and N concentrations and contents of the Fremont site (the harsher, less fertile location) trees decreased 23%, 14%, and 33% respectively. At the Ochoco, the fascicle weights decreased just 6% and N concentration increased 14% although Ochoco seedlings grew less than those on the Fremont during the first growing season. The higher nutrient levels and heavier fascicles exhibited by the Ochoco trees could be a good indicator of how those seedlings respond in the coming years. Second year results should be analyzed before any final conclusions are made about this study, especially concerning field fertilization and how the seedling responses vary by site.

Fertilization of 2-0 Ponderosa Pine Seedlings in the Nursery and Field: Morphology, Physiology, and Field Performance

by

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Fertilization of 2-0 Ponderosa Pine Seedlings in the Nursery and Field: Morphology, Physiology, and Field Response

INTRODUCTION

Forest regeneration is a key step in the forest management process. An important ingredient in this reforestation process is the production of quality seedlings. Seedlings of high quality are able to withstand the stresses they encounter after outplanting and respond with good survival and growth. This quality consists of the tree's morphological and physiological characteristics.

Seedling morphology can be tailored somewhat to match the seedling to its planting site (Cleary et al. 1978, Hobbs 1984). Yet seedlings which have ideal morphological characteristics for a given site may show poor field performance once outplanted. The apparently healthy looking trees are possibly of poor physiological quality or they may be healthy but not suited to the outplanting site factors such as low moisture or soil poor fertility (Sutton 1979, Schmidt-Vogt 1981, Ritchie 1984). The majority of forest soils in central Oregon are derived from pumice. One of the main characteristics of pumice soils is their low fertility with nitrogen most lacking (Youngberg and Dyrness 1965, Hermann 1970).

With the improvements in nursery cultural practices in the last decade, it has become common to alter seedling physiology according to the seedlings' outplanting needs. It is now common practice in Northwest nurseries to subject seedlings to increasing water stress beginning in mid-July in order to induce dormancy and frost hardiness so that the trees are less subject to the stresses of lifting, grading, storage, and planting.

Another physiological trait that can manipulated to some extent is a plant's mineral status. It might be possible to increase or alter a tree's nutrient concentration and content in order to match the seedling to the specific demands of its outplanting site such as poor soil fertility (Pharis and Kramer 1964, Etter 1969, Loewenstein 1970, Timmis 1974, Williams et al. 1974, van den Driessche 1980, Thompson 1983).

Two possible techniques for dealing with this problem of low soil fertility are: 1) to increase the seedlings' nutrient reserves before the trees leave the nursery or, 2) to fertilize the seedlings at the time of planting.

One potential method that can be used to alter a tree's nutrient status before outplanting is fall, or late-season, nursery fertilization. This technique involves fertilizing seedlings after they have ceased growth and entered deep dormancy (Lavender and Cleary 1974). In this way, the nutrient concentration and content of the trees can be increased without altering the seedling's dormancy cycle, which could cause poor performance once outplanted (Shoulders 1959).

No studies of fall nursery fertilization conducted so far have addressed its effect on ponderosa pine (*Pinus ponderosa* Laws.). The goal of the research conducted in this study was to examine the effects of late-season fertilization with N and K, and fertilization with a slow-release fertilizer at the time of outplanting, of 2-0 ponderosa pine seedlings raised in two nurseries.

Chapter I describes the effects the fall nursery fertilization had on the foliar nutrient status, morphology, frost hardiness, and phenology of 2-0 ponderosa pine. Chapter II examines the effects the fall nursery fertilization and field fertilization at planting time had on the survival, growth, and foliar nitrogen status of the trees during their first growing season.

CHAPTER I

FALL FERTILIZATION OF PONDEROSA PINE: NURSERY RESULTS

ABSTRACT

Two-year-old ponderosa pine (*Pinus ponderosa* Laws.) from two seed sources were grown at two nurseries. The Fremont seed source was raised at Bend and Stone Nursery; the Ochoco was grown at only the Bend Nursery. The seedlings were fertilized in late September-early October with nitrogen (N) or nitrogen plus potassium (NK).

Foliar nutrient analysis indicated the treatments increased N concentration 7-10% in two of the three nursery/seed source combinations but had no effect on the other. The added K had no effect on K concentrations.

None of the nursery treatments had an effect on any of the morphological characteristics measured except for a 9-12% decrease in the shoot/root dry weight ratio of the N and NK treated seedlings of one seed source.

The N treated seedlings from the Bend nursery appeared to be less susceptible to frost damage. In seedlings from the same nursery, there were no differences in mean days to budbreak among any of the treatments.

INTRODUCTION

Forest regeneration is a key step in the forest management process. Regeneration failures are costly because they lead to a lengthened time until stand establishment and may require site re-entries for vegetation control and/or replanting.

An important ingredient in this reforestation process is the production of quality seedlings. Seedling quality is perhaps an over-used term these days and has many definitions. One general but good definition of seedling quality is the ability to survive and grow well after out planting, i.e., outplanting performance (Duryea 1985, Landis 1985). Seedlings of high quality are able to withstand the stresses they encounter after outplanting and respond with good survival and growth. This quality is represented by the tree's morphological and physiological characteristics.

Seedling morphology can be tailored somewhat to match the seedling to its planting site (Cleary et al. 1978, Hobbs 1984). Regeneration foresters often request nurseries to produce seedlings that meet criteria such as a certain height, stem caliper, or shoot/root ratio. Yet seedlings which have ideal morphological characteristics for a given site may show poor field performance once outplanted. The apparently healthy looking trees are possibly of poor physiological quality or they may be healthy but not suited to the outplanting site factors such as low moisture or soil poor fertility (Sutton 1979, Schmidt-Vogt 1981, Ritchie 1984).

With the improvements in nursery cultural practices in the last decade, it has also become common to alter seedling physiology according outplanting needs. It is now common practice in Northwest nurseries to subject seedlings to increasing water stress beginning in mid-July in order to induce dormancy and frost hardiness so that the trees are less subject to the stresses of lifting, grading, storage, and planting.

Another physiological trait that can manipulated to some extent is a plant's mineral status. It might be possible to increase or alter a tree's nutrient concentration and content in order to match the seedling to the specific demands of its outplanting site (Pharis and Kramer 1964, Etter 1969, Loewenstein 1970, Timmis 1974, Williams et al. 1974, van den Driessche 1980, Thompson 1983).

Nitrogen (N) and potassium (K) are two nutrients that could be potentially adjusted within seedlings to meet the demands of their outplanting site (Pharis and Kramer 1964, Etter 1969, Loewenstein 1970, Timmis 1974, Williams et al. 1974, van den Driessche 1980, Thompson 1983). Nitrogen is the most common nutrient limiting growth in the Pacific Northwest (Gessel and Atkinson 1979, Heilman 1979, Miller and Tarrant 1983). Nitrogen is a key plant nutrient since it is a central part of the chlorophyll molecule as well as being a necessary component of all plant enzymes used for photosynthesis, respiration, and growth. Some studies have found a positive relationship between N concentration and photosynthetic rate (Brix 1971, 1981). Growth response in conifers is generally associated with an increase in N concentration (Weetman and Algar 1974). These responses are probably due to increased chlorophyll concentration and needle biomass often produced in N fertilization studies (Brix 1971, Brix and Ebell 1969, Fagerstrom and Lohm 1977, Powers and Jackson 1978, Turner and Olson 1976). Nitrogen becomes an even more important plant nutrient on soils derived from pumice and ash east of the Cascades. For example, the average total N content in the surface two feet of a Newberry pumice soil is 224 kg/ha compared to a medium site Douglas-fir (<u>Pseudotsuga menziesii</u> [Mirb.] Franco) soil from the west side of the Cascades which contains almost 9000 kg/ha (Hermann 1970).

Potassium is another nutrient that can play an important role in seedling outplanting performance especially on the colder and drier soils of central and eastern Oregon. Although K is not an organic component of the plant, it plays a central role in carbohydrate synthesis and translocation, nitrate reduction, protein synthesis, and cell division (Lawton and Cook 1954). Potassium has also been reported to affect frost hardiness, drought resistance, and osmotic potential of plants (Sato and Muto 1953, Kopitke 1941, van den Driessche 1980). Timmis (1974) showed frost hardiness to be more related to the ratio of K to N than any single nutrient. Similarly, Hauxwell (1966) found that drought resistance of plants was best when supplied with lower levels of N and higher levels of K.

It seems apparent that both N and K can play key roles in the success or failure of seedling outplanting performance. One potential method that can be used to alter a tree's nutrient status before outplanting is fall, or late-season, nursery fertilization. This technique involves fertilizing seedlings after they have ceased growth and entered deep dormancy (Lavender and Cleary 1974). In this way, the nutrient concentration and content of the trees can be increased without altering the seedling's dormancy cycle, which could cause poor performance once outplanted (Shoulders 1959).

Early studies investigated fall fertilization's effect on survival and growth of the treated trees and did not examine their nutrient status or physiology (Gilmore et al. 1959, Ursic 1956, Shoulders 1959, Anderson and Gessel 1966). The experiments conducted during the 1950's produced variable results due, in part, to the late fertilization inducing active shoot growth in the nursery during mild southern winters when the seedlings should have been dormant.

Later studies have addressed some of the physiological aspects of fall fertilization. Benzian et al. (1974) found that a September application of Nitro-Chalk (ammonium nitrate and calcium carbonate) increased the N concentration of Sitka spruce (Picea sitchensis), lodgepole pine (Pinus contorta), western hemlock (Tsuga heterophylla), Norway spruce (Picea abies), and grand fir (Abies grandis). Potassium sulfate treatments also increased K concentrations in Sitka spruce although the authors stated it was more difficult to raise the K concentrations compared to N. Except for grand fir, the "extra" N advanced the budbreak of all other species their first year in the field. The N slightly increased frost damage in the Sitka spruce outplants whereas the K treatments had no effect on frost damage.

A study conducted by Hinesley and Maki (1980) with 1-0 longleaf pine showed that fall fertilization with several treatments of NH_4NO_3 (ammonium nitrate), limestone, KNO_3 (potassium nitrate), and $Ca(H_2PO_4)_2$ (triple superphosphate) produced overwinter dry weight gains and increases in N, P, Ca, and Mg nutrient concentrations. Thompson (1983) found that increasing N supplies to 2-0 Douglas-fir seedlings in October increased percent budbreak, frost hardiness, bud height, and root growth rate. Van den Driessche (1985) showed that late-season fertilization of Douglas-fir also advanced budbreak as well as increased the number of new roots produced after 14 and 28 days. The author attributed these results to the greater mineral nutrient reserves. Margolis and Waring (1986a) found that fertilization of Douglas-fir in October increased free amino acid and N concentrations in the needles, stems, and fine roots one month after treatment.

No studies of fall nursery fertilization conducted so far have addressed its effect on ponderosa pine (*Pinus ponderosa* Laws.). This species commonly grows on pumice soils low in N and in climates that can be both very cold and dry. This study examines the effects of late-season fertilization with N and K of 2-0 ponderosa pine seedlings raised in two nurseries. It was hypothesized that the treatments would increase the mineral nutrient concentrations, have no effect on seedling morphology, improve frost hardiness, and advance budbreak of the fertilized seedlings coming out of the nursery.

MATERIALS AND METHODS

Seedlings for this experiment were grown at the Bend Pine Nursery located in Bend, Oregon and the J. Herbert Stone Nursery located in Central Point, Oregon. Two seed sources, one from the Ochoco National Forest (seed zone 673) and the other from the Fremont National Forest (seed zone 703), were also used. The Ochoco seedlings were raised only at the Bend nursery; the Fremont seedlings were grown at both Bend and Stone nurseries. The locations of the nurseries and seed sources are shown in Figure I.1.

The two-year-old ponderosa pine seedlings were operationally grown according to standard nursery practices. The cultural regime for each nursery/seed source combination is shown in Tables I.1 and I.2. On September 24, 1985 at the Bend nursery and October 4, 1985 at the Stone nursery, the trees were fertilized with one of three treatments: 1) control (CO), no fertilizer, 2) NH_4NO_3 at a rate of 46 kg N/ha (N), and 3) NH_4NO_3 at a rate of 46 kg N/ha plus KCl (potassium chloride) at a rate of 37 kg K/ha (NK). These rates were based on a similar fall fertilization study with Douglas-fir (Thompson 1982). The fertilizers were dissolved in water and applied over the seedlings. The initial application of dissolved fertilizer was immediately followed by an application of

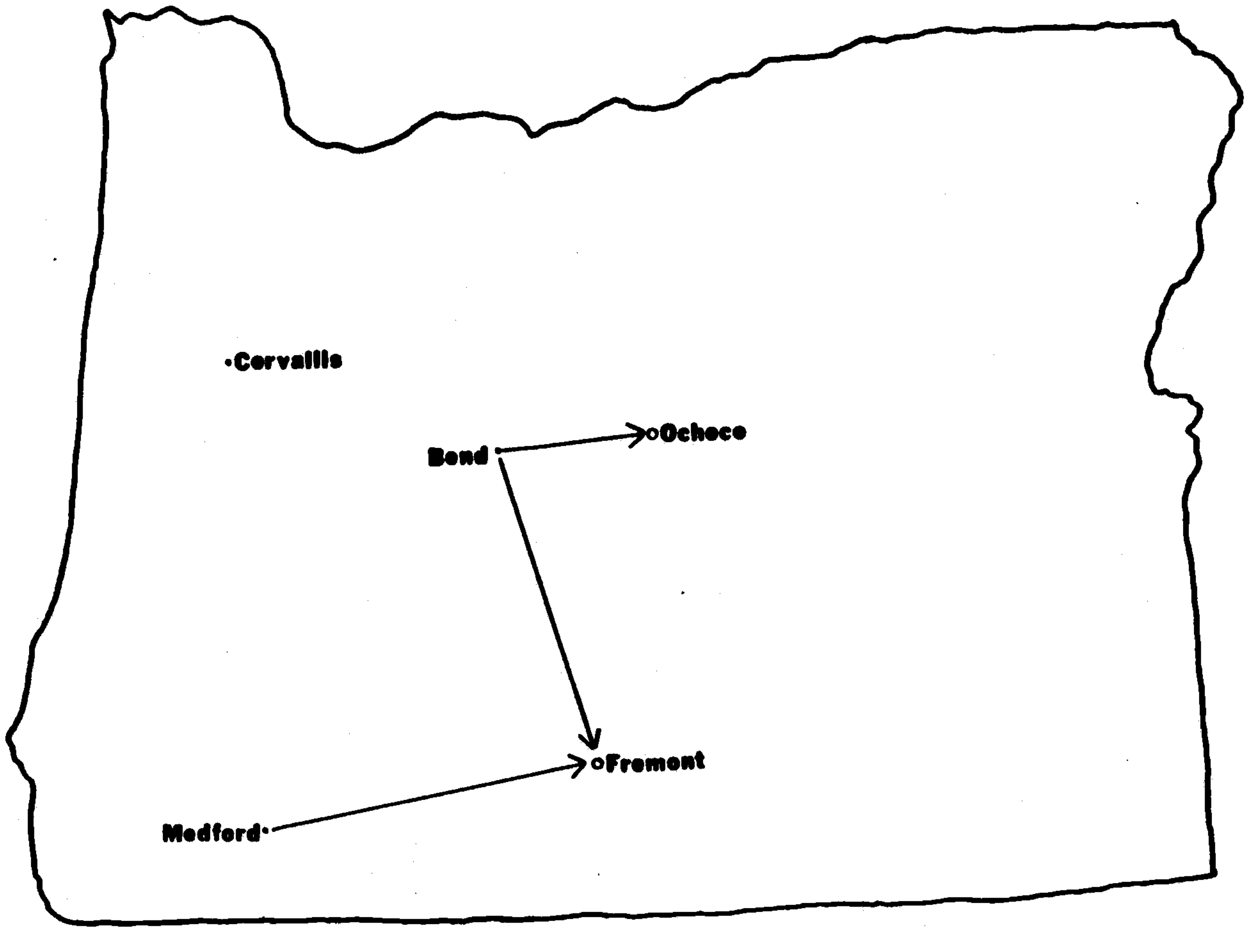

Figure I.1. Location of nurseries and outplanting sites.

