Intermountain Forest Tree Nutrition Cooperative

Supplemental Report No. 8

December 1999

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Submitted to New Forests

BIOMASS ALLOCATION OF PLANTED CONTAINER-GROWN PONDEROSA PINE SEEDLINGS WITH CONTROLLED-RELEASE FERTILIZER INCORPORATED IN THE ROOT PLUG

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ABSTRACT

Three controlled-release fertilizers (fast release (FR), moderate release (MR) and slow release (SR)) were incorporated in the growing media at rates of 0.8, 1.6 or 3.2 grams per seedling at the time of sowing as supplements to nursery supplied soluble fertilizer. Effects on seedling biomass allocation of the "160/90" container ponderosa pine (*Pinus ponderosa Doug. ex Laws*) were evaluated in the field. Two years after outplanting, fertilization significantly increased foliage, stem, root and total biomass of ponderosa pine seedlings, but did not change foliage, stem and root dry weight ratios and shoot/root ratios. Fertilization changed height/caliper ratios of ponderosa pine seedlings. For small calipers (<20mm), fertilized seedlings were taller than unfertilized seedlings of the same caliper; however, for larger calipers (>20 mm), fertilized seedlings were shorter than unfertilized seedlings of the same caliper. Caliper was more strongly related to total and component biomass of ponderosa pine than was height. The strong association between caliper and biomass provides an efficient way to measure fertilizer treatment effects on biomass for future studies.

Key words: *Pinus ponderosa Doug. Ex Laws*, height/caliper ratio, fertilization, dry weight, foliage, root.

INTRODUCTION

Controlled release fertilizers provide a continuous nutrient supply over an extended time period. Treating container-grown stock with controlled release fertilizers to improve seedling nutrient status and stimulate field growth has recently become a topic of great interest (Donald 1991). In the nursery, controlled release fertilizers have been applied either into the growing medium (Brockley 1988) or as top dressing (Hunt 1989, Walker and Huntt 1992, Walker and Kane 1997). Walker and Huntt (1992) reported controlled release fertilizer were more effective for producing container-grown Jeffrey pine seedlings than water-soluble fertilizers. However, nursery and outplanting performance greatly depends on fertilizer nutrient release characteristics and application rates (Brockley 1988). However, extensive greenhouse and field tests are still needed to develop effective fertilization regimes particularly good release and application rate combinations. The primary objective of this study was to evaluate the effect of three controlled release fertilizers incorporated in the root plug at three levels on biomass allocation of ponderosa pine seedlings after two growing seasons in the field.

MATERIALS AND METHODS

Site description

The experiment was located in Latah county in northern Idaho at 46° 51′ N and 116°50′ W., elevation 950 m. The Vassar Silt Loam soil at the site is 1.5 m deep. The habitat type is *Abies grandis/Clitonia uniflora* (Daubenmire and Daubenmire 1968). A maritime climate moderates the extremes in temperature often associated with the Northern Rocky Mountains. In winter, the average temperature is 0 °C, and the average daily minimum temperature is –4

°C. In summer, the average temperature is 17 °C, and the average daily maximum temperature is 27 °C. Located just out of the rain shadow of the Cascade Mountains, the summers begin moist and gradually turn dry by mid-July and continue mostly without appreciable rain through mid-September. October has an increasing chance of rainfall. As autumn progresses into winter, the precipitation increases dramatically falling as either snow or rain. The total annual precipitation is 763 mm. Of this, 267 mm, or 35 percent, usually falls in April through September (Osborne and Appelgren 1996). The study site was clearcut in 1995 and the slash burned in the spring of 1996.

Experimental design and treatments

A randomized complete block design was used with six blocks per treatment on the one-acre experimental site. In each block, thirty-six ponderosa pine seedlings from each treatment were assigned randomly to a square plot of size 8*8 m with trees planted at 1.3 by 1.3 m spacing. All ponderosa pine seedlings planted for this study were raised the previous year (1996) at the University of Idaho Forest Research Nursery. Seedlings were stored at 0.5 °C, with relative humidity near 100 percent for 5 months (from December of the previous year to April) before planting. The three types of controlled-release fertilizers (Table 1): fast release (FR, release period approximately 9 months), moderate release (MR, release period approximately 12-14 months) and slow release (SR, release period approximately 16-20 months) were applied into the planting medium at sowing at 0.8, 1.6 and 3.6 grams per cell (seedling). The containers used for growing ponderosa pine seedlings were 160/90 (160 cavities per block, 90 cm^3 per cavity). All seedlings were planted between April 20th and 22nd, 1997.

