AN ABSTRACT OF THE THESIS OF

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Northeastern Oregon geology and climate provides moderately productive conditions for forest management and timber production. Although site preparation and planting are commonly used silvicultural practices, little research exists on the efficacy of specific forest herbicides and responses of seedling survival and growth in this region. This research seeks to improve the knowledge and understanding of these practices by examining the short and long-term effects of controlling competing vegetation on early plantation establishment and growth. The first study re-evaluates ponderosa pine (*Pinus ponderosa*) growth and survival twenty years after hexazinone was applied in broadcast and spot treatments for control of competing vegetation. Early treatment differences in survival and growth were detected (Oester et al. 1995), and tree size has continued to diverge among treatments twenty years after planting.

The second study evaluated a suite of chemical site preparation treatments and several responses: western larch (*Larix occidentalis*) and Douglas-fir (*Pseudotsuga meziesii*) seedling survival and growth, vegetation cover development, and change in growing season volumetric soil moisture. Seedling survival, seedling volume growth,

and volumetric soil moisture at the end of the first and second growing seasons did not always differ among treatments, but consistently decreased where competing vegetation cover was greater.

These studies provide evidence that controlling competing vegetation on these sites increases survival and growth of western larch and Douglas-fir seedlings in the first few years after planting. Although direct effects of treatment do not persist, differences in tree size among treatments are still evident after two years for Douglas-fir and western larch, and after 20 years for ponderosa pine. Results pertain directly to ponderosa pine, western larch, and Douglas-fir planted in Douglas-fir/spiraea (*Pseudotsuga menziesii/Spiraea betulifolia*) and Douglas-fir/common snowberry (*Pseudotsuga menziesii/Symphoricarpos albus*) plant associations in northeastern Oregon, but may reasonably be applied to similar sites with the same species composition throughout much of the Intermountain West.

# Seedling Response to Vegetation Management in Northeastern Oregon

by
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Amanda A. Lindsay, Author

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CONTRIBUTION OF AUTHORS

Liz Cole assisted with data collection, data analysis, and was involved in the design and writing of Chapter 1.

Paul Oester assisted with data collection and was involved in the design and writing of Chapter 1.

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# INTRODUCTION

Private forest land managers in eastern Oregon commonly apply herbicides for silvicultural site preparation and release treatments. The primary commercial tree species in this region are ponderosa pine (*Pinus ponderosa*), western larch (*Larix occidentalis*), and Douglas-fir (*Pseudotsuga menziesii*) due to their hardiness, relatively fast growth, and high commercial value. Droughty conditions east of the Cascade Mountains are intensified by dense plant cover, necessitating cover reduction to enhance plantation success. My research evaluates whether herbicides may provide the vegetation control needed to establish these plantations and increase net seedling growth. However, there is very little documented research regarding the efficacy of herbicides used in this region or the benefits they may provide for growth of these species. Managers base their prescriptions on published research from southern and western Oregon, the Hall Ranch ponderosa pine study implemented by Oester et al. (1995), and visual interpretations of operational treatments with respect to vegetation control and seedling survival and growth. My research is among the first to document outcomes from different herbicides and combinations of herbicides, in terms of efficacy of treatments (i.e., reduction in competing vegetation cover) and the mechanisms of seedling survival and growth. This research examined specific herbicide prescriptions for weed control in ponderosa pine, western larch, and Douglas-fir plantations. Specific treatments were designed to understand herbicide efficacy on eastern Oregon species that typically compete with planted seedlings, and to gain some insight into the mechanisms by which herbicides improve seedling survival and growth. Treatments were also considered operationally feasible under current economic conditions assuming minimal increases in the amount of harvestable volume and an improved rate of return.

The climate, geology, and management history of eastern Oregon influence conifer survival and growthp; hence, sound silvicultural decisions are needed to ensure reforestation success. Eastern Oregon geology was formed through many processes, but some common processes include glaciations, volcanic eruptions, and river down-cutting. The Blue and Wallowa Mountains are part of the Blue Mountains physiographic province (Johnson and Clausnitzer 1991). Approximately 65 million years ago the Columbia River basalts were formed through extensive volcanism, and the Blue Mointains were uplifted with folding and faulting of the ranges. Volcanic intrusions and eruptions continued depositing basalts and lava flows that built up on each other to create layers more than 600 m deep. Then, approximately 2-3 million years ago erosion and deposition of alluvial sand and gravel, downcutting by rivers and streams, and wind deposition of loess shaped the landscape. Approximately 12,000 and 6,000 years ago Glacier Peak and Mt. Mazama, respectively, erupted and covered much of the region with a coat of sandy volcanic ash, that now characterizes many of this region’s more productive sites.

Differences in soil characteristics result from variations in climate, topography, parent material, vegetation, and time (Johnson and Clausnitzer 1991). Probably the two most important soil factors are ash deposits from Mt. Mazama and Glacier Peak, along with other volcanic eruptions, and deposition of loess from central Washington.

Productivity is closely related to ash and loess content in these soils. Ash soils have high water holding capacity, high infiltration rates, low compactability, high detachability, and disproportionately high proportions of nutrients in the upper layers. These ash layers enhance water storage and increase water availability for seedlings during summer drought in the Blue Mountains (Emmingham 2006). Loess soils have high base saturation, high nutrient reserves, and generally have excellent physical properties.

The climate of eastern Oregon also influences forest productivity in the region. Eastern Oregon is hot and dry during the summer, and cold and moist in the winter with much of the annual precipitation occurring in the form of snow (Emmingham 2006). Elevation has a large influence on total precipitation and evaporative demand; the average annual precipitation for La Grande is only 43.2 cm (Climatological Summaries 2005), but precipitation increases with elevation. During the summer three to five months average insignificant amounts of rain (Emmingham 2006), creating drought conditions that are not conducive to seedling survival and growth. However, the severity of drought on a site depends on moisture demand by plant cover that may be reduced by the occasional summer thunderstorm perhaps as much as the annual rainfall, elevation, soils, soil moisture holding capacity, and evaporative demand (Emmingham 2006). The Columbia River Gap allows storms through the Cascades that provide higher precipitation and relative humidities, less fluctuation in winter temperatures, and probably most importantly summer and early autumn convectional storms that bring lightning and sometimes precipitation (Johnson and Clausnitzer 1991).

The history of management in eastern Oregon has also contributed a great deal toward shaping the landscape of today. According to Oliver et al. (1994) the most influential management practices of eastern Oregon are (and have been) selective timber harvest (high-grading), fire management, grazing, mining, roading, pest management, riparian management, wildlife management, wilderness management, and silvicultural operations. My research addresses the silvicultural operations of planting and weed control, processes that are key elements for restoration of commercial conifers in the region.