Table I.1. Cultural regime for the Bend/Ochoco and Bend/Fremont nursery/seed source combination.

Date	Treatment
	Bend Nursery/Ochoco Seed Source
April 18, 1984	Pre-sow with 98 lb/ac 16-20-0
July 2, 1984	Ammonium sulfate at 150 lb/ac
July 23, 1984	30-10-0 at 100 lb/ac
August 20, 1984	Triple superphosphate at 250 lb/ac
August 28, 1984	Horizontal root prune
May 2, 1985	16-20-0-15 at 150 lb/ac
June 1, 1985	16-20-0-15 at 100 lb/ac
September 24, 1985	Experimental fall fertilization application
	Bend Nursery/Fremont Seed Source
April 19, 1984	Pre-sow with 98 lb/ac 16-20-0
July 20, 1984	30-10-0 at 100 lb/ac
August 1, 1984	Chelated iron at 1 lb/ac
August 15, 1984	Ammonium sulfate at 75 lb/ac Triple superphosphate at 250 lb/ac
August 27, 1984	Horizontal root prune
May 6, 1985	16-20-0-15 at 150 lb/ac
June 1, 1985	16-20-0-15 at 100 lb/ac
September 24, 1985	Experimental fall fertilization application

Table I.2. Cultural regime for the Stone/Fremont nursery/ seed source combination.

Stone Nursery/Fremont Seed Source	
March, 1984	Pre-sow with 800 lb/ac 0-25-0-10 and 500 lb/ac 0-0-60
June 10, 1984 June 25, 1984 August 12, 1984	Ammonium sulfate at 600 lb/ac
March 15, 1985	Horizontal and vertical root prune Ammonium nitrate at 100 lb/ac
April 15, 1985	Ammonium nitrate at 195 lb/ac
May 15, 1985	Ammonium nitrate at 50 lb/ac
June 15, 1985	Ammonium sulfate at 80 lb/ac
October 4, 1985	Experimental fall fertilization application
October 10, 1985	Vertical root prune

water only, in order to prevent fertilizer burn and to help the nutrients infiltrate into the soil. All treatments received the same amount of water, including the controls.

For each nursery/seed source combination, the three treatments were placed in a randomized complete block design using six blocks. Each treatment plot occupied a 3 m length of bed so that every block was 9 m in length. Only the middle 1.5 m of each three-meter plot were fertilized producing a buffer of 1.5 m between each treatment plot (Figure I.2).

-Foliar nutrient analysis

Baseline nutrient information was obtained by sampling seedlings immediately prior to fertilizer treatment (Sept. 24, 1985 for Bend and Oct. 4, 1985 for Stone) and immediately prior to lifting (Jan. 15, 1986 for Stone and March 13 and 14, 1986 for Bend). For each treatment plot, a composite of eight seedlings was sampled by cutting off the top (stem + needles) 6-7 cm of the tree, placing this composite in a cooler of ice, and then transporting the samples to Oregon State University where they were put in cold storage at $2^{o}C$ until they could be washed and dried for analysis a week later. Each composite sample was washed to remove all soil and dried seedling tops were then ground in a Wiley mill using a 20 mesh screen. Total N concentration was determined with a

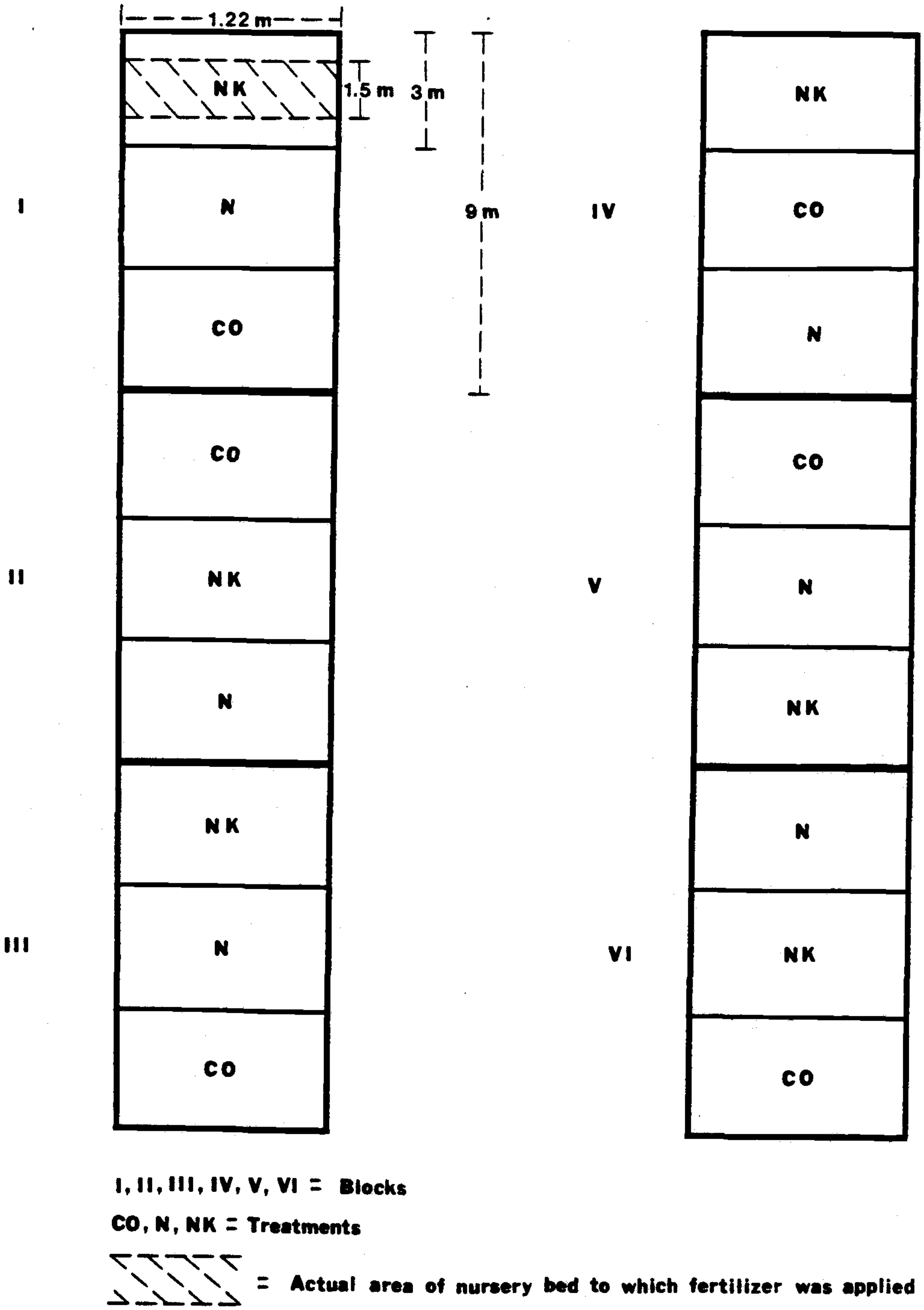

Figure I.2. Nursery experimental design for each nursery/ seed source combination.

micro-Kjeldahl process followed by ammonium analysis using an autoanalyzer (Schuman et al. 1973). A Se/$CuSO_4$ catalyst was used. All other elements (P, K, S, Ca, and Mg) were determined on an ICAP (inductively coupled argon plasma) spectrometer after the samples had been dry ashed in a muffle furnace at 500^{o}C for 6 hr. All analyses were performed at the Department of Horticulture's Plant Analysis Laboratory located at Oregon State University. Statistical analyses were performed on the nutrient concentrations, as well as P/N, K/N, S/N, Ca/N, and Mg/N ratios.

-Lifting procedures

On January 15, 1986 at Stone and March 13 and 14, 1986 at Bend, the seedlings were undercut, lifted, and graded according to operational standards. Only seedlings from the middle half of every 1.5 m treated area were used in the study. After grading, trees for morphological analysis, frost hardiness evaluation, and rate of budbreak analysis were randomly chosen, placed into plastic bags, and put in cold storage at 2^{o}C. Seedlings for outplanting were also selected at this time. Field results will be explained in the second chapter.

-Morphological analysis

For each nursery/seed source combination a sample of 15 seedlings per treatment per block was randomly chosen immediately after lifting and grading, transported to Oregon State University, and placed in cold storage at 2^{o}C. The seedlings were then washed to remove all soil and measured for stem diameter at the root collar and height from the root collar to tip of the terminal bud. After measurement, the trees were dried at 70^{o}C in a forced-air oven for 48 hr and were later measured for needle, stem, and root dry weight.

-Frost hardiness

Frost hardiness was measured using the whole plant freezing test and visual injury estimation (Glerum 1985). For both seed sources at the Bend nursery, a sample of 16 seedlings per treatment per block was randomly selected immediately after lifting and grading, transported to Oregon State University, and placed in cold storage at 2^{o}C. Two weeks later the trees were taken to International Paper Company's Western Forest Research Center where the seedlings were tested using their operational procedure. The roots of each seedling were pruned 5 cm below the root collar and placed into individual vials containing 2 cm of water with the root collar placed above the vial rim. The vials were then randomly put into wooden racks and placed into a programmable freezer. The trees were frozen at a rate of 5^{o}C/hr and maintained at a predetermined temperature for 2 hr. The samples were then allowed to thaw at a rate of 20°C/hr. For each seed source 72 seedlings (4 trees x 6 blocks x 3 treatments) were frozen to four predetermined test temperatures, -16, -18, -20, and -22°C. These temperatures were chosen in an attempt to bracket the seedlings' LT50's, the temperature at which 50% of the plants are lethally damaged.

After freezing and thawing, the seedlings were placed into 400 ml containers with the roots kept in water. The containers were put in a greenhouse at 24°C and 16 hr photoperiod for seven days to allow the damage symptoms to appear. Needle, bud, and cambium damage were then rated on a scale from 0 to 9 (odd numbers only), 0 meaning no damage and 9 meaning 100% damage.

-Budbreak analysis

Budbreak was determined in order to assess if there were treatment differences in budbreak when seedlings were placed under optimal growing conditions. For both seed sources at the Bend nursery, a sample of ten seedlings per treatment per block were randomly chosen after lifting and grading, transported to Oregon State University , and placed in cold storage at 2°C. On April 11, 1986 the trees from each replication and treatment were potted in three pots (10 seedlings per pot) containing a forest soil and placed in a growth room where a 16-hr photoperiod and a constant temperature of 22°C were provided. The plants were kept well watered. Budbreak (emergence of 50% of needles on the terminal bud through their fascicle sheaths) was evaluated every three days for 28 days.

-Statistical analyses

Randomized complete block analyses of variance were performed for the data using SAS (Statistical Analysis System). The analysis of variance and covariance models for treatment mean separation can be found in Appendix A. Fisher's least-significant-difference test was used to separate means at the 0.05 significance level.

RESULTS

-Foliar nutrient analysis

Tables I.3 to I.7 indicate the plant nutrient concentration responses to the fall nursery fertilization treatments. Analysis of covariance was used to examine whether the pre-treatment values had a significant effect on the post-treatment means (see Appendix A). In all but two instances (S concentration at Stone/Fremont and Mg concentration at Bend/Fremont), the pre-treatment values had no significant effect on the post-treatment means. For example, the N concentrations of the treatment plots for Bend/Ochoco were not equal before the plots were fertilized. The control seedlings were significantly lower in N concentration than the N and NK trees (Table I.3). The analysis of covariance, however, indicated the pre-treatment differences did not affect the post-treatment results, i.e., the post-treatment differences were the result of the fertilizer treatments and not the pre-treatment differences. The N and NK seedlings had about 8% greater N concentration compared to the CO plants.

There was also a similar significant treatment effect for the Stone/Fremont seedlings--N and NK had higher N concentrations than CO. Bend/Fremont trees were significantly different before treatment but not after treatment.

Table I.3. Nursery nitrogen concentration treatment means for each nursery/seed source combination. Within the same column and nursery/seed source, means followed by the same letter are not significantly different at the 5% level.