Biomass harvest and soil nutrient analysis

A random sample of 12 seedlings (two seedlings per plot) was selected for each treatment. The seedlings' root systems were excavated from the soil in a 60- cm radius circle around the stem to 60-cm depth on May 7, 1999 when the soil was moist. Seedling roots were hand washed, and diameter at the root collar and height from the root collar to the base of the dominant bud was measured. Each seedling was cut at the root collar and separated into root, stem and foliage components. The root, stem and foliage samples were separately oven dried at 70° C for 72 hours and then weighed. Foliage weight ratio (FWR), stem weight ratio (SWR) and root weight ratio (RWR) were calculated as the ratio of the foliage, stem and root weights, respectively, to total seedling dry weight. Shoot/root ratio was calculated as the ratio of shoots' dry weight (foliage + stem) to roots.

Data analysis

Dunnett's multiple comparison test (Kirk 1995) was conducted to detect differences in average total dry weight, foliage, stem and root dry weight, and foliage, stem and root dry weight ratios, and shoot/root ratios for the nine fertilization treatments and the control. Multivariate analysis of variance (MANOVA) and two-way classification analysis of variance (ANOVA) were conducted on foliage, stem, root dry weight, and foliage, stem and root weight ratio, shoot/root ratio and total biomass data, respectively, to estimate the effects of the three different release rate fertilizers and the three application rates on biomass allocation of ponderosa pine seedlings. Simple linear regression was performed to quantitatively describe relationships between caliper, height, foliage, stem, root and total biomass of ponderosa pine seedlings grown under different treatments. All statistical computations were conducted using the General Linear Model (GLM) procedure of SAS (SAS® Institute Inc. 1995).

RESULTS

Total and component biomass and biomass ratios

Compared with the controls (no controlled-release fertilizer incorporated in the root plug), some fertilization treatments resulted in significantly (p=0.05) larger foliage, stem, root and total dry weight of ponderosa pine seedlings (Figure 1). Both fertilizer source (release characteristics and nutrient composition) and application rate contributed to the significant biomass increase. Two treatments, the 1.6 or 3.2 grams of MR fertilizer in the root plug significantly increased seedling foliage dry weight. Three treatments, the 1.6 grams of FR, MR or SR fertilizers resulted in significantly larger stem dry weight. Seven treatments produced significant root dry weight increase, as follows: all rates of FR fertilizer, 1.6 or 3.2 grams of MR fertilizer, and 0.8 or 3.2 grams of SR fertilizer. The significant increase in seedling total dry weight resulted from four fertilization treatments: 1.6 grams of FR, MR or SR fertilizer and 3.2 grams of MR fertilizer.

MANOVA showed that there was no significant difference in foliage, stem and root dry weights between fertilizer sources (Wilks' Lambda = 0.8547), application rates (Wilks' Lambda = 0.3845) and the interactions of fertilizer source by application rate (Wilks' Lambda=0.6978).

In contrast to absolute dry weights, ratios of foliage, stem and root weights were not affected by fertilization. No significant differences in foliage, stem or root weight ratios or root/shoot ratios were found between fertilization treatments and the control.The fertilization treatments and the control biomass ratios were nearly identical (Figure 2).

Caliper and height response

Neither fertilizer source nor the interaction of fertilizer source and application rate had an effect on caliper and height growth. Caliper growth was marginally affected only by application rate ($p=0.0362$). Seedling caliper grew faster when 1.6 grams of controlled release fertilizer was incorporated in the container compared to either the 0.8 or 3.2 grams application rates. No difference in caliper was found between 0.8 and 3.2 grams application rates. Heights were not significantly different for the three application rates at the end of the second growing season. The relationship between final caliper and height was significantly affected by application rates ($p<0.001$) (Figure 3) as described by equations (1), (2) and (3).

Control: $\text{Height} = -10.25 + 3.20\ \text{Caliper}$ $R^2 = 0.66$ $P>F=0.0008$ (1)

(12.02) (0.69)

0.8 and 3.2 g: $\text{Height} = 12.61 + 1.93\ \text{Caliper}$ $R^2 = 0.66$ $P>F=0.0001$ (2)

(5.06) (0.24)

1.6 g: $\text{Height} = 33.36 + 0.96\ \text{Caliper}$ $R^2 = 0.22$ $P>F=0.0057$ (3)

(7.26) (0.32)

Caliper, height, total and component biomass relationships

Regression equations are given in Table 2 relating the following components: total and foliage dry weight, stem and root dry weight, caliper and height. Residual analysis showed a random pattern around zero with no detectable trend. Total dry weight of ponderosa pine seedlings was closely related to foliage, stem, and root dry weight, caliper and height.