# TWENTY-YEAR RESPONSE OF PONDEROSA PINE TO TREATMENT WITH HEXAZINONE IN NORTHEASTERN OREGON

## Abstract

Planted seedlings compete with forbs, grasses and small shrubs for limited moisture, nutrients and growing space. This competition often leads to seedling mortality. Chemical control of competing vegetation with hexazinone is a common and effective silvicultural treatment for ensuring ponderosa pine (*Pinus ponderosa* Laws.) plantation success on dry sites in the western U.S., yet few studies document the effect for more than the first few years after planting. This study evaluates ponderosa pine growth and survival twenty years after planting after hexazinone was applied in broadcast and spot treatments for control of competing vegetation. During the first five years after establishment treatment imposed differences in ponderosa pine seedling survival and growth (Oester et al. 1995). Conditional on initial tree size in year 19, growth in basal diameter, height, individual tree volume and vol $ha^{-1}$ during the twentieth growing season was similar across treatments. However, because trees receiving herbicide treatment were larger, their average growth was greater and basal diameter, height, tree volume and vol $ha^{-1}$ continued to diverge among treatments. The economic implications of treatment differences include shorter periods of time required to reach a given yield under broadcast applications. Initial control of competing vegetation increases seedling survival and mean tree size 20 years after treatment. Results pertain to ponderosa pine planted in Douglas-fir/spiraea

(*Pseudotsuga menziesii/Spiraea betulifolia*) and Douglas-fir/common snowberry (*Pseudotsuga menziesii/Symphoricarpos albus*) plant associations in northeastern Oregon, but should apply to similar sites with the same vegetation community throughout much of the Intermountain West.

## Introduction

Vegetation management increases the success of ponderosa pine (*Pinus ponderosa* Laws.) plantation establishment in the western U.S (Oliver 1990, Powers and Reynolds 1999, Wagner et al. 2006). Typically ponderosa pine is planted on sites that are seasonally hot and dry with most of the precipitation occurring during the winter as snow. During the first few years of plantation establishment, roots of ponderosa pine seedlings share portions of the soil profile used by forbs, grasses and small shrubs (Newton 1973). Low summer moisture, moderate soil water holding capacity, and low humidity during the growing season make competition from forbs, grasses and small shrubs on dry sites potentially lethal for ponderosa pine seedling establishment; thus, minimizing water use by competing vegetation is essential (Newton 1973). Decreasing leaf area of competing species in early spring increases soil water and nutrients available for establishing tree seedlings by reducing demand. Competing vegetation also delays the onset of maximum growth of conifer plantations (Oliver 1990, Wagner et al. 2006), potentially resulting in economic loss from plantations managed on short rotations.

In previous work in northeastern Oregon, Oester et al. (1995) found that hexazinone applied for control of herbaceous species significantly improved short-term ponderosa pine seedling survival, growth, and vigor, and reduced seedling establishment costs. The original objective of their study was to identify promising vegetation control treatments for establishment of ponderosa pine to meet regulatory standards, timber management objectives and wildlife habitat targets on cut-over, burned or insect-killed forests. Similar short-term survival and growth results have been documented for ponderosa pine from studies in northeastern California, eastern Washington, western Montana, and Idaho (Christensen et al. 1974, Boyd et al. 1995).

Hexazinone is sometimes used in conifer site preparation and release treatments in the Intermountain West (Boyd et al. 1995). Other commonly tested chemicals for ponderosa pine plantations in the western U.S. include atrazine (Christensen et al. 1974; Crouch 1979), 2,4,5-T (Oliver 1990), imazapyr (Boyd et al. 1995), and glyphosate (Powers and Reynolds 1999). These herbicides successfully control competing vegetation and increase seedling survival and growth. However, studies in Montana, Washington, and Idaho found that hexazinone is the most effective herbicide with respect to both weed control and conifer growth (Boyd et al. 1995). Hexazinone has both foliar and soil activity, and kills competing vegetation by inhibiting photosynthesis (Ahrens et al. 1994). It can be absorbed by roots and translocated through the xylem, or absorbed by leaves with very limited transport to other plant parts. Hexazinone controls herbaceous vegetation, such as grasses, sedges, and forbs, but does not consistently control shrubs (Boyd et al. 1995). Control of competing vegetation with hexazinone may last two to ten years; residues are relatively short lived.

To determine the long-term effect of early vegetation management on growth of ponderosa pine, studies ideally need to evaluate differing degrees of competing vegetation and plantation growth through rotation age (Oliver 1990, McLeod and Mandzak 1991). Here we build on earlier results by extending assessment of seedling performance through the first 20 years of plantation development. Our current objective was to test if the early effect of different competing vegetation control treatments presented by Oester et al. (1995) persisted 20 years after plantation establishment.

## Methods

Oester et al. (1995) applied hexazinone to control competing vegetation in 1988 and 1989, and followed survival and growth of ponderosa pine seedlings through 1992 (excluding 1991) to quantify short-term responses. Their study was implemented in eastern Oregon at the Hall Ranch, part of the Oregon State University Eastern Oregon Agricultural Research Center east of Union, Oregon, (45.13°N, 117.73°W). Plots are located at elevations from 1000 to1220 meters, and face north-northeast on 2%-15% slopes. Average annual precipitation between 1980 and 1992 was 63.5 cm. The Hutchinson Variant and Klicker soil series occur in this area. The Hutchinson Variant series is moderately deep, well drained, and derived from basalt, granite, and volcanic tuff, with some volcanic ash and loess on the surface. The Klicker series is a stony silt loam, moderately deep and well drained, and derived mainly from basalt with a thin ash and loess cap. Site indices for the two soils range from 22 to 29 m (base age 100: Site V-III)) for ponderosa pine. Plant associations in the study area include Douglas-fir/spiraea (*Pseudotsuga menziesii/Spiraea betulifolia*) and Douglas-fir/common snowberry (*Pseudotsuga menziesii/Symphoricarpos albus*) (Johnson and Simon 1987). The plots were clear cut during summer and fall of 1986 and non-merchantable trees were felled in 1987. In general, the site was of average quality for ponderosa pine and had developed a moderately heavy grass cover following clearcutting and grazing. The plots were planted with 2-0 bareroot ponderosa pine seedlings on April 20, 1988, and at the time of planting pine grass (*Calamagrostis rubescens*), elk sedge (*Carex geyeri*), and Kentucky bluegrass (*Poa pratensis*) were abundant on the site.

The Hall Ranch study was a randomized complete block design with four blocks. Each block was divided into five treatment plots. Each plot was 0.08 ha (21.3 m x 35.6 m) and was planted to a density of 650 trees per hectare. The five treatments were (1) complete: two consecutive years of identical broadcast applications of hexazinone, (2) standard: a single broadcast application of hexazinone, (3) large spot: a 2.3 $m^2$ spot application of hexazinone around each seedling, (4) small spot: a 0.4 $m^2$ spot application of hexazinone around each seedling and (5) control: untreated. Hexazinone was applied with a backpack sprayer at 2.24 kg $ha^{-1}$ with a total spray volume rate of 187.12 L $ha^{-1}$. In each treatment plot, before hexazinone treatments were applied, 50 2-0 bareroot ponderosa pine seedlings were planted. Seedling survival and growth, including total height (cm), basal diameter at ground line (mm) and ocular estimates of vigor were recorded for the first five years after planting (with the exception of the fourth year), and analyzed in the fifth year.

We identified every survivor and remeasured trees in the fall of 2006 and 2007, 19 and 20 years after study establishment, respectively. The 2006 observations included survival, basal diameter (mm) 15 cm above groundline, diameter at breast height (1.37 m; dbh) (mm), total height (cm), and internodal lengths for the past five years where measurable. In 2007 observations included survival, basal diameter, dbh, and total height.