Nursery	Seed source	Tmt	Pre (%)	Post (%)
Bend	Ochoco	CO	1.70a	1.75a
		N	1.79b	1.86b
		NK	1.80b	1.85b
Bend	Fremont	CO	1.77a	1.86a
		N	1.82b	1.92a
		NK	1.79ab	1.89a
Stone	Fremont	CO	1.62a	1.52a
		N	1.63a	1.67b
		NK	1.64a	1.63b

The NK treatment did not affect the K concentrations of any of the nursery/seed source combinations (Table I.4).

Table I.5 shows the sulfur (S) concentrations for each treatment by nursery/seed source. No significant treatment differences were found for the Bend/Ochoco and Bend/Fremont seedlings. For Stone/Fremont, analysis of covariance indicated that the fertilized trees (N and NK) had lower S concentrations than the controls.

Table I.6 summarizes the magnesium (Mg) concentration treatment means by nursery/seed source. No differences were found for the Bend/Ochoco seedlings. The NK treated seedlings at Bend/Fremont had higher Mg concentrations compared to the CO and N treatments whereas the NK treated trees at Stone/Fremont had lower Mg concentrations. Table I.7 summarizes the treatment means for P and Ca. There were no significant treatment differences for all three nursery/seed source combinations.

Tables I.8 to I.10 show the pre-treatment and post-treatment proportions for each nutrient compared to N, with N set at 100. Analysis of covariance was used to examine whether the pre-treatment values had a significant effect on the post-treatment means. The analysis indicated the only instance in which the pre-treatment values had an effect on post-treatment means was the S/N ratios for the Stone/Fremont seedlings.

Table I.4. Nursery potassium concentration treatment means for each nursery/seed source combination. Within the same column and nursery/seed source, means followed by the same letter are not significantly different at the 5% level.

Nursery	Seed Source	Tmt	Pre (%)	Post (%)
Bend	Ochoco	CO	0.673a	0.508a
		N	0.675a	0.497a
		NK	0.677a	0.510a
Bend	Fremont	CO	0.728a	0.518a
		N	0.765a	0.527a
		NK	0.730a	0.493a
Stone	Fremont	CO	0.756a	0.565a
		N	0.750a	0.560a
		NK	0.783a	0.522a

Table I.5. Nursery sulfur concentration treatment means for each nursery/seed source combination. Within the same column and nursery/seed source, means followed by the same letter are not significantly different at the 5% level.

Nursery	Seed Source	Tmt	Pre (%)	Post (%)
Bend	Ochoco	CO	0.105a	0.082a
		N	0.113a	0.077a
		NK	0.113a	0.077a
Bend	Fremont	CO	0.087a	0.077a
		N	0.087a	0.077a
		NK	0.085a	0.077a
Stone	Fremont	CO	0.168a	0.141a
		N	0.183a	0.119b
		NK	0.182a	0.112b

Table I.6. Nursery magnesium concentration treatment means for each nursery/seed source combination. Within the same column and nursery/seed source, means followed by the same letter are not significantly different at the 5% level.

Nursery	Seed Source	Tmt	Pre (%)	Post (%)
Bend	Ochoco	CO	0.193a	0.183a
		N	0.193a	0.177a
		NK	0.185a	0.183a
Bend	Fremont	CO	0.180a	0.174a
		N	0.173a	0.178a
		NK	0.180a	0.187b
Stone	Fremont	CO	0.148a	0.127a
		N	0.156a	0.125a
		NK	0.149a	0.113b

Table I.7. Nursery phosphorus and calcium concentration treatment means for each nursery/seed source combination. Means within the same column and nursery/seed source are not significantly different at the 5% level.

			P		Ca	
Nurs.	Sd. srce.	Tmt	Pre (%)	Post (%)	Pre (%)	Post (%)
Bend	Ochoco	CO	0.208	0.198	0.277	0.268
		N	0.205	0.203	0.272	0.270
		NK	0.210	0.208	0.268	0.267
Bend	Fremont	CO	0.225	0.195	0.240	0.235
		N	0.220	0.198	0.233	0.238
		NK	0.213	0.197	0.227	0.242
Stone	Fremont	CO	0.192	0.202	0.343	0.315
		N	0.194	0.207	0.351	0.318
		NK	0.198	0.200	0.348	0.287

Table I.8. Phosphorus/nitrogen and potassium/nitrogen nutrient treatment mean ratios for each nursery/seed source combination (nitrogen = 100). Within the same column and nursery/seed source, means followed by the same letter are not significantly different at the 5% level.

Nursery	Seed source	Tmt	Pre	Post
		Phosphorus/Nitrogen		
Bend	Ochoco	CO	12.2a	11.3a
		N	11.5b	11.0a
		NK	11.7b	11.3a
Bend	Fremont	CO	12.8a	10.5a
		N	12.1a	10.3a
		NK	11.9a	10.4a
Stone	Fremont	CO	12.0a	13.3a
		N	11.9a	12.4a
		NK	12.1a	12.3a
		Potassium/Nitrogen		
Bend	Ochoco	CO	39.6a	29.0a
		N	37.8b	26.8b
		NK	37.6b	27.6b
Bend	Fremont	CO	41.2a	28.0a
		N	41.9a	27.4a
		NK	40.8a	26.1a
Stone	Fremont	CO	46.9a	37.1a
		N	46.0a	33.5ab
		NK	47.8a	32.0b

Table I.9. Sulfur/nitrogen and calcium/nitrogen nutrient treatment mean ratios for each nursery/seed source combination (nitrogen = 100). Within the same column and nursery/seed source, means followed by the same letter are not significantly different at the 5% level.

Nursery	Seed source	Tmt	Pre	Post
		Sulfur/Nitrogen		
Bend	Ochoco	CO	6.2a	4.7a
		N	6.3a	4.1b
		NK	6.3a	4.2b
Bend	Fremont	CO	4.9a	4.1a
		N	4.7a	4.0a
		NK	4.7a	4.1a
Stone	Fremont	CO	10.5a	9.1a
		N	11.2a	7.2b
		NK	11.1a	7.0b
		Calcium/Nitrogen		
Bend	Ochoco	CO	16.3a	15.3a
		N	15.2a	14.5a
		NK	14.9a	14.4a
Bend	Fremont	CO	13.6a	12.7a
		N	12.8a	12.4a
		NK	12.6a	12.8a
Stone	Fremont	CO	21.3a	20.7a
		N	21.5a	19.1ab
		NK	21.2a	17.6b

Table I.10. Magnesium/nitrogen nutrient treatment mean ratios for each nursery/seed source combination (nitrogen = 100). Within the same column and nursery/seed source, means followed by the same letter are not significantly different at the 5% level.

			Magnesium/Nitrogen	
Nursery	Seed source	Tmt	Pre	Post
Bend	Ochoco	CO	11.4a	10.5a
		N	10.8a	9.5a
		NK	10.3a	9.9a
Bend	Fremont	CO	10.2a	9.4ab
		N	9.5b	9.2a
		NK	10.1ab	10.0b
Stone	Fremont	CO	9.2a	8.3a
		N	9.5a	7.5b
		NK	9.1a	7.0b

There was a significant pre-treatment difference in the P/N ratios at Bend/Ochoco but the post-treatment means showed no significant difference (Table I.8). Pre- and post-treatment P/N ratios at Bend/Fremont and Stone/Fremont were not significantly different. Looking at the K/N ratios at Bend/Ochoco, there was again a significant pre-treatment and post-treatment difference--the N and NK treatment K/N ratios were 8% and 5% less, respectively, than the CO ratio. At Bend/Fremont there were no treatment differences while at Stone/Fremont the NK treatment was 14% lower than the CO K/N ratio.

The S/N ratios at Bend/Ochoco and Stone/Fremont both showed similar significant treatment ratio differences--N and NK treatments had lower S/N ratios than the CO (Table I.9). There were no differences in S/N ratios at Bend/Fremont.

There were no significant differences in the treatment Ca/N ratios at Bend/Ochoco and Bend/Fremont. At Stone/Fremont, there was a 15% decrease in the Ca/N ratio in the NK treatment relative to CO.

With Bend/Ochoco, there were no differences in the treatment Mg/N ratios (Table I.10). At Bend/Fremont there were significant pre-treatment and post-treatment differences--the NK post-treatment Mg/N ratio was 9% larger than the N post-treatment ratio. With Stone/Fremont, the N and NK treatments had Mg/N ratios which were 10% and 16% less than the CO treatment, respectively.

-Seedling morphology

Table I.11 summarizes the treatment means for various seedling morphological characteristics at lifting for each nursery/seed source combination. There were no significant differences for any of the characteristics except for Bend/Ochoco shoot/root ratio. The N and NK treatments had significantly smaller shoot/root ratios compared to the CO seedlings.

-Frost hardiness

As is usually found for ponderosa pine (Faulconer 1986), there was little needle or bud frost damage so the damage ratings were based entirely on cambial damage. The Bend/Ochoco and Bend/Fremont seedlings that were tested proved to be less hardy than expected resulting in high levels of damage and mortality. The four test temperatures are normally supposed to bracket the LT50, but in this case, even the less severe temperatures caused a great deal of damage. This prevented derivation of an LT50 for the treatments.

Since no LT50's could be determined, the data were analyzed using analysis of variance. Each damage rating was changed into its corresponding percentage (0 = 0%, 3 = 25%, 5 = 50%, 7 = 75%, and 9 = 100% damage). In order

Table I.11. Treatment means by nursery/seed source for height, stem caliper, total plant dry weight, total needle dry weight, stem dry weight, total shoot dry weight, total root dry weight, and shoot/root ratio. Within each column and nursery/seed source, means followed by the same letter are not significantly different at the 5% level.

Nursery	Seed Source	Nurs. Tmt.	Hgt. (cm)	Cal. (mm)	Tot. wt. (g)	Needle wt. (g)	Stem wt. (g)	Shoot wt. (g)	Root wt. (g)	Shoot\ root ratio
Bend	Ochoco	CO	14.2a	6.0a	7.86a	3.68a	1.78a	5.46a	2.40a	2.31a
		N	14.1a	6.0a	7.75a	3.43a	1.76a	5.18a	2.56a	2.02b
		NK	14.3a	5.8a	7.54a	3.34a	1.73a	5.07a	2.48a	2.10b
Bend	Fremont	CO	13.1a	6.5a	9.15a	4.51a	1.92a	6.43a	2.72a	2.38a
		N	13.0a	6.3a	8.51a	4.12a	1.84a	5.96a	2.55a	2.35a
		NK	13.3a	6.5a	9.05a	4.34a	1.92a	6.25a	2.80a	2.31a
Stone	Fremont	CO	12.2a	4.9a	7.23a	3.60a	1.42a	5.02a	2.21a	2.33a
		N	12.4a	4.9a	7.67a	3.91a	1.51a	5.42a	2.25a	2.49a
		NK	12.7a	5.1a	8.11a	3.93a	1.64a	5.57a	2.54a	2.32a

to meet the statistical assumption that the data comes from a "normal" population, the values were transformed before analysis using the arcsine of the squareroot. It was found that the damage rating of each treatment increased in an approximately linear manner to decreasing temperatures so that the data could analyzed by combining temperatures into one analysis of variance for each seed source. Table I.12 shows the treatment mean seedling damage ratings for each seed source (converted back from the arcsine of the squareroot). The results indicate that the N treatment, for both seed sources, was the least affected by freezing (i.e., most frost hardy at the time of sampling) compared to CO and NK. The values for N show 8-13% less damage than CO and NK.

-Budbreak

There were no significant differences in mean days until budbreak among treatments for both seed sources (Table I.13).

Table I.12. Average seedling treatment freeze damage rating for the Ochoco and Fremont seed sources grown at the Bend Nursery. Within each seed source, means followed by the same letter are not significantly different at the 5% level.

Nursery	Seed source	Tmt	Damage Rating (%)
Bend	Ochoco	CO	86.8a
		N	75.0b
		NK	88.5a
Bend	Fremont	CO	81.2a
		N	73.3b
		NK	82.6a

Table I.13. Treatment mean days until budbreak for each nursery/seed source combination. Within each seed source, means followed by the same letter are not significantly different at the 5% level.

Nursery	Seed source	Tmt	Means days until budbreak
Bend	Ochoco	CO	15.5a
		N	15.8a
		NK	15.2a
Bend	Fremont	CO	16.5a
		N	15.8a
		NK	14.9a

DISCUSSION

The seven to ten percent increase in N concentration in the fertilized Bend/Ochoco and Stone/ Fremont seedlings suggests that the added nutrients were absorbed by these trees. The potential is there for these seedlings to use this extra N upon outplanting to grow more vigorously. Although there was a slight increase in N concentration in the fertilized Bend/Fremont trees, the lack of significant differences indicated there was little uptake of the added N by these seedlings. The effectiveness of the fall nursery fertilization could probably have been improved by dividing the treatment into several applications and by increasing the total amount of N added.

The addition of K in the NK treatment appears to have had no effect upon the K concentrations within the seedlings. At the Bend Nursery this was not surprising because the available soil K was already high--from 900 to 2000 ppm. At J. Herbert Stone the soil K levels were much lower--approximately 100 ppm. Even though there was much more available soil K at Bend, the level of K within the seedlings was approximately the same at Bend and Stone indicating that the level of soil K at Stone was also adequate. Other researchers have also had problems increasing the K concentration within seedlings. Rowan (1987) applied, over four months, a total of 280 kg/ha of K to pine seedlings grown in a nursery soil well supplied with K. The K concentration of the fertilized trees was 1.89% whereas that of the controls was 1.94%. At another nursery, the same K application rate increased the K concentration from 0.545% for the controls to 0.626% for the treated seedlings. A study conducted by Benzian et al. (1974) found that it was difficult to raise the K concentration of Sitka spruce transplants above what they defined as the sufficiency level of 0.8%. At one nursery the researchers were able to increase the K concentration from 0.4-0.5% for the controls to 0.7-0.8% for the fertilized seedlings with an application of 140 kg K/ha. In the same study at another nursery, untreated trees had K at 0.82%, right at the sufficiency level, and added K produced no increases.

The other nutrient affected by the fall fertilization appeared to be the S concentration at Stone/Fremont. The addition of N (since it was the only added nutrient that was taken up by the plants) resulted in a 16 to 21% decrease in the level of S within the treated seedlings.