Neither fertilizer source or application rate nor their interaction significantly affected the relationships. Based on the R-square values for all equations, foliage weight was best correlated with total seedling dry weight ($R^2 = 0.962$, Figure 4), and the next highest correlation was foliage with stem weight. Caliper alone accounts for 85.3 % of variation in total dry weight, while height only interprets 58.2% of variation in total dry weight. In addition, caliper was also more closely related to foliage, stem and root dry weight than was height (Table 2).

DISCUSSION

Fertilization increased foliage, stem, root and total biomass, but did not change foliage, stem and root weight ratios nor shoot/root ratios. This result agrees with studies on western hemlock (*Tsuga heterophylla*) (Carlson 1981) and on Douglas-fir (*Pseudotsuga menziesii*) (Carlson and Preisig 1981), but differed from studies on Douglas-fir (Keyes and Grier 1981; Grier et al. 1984; Vogt et al. 1985; Grier et al. 1986) and on paper birch (*Betula papyrifera*) (Wang et al. 1997). The change in proportion (allometric relationships) of various parts of a tree depends on both biotic (species, genotype, size) and abiotic (water and nutrient availability) factors (Calson 1981; Gower et al. 1987; Wang et al. 1997). The allometric relationships are predominantly determined by abiotic factors such as soil moisture and nutrient availability for a specific tree species or genotype of the same age or growth phase. Based on studies of lowland Douglas-fir forests, Grier et al. (1986) proposed a conceptual model to illustrate the effects of water and mineral nutrient availability on Douglas-fir productivity and carbon allocation patterns. Soil moisture and mineral nutrients influence productivity directly through its effects on leaf area (biomass) and/or on the photosynthetic efficiency of the leaf area. This concept was supported by our study since fertilized seedlings had greater foliage biomass than unfertilized seedlings, and our unpublished data that shows photosynthesis rates of fertilized seedlings were higher than those of unfertilized seedlings. Trees invest less to belowground biomass with increasing soil nutrient and water availability (Berntson et al. 1995). Tree biomass allocation in response to fertilization appears to be related to the degree of nutrient (such as nitrogen) limitation prior to fertilization (Grier et al. 1986). Since we fertilized the seedlings in the greenhouse, the treatments did not affect soil properties at the planting site (Fan 1999). Although the treatments caused different root/shoot ratios at the time of planting, after two field growing seasons the seedlings adjusted carbon allocation such that the only fertilizer effect was on seedling size. Significant differences in foliage, stem, root and total dry weights between fertilized and unfertilized seedlings were due to greater foliage biomass and higher nutrient concentrations of fertilized seedlings compared to the unfertilized seedlings. This suggests that productivity is more directly related to foliage biomass and foliar nutrient status, while shoot/root ratio is more directly related to soil nutrient availability. In our study, fertilized ponderosa pine seedlings had larger root systems (increased number and diameter of lateral roots) than unfertilized seedlings, but there were no differences in root symmetry between fertilized and unfertilized seedlings nor between the various fertilizer treatments.

Seedling height/caliper relationships were changed by fertilization in our study. For small diameters (<20mm), fertilized seedlings were taller than unfertilized seedlings of the same diameter; however, for large diameters, unfertilized seedlings were taller than fertilized seedlings of the same diameter (Figure 3). This means that within the diameter range, fertilized seedlings were more uniform (less variation) in height compared to unfertilized seedlings; and conversely, within a specific height range, fertilized seedlings had more variation in caliper than unfertilized seedlings. The differences in the intercepts and slopes of regression equations between fertilized and unfertilized seedlings suggest that fertilization can be used to change shoot morphology. Burdett et al. (1984) reported a sharp drop in height/diameter ratios of planted spruce (*Picea mariana*) during the observation period. The decrease in height/diameter ratios with increasing tree size is a survival strategy that is also affected by environmental conditions such as soil moisture and nutrient availability (as in our study) and light intensity (Naidu et al. 1998). The pipe model theory of plant form suggests that tree foliage biomass is proportional to stem cross-sectional area at live crown base but not so for height (Shinozaki et al. 1964a, 1964b; Waring et al. 1982). For seedlings or young trees, foliage biomass is proportional to stem diameter (or cross-sectional area) at the root collar. In our study the coefficient of determination for the regression of foliage biomass versus diameter at the root collar was as high as 0.96. A direct consequence of significant increases in foliage and total biomass was the increase in diameter at the root collar more so than height. The coefficient of determination for the foliage biomass versus height regression was 0.53, much lower than for the regression of foliage biomass versus root collar diameter. As expected, fertilized seedlings had lower height/diameter ratios than unfertilized seedlings.