Analysis of variance (ANOVA) was used to compare treatment means for basal diameter, dbh, basal area ($cm^2$), height, individual tree volume ($m^3$, calculated as gross total stem volume from Walters et al. (1985)), volume per hectare ($m^3$ $ha^{-1}$), and percent survival at the end of the 2007 growing season. Analysis of variance also was used to compare treatment means for current annual increment (CAI) in height, basal area, and individual tree volume for the 2007 ($20^{th}$) growing season. To meet assumptions of homoscedascity and normality, all response variables except survival were log transformed; percent survival was transformed with the arcsin square root function. All results have been back-transformed to the original scale. Based on the Tukey's test for nonadditivity, most of the responses displayed the same relative treatment effects across blocks, with the exception of survival and volume $ha^{-1}$. Unusually high survival occurred in the control treatment and unusually low survival occurred in the standard treatment in block two, causing a treatment interaction with block two. These differences were apparently caused by heterogeneity in soil depth, so the entire block was omitted from the analysis for survival. None of the trees survived in the control plot of block three causing it to be an extreme outlier, so it was eliminated from the analysis for volume $ha^{-1}$. Treatment comparisons for each response variable were adjusted using the conservative Bonferroni approach for multiple comparisons. Hypothesis tests were considered significant when $p < 0.05$ and marginally significant when $0.05 < p < 0.10$.

Analysis of covariance was used to determine if treatment differences still exist for basal area, height, and individual tree volume growth for the 2007 growing season when conditioned on initial size at the end of year 19. Analyses of variance and covariance were conducted with the MIXED procedure in SAS v.9.1 based on a randomized complete block design with treatment as a fixed effect and block as a random effect.

Regression analysis was used to model 20-yr trends in height, basal diameter, individual tree volume and vol $ha^{-1}$. For this analysis individual tree volume was calculated as the volume of a cone ($m^3$) based on basal diameter and height:

$$\mathrm{V} = \frac{1}{3}\left(\pi \times (basalradius)^2 \times height\right)$$

Model selection was based on the pattern of residuals, graphs of the predicted versus actual values, expected patterns of tree growth, and simplicity. Non-linear regression models were fit with the SAS NLIN procedure by using the Chapman-Richards generalization of Von Bertalanffy's growth model (Richards 1959, Chapman 1961, Pienaar and Turnbull 1973):

$$Y = a\left(1 - e^{b*year}\right)^c$$

where Y is growth, and a, b, and c are asymptote, scale, and shape parameters, respectively. The data were not adequate to estimate the upper asymptote of the growth equation because the plantings were only 20 years old. It therefore was set to the approximate size of 200-yr-old ponderosa pine at site index 27 m (100-year base age) (Meyer 1938). This fixed the asymptote for basal diameter at 770 mm, height at 3900 cm, volume per tree at 6.05 $m^3$, and volume per hectare at 647 $m^3$. Mean survival was plotted against years since planting for graphical analysis of treatment differences.

## Results

Survival (Figure 1.1) decreased across all treatments between years 5 and 20. Twenty years after planting, mean survival was greater than 50% with the complete treatment while mean survival in the control ranged around 15%. Survival with both spot applications was intermediate. There were no differences in survival among herbicide treatments, but all were greater than the control ($P = 0.001$). While most of the mortality occurred in the first five years after planting, additional mortality continued at a slower rate between years 5 and 20, but at an approximately equal rate among treatments (Figure 1.2).

Twenty years after planting the mean individual tree volume (Figure 1.3) in the complete treatment was slightly below 0.10 $m^3$, while the mean individual tree volume

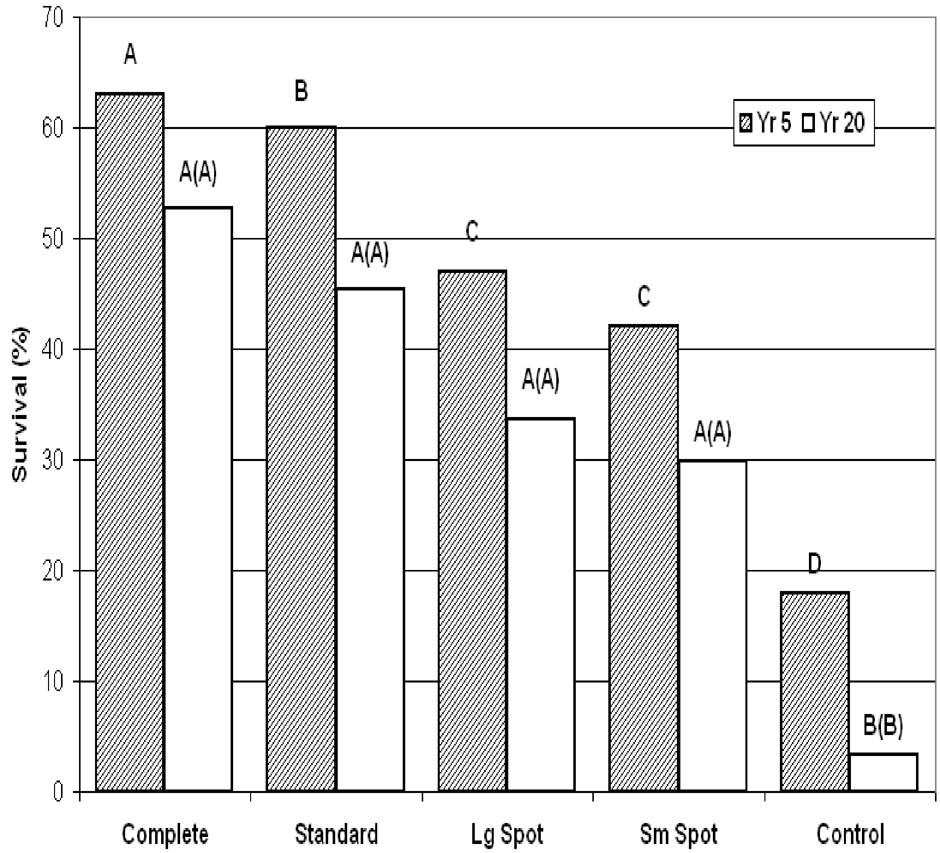


Figure 1.1 Survival of planted ponderosa pine five and twenty years after competing vegetation control treatments in northeastern Oregon. Letters designate significant differences at the $\alpha = 0.05$ ($\alpha = 0.10$) levels.