Nitrogen, and in many instances S, are nutrients that are limiting to growth on the pumice soils of eastern Oregon (Youngberg and Dyrness 1965, Hermann 1970, Will and Youngberg 1978) so that the N and S status of the seedlings can have an important impact upon their outplanting performance. But it is not only the absolute level of each element that is important but also the balance of those nutrients within the seedlings (Ingestad

1979). Ingestad's optimum proportions of macronutrients (Ingestad 1967) are 100:13:65:6:8.5:9 for N:P:K:Ca:Mg:S. These values were defined specifically for *Betula verrucosa*, *Pinus silvestris*, and *Picea abies* although he states that these proportions vary insignificantly with species or age of plant. The ratios for *Pinus* are closer to 100:10-14:35-50:16-20:6-11:9 (from data cited in Zinke and Stangenberger 1979, Adams and Allen 1985). The nutrient ratios for this experiment are generally in agreement with those found for pine elsewhere. The only exceptions are the K/N ratios which were slightly lower, especially at Bend, as were the S/N ratios at Bend. This seems to be primarily because of the somewhat higher N and lower S concentrations at Bend. The lower S/N ratios could have an effect on the field performance of the seedlings since they were planted on pumice soils. It has been found in radiata pine and Douglas-fir that low S availability can limit the rate of N uptake apparently due to the fact that a certain amount of S is needed to balance the N contained in foliar protein (Kelly and Lambert 1972, Turner et al. 1977, Turner 1979).

The primary goal of fall nursery fertilization is to increase the concentration of selected nutrients within the plants without inducing further shoot growth. Continuation of growth into the fall could cause the seedlings to delay their dormancy cycle so that they would be much more susceptible to the stresses of lifting, grading, and planting. The seedlings in this experiment were fertilized in late-summer to early fall after shoot growth had ceased and the seedlings had entered the stages of dormancy. Therefore, it was expected that no further growth would occur because of the treatment although an increase in root growth and root growth capacity is often associated with late-season applications of N (Tukey and Meyer 1966, Hinesley and Maki 1980, van den Driessche 1985). The morphological data indicate that, indeed, no further growth was stimulated by the fertilization except for a slight, but not statistically significant, trend towards increases in the dry weights of the above-ground plant parts at Stone. Warm temperatures at the Stone nursery last longer into the season than at Bend so fall fertilization applications at Stone may need to be carried out later in autumn in order to prevent continued shoot growth. It also appears that root growth may have increased slightly, but non-significantly, at Bend/Ochoco and Stone/Fremont. Although the root growth increase was not statistically significant, the shoot/root ratio was decreased significantly at Bend/Ochoco which could help the seedlings' field performance on the dry sites of central Oregon (Lopushinsky 1976). Hinesley and Maki (1980) also found that fall fertilization decreased the shoot/root ratio.

Although the frost hardiness data was limited in scope due to heavy damage and mortality, the N treatment appeared to be the most hardy within both seed sources. Thompson (1982) also found that fall fertilization with N increased frost hardiness. It may not be wise to read too much into the data, however, because it is difficult to explain why the NK treatment always had the highest mortality because K is often linked with improvement, not impairment, of frost hardiness (Kopitke 1941, Sato and Muto 1953). Timmis (1974) found cold hardiness was more closely related to the balance between N and K and suggested a K/N ratio of .6/1 to maintain hardiness. The K/N ratios in this study, however, were approximately .3/1.

Previous studies have found that fall fertilization advances budbreak (Benzian et al. 1974, Thompson 1982, van den Driessche 1985, Margolis and Waring 1986b). The results of this experiment showed no evidence of this.

In summary, the initial primary objective of fall nursery fertilization was met with 2 out of the 3 nursery/seed source combinations--the fall fertilization with N did increase the nitrogen concentrations of the Bend/Ochoco and Stone/Fremont seedlings but had no effect on the Bend/Fremont trees. This increase in N concentration was accomplished without essentially affecting the morphology (shoot growth in particular) of the seedlings except for a potentially advantageous decrease in the shoot/root ratio of the treated trees at

Bend/Ochoco. The second objective was to investigate whether the increased N concentrations improve the seedlings' field performance. This will be addressed in the next chapter. The K treatment had no effect on the K concentrations for all three nursery/seed source combinations. The S concentration of the Stone/Fremont seedlings was the only other nutrient that appeared to be affected by the addition of N. A large number of the nutrient ratios were altered by the N addition. Budbreak was unaffected by the treatments while the frost hardiness data indicate that the N treatment may have decreased frost damage.

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CHAPTER II

FERTILIZATION OF 2-0 PONDEROSA PINE SEEDLINGS IN THE NURSERY AND FIELD: FIELD RESULTS

ABSTRACT

Two-year-old ponderosa pine (*Pinus ponderosa* Laws.) from two seed sources were grown at two nurseries. The Fremont seed source was raised at Bend and Stone Nursery; the Ochoco was grown at only the Bend Nursery. The seedlings were fertilized in late September-early October with nitrogen (N) or nitrogen plus potassium (NK).

The seedlings were lifted from the nurseries and planted back to their respective seed sources. One-half of the seedlings at both sites were fertilized with a slow-release fertilizer one month after planting. There were no nursery or field fertilizer treatment differences in first-year survival, which ranged from 96-100%, although there were slight survival differences between nurseries at the Fremont site.

Foliar samples taken immediately before the slow-release fertilizer application (after outplanting) indicated that the NK nursery treatment at the Fremont site was the only nursery treatment with increased N concentration. These seedlings grew 26% more than the control seedlings and 19% more than the N treated trees.

The field fertilized seedlings at the Fremont site had higher N concentrations and contents and heavier

fascicles by the end of the first growing season although the non-field fertilized trees grew 12% more.

At the beginning of the growing season at the Fremont site, seedlings from the Bend nursery had heavier fascicles and greater N concentrations and contents than the Stone Nursery's seedlings. However, the Stone Nursery trees grew 44% more during the first growing season.

The seedlings responded differently depending upon the field site at which they were planted. A graphical representation of the changes in fascicle weight, nutrient concentration, and nutrient content during the first growing season assisted in the interpretation of the responses at the two sites and provided an indication of the potential for future growth. The fascicle weights and N concentrations and contents of the Fremont site (the harsher, less fertile location) trees decreased 23%, 14%, and 33% respectively. At the Ochoco, the fascicle weights decreased just 6% and N concentration increased 14% although Ochoco seedlings grew less than those on the Fremont during the first growing season. The higher nutrient levels and heavier fascicles exhibited by the Ochoco trees could be a good indicator of how those seedlings respond in the coming years. Second year results should be analyzed before any final conclusions are made about this study, especially concerning field fertilization and how the seedling responses vary by site.

INTRODUCTION

The main objective of every reforestation effort is to get a certain number of trees established on the site. As obvious and simple as that may sound on paper, how to achieve adequate regeneration is often less than obvious and usually not simple. Sometimes, depending on the site in question, the initial goal of regeneration is to have the seedlings survive. But the true, long-term goal of any plantation is to <u>grow</u> trees. If the seedlings do not grow, they run into problems with weed competition and animal damage which may cause mortality.

The majority of forest soils in central Oregon are derived from pumice. One of the main characteristics of pumice soils is their low fertility. In a biological assay of the fertility of four pumice soils common to central Oregon, Youngberg and Dyrness (1965) found that ponderosa pine responded most to additions of N and P or N and S, and grew best with a combination of all three nutrients. Nitrogen was the most deficient element since it was the only nutrient that produced a large growth response when added alone. A good example of the N deficiency that can be found in pumice soils is seen when comparing such a soil to a west-side Douglas-fir soil. The average total N content in the surface two feet of a Newberry pumice soil is 224 kg/ha compared to a medium site Douglas-fir soil which contains almost 9000 kg/ha

(Hermann 1970).

Two possible techniques for dealing with this problem of low soil fertility are: 1) to increase the seedlings' nutrient reserves before the trees leave the nursery using fall nursery fertilization (Chapter I), or 2) to fertilize the seedlings at the time of planting.

It has already been shown that fall nursery fertilization can increase the plants' mineral nutrient reserves (Benzian et al. 1974, Hinesley and Maki 1980, Margolis and Waring 1986a). Do these increased nutrient reserves result in improved outplanting performance?

Studies of late-season nursery fertilization in the southern U.S. have produced variable results. Gilmore et al. (1959) found that late October fertilization of slash pine (_Pinus elliotii_ Engelm.) and loblolly pine (_pinus taeda_ L.) with up to 448 kg N/ha resulted in no differences in survival after three years in the field. Ursic (1956) showed that a NK application to loblolly pine one month prior to lifting produced a 12% decrease in field survival with no significant effect on height growth compared to unfertilized trees. In Shoulder's (1959) study with a prelifting N application to 1-0 longleaf (_Pinus palustris_ Mill.) and slash pine seedlings, all fertilized trees broke bud before lifting, and fertilization decreased survival of the loblolly and slash pine.

A later study with Douglas-fir showed positive findings from a September top-dressing of 280 kg/ha of ammonium sulfate. The fall application produced 7% better survival with the fertilized trees consistently showing more growth (Anderson and Gessel 1966). In each of five years, the fertilized trees grew 2-5 cm more than control seedlings. The differences in total height became more pronounced every year. The authors hypothesized the results would have been even more pronounced if the trees had been planted on a poorer site.

The study conducted by Benzian et al. (1974) found that a late-season top-dressing of N improved the height growth of Sitka spruce by up to 18% the season after planting but had little effect on four other species. Hinesley and Maki's study (1980) with longleaf pine showed that fall fertilization did not affect seedling survival or height two years after outplanting but did improve the seedlings' rate of emergence from the grass stage. After eight years in the field the fertilized seedlings were 11% taller. The authors credit this to the trees' more rapid emergence from the grass stage. The late-season N fertilization in the Margolis and Waring study (1986b) enhanced height growth by 37%, the number of terminal leader stem units by 37%, the leaf area of new growth by 44%, and the relative growth rate by 32%.

The second technique to overcome low soil fertility on the outplanting site is to fertilize the seedlings at the time of planting. Like fall nursery fertilization, field fertilization at planting has produced variable results in past studies (Austin and Strand 1960, Smith et al. 1966, Smith et al. 1968, Smith et al. 1971). A major problem with fertilizing seedlings at the same time they are planted is that the soluble salts released from the fertilizer often damage and/or kill the plant (Austin and Strand 1960, White 1963, Jakoy 1965, Smith et al. 1966, Smith et al. 1971). Surface applications are subject to surface losses and can lend more of an advantage to competing vegetation than the crop trees.

The common method of trying to solve this problem has been to use slow release formulations of fertilizers and to apply them right in the planting hole. Highly concentrated, slowly soluble forms cut down on root damage, decrease leaching, and lessen the transportation and handling difficulties found in bulkier, low concentration sources (Austin and Strand 1960, White 1963, Jakoy 1965, Smith et al. 1966, Barrett and Youngberg 1970, Smith et al. 1971). Planting hole application eliminates surface losses and decreases the potential advantage to competing vegetation.

Austin and Strand (1960) were two of the first to evaluate the use of slow release fertilizers. They used urea formaldehyde which was found to decompose slowly in the soil as desired and has a relatively high N content of 38%. By using a urea formaldehyde fertilizer called

Uramite along with superphosphate and in combination with site treatment to control weed competition, they increased height growth and basal stem diameters of Douglas-fir seedlings.

Not surprisingly, quite a few studies have shown negative results from fertilization at the time of planting. Jakoy (1965) showed that more readily soluble forms of N resulted in excessive mortality of Douglas-fir seedlings. He concluded that even the more slowly soluble forms produced only limited advantages. Smith et al. (1966) examined the usefulness of seven different fertilizer formulations, which were either 1) placed in the bottom of the planting hole or 2) mixed with the soil in the planting holes of Douglas-fir. They, too, found excessive mortality from the use of readily soluble N sources, but this was reduced somewhat by deep placing or by separation of the fertilizer from the roots using soil as a barrier. Seedling appearance generally improved and occasionally, statistically significant, but unimportant increases in height growth were found. A study by Smith et al. (1968) showed that a 9.72 g pellet of a urea formaldehyde produced seedlings of taller than average height, but with also 23.3% mortality compared to 6.7% mortality for the controls.

Studies by White (1963) and Smith et al. (1971) also found variable results showing improved growth in some instances but with increases in mortality, too. White found, though, that using a soil barrier between the roots and fertilizer increased survival. Smith concluded that the slowly soluble urea formaldehyde fertilizers were quite an improvement over the more readily soluble N formulations showing less induced mortality. He thought the tolerance of ureaform by young pines and its slow release pattern make it an attractive fertilizer for use. The authors stated "...a slow release of fertilizer at a rate forest plants can absorb and recycle for subsequent use in later development may be desirable" (Smith et al. 1971, pg. 821).

Quite a few studies have shown very positive results from planting hole fertilization. In an experiment by Rothacher and Franklin (1964), urea formaldehyde, superphosphate pellets were placed in Douglas-fir planting holes and covered with a small amount of soil before the trees were planted on an old landing. After five years, the survival (87%) was equal between fertilized and unfertilized seedlings, but fertilized trees were found to have significantly better growth rates all five years.

Arnott and Brett (1973) examined outplanting fertilization of Sitka spruce and Douglas-fir container stock. They placed 15.7 g of hoof and horn meal (4-11-7 NPK) in an 11.4 cm Walters bullet and planted these three inches away from the seedlings. This apparently had neither a beneficial nor negative effect upon survival but produced substantial increases in height growth. The fertilization almost doubled the height growth of Douglas-fir seedlings at the end of three seasons. One negative aspect is that the roots tended to concentrate beneath the capsules containing the hoof and horn meal resulting in an asymmetric root system.

Carson and Presig (1981) blame past field fertilization failures on poor physiological conditioning of the planting stock used since even the growth of unfertilized seedlings was poor in these older studies. Their study showed that controlled release fertilizers applied to the root zone of 1-0 plug Douglas-fir stimulated shoot and root growth showing no localized root growth or asymmetry due to fertilizer placement. In a similar study by Carlson (1981), 1-0 western hemlock seedlings exhibited height growth 1.3 times that of unfertilized trees, again showing no signs of asymmetric root growth from adjacent placement.