Many morphological measurements such as caliper, height and height/caliper ratio have been used to predict seedling performance after planting (Donald 1991). Generally, caliper is a better predictor of performance than height, partly because it is more closely related to root size than is height. Our study validated this point, since caliper was more strongly correlated with foliage, stem, root and total biomass than was height (Table 3). Height/caliper ratio can also be used along with caliper for predicting seedling performance.

In our study, the strong association between caliper and total and component biomass of ponderosa pine seedlings (Table 2) suggests that caliper may be used to estimate above- and below-ground biomass and to index stand productivity.

CONCLUSIONS

Fertilizers placed in the container at the time of sowing increased foliage, stem, root and total biomass of ponderosa pine seedlings from 80 to 120% compared to unfertilized seedlings, but did not change foliage, stem, root dry weight ratios and shoot/root ratios. The significant increase in foliage, stem, root and total biomass was attributable to larger foliage biomass and higher foliar nutrient concentrations prior to planting; while the non-significant change in foliage, stem, root dry weight ratios and shoot/root ratios was predominantly due to the same soil nutrient status for both fertilized and unfertilized plots at the planting site. Moderate release fertilizer appears to be better than FR fertilizer for increasing biomass production that was in turn better than SR fertilizer, and 1.6 grams per seedling was superior to 3.2 grams per seedling and to 0.8 grams per seedling. Fertilization altered height/diameter ratios of ponderosa pine seedlings as follows; for small calipers (<20mm), fertilized seedlings were taller than unfertilized seedlings of the same diameter; however, for large diameters, unfertilized seedlings were taller than fertilized seedlings of the same diameter. Overall, fertilized seedlings had lower height/diameter ratios than did unfertilized seedlings. The strong association between caliper and total and component biomass of ponderosa pine seedlings suggests that simply measuring caliper is a reliable (and less time-consuming) method for assessing treatment effect in future biomass allocation and productivity studies.

Acknowledgments:

The authors thank the Scotts Company and members of the Intermountain Forest Tree Nutrition Cooperative for supporting the project. Additional assistance from the University of Idaho Forest Research Nursery and the University of Idaho Experimental Forest is gratefully acknowledged. University of Idaho, College of Forestry, Wildlife, and Range Experiment Station.

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Table 1. Percent by weight of macronutrients and micronutrients provided by three controlled release fertilizers used in the ponderosa pine experiment.

	Product		
Nutrient	Fast release	Moderate release	Slow release
N	16	18	18
P (P_2O_5)	9	6	5
K (K_2O)	12	12	12
Ca	1.5	1.5	1.5
Mg	1	1	1
B	0.02	0.02	0.02
Cu	0.05	0.05	0.05
Zn	0.05	0.05	0.05
Fe	0.4	0.4	0.4
Mn	0.1	0.1	0.1
Mo	0.001	0.001	0.001

Table 2. Regression equations for describing caliper, height, total and component biomass relationships of ponderosa pine seedlings at the experimental site.

Fitted equations	R^2	Pr> F
Total dry weight = 11.14 + 2.43 foliage dry weight (3.36) (0.04)	0.962	0.0001
Total dry weight = 13.57 + 2.38 stem dry weight (3.91) (0.05)	0.947	0.0001
Total dry weight = 6.51 + 4.19 root dry weight (6.68) (0.16)	0.867	0.0001
Total dry weight = -177.27 + 16.93 caliper (14.19) (0.68)	0.853	0.0001
Total dry weight = -105.12 + 5.32 height (22.96) (0.43)	0.582	0.0001
Foliage dry weight = -66.48 + 6.42 caliper (7.36) (0.35)	0.962	0.0001
Foliage dry weight = -40.85 + 2.05 height (9.78) (0.19)	0.533	0.0001
Stem dry weight = -75.20 + 6.87 caliper (6.04) (0.29)	0.841	0.0001
Stem dry weight = -51.75 + 2.27 height (8.77) (0.17)	0.635	0.0001
Root dry weight = -35.59 + 3.64 caliper (3.71) (0.18)	0.796	0.0001
Root dry weight = -12.52 + 1.00 height (6.05) (0.11)	0.413	0.0001