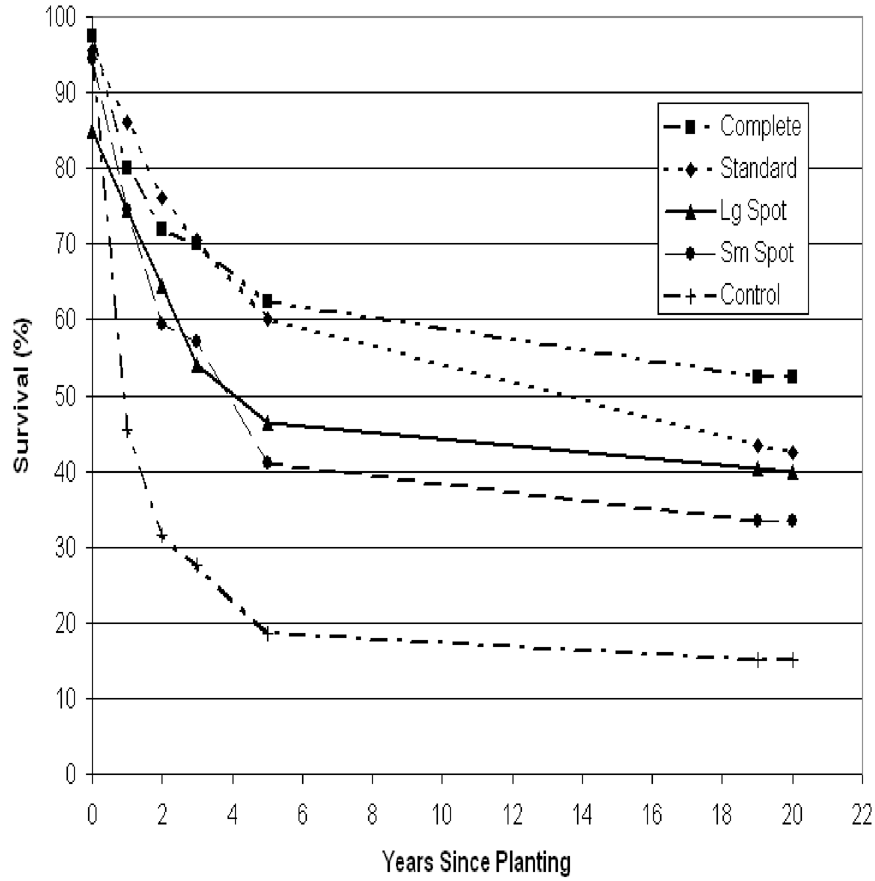


Figure 1.2 Mean ponderosa pine survival trends after competing vegetation control treatments in northeastern Oregon.

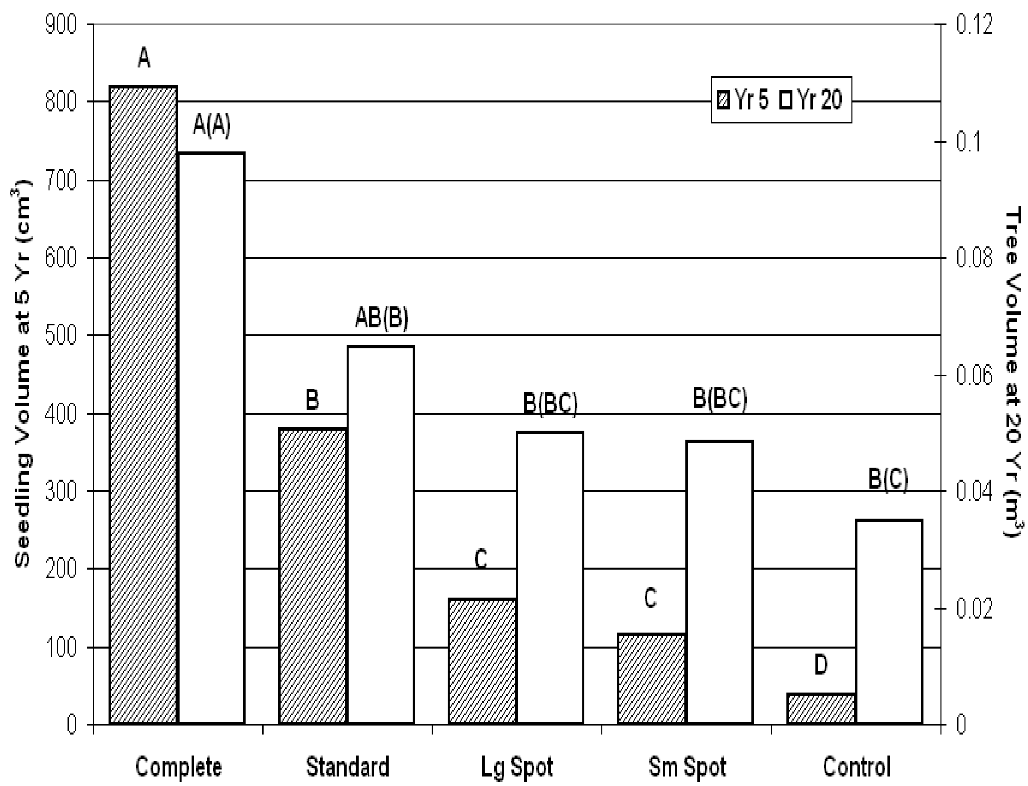


Figure 1.3 Mean ponderosa pine seedling and tree volumes five and twenty years after competing vegetation control treatments in northeastern Oregon. Letters designate significant differences at the $\alpha = 0.05$ ($\alpha = 0.10$) levels

in the control was 0.03 $m^3$. Mean individual tree volume after the complete treatment was greater than volume after the spot applications and the control ($P < 0.001$). The complete treatment also resulted in greater basal diameter ($P < 0.001$), dbh ($P < 0.001$), basal area ($P < 0.001$) and height ($P < 0.001$) when compared to the spot applications and the control, and vol $ha^{-1}$ ($P = 0.003$) when compared to the control (Table 1.1). If the tests were performed at $\alpha = 0.10$ the complete treatment resulted in greater basal diameter, dbh, basal area and height compared to the standard treatment, while the standard treatment resulted in greater basal diameter, dbh, basal area and height compared to the control treatment.

When tree growth for the 2007 growing season was conditioned on initial tree size, growth in basal diameter, dbh, basal area, height, individual tree volume and vol $ha^{-1}$ did not differ significantly among any of the treatments ($P > 0.753$).

Mean individual tree volume growth (CAI) between 19 and 20 years after planting tended to increase with apparent intensity of vegetation control (control, small spot, large spot, standard, complete), yet differences among the treatments were only marginally significant ($P = 0.073$) (Table 1.1). There were no detectable differences among treatments for basal area growth ($P = 0.608$) or height growth ($P = 0.686$).

Basal diameter and height by treatment both increased along somewhat parallel trajectories for the most recent portion of the 20 years of stand development (Figures 1.4 and 1.5 and Table 1.2). Growth of individual tree volume and vol $ha^{-1}$ increased

Table 1.1 Summary of mean basal diameter (bd), diameter at breast height (dbh), basal area (ba), height (ht), and volume per hectare (vol $ha^{-1}$), and current annual increment (CAI) for mean basal area, height, and individual tree volume (vol) at year 20 for ponderosa pine after competing vegetation control treatments in northeastern Oregon. Letters designate significant differences at the $\alpha = 0.05$ ($\alpha = 0.10$) levels.

| | Treatment Comparisons (Yr 20) | | | | | CAI | | |
|---|---|---|---|---|---|---|---|---|
| Treatment | bd (mm) | dbh (mm) | ba ($cm^2$) | ht (cm) | vol $ha^{-1}$ ($m^3$) | ba ($cm^2$) | ht (cm) | vol ($m^3$) |
| Complete | 269 a(a) | 200 a(a) | 327 a(a) | 831 a(a) | *32* a(a) | 23 a(a) | 42 a(a) | 0.011 a(a) |
| Standard | 229 ab(b) | 171 ab(b) | 241 ab(b) | 708 b(b) | 17 a(a) | 24 a(a) | 40 a(a) | 0.009 a(a) |
| Lg Spot | 210 b(bc) | 156 bc(bc) | 195 bc(bc) | 651 b(bc) | 10 ab(a) | 21 a(a) | 44 a(a) | 0.008 a(a) |
| Sm Spot | 209 b(bc) | 153 bc(bc) | 191 bc(bc) | 651 b(bc) | 10 ab(ab) | 21 a(a) | 44 a(a) | 0.007 a(a) |
| Control | 177 b(c) | 127 c(c) | 141 c(c) | 565 b(c) | 2 b(b) | 19 a(a) | 42 a(a) | 0.006 a(a) |