Two more recent studies have noted the importance of P in combination with N in improving the early growth of seedlings on certain soils. Neilsen et al. (1984) found in Tasmania that fertilizing <u>Pinus</u> <u>radiata</u> seedlings with urea plus superphosphate resulted in higher N and P levels and greater growth than either urea or superphosphate alone or with no fertilizer. Fertilization trials conducted by Gent et al. (1986) have shown that the response to treatment varies with the soil type. Plantations of loblolly pine on poorly drained clay soils did not respond as well to fertilization as those planted on poorly drained loam soils. On the clay sites, a combination of P and N produced the best results compared to P alone while on other soil types, P alone was shown to be as good as, or better, than the combination of P and N.

The Forestry Intensified Research program of Oregon State University has undertaken several studies investigating field fertilization at the time of planting in southwest Oregon. One experiment with 1-0 container-grown Douglas-fir seedlings found that fertilizing with slow-release briquets increased the diameter, height, and volume of the trees by 33%, 17%, and 91% respectively after one growing season (Helgerson and Atalla 1987). Another study with 2-0 bareroot Douglas-fir seedlings and nine different fertilizer treatments resulted in diameter increases ranging from 114% to 358% and height increases ranging from 96% to 348% two years after treatment (McNabb and Haas 1987).

The previous research cited above has shown that fall nursery fertilization and field fertilization have the potential to improve the survival and/or growth of various tree seedling species but very little research has been conducted with ponderosa pine to examine how fall nursery fertilization or field fertilization affect ponderosa pine. The purpose of this experiment was to determine 1) if fall nursery fertilization could improve first year field performance, 2) if field fertilization at planting time could improve first year field performance, and 3) if the combination of the two treatments could improve first year field performance of ponderosa pine.

MATERIALS AND METHODS

The unfertilized and fertilized ponderosa pine seedlings described in Chapter I were lifted on January 15, 1986 at the J. Herbert Stone Nursery and on March 13 and 14, 1986 at the Bend Pine Nursery. The plants were then placed to cold storage at 2^{o}C.

The Ochoco seed source grown at Bend was outplanted April 13, 1986 on the Big Summit Ranger District, Ochoco National Forest. Each planting spot was scalped and the seedlings were auger-planted at a 1.22 x 1.22 m spacing by the contract crew used by the district . After planting, the trees were covered with vexar tubing to prevent deer browse. The clearcut site was on a 45^{o} north facing slope at an elevation of approximately 1372 m and receives about 64 cm of rain annually, most falling during the winter months. The soil was a Typic Vitrandept of ash over lying colluvium (Paulson 1977). The site was broadcast burned the fall previous to planting. A randomized complete block experimental design was used with six blocks, six treatments per block in a 3 x 2 factorial combination, and twelve trees per treatment row for a total of 432 seedlings . The six treatments (Table II.1) consisted of the three fertilizer nursery treatments (CO, N, NK; see Chapter I) in factorial combination with two field fertilizer treatments (FERT, NO FERT; field fertilizer treatments described later).

Table II.1. Six field treatments (X) showing factorial combination of three nursery fertilization treatments with two field fertilization treatments.

Nursery Fertilization	Field Fertilization	
	1) No Fertilizer (NO FERT)	2) Fertilizer (FERT)
1) Control (CO)	X	X
2) Nitrogen (N)	X	X
3) Nitrogen + Potassium (NK)	X	X

The Fremont seed source grown at both Bend and Stone Nurseries could not be planted until May 13, 1986, on the Paisley Ranger District of the Fremont National Forest, because of the site's higher elevation and snowpack. The seedlings were auger-planted at a 1.22 x 1.22 m spacing by a crew from the district and the seedlings were covered with vexar tubing. The clearcut site was on a slope of about 10° at an elevation of 1980 m and receives approximately 38-46 cm annual precipitation, mostly in the winter. The soil was a coarse-textured Typic Xerothent consisting of ashy soils over residual and colluvial soils weathered from rhyolite (Wenzel 1979). The site was mechanically cleared and the slash piles burned the fall previous to planting. A split-plot randomized complete block design was used with six replications. Nurseries served as the main treatment within each block and the fertilizer treatments were the subplots within each nursery. There were six blocks, two nurseries per block, six treatments per nursery, and twelve trees per treatment row for a total of 864 seedlings (Figure II.1).

About four weeks after planting, the sites were revisited in order to take initial survival and height measurements, to apply the field fertilizer treatments, and to take soil samples. The field fertilizer treatment consisted of placing a single Agriform (Sierra Chemical Company, Milpitas, CA, 95035) slow-release fertilizer

BLOCK 1

NURSERY: (main plot)

TREATMENT: (subplot)

X = SEEDLING (1.22 X 1.22 m spacing)

NURSERY:	STONE						BEND					
TREATMENT:	CO FERT	NK NO FERT	N NO FERT	N FERT	CO NO FERT	NK FERT	N NO FERT	CO FERT	CO NO FERT	NK NO FERT	N FERT	NK FERT
	X	X	X	X	X	X	X	X	X	X	X	X
	X	X	X	X	X	X	X	X	X	X	X	X
	X	X	X	X	X	X	X	X	X	X	X	X
	X	X	X	X	X	X	X	X	X	X	X	X
	X	X	X	X	X	X	X	X	X	X	X	X
	X	X	X	X	X	X	X	X	X	X	X	X
	X	X	X	X	X	X	X	X	X	X	X	X
	X	X	X	X	X	X	X	X	X	X	X	X
	X	X	X	X	X	X	X	X	X	X	X	X
	X	X	X	X	X	X	X	X	X	X	X	X
	X	X	X	X	X	X	X	X	X	X	X	X
	X	X	X	X	X	X	X	X	X	X	X	X

Figure II.1. Example of one replication of the Fremont outplanting site. The field design is a split-plot randomized complete block with six replications, two nurseries (main plots), and six fertilizer treatments (subplots). The Ochoco site's field design is a randomized complete block with six replications and six treatments.

tablet, 10-13 cm away from the tree and 3-5 cm deep, in a hole made by a planting bar. Each tablet weighed 21 g and was composed of 20% nitrogen, 10% available phosphoric acid (P_2O_5), 5% soluble potash (K_2O), 2.6% calcium, 1.6% sulfur, and 0.35% iron. This was equivalent to 4.2 g of N, 0.92 g elemental P, 0.87 g elemental K, 0.55 g of Ca, 0.34 g of S, and 0.07 g of Fe per tree. The pellets were placed away from the tree and below ground in order to minimize fertilizer burn to the tree and to avoid fertilizing competing vegetation.

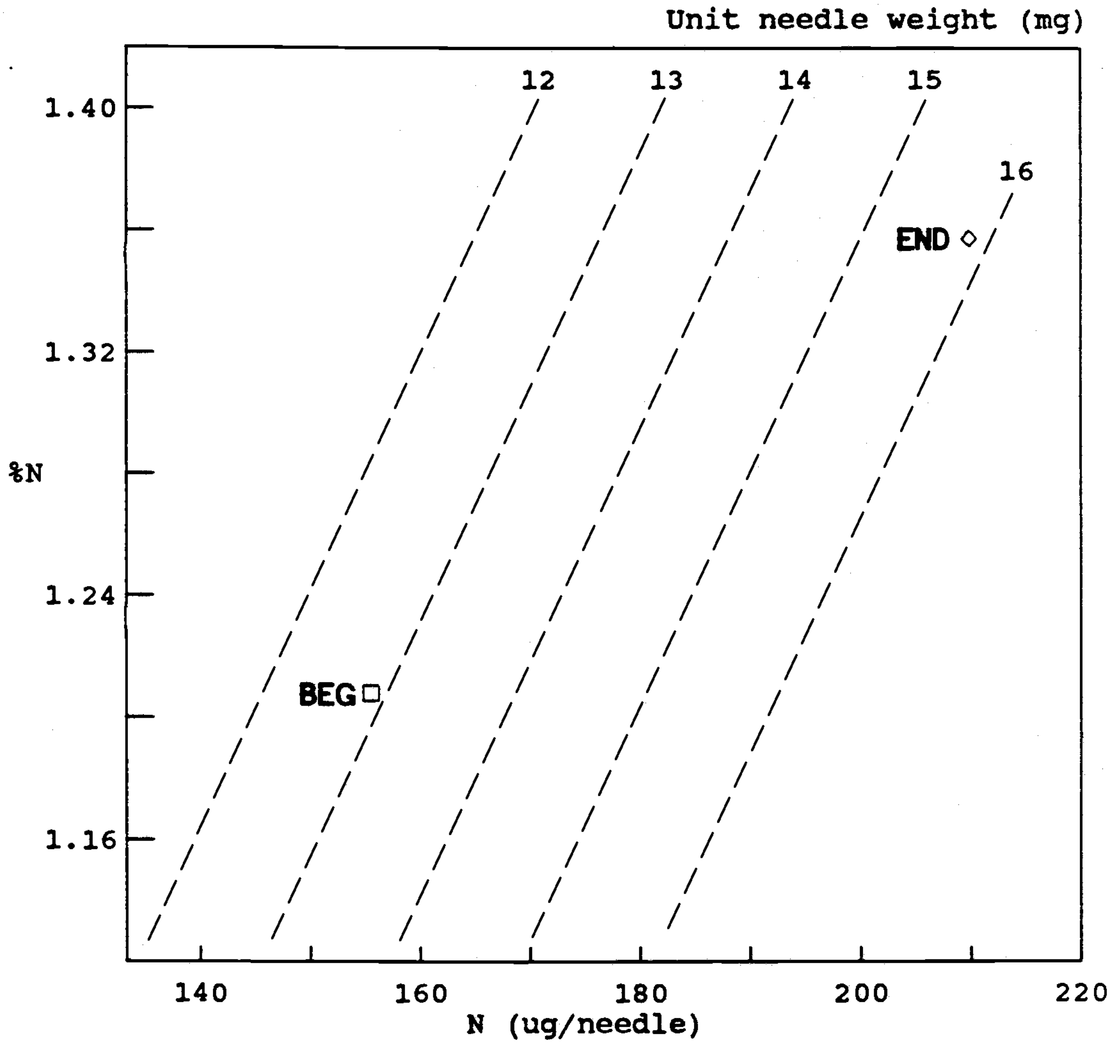
Four soil samples (to a 15 cm depth) were taken from each block at both sites. The four samples were bulked into one sample and analyzed for pH, P, K, Ca, Mg, and percent organic matter.

Immediately after the initial measurements were recorded and before field fertilization, samples were taken for plant nutrient analysis. Two trees from each treatment row were chosen at random and flagged. The seedlings were carefully excavated, placed into zip-lock bags, and put in a cooler with ice. The cooler of trees was transported back to Oregon State University and placed in a freezer until further processing.

On September 24, 1986 and October 2, 1986, at the Fremont and Ochoco sites respectively, survival and height were measured again. Samples for plant nutrient analysis were taken at this time as described earlier.

The processing of the foliar samples involved several steps. First, the samples were thawed and washed. Fifty good fascicles were then picked from each tree beginning at the top. A "good" fascicle was one that was whole, contained three needles, and was of typical health for that tree. The samples of fifty fascicles each were dried in a convection oven at 70^{o}C for 48 hr. After drying, every sample was weighed. Each sample was then processed and analyzed as described in Chapter I.

To aid in interpreting the foliar nutrient information, changes in nutrient concentration (% dry weight), content (ug of nutrient per needle or per 50 fascicles), and fascicle weight are all displayed on one graph. The technique was first used by German scientists and later adapted by North American researchers (Weetman 1971, Timmer and Stone 1978, Weetman and Fournier 1982, Timmer and Morrow 1984). Their graphs consisted of plotting the element concentration on the Y-axis, the element content on the X-axis, and the unit needle weight on a third axis (Figure II.2). The authors cited above do not explain how their graphs were generated although Weetman and Fournier (1982) state that they used "specially prepared computer plotting programs". The graphs created by the authors cited above are difficult to understand at first and are also difficult to produce without "specially prepared computer plotting programs". Because of these two problems, the graphs shown in this



<u>Figure II.2.</u> Example of nutrient response graph with percent N on the Y-axis, N content on the X-axis, and needle dry weights on third, diagonal axes. (from Timmer and Morrow 1984)

thesis are modifications of those used by the above authors. Nutrient concentration is still plotted on the Y-axis, but instead of plotting the fascicle weights on diagonal lines in the graph, they are placed on the X-axis. The nutrient contents are now used as labels next to each data point (Figure II.3).

There are two main points to keep in mind when interpreting these graphs. First, nutrient response curves are characterized by two important zones (Figure II.4). The deficiency zone shows foliar concentration increasing as growth increases. The point at which growth no longer increases with the concentration is called the critical level. Beyond this point is a range in which growth remains relatively constant as the concentration continues to rise. This is commonly referred to as luxury consumption. The second main point to bear in mind with these graphs is that the needle mass produced the year following fertilization is well correlated with the long-term growth response in many coniferous species (Timmer and Morrow 1984). Based on these two points, interpretation of the graphs depends on the changes in nutrient concentration and content, and foliage weight after treatment.