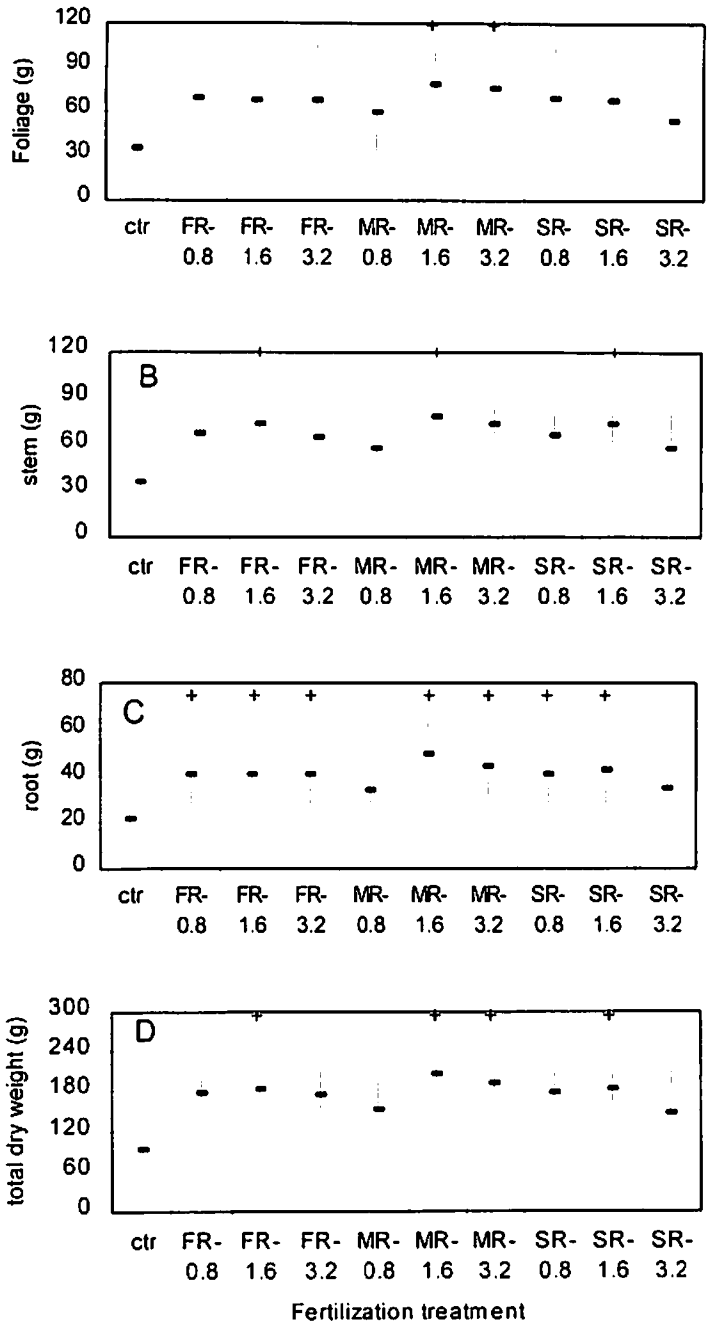

Figure 1. Means and standard deviations of foliage, stem, root and total biomass of ponderosa pine seedlings under various treatments at the experiment site. "+" indicates that the treatment are significantly different from the control. A= foliage; B= stem; C= root; D= total dry weight.