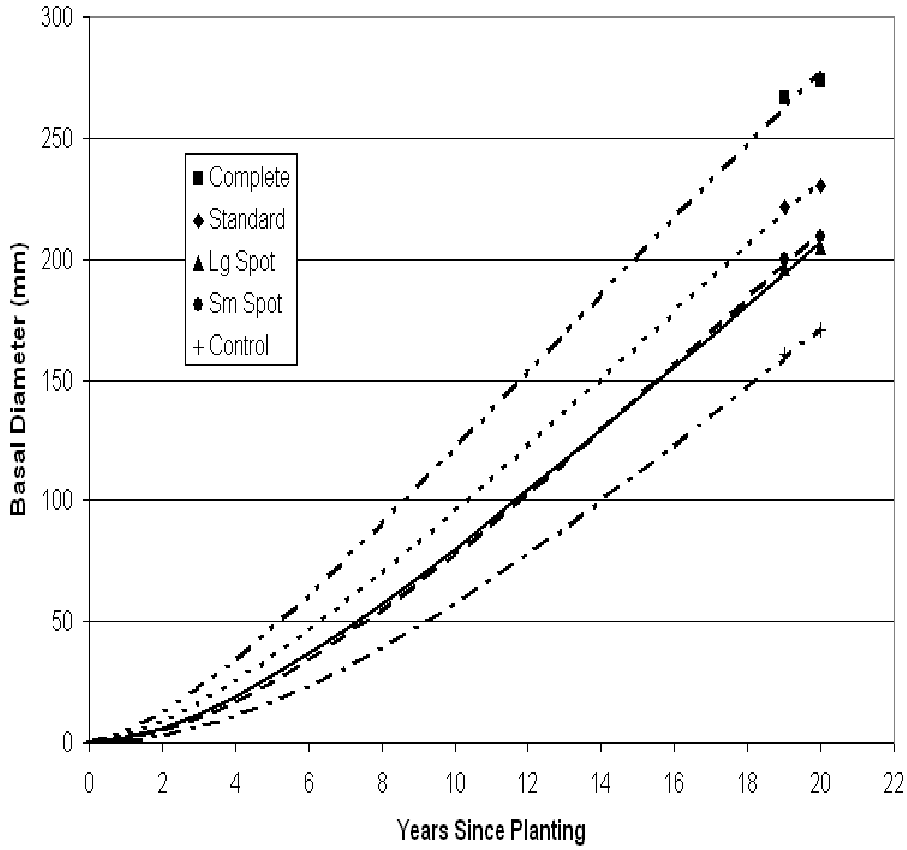


Figure 1.4 Mean basal diameter for ponderosa pine after competing vegetation control treatments in northeastern Oregon.

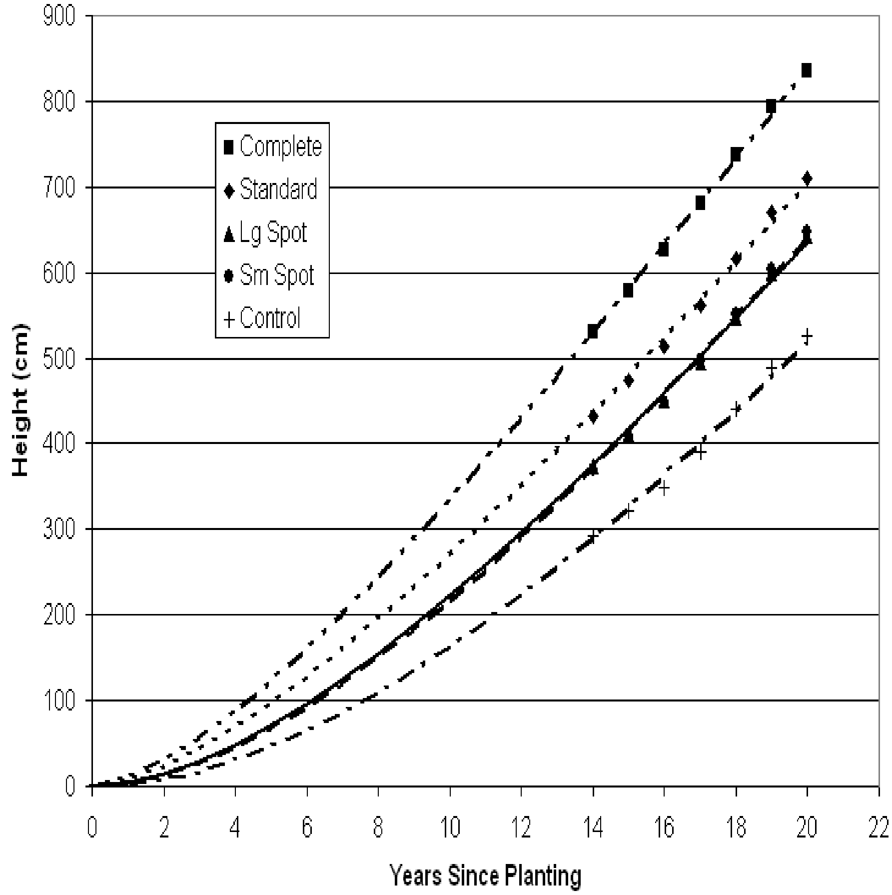


Figure 1.5 Mean height for ponderosa pine after competing vegetation control treatments in northeastern Oregon.

Table 1.2 Regression equations for tree size and survival through time.

| Treatment | BD (mm) | HT (cm) |
|---|---|---|
| Complete | $= 770*((1-e(^{-0.04*yr}))^{1.57})$ | $= 3,900*((1-e^{(-0.02*yr)})^{1.57})$ |
| Standard | $= 770*((1-e^{(-0.03*yr)})^{1.63})$ | $= 3,900*((1-e^{(-0.02*yr)})^{1.61})$ |
| Lg Spot | $= 770*((1-e^{(-0.03*yr)})^{1.73})$ | $= 3,900*((1-e^{(-0.02*yr)})^{1.79})$ |
| Sm Spot | $= 770*((1-e^{(-0.03*yr)})^{1.86})$ | $= 3,900*((1-e^{(-0.02*yr)})^{1.86})$ |
| Control | $= 770*((1-e^{(-0.03*yr)})^{2.00})$ | $= 3,900*((1-e^{(-0.02*yr)})^{1.97})$ |
| | Vol ($m^3$) | Vol $ha^{-1}$ ($m^3$) |
| Complete | $= 6.05*((1-e^{(-0.02*yr)})^{3.09})$ | $= 647*((1-e^{(-0.03*yr)})^{3.47})$ |
| Standard | $= 6.05*((1-e^{(-0.02*yr)})^{3.31})$ | $= 647*((1-e^{(-0.02*yr)})^{3.26})$ |
| Lg Spot | $= 6.05*((1-e^{(-0.02*yr)})^{3.59})$ | $= 647*((1-e^{(-0.02*yr)})^{3.53})$ |
| Sm Spot | $= 6.05*((1-e^{(-0.02*yr)})^{4.02})$ | $= 647*((1-e^{(-0.03*yr)})^{4.29})$ |
| Control | $= 6.05*((1-e^{(-0.02*yr)})^{4.31})$ | $= 647*((1-e^{(-0.02*yr)})^{4.49})$ |