-Statistical analyses

Randomized complete block analyses of variance were performed for the data using SAS (Statistical Analysis

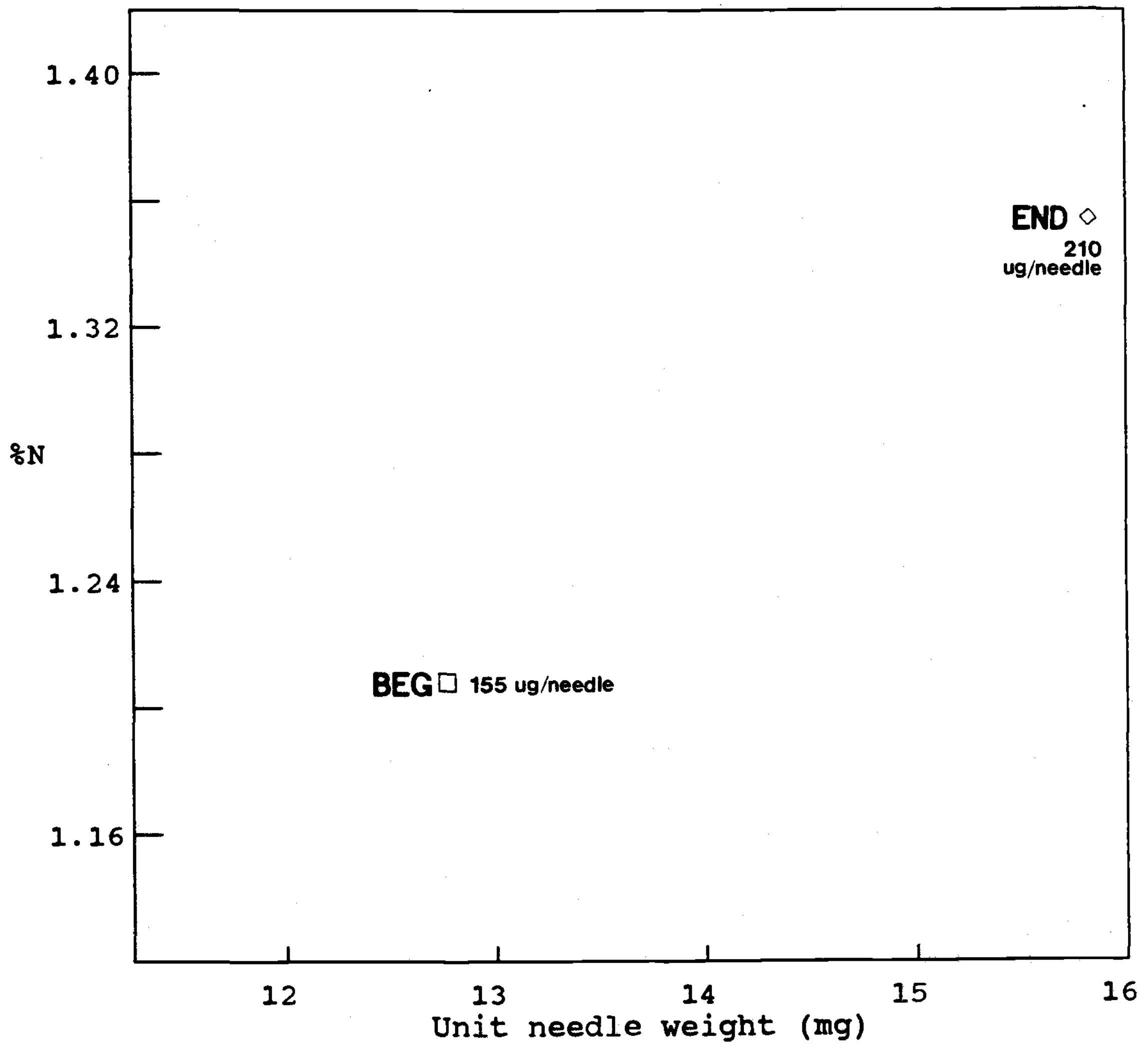
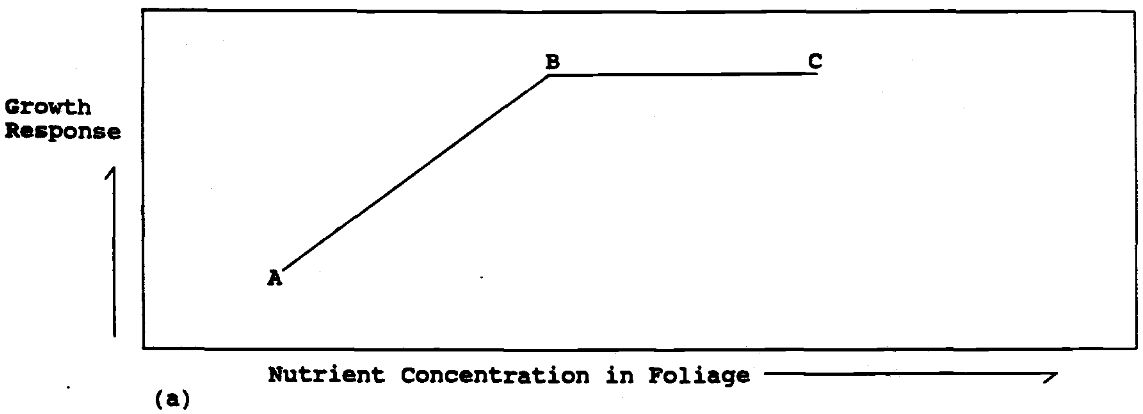


Figure II.3. Example of nutrient response graph used in this thesis using the same data as in Figure II.2.

(a)



(a)

Section	Change In		Interpretation
	Growth Response	Nutrient Concentration	
A → B	+	+	Deficiency
B → C	0	+	Luxury consumption

(b)

Response in			Interpretation	Possible Diagnosis
Needle weight	Nutrient			
	Conc.	Content		
+	-	+	Dilution	Non-limiting
+	0	+	Sufficiency	Non-limiting
+	+	+	Deficiency	Limiting
0	+	+	Luxury consumption	Non-limiting
-	-	-	Physiological stress	Drought, cold, nutrient antagonisms

Figure II.4. (a) Relationship between tree growth response and foliar nutrient concentration (from Timmer and Stone 1983). (b) Interpretation of directional shifts in nutrient concentration, content, and needle (or fascicle) dry weight following treatment (from Timmer and Morrow 1984).

System). The analysis of variance models for treatment mean separation at the two field sites can be found in Appendix B. Fisher's least-significant-difference test was used to separate means at the 0.05 significance level.

RESULTS

-Soil analysis

Figure II.5 indicates that there are quite pronounced soil differences among the two outplanting sites. The Ochoco site appears to be more fertile with higher levels of P, K, Ca, and Mg as well as a higher pH level. The percent organic matter, however, is twice as high at the Fremont site compared to the Ochoco.

-Fascicle dry weights

Table II.2 shows the fascicle weight means, the foliar N concentration means, and the N content means for the two field sites at the beginning and end of the growing season. At the Fremont site, there was no nursery by nursery treatment, nursery by field treatment, or nursery treatment by field treatment (also at Ochoco) interaction so the analysis of each treatment group could be done independently of the others. At both sites the nursery fertilization treatments had no significant effect upon the fascicle weights at the beginning or end of the growing season. The field fertilization treatment (FERT) at the Fremont did result in an increased fascicle weight by the end of the growing season for seedlings from both nurseries. In comparing the two nurseries at the Fremont site, the fascicle weights of the seedlings grown at Bend were 11.7% larger at the beginning of growing season than

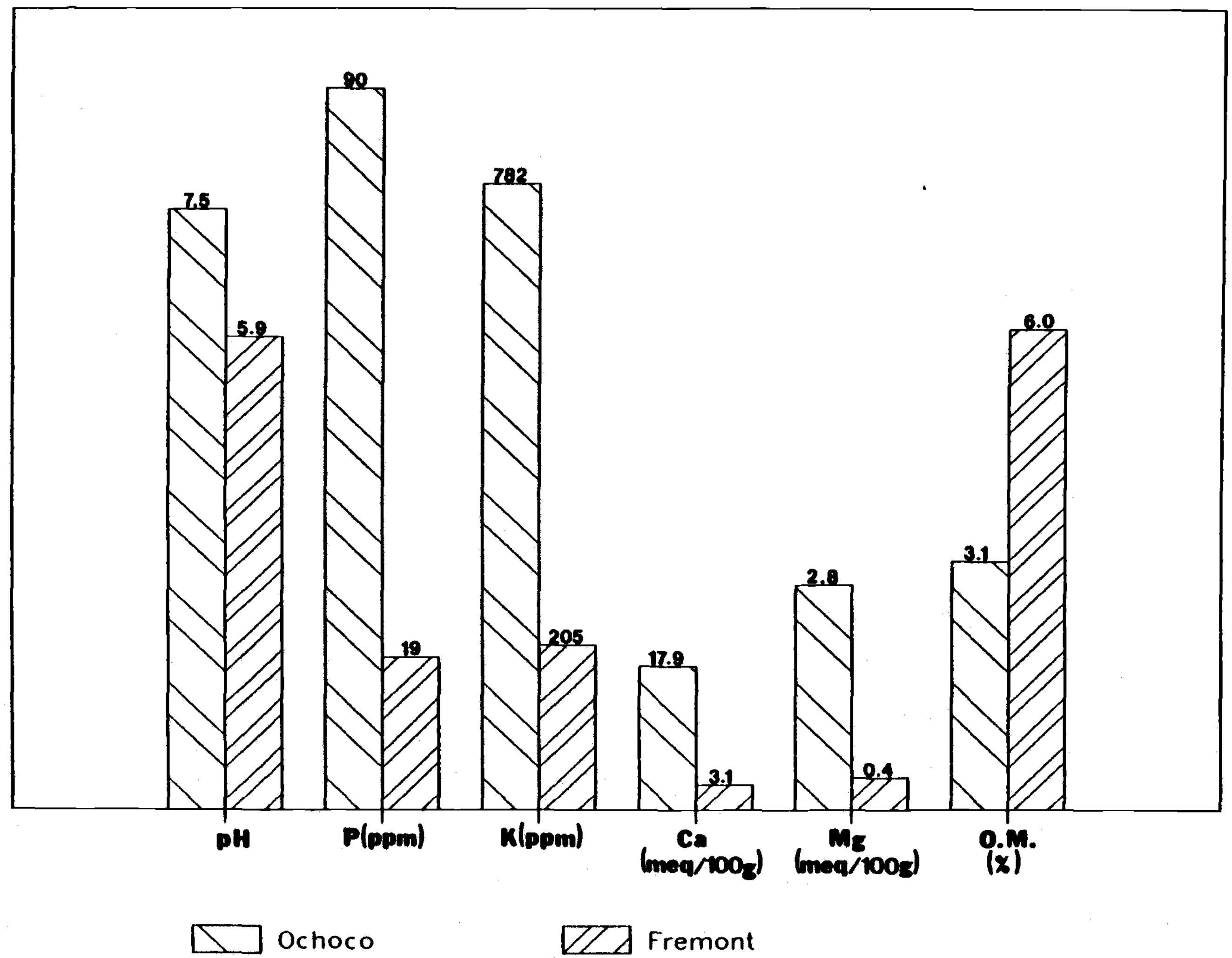


Figure II.5. Soil data for the two outplanting sites.

Table II.2. Nursery treatment, field treatment, and nursery (only at Fremont) mean fascicle weights, nitrogen concentrations, and nitrogen contents for the two field sites at the beginning and end of the first growing season. Within the same column, field site, and nursery, means followed by the same letter are not significantly different at the 5% level.

Field site	Nurs.	Nursery treatment	Field treatment	Fascicle weight (mg) Beg.	End	N conc.(%) Beg.	End	N cont.(ug/fasc) Beg.	End
Fremont	Bend & Stone	CO		65.8a	53.1a	1.47a	1.31a	968a	703a
		N		70.4a	51.3a	1.53ab	1.28a	1083a	668a
		NK		70.5a	54.6a	1.55b	1.30a	1103a	733a
			FERT	68.7a	56.6a	1.52a	1.37a	1053a	786a
			NO FERT	69.0a	49.4b	1.51a	1.23b	1050a	617b
	Bend			73.2a	54.3a	1.66a	1.43a	1220a	786a
	Stone			64.6b	51.7a	1.37b	1.17b	882b	616b
Ochoco	Bend	CO		60.9a	56.0a	1.56a	1.80a	951a	1022a
		N		59.0a	60.9a	1.60a	1.85a	950a	1156a
		NK		67.0a	58.0a	1.60a	1.78a	1068a	1034a
			FERT	59.3a	59.7a	1.59a	1.82a	938a	1089a
			NO FERT	65.3a	57.2a	1.59a	1.80a	1041a	1052a

those from the Stone Nursery. This difference was not evident by the end of the first growing season.

-Foliar nutrient analysis

Examining the seedling N concentrations at the two sites indicated that at the Fremont, the N and NK nursery treatments at the beginning of the growing season had significantly greater N concentrations than the control. By the end of the growing season, these differences were not present. The nursery treatments at the Ochoco site had no significant effect upon the N concentrations at the beginning or end of the growing season.

The field fertilization treatment (FERT) at the Fremont site had a greater N concentration by the end of the growing season than the untreated (NO FERT) although there appeared to be no effect of the field treatment at the Ochoco site. The two nurseries at the Fremont site were quite different in their N concentrations with the seedlings from Bend Nursery having 17.4% more N. This difference lasted throughout the first growing season.

Looking at the N content means at the field sites showed the nursery treatments had no significant effect upon the N content levels at the start or end of the season. The field fertilization increased the N content of the treated seedlings by the end of the first year. Nitrogen content differed substantially by nursery at the Fremont site throughout the growing season although the difference narrowed from 27.7% to 21.6% from beginning to end of the season respectively.

-Seasonal shift in fascicle weight, N concentration and content

Foliar samples were taken at the beginning and end of the growing season. The fascicle weight and nutrient data could be expected to change during that first growing season regardless of treatment. Table II.3 shows the results of the analysis conducted to examine the seasonal shift, if any, in foliage weight and nutrients. At both the Fremont and Ochoco field sites the fascicle weights decreased from the beginning to the end of the season although the Fremont declined 23% while the Ochoco fell only 6%. The nutrient concentrations at the two sites behaved differently from each other in most instances. At the Fremont site, N, S, and Mg decreased 14%, 55%, and 12% respectively whereas K increased 16%. At the Ochoco, N, P, and K increased 12%, 23%, and 24% respectively whereas S declined 49%. The foliar nutrient contents for the two sites also responded differently from each other. Those at the Fremont all decreased in content from the start to end of the growing season, ranging from -10% for K to -65% for S. Most of the nutrient contents at the Ochoco remained constant except for P which actually increased from 104 to 128 ug/fascicle. Sulfur was the only element at the Ochoco that declined.

Table II.3. Fascicle weight, nutrient concentration, and nutrient content means for the beginning and end of the first growing season at the Fremont and Ochoco field sites. Within the column and field site, means followed by the same letter are not significantly different at the 5% level.