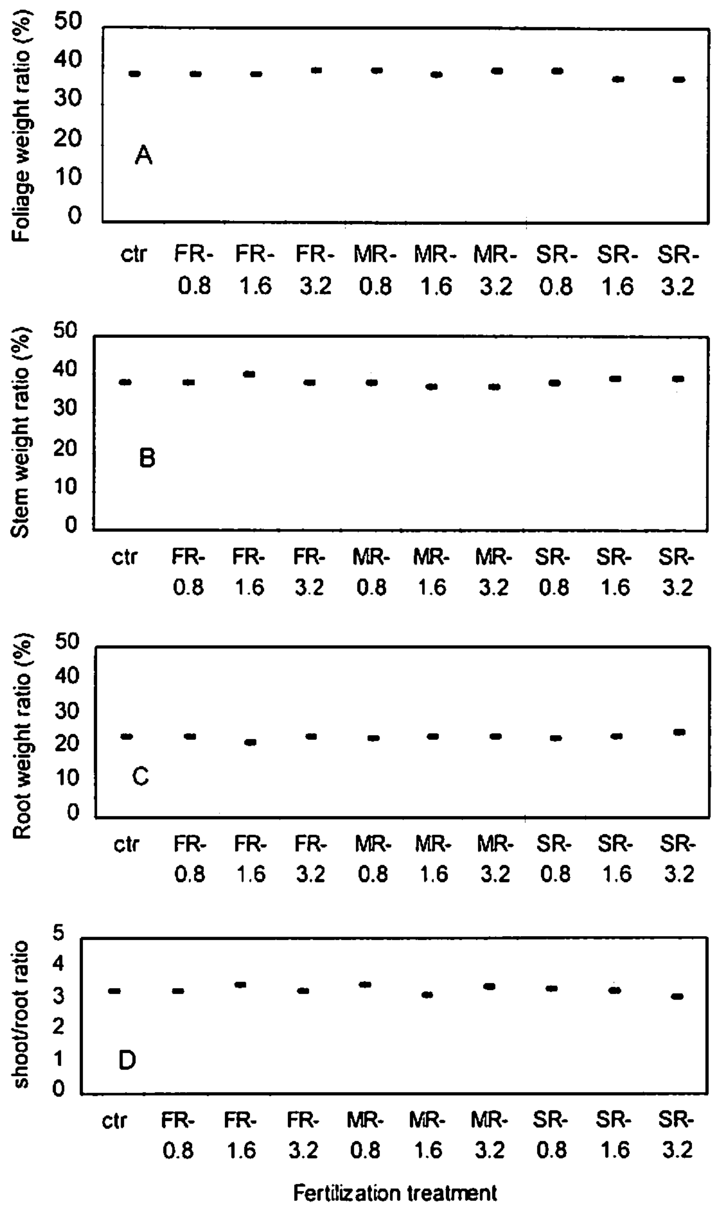

Figure 2. Means and standard deviations of foliage, stem and root dry weight ratios and shoot/root ratios of ponderosa pine seedlings under various treatments at the experiment site. A= foliage; B= stem; C= root; D= total dry weight.

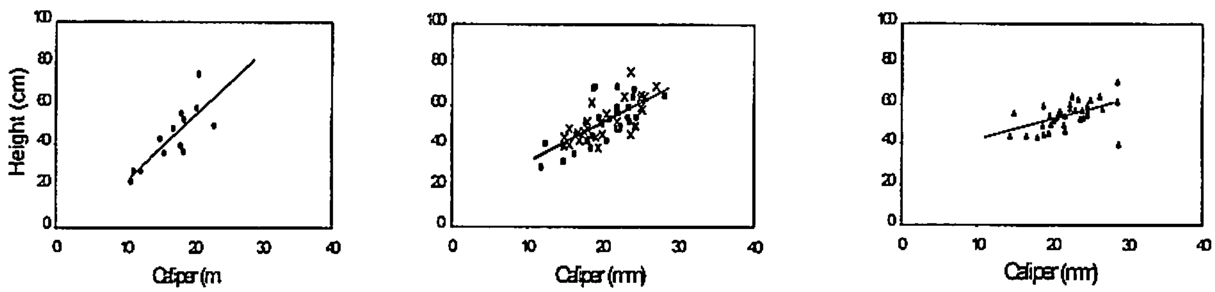

Figure 3. The relationship between final caliper and height of ponderosa pine seedlings fertilized at different application rates. A = control; B = 0.8 and 3.2 grams per seedling; C = 1.6 grams per seedling

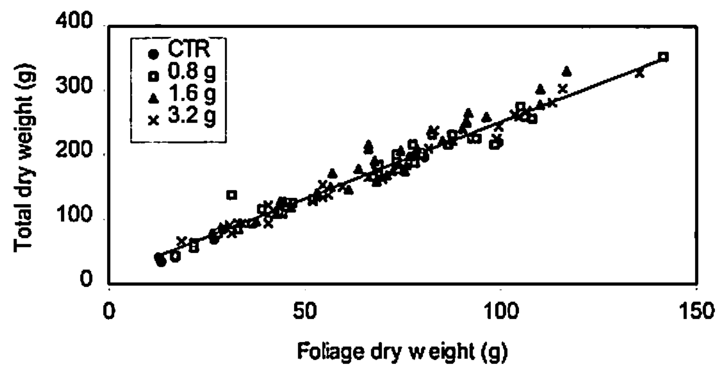

Figure 4. The relationship between foliage dry weight and total dry weight of ponderosa pine seedlings at the experimental site