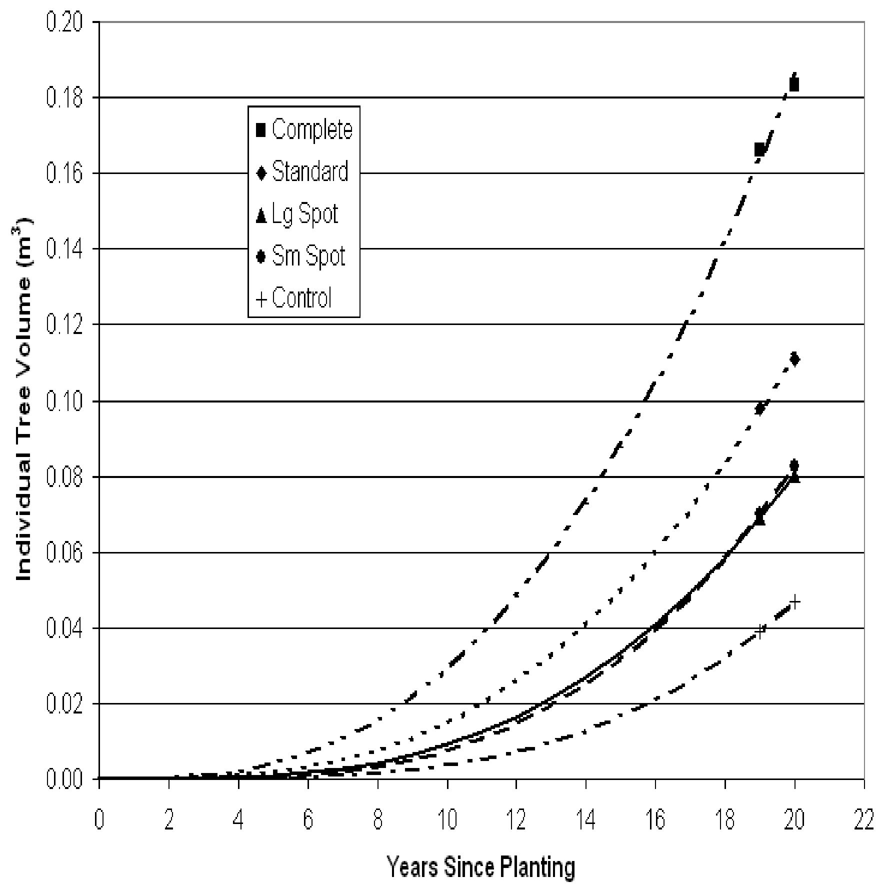


Figure 1.6 Mean volume growth for ponderosa pine after competing vegetation control treatments in northeastern Oregon.

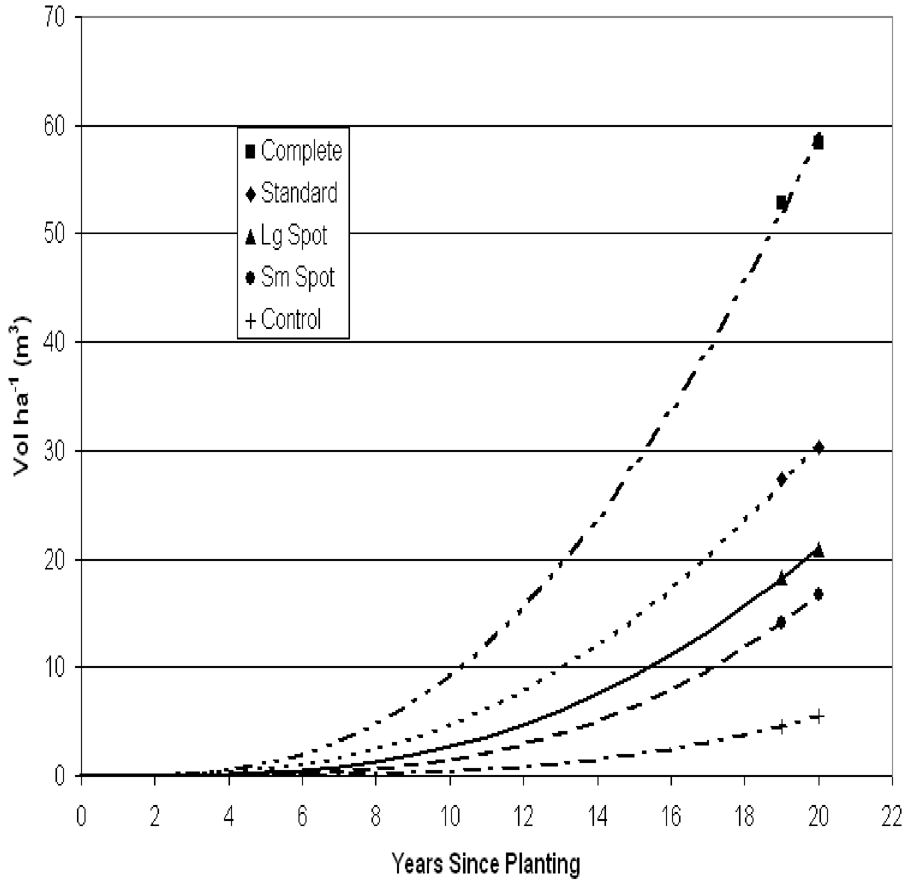


Figure 1.7 Mean volume per hectare for ponderosa pine after competing vegetation control treatments in northeastern Oregon.

with intensity of vegetation control; i.e., trees in the complete treatment are growing the fastest (Figures 1.6 and 1.7).

## Discussion

Five years after plantation establishment Oester et al. (1995) found that planted ponderosa pine had higher survival after broadcast treatments than after spot applications, and spot applications promoted higher survival than the control (Figure 1.1). Mean survival between 5 and 20 years after planting decreased for all treatments at approximately the same rate (Figure 1.2), suggesting that differences in survival due to treatment effects were realized by the fifth year after planting, and mortality after year five was probably due to extraneous variables such as rodent damage, climatic influences and cattle grazing.

Studies of various silvicultural treatments in the western U.S. have found that chemical vegetation control is more effective than spacing (Oliver 1990, Zhang et al. 2006), genetic improvement (McDonald et al. 1998), or insect control and fertilization (Powers and Reynolds 1999) for increasing the initial growth and survival of ponderosa pine seedlings. Ten years after treatment with hexazinone in western Montana, McLeod and Mandzak (1991) found that vegetation control greatly increased the plantation growth index (PGI = survival*stem volume) over controls, although there was little difference between spot and broadcast applications. On the western slope of the Sierra Nevada, California, Oliver (1990) found that ponderosa pine trees on plots treated 20 years earlier with 2,4,5-T to control shrub competition had about 25% larger diameters, 20% taller total heights, 27% greater basal area $ha^{-1}$

and 47% greater volume $ha^{-1}$ compared to untreated trees. Oester et al. (1995) found that seedling volumes in the complete treatment were greater than in the standard treatment, and seedling volumes in these two treatments were greater than in the spot applications (Figure 1.3). At Hall Ranch, vegetation control with hexazinone increased the short-term growth of ponderosa pine seedlings; treating twice or treating using broadcast methods increased survival and growth 20 years after planting when compared to a control. In addition, broadcast treatments (complete and standard) increased the vol $ha^{-1}$ over spot and control treatments.