Field site	Beginning or End of Growing Season	Fascicle weight (mg)
Fremont	Beg	68.9a
	End	53.0b
Ochoco	Beg	62.3a
	End	58.4b

		Nutrient Concentration (%)					
Field site	Beginning or End of Growing Season	N	P	K	S	Ca	Mg
Fremont	Beg	1.52a	.151a	.440a	.094a	.257a	.134a
	End	1.30b	.152a	.520b	.042b	.228a	.118b
Ochoco	Beg	1.59a	.169a	.421a	.067a	.314a	.150a
	End	1.81b	.220b	.554b	.034b	.324a	.142a

		Nutrient Content (ug/fascicle)					
Field site	Beginning or End of Growing Season	N	P	K	S	Ca	Mg
Fremont	Beg	1052a	103a	302a	63a	177a	94a
	End	701b	80b	272b	22b	125b	64b
Ochoco	Beg	990a	104a	260a	42a	194a	94a
	End	1071a	128b	323a	20b	193a	84a

-Survival

Table II.4 shows the survival, height, and height growth means for the two field sites after the first growing season. At the Fremont site, there was no nursery by nursery treatment, nursery by field treatment, or nursery treatment by field treatment (also at Ochoco) interaction so the analysis of each treatment group, could be done independently of the others. There were no differences in survival among any of the nursery or field fertilization treatments with the survival ranging from 96% to 100% (Table II.4). At the Fremont field site, the seedlings from Stone Nursery had slightly higher survival (99%) compared to those from Bend Nursery (96%).

-Initial and total height

At the Ochoco site none of the nursery or field fertilization treatments had any effect upon initial or total height of the Ochoco seedlings. There was no nursery by treatment interaction at the Fremont site so the analysis was combined over both nurseries. The initial height of all the trees was equal. By the end of the first growing season at the Fremont site, the NK nursery fertilized seedlings were larger than the CO and N trees. The other fertilization treatments had no effect upon final height. The seedlings from Stone Nursery were taller by the end of the first growing season.

Table II.4. Treatment and nursery means for percentage survival, initial height, total height after the first growing season, and first year height growth for the Fremont and Ochoco field sites. Within the same column and field site, means followed by the same letter are not significantly different at the 5% level.

Field site	Nursery	Nursery treatment	Field treatment	Surviv. (%)	Initial ht. (cm)	Total ht. (cm)	Height growth (cm)
Ochoco	Bend	CO		97a	14.9a	17.2a	1.80a
		N		96a	15.7a	17.4a	2.02a
		NK		100a	15.2a	17.8a	2.43a
			FERT	98a	14.9a	17.3a	1.93a
			NO FERT	97a	15.5a	17.6a	2.23a
Fremont	Bend & Stone	CO		98a	11.0a	13.1a	2.28a
		N		98a	10.9a	13.2a	2.42a
		NK		98a	10.9a	13.7b	2.88b
			FERT	98a	11.0a	13.2a	2.38a
			NO FERT	98a	10.9a	13.5a	2.67b
	Bend			97a	11.0a	12.9a	2.07a
	Stone			99b	10.9a	13.8b	2.98b

-Height growth

At the Ochoco site none of the fertilization treatments (nursery or field) had any effect upon height growth. At Fremont, the nursery treatment NK grew slightly more than the CO and N treatments whereas the field fertilized trees (FERT) grew less than those that received no field fertilization (NO FERT). The seedlings from the Stone nursery grew 44% more at the Fremont site than those from Bend Nursery.

-Descriptive response graphs

The site differences in nutrient response stand out more clearly when examined graphically. Figures II.6-II.8 present the N and fascicle weight responses for the nursery and field treatments at both sites (statistical differences in Table II.2) as well as a graph summarizing the overall seasonal shifts (treatments pooled; statistical differences in Table II.3). In looking at the nursery fertilizer treatments at the Fremont site at the beginning of the growing season, the N and NK treated trees were separated from the CO exhibiting greater N concentration, content, and fascicle weight than the CO seedlings (Fig. II.6a). By the end of the first growing season the treatments were more tightly grouped and all the treatments shifted downward in N concentration, N content, and fascicle weight. Looking at the nursery

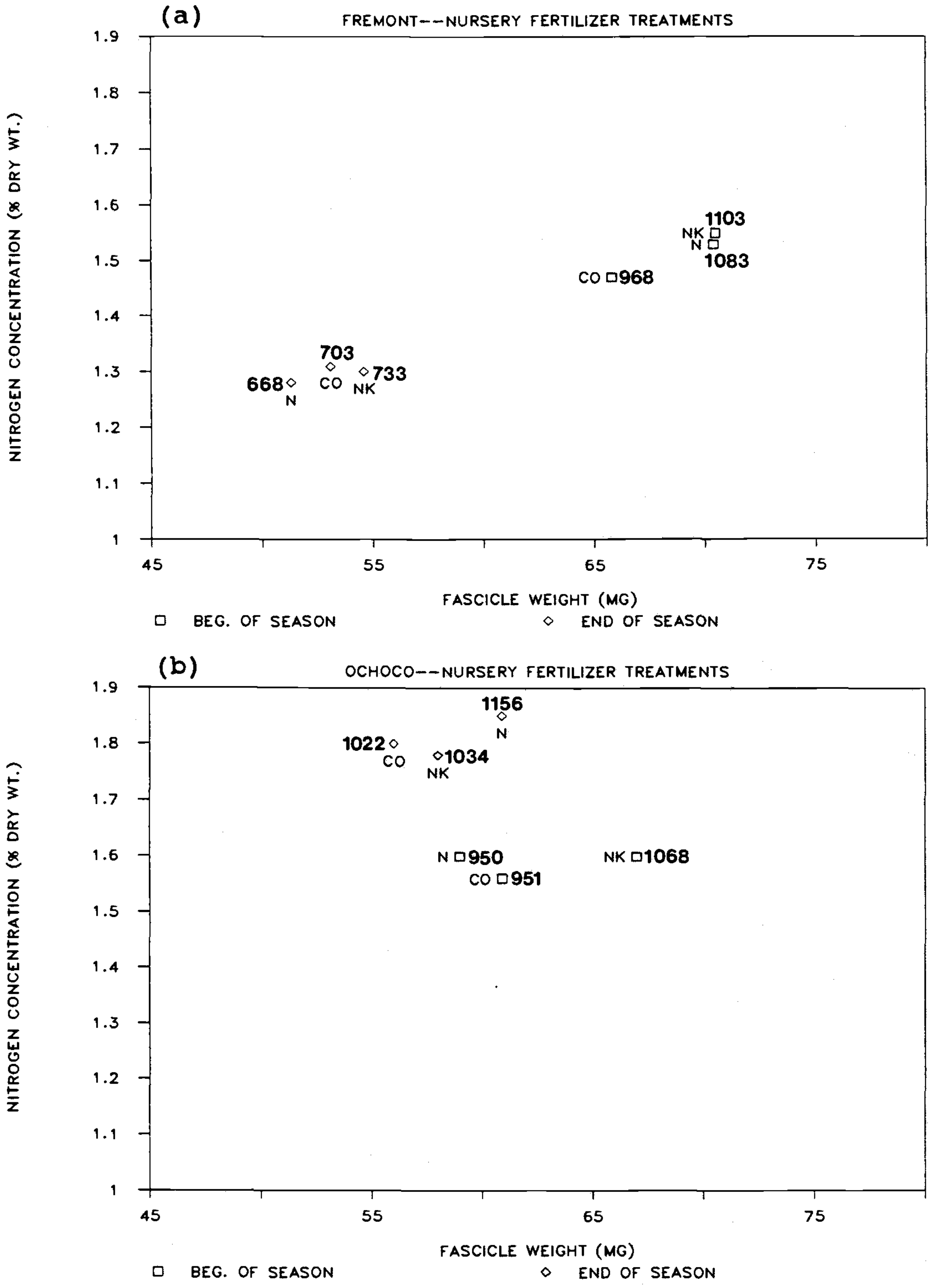
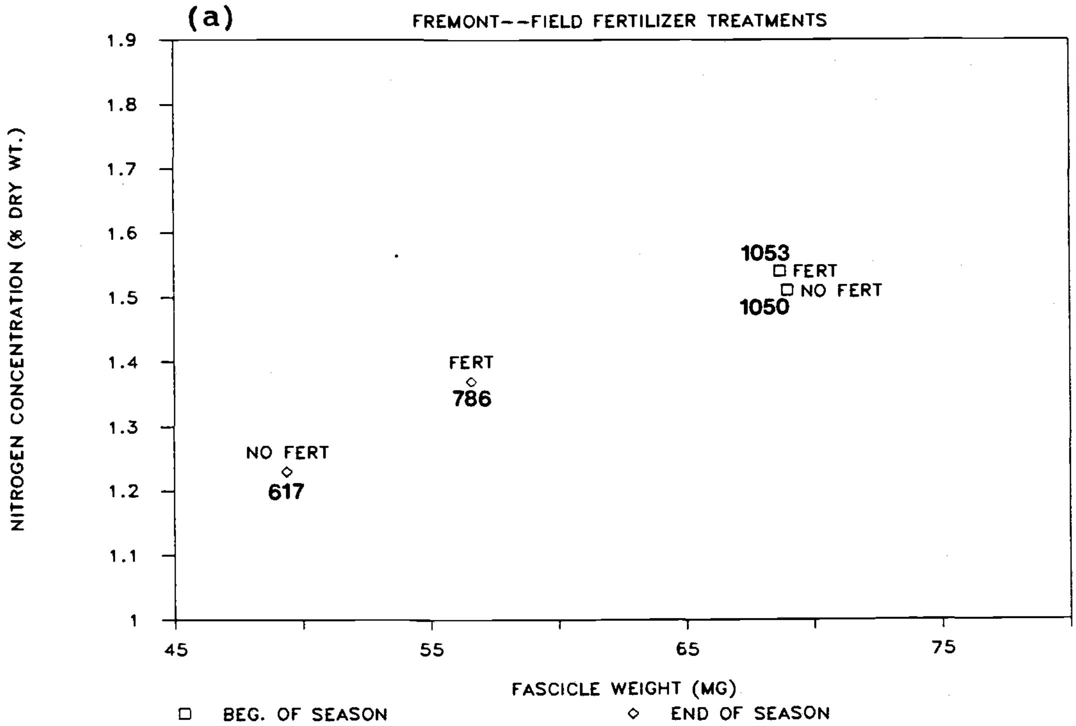


Figure II.6. Descriptive response graphs showing mean values for fascicle dry weight, nitrogen concentration, and nitrogen content for each nursery fertilization treatment at the beginning and end of the first growing season. (a) Fremont field site. (b) Ochoco field site.

treatments at the Ochoco field site at the beginning of the season, it is the NK treatment that stands apart from the CO and N with its higher nutrient content and fascicle weight (Fig. II.6b). By the end of the growing season the NK treatment is no longer an outlier. The treatments have shifted upward in N concentration and content but decreased in fascicle weight.

Examining the Fremont graph of the field fertilizer treatments shows the two treatments close together at the start of the year but, by the end of the first growing season, the FERT treatment had distinctly heavier fascicles and greater N concentration and content compared to the non-fertilized seedlings (Fig. II.7a). Both treatments, however, shifted downward in N concentration, N content, and fascicle weight. Examining the Ochoco graph of the field treatments, the NO FERT seedlings had slightly heavier fascicles and a little greater nitrogen content at the beginning of the growing season but by the end of the season the two treatments were tightly grouped and both had shifted upwards in N concentration and N content, but decreased slightly in fascicle weight (Fig. II.7b).

The seedlings' fascicle weight and N responses during the first growing season differed depending upon planting site. The differences between the two planting sites are most distinct when the treatments are pooled and the two sites are plotted on one graph (Fig. II.8). The seedlings



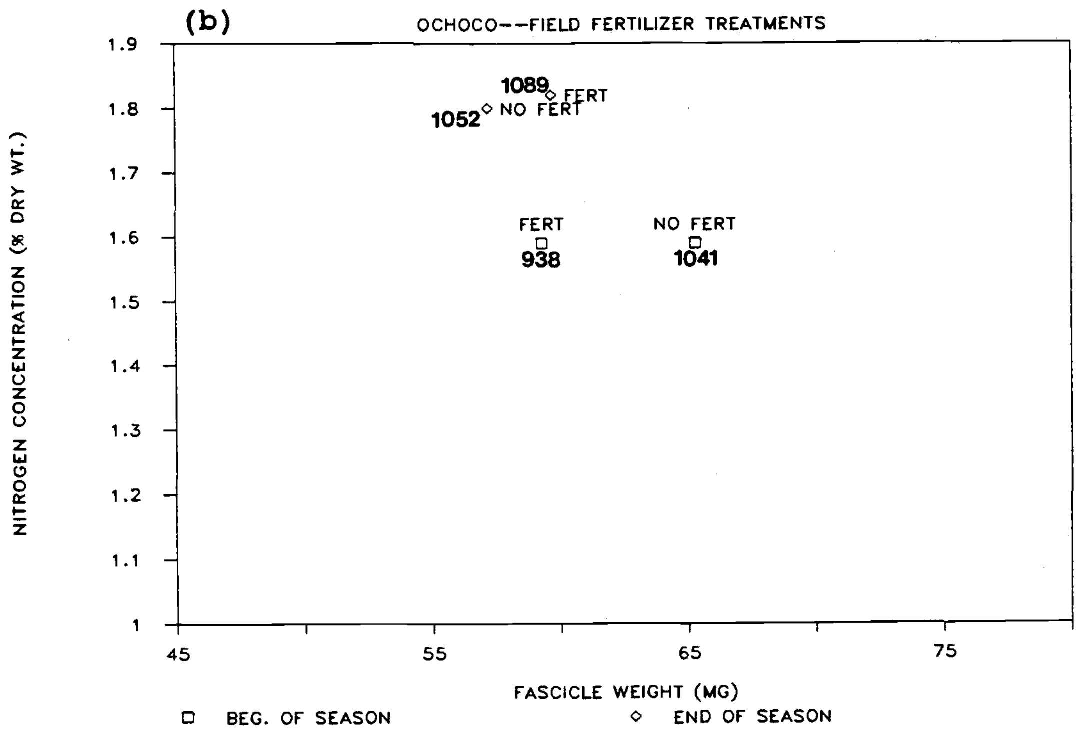


Figure II.7. Descriptive response graphs showing mean values for fascicle dry weight, nitrogen concentration, and nitrogen content for each field fertilization treatment at the beginning and end of the first growing season. (a) Fremont field site. (b) Ochoco field site.