Several studies have shown an interaction between spacing of ponderosa pine seedlings and vegetation control. Oliver (1990) reported that, after twenty years, mean tree size was positively correlated and stand totals negatively correlated with spacing in the absence of competing vegetation in California. Zhang et al. (2006) reported that, after thirty years, stand volume and periodic annual increment were higher for some levels of spacing when competing vegetation was controlled, but that effects of vegetation control may be disappearing on plots with high tree densities. Tree growth in the highest densities is slowing due to high intra-specific competition, while tree growth in lower density plots continues at similar rates due to less intra-specific competition. Twenty years after planting, we have found that variance among treatments is high and differences in tree size and growth are difficult to detect. Growth trajectories and comparisons of various tree dimensions illustrate both parallel and diverging trends between treatments. Trees in the control and spot treatments are now essentially 'open grown' and likely are not competing with other trees for resources. Tree crowns in the standard and complete treatments, however, are beginning to overlap, and intra-specific competition has begun. The effects of vegetation control therefore may be more persistent in plantations of lower densities or where thinning is planned before the end of the rotation, although total yield will be highest where sites are fully occupied by crop species at the time most trees become merchantable.

Long-term growth trends in response to vegetation management have been described as one of two general forms (Snowdon and Waring 1984). Type 1 responses lead to parallel growth trends after an initial treatment effect and type 2 responses lead to persistently diverging growth trends among treatments. Wagner et al. (2006) provide evidence that tree growth after vegetation management generally follows the type 1 response. Growth trajectories tend to become parallel at the time of crown closure and intra-specific competition, and the difference in the time that it takes for this to occur between two vegetation management treatments is the time delay of the type 1 response onset (Richardson et al. 1999, Kimberly and Richardson 2004, Wagner et al. 2006). However, Newton and Cole (2008) report continued divergence after 26-27 years, hence the type 2 response. They also point to differences in apparent site index and growth curves with early cultural treatments, suggesting that there may be a third type of response indicating true potential of a site when resources are not shared. We found no differences among treatments for basal diameter, height, individual tree volume and vol $ha^{-1}$ growth for the 2007 growing season when conditioned on initial tree size in year 19. The continued divergence in basal diameter, height, volume and vol $ha^{-1}$ suggests that a direct treatment effect in the first few years of seedling establishment led to increased seedling size, causing an age shift in the development of treated seedlings. This direct effect did not persist through 20 years, but the resulting differences in size have led to an indirect effect of tree size that has compounded over 20 years. Full crown closure has yet to occur across our study site, and for some of the treatments it may never occur due to low survival and low density. With time, individual tree growth after the control and spot treatments may approach individual tree growth after broadcast applications due to the low stand density and intra-specific competition, yet vol $ha^{-1}$ and tree quality of the control and the spot treatments will not likely equal that of the broadcast treatments due to the large differences in survival and unoccupied site area.

Key objectives of competing vegetation management on dry sites may include ensuring sufficient seedling survival to meet federal or state regulations. Oregon Forest Practices regulations for ponderosa pine planted on similar sites require that at least 309 trees per hectare survive and are free to grow six years after harvesting. Plantations of the same density as this study will require a minimum of 48% survival to meet these regulations.

Wagner et al. (1989) reported that pine growth and survival may need to be considered as separate management objectives. We suggest that on dry sites, emphasis placed on ensuring seedling survival will also increase seedling growth, and the main objective for competing vegetation management is to provide greater consistency and predictability in both seedling survival and growth that can be projected through time.

On dry sites, such as where our study plots are located, proper vegetation management is even more critical to meet this objective.

The ranking of mean treatment responses differed among blocks. Several unquantified factors may contribute to the large variation among treatments and blocks. No information is available on the effect of the hexazinone treatments on plant species dynamics (vegetation cover or composition). Cattle grazing over the past 15 years undoubtedly affected seedling growth and survival through physical damage and impacts on understory vegetation. These differences were generally not large enough to cause block by treatment interactions, but they did complicate the interpretation of treatment effects for survival and vol $ha^{-1}$. We suspect that one reason for large variation in survival was variability in soil depth. On dry sites vegetation management does not always guarantee high seedling survival and growth, but with no vegetation management few trees may survive the first 20 years.

The scope of inference for this study is limited to the twenty years of tree growth analyzed for these and similar sites characterized by the same plant associations. Our results are consistent with trends from short-term vegetation management studies conducted elsewhere (Balneaves and Christie 1988, Wagner et al. 1999, Miller et al. 2006, Wagner et al. 2006, Wagner and Robinson 2006) and it's reasonable to expect similar results on dry, low elevation sites across the western U.S. Continued remeasurement of surviving trees will give researchers and managers a better understanding of how ponderosa pine trees respond to vegetation management over the full rotation, and how the onset of intra-specific competition influences longer-term patterns of competing vegetation control.

## Conclusion

Chemical control of competing vegetation with hexazinone has proven to be a very effective silvicultural treatment for ensuring ponderosa pine plantation success in the western U.S. Our results indicate that after 20 years of plots receiving broadcast treatments continue to display greater survival and growth than do spot treatments. All treatments showed improved growth and survival relative to the control; however, the high variability among plots prevents some treatments from being statistically significant. Spot treatments improved survival compared to the control and were enough to meet the minimum requirements of Oregon's Forest Practices Act. However, full site occupancy was not achieved even by year 20, causing a loss of potential wood fiber and quality associated with open stands. This option may be attractive to managers who want to invest minimally on reforestation costs and maximize forage production, but wood fiber quantity as well as wood quality will be sacrificed because of low stocking and the delay in self-pruning. For managers interested in maximizing wood fiber yield and value, the broadcast treatments provided adequate individual tree growth and reasonable per hectare yields, with measurable marketable sawlog volume available after twenty years under the complete treatment. Continued measurements of the remaining trees will reveal how much influence early weed control and stand density have on growth responses through a rotation, including the age shift or time gain at rotation age.

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# RESPONSES AND RELATIONSHIPS OF WESTERN LARCH AND DOUGLAS-FIR SEEDLINGS, VEGETATION COVER, AND SOIL MOISTURE THE FIRST TWO YEARS AFTER TREATMENT WITH COMMONLY USED FORESTRY HERBICIDES IN NORTHEASTERN OREGON

## Abstract

Vegetation control is essential in establishing conifer plantations in northeastern Oregon and the Intermountain West. Western larch (*Larix occidentalis*) and Douglas-fir (*Pseudotsuga menziesii*) are two of the species that private and industrial land managers grow due to their relatively fast growth rates and high market value. Although vegetation control and regeneration practices are often used, little documented research exists on herbicide selectivity and efficacy, including seedling survival and growth. Our results indicate that treatment responses vary widely by herbicides and rates applied, stock types planted, vegetation cover before treatment, and sites. Clear treatment patterns did not always exist, but our results demonstrate that relationships between vegetation cover and seedling and soil moisture responses are similar to those found in other regions. As vegetation cover increased, seedling survival and volume growth, as well as volumetric soil moisture at the end of the growing season, decreased. These results provide evidence that treatments were beneficial, but site specific prescriptions are necessary to maximize vegetation response. Results pertain to western larch and Douglas-fir planted in Douglas-fir/spiraea (*Pseudotsuga menziesii/Spiraea betulifolia*) and Douglas-fir/common snowberry (*Pseudotsuga menziesii/Symphoricarpos albus*) plant associations in

northeastern Oregon, but should apply to similar sites containing the same vegetation communities throughout much of the Intermountain West.