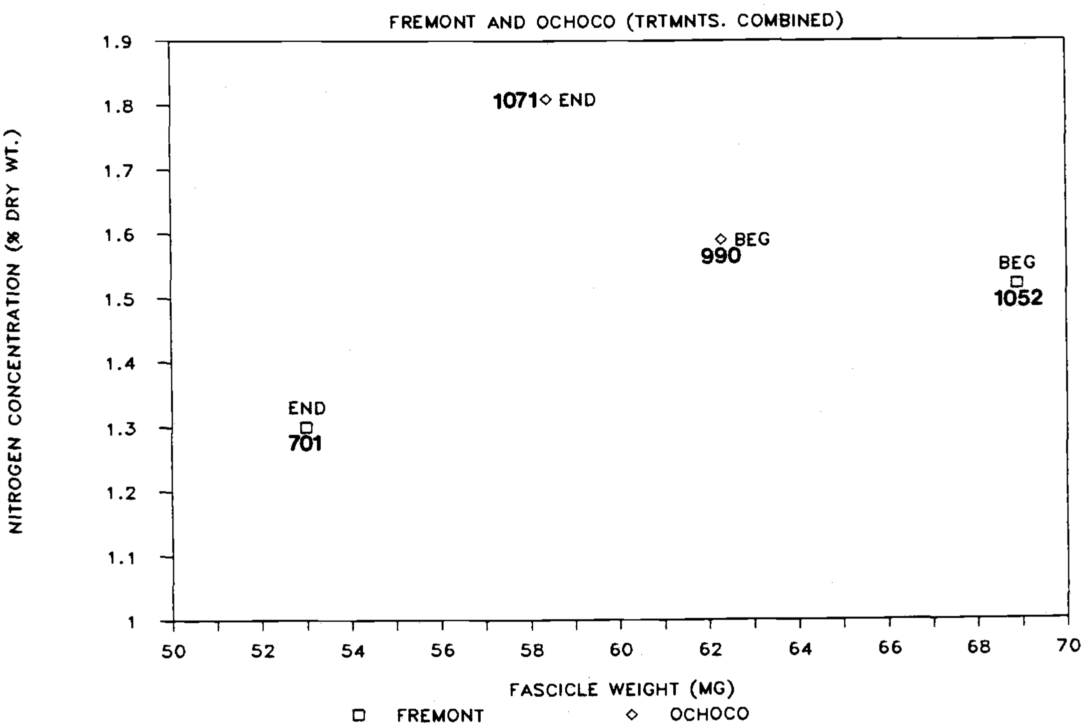


Figure II.8. Descriptive response graph showing mean values for fascicle dry weight, nitrogen concentration, and nitrogen content at the beginning and end of the first growing season for each field site (treatments combined).

at the Fremont site decreased quite dramatically in fascicle weight and N content with a smaller decrease in N concentration. The Ochoco seedlings reacted very differently. Nitrogen concentration increased and the N content remained constant whereas the decrease in fascicle weight was about25% of the Fremont's.

DISCUSSION

-Survival

In previous research, fall nursery fertilization with N increased the rate of budbreak and increased root growth rates (Thompson 1982, Margolis and Waring 1986b, van den Driessche 1985). Advanced budbreak may allow seedlings to begin growth before soils dry out during the heat of summer. A higher root growth rate might also allow the trees to take better advantage of any available moisture. Margolis and Waring's study indicated that fall fertilized Douglas-fir seedlings growing with grass may have been less susceptible to moisture stress during the summer than unfertilized seedlings growing with grass. Given these results, one might expect fall nursery fertilization with N to improve seedling survival once outplanted (especially on droughty sites) unless the treatment causes the seedlings to become more vulnerable to spring frosts.

In this study, root growth rate and budbreak in the field were not examined although a greenhouse budbreak evaluation showed no treatment effects (Chapter I). First-year survival was high at both sites and no differences were seen among the nursery or field fertilization treatments. Few studies have reported first year survival of fall fertilized seedlings and those that have, have shown fall fertilization decreased survival

(Ursic 1956, Shoulders 1959). The late season fertilization in Shoulders' study induced the seedlings to grow while still in the nursery bed so it's not surprising it resulted in lower survival. Other studies reported survival of fall fertilized trees 2-8 years after outplanting so one assumes that there were either no first year differences or no first year evaluations conducted. These studies either show no survival differences (Gilmore et al. 1959, Benzian et al. 1974 [except for decreased grand fir survival]) or that a late-season N application improved survival (Anderson and Gessel 1966, Hinesley and Maki 1980). The Hinseley and Maki fall fertilization experiment with 1-0 longleaf pine showed no second year survival difference but by the eighth year, N fertilized trees had about 8% greater survival than controls. Anderson and Gessel state that although the survival differences are not too impressive from a practical standpoint, it <u>is</u> significant that fall fertilization did not reduce survival since it is "contrary to accepted practices." Based on these past studies and the results of this experiment, two points regarding fall nursery fertilization and first year survival are 1) seedlings should be fertilized after the seedlings have set bud to prevent inducing active growth during harvest and 2) survival differences due to fertilization may only express themselves only <u>after</u> the first growing season.

In the past, field fertilization at the time of planting has often resulted in reduced survival (Jakoy 1965, Austin and Strand 1960, Smith et al. 1966, White 1965). This lower survival has been associated with the more readily soluble forms of N so slow-release formulations and soil barriers have come to play a key part of field fertilization. In this study slow-release pellets were placed 10-13 cm away from the root to prevent mortality. At the Fremont outplanting site, N concentration and content at the end of the first growing season were increased by field fertilization yet survival was unaffected. One or two more growing seasons may be required before any survival differences appear.

-Nursery fertilization effects

The effect of the nursery fertilization resulted in two different foliar nutrient responses depending on the time of sampling and the sampling technique used. Samples for foliar nutrient analysis were taken at four different times in this experiment-- 1) immediately before application of the nursery fertilization treatments, 2) immediately before lifting in the nursery, 3) approximately four weeks after planting in the field, and 4) at the end of the first field growing season. Theoretically, sampling times 2 and 3 should indicate whether the nursery fertilization treatments had any effect upon the seedlings' nutrient concentrations. The nursery samples (sample time #2) showed that the N <u>and</u> NK treatments significantly increased the N concentrations of the treated trees in both the Bend/Ochoco (nursery/seed source) and Stone/Fremont seedlings (see Chapter I). The sample at the beginning of the growing season in the field (sample time #3), however, indicated that <u>only</u> the NK treatment at the Fremont had any effect upon the N concentration; none of the nursery treatments at the Ochoco site had an effect upon the N concentrations. There was also a general reduction in N concentrations in all the seedlings at both sites between sampling times two and three.

There are several possible explanations for this general decline in N level between sampling times 2 and 3. First, the time period between the two ranges from two to five months depending on when the seedlings were lifted and then measured in the field. Although the objective was to measure the seedlings in the field <u>before</u> they began growth, the trees were in the ground for about one month before they were sampled, in addition to the time they spent in storage. Many of the trees had white root tips at the time of the first field sampling but none appeared to have begun height growth. Based on the observation that N is translocated in the plant to the growing points before and during growth, it makes sense for the N concentration in the fascicles (plant part sampled for analysis) to decline as the N moves from the needles to the roots, where growth is occuring, and to the bud, where growth will soon begin (Kramer and Kozlowski 1979, Mengel and Kirkby 1982, van den Driessche 1985, Margolis and Waring 1986a).

The second explanation is related to the first. The samples taken in the nurseries consisted of the top 2 cm of the plant, including the stem and bud, as well as the fascicles, whereas the field samples were made up of only needles. Although the stem is woody material which might decrease the N concentration of the sample, the bud is a meristem which may contain higher concentrations of N than the needles alone if the seedlings had begun N retranslocation to the growing points.

The only nursery treatment to show statistically greater first year height growth was the NK treatment at the Fremont, which is also the only treatment to exhibit (in sample #3) any effect of the nursery fertilization upon the N concentration. There were no nursery treatment differences in the Fremont seedlings' nutrient levels by the end of the first growing season so one would not expect any more differences in height growth for the following growing season unless the nursery fertilized trees were somehow more physiologically healthy.

The field results seem to indicate that if the nursery fertilization was able to increase the N concentration and maintain this difference once in the ground, then the treatment had a positive influence on the trees' subsequent growth. Overall, the fall nursery fertilization had little significant impact upon the seedlings' nutrient levels as well as their first year field performance. The fall fertilization may have been more effective if the application rate had been higher and/or if the application had been in several doses instead of one in order to improve the efficiency of uptake (Ingestad 1977, Mengel and Kirkby 1982).

-Field fertilization effects

On the Ochoco, the field fertilization at the time of planting had no effect on either the N status of the seedlings or their subsequent first year field performance. Based on the soil samples and the general increase in the seedlings' nutrient levels during the first growing season, the site has an adequate nutrient supply, at least compared to the Fremont site. The broadcast burning on the Ochoco may also have mineralized some N for more immediate plant uptake (Ahlgren and Ahlgren 1960, Mroz et al. 1980, Harris and Covington 1983). At the Fremont, with its lower soil fertility, the field fertilization did increase the N concentration and content yet decreased first year height growth slightly. This reduced height growth indicates a negative effect but the increased average fascicle weight due to the field fertilization says otherwise. The higher N levels and heavier fascicles of the fertilized trees may result in improved growth during the second growing season compared to the unfertilized seedlings (Weetman 1971, Timmer and Stone 1978, Weetman and Fournier 1982, Timmer and Morrow 1984).

-Nursery effects

At the Fremont field site, seedlings from Stone Nursery, compared to those from Bend, were significantly lower in N concentration and content at the beginning of the growing season yet the Stone trees had better survival and growth. This shows N status by itself is not a very reliable index of seedling quality. The balance of different nutrients within the plant can be more important than the absolute level of any one nutrient (Ingestad 1979). In this experiment other factors besides nutrient status probably had an important impact upon first year field performance. The seedlings from Stone were lifted in the middle of January while those from Bend could not be lifted until the middle of March due to the frozen soil during the winter months. Seedlings lifted in January were probably still "hardened off" and, therefore, able to withstand the stresses of lifting, grading, storage, and planting, whereas seedlings lifted in March may have been dehardening and been more vulnerable to any stresses even though they had been in storage for a shorter period of time (Lavender 1985, Ritchie 1986). Once outplanted, these trees lifted later may spend more of their energy repairing any damage caused during processing instead of using that energy for growth.

-Site differences and changes during the growing season

When treatments and nurseries were combined at the different planting sites, there were quite pronounced changes in nutrient levels from the beginning to end of the growing season, and in how these changes occurred at the two sites.

In general, the nutrient levels in the Ochoco seedlings increased or remained constant (except S) from beginning to end of the first growing season whereas the nutrient levels in the Fremont trees declined or remained constant. Although the Ochoco seedlings grew approximately 0.5 cm less than those on the Fremont during their first growing season, the decrease in average fascicle weight was only 6% on the Ochoco trees compared to a 23% reduction on the Fremont's. Timmer and Morrow (1984) would interpret these responses to be an excess of N. These symptoms, however, may not be due to N toxicity, but may be the result of the physiological stress the seedlings experienced their first growing season. Compared to the Ochoco site, the lower N levels and smaller fascicles at the Fremont site could have been caused by a lack of N in addition to moisture stress whereas the increased N levels at the Ochoco site may indicate that N was not the prime growth limiting factor the first growing season.

The second year growth results should show which of the two interpretations was better. If the plant N levels were toxic, seedling growth at the two sites would probably not improve. If, however, the N was (and still is) limiting at the Fremont site but adequate for growth at the Ochoco site, the seedlings at the Ochoco might begin to grow better than those on the Fremont during the second growing season. Compared to seedlings at the Fremont site, the higher nutrient levels and heavier fascicles exhibited by the Ochoco trees after their first growing season could be a good indicator of how those seedlings will respond in the coming years (Weetman 1971, Timmer and Stone 1978, Weetman and Fournier 1982, Timmer and Morrow 1984).

-Summary

The nurseries and outplanting sites in this study had a larger impact on first year seedling performance than any fertilizer treatment. It appears that the fall nursery fertilization and field fertilization had little, if any, effect on first year field performance. Although there were some statistically significant treatment differences, they were small and biologically unimportant.

This is not to say that fall nursery fertilization and field fertilization are of no use in ponderosa pine. When the fall applied N increased the N levels within the seedlings at planting time, the treatment also improved first year growth. The problem was that the applied N often did not get taken up by the trees. The treatment effectiveness should be improved by increasing the fertilization rate and/or by using several applications instead of one.

The effect of the field fertilization should be seen in the next few growing years. It was actually surprising to see <u>any</u> effect during the first growing season because one would expect more time to be needed for the added nutrients to reach the seedling roots, especially on such a dry outplanting site like the Fremont. If nutrient and needle weight responses to treatment are indeed good predictors of expected growth then the higher nutrient levels and heavier fascicles of the field fertilized seedlings should lead to improved growth in the next growing season compared to the non-field fertilized trees.

I believe the second year results should be analyzed before any final conclusions are made about the results of this study, especially concerning field fertilization and how site fertility affects field performance. The first year results of this study are inconclusive regarding fall nursery fertilization and further research should be conducted to determine if such treatment can improve the field performance of outplanted seedlings.

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APPENDIX

Appendix A

Analysis of Variance Table for Nursery Fertilization Treatments for Each Nursery/Seed Source Combination

Source of Variation	Degrees of Freedom
Blocks	5
Nursery Fert. Treatments	2
Error	10
Total	17

Analysis of Covariance Table for Nursery Fertilization Treatments for Each Nursery/Seed Source Combination

Source of Variation	Degrees of Freedom
Blocks	5
Nursery Fert. Treatments (Post-treatment)	2
Nursery Fert. Treatments (Pre-treatment)	1
Error	9
Total	17