## Introduction

The dry climate of northeastern Oregon leads to severe moisture stress in planted seedlings, and competing vegetation exacerbates this stress. Vegetation control is essential for reliable establishment of conifer plantations acceptable for commercial timber production in northeastern Oregon and the intermountain region. This region is characterized by hot summers with little precipitation, with most of the precipitation occurring during the winter in the form of snow. Limited, but variable soil water holding capacity, and low humidity during the growing season lead to high probability of depleting soil water by transpiration, making competition on these drier sites highly detrimental to seedling survival and growth. Conservation of soil moisture is generally critical for plantation success (Newton 1973; Newton and Preest 1988). Reducing competition extends the net growing season length, and increases the proportion of site water and nutrients that are available to establishing seedlings. This is especially important in the first few years of plantation establishment when seedling roots share the same part of the soil profile as the competing vegetation (Newton 1973). As the seedlings grow, they dominate low growing vegetation, but the reduction of available resources and the reduction in the survival and growth of seedlings lead to a time delay in the onset of maximum growth of conifer plantations (Oliver 1990; Wagner et al 2006). This delay causes substantial economic loss, especially in plantations managed on short rotations. If timber markets continue to grow, very harsh sites will see a greater proportional increase in value when competing vegetation is treated with herbicides (McLeod and Mandzak 1993). To alleviate the losses from mortality and delayed growth, and increase wood fiber yield over a specific rotation period, effective vegetation management is essential (Wagner et al 2006), and herbicide treatments are the most effective and economical way to achieve vegetation control. Weed control has become a standard component of forest plantation management on forest industry lands in the southeastern and west coastal U.S. Western larch (*Larix occidentalis*) is among the most valuable conifers in the Intermountain West, but has not received much attention with regard to chemical control of its competitors. This study seeks to remedy deficiencies in technology for establishing both western larch and Douglas-fir (*Pseudotsuga menziesii*) in northeastern Oregon.

We examined the responses of Douglas-fir and western larch seedlings to different chemical weed control site preparation regimes. The effects of weed control in Douglas-fir plantations of the western U.S. have already been well established in the western and southern regions of Oregon. Weed control that substantially reduces the cover of competing vegetation prolongs the availability of summer soil moisture and decreases seedling xylem water stress (Newton and Preest 1988), and increases seedling survival and growth (Newton and Preest 1998; Rose and Ketchum 1998; Rose and Ketchum 2002; Rose et al 2006; Rosner and Rose 2006; Wagner et al 2006).

Western larch is reported to be negatively influenced by competitors and can be very susceptible to damage from chemical treatments, especially hexazinone (Boyd et al 1995; McLeod and Mandzak 1992). McLeod and Mandzak (1992) found that western larch seedlings planted one to 1.5 years after treatment with granular hexazinone (Pronone 10G®) exhibited very little chemical damage with respect to survival, but first-year's growth was not satisfactory. Oester (2005) found that shade and weed control with Oust® in northeastern Oregon increased Douglas-fir and western larch seedling survival two years after treatment. After ten years, weed control had a large positive effect on the growth of western larch compared to the control (Oester 2008). Even though chemical weed control for western larch plantation establishment is not widely reported, the use of prescribed fire for stimulating germination and controlling weeds has been documented, as have the effects of drought on western larch seedlings (Graham et al 1992; Oswald and Neuenschwander 1992). These studies found that decreasing the vegetation cover and increasing soil moisture allowed for better survival and growth in naturally regenerated western larch seedlings.

We report here two-year results from evaluation of chemical weed control treatments leading to a wide array of competing vegetation cover. Our specific goal is to determine how western larch and Douglas-fir seedlings respond to residual competing vegetation cover and soil moisture availability, and any chemical damage to seedlings that affects the response to competition. The research questions that will be answered include:

- Does the cover of grass, forb, shrub, and non-coniferous vegetation differ in the first-year after treatment between the common treatments applied in spring 2007 versus spring 2008?

- Do the cover of grass, forb, shrub, and total non-coniferous vegetation differ between controls and each of the 20 different chemical treatments in the first and second-year after treatment?
- Is the mean pre-treatment total grass, total forb, total shrub, and total non-coniferous vegetation cover correlated with the first-year post-treatment total grass, total forb, total shrub, and total non-coniferous vegetation cover?
- Does the first and second-year mean basal area ($mm^2$) and height (mm) growth for three stock types of Douglas-fir and western larch seedlings differ between controls and each of the 20 different chemical treatments?
- Does the first-year mean basal area ($mm^2$) and height (mm) growth for three stock types of Douglas-fir and western larch seedlings differ between the common treatments applied in spring 2007 versus spring 2008?
- Does the first and second-year mean survival for three stock types of Douglas-fir and western larch seedlings differ between controls and each of 20 different chemical treatments?
- Does the first-year mean survival for three stock types of Douglas-fir and western larch seedlings differ between the common treatments applied in spring 2007 versus spring 2008?
- What is the relationship between competing vegetation cover and volumetric soil moisture at 23 and 46 cm at the end of the 2007 and 2008 growing seasons?
- What is the relationship between competing vegetation cover and first-year survival, first-year volume growth, and second-year volume growth?

## Methods

### *Site Description*

This work was conducted on recently cutover land scheduled for reforestation with western larch and Douglas-fir, but where shrubs, herbs and grasses were expected to offer major obstacles to plantation success. The experimental design for this study is a generalized randomized block design with split plots. This study was replicated on three sites (sites = blocks) located on Forest Capital Partners LLC property north-northeast of Elgin, Oregon. The sites include Hooker (H), Upper Sam (US), and Lower Sam (LS), named after the harvest units they are located in. The Hooker unit (45.73°N, 117.82°W) is approximately 1200 m elevation, flat or faces southwest, and has slopes between 0-10%. The Lower Sam unit (45.64°N, 118.00°W) is approximately 990 m elevation, faces southeast, and has slopes between 5-30%, and the Upper Sam unit (45.64°N, 118.00°W) is approximately 1080 m elevation, with a southwest aspect and slopes 0-25%. Average annual maximum and minimum temperatures between 1948 and 2005 for Elgin, Oregon (elevation 810 m), were 16.7° C and 0.7° C, respectively (Oregon Climate Summaries). Average annual total snowfall for Elgin between 1948 and 2005 was 113.5 cm and average annual total precipitation was 59.9 cm, with 25% of that falling between May and September in the form of thundershowers of moderate intensity. Precipitation for this region may be very localized, but tends to increase with elevation.

Three soil types occur at these units (Dyksterhuis and High 1978). Most of the study area consists of the Tolo Silt Loam series, which is found at all three of the study sites. The Tolo Silt Loam series is a Typic Vitrandept, deep, well drained, and formed from volcanic ash and loess deposited over loess and basalt. The Klicker-Anatone Complex and the Kamela series only occur in small areas at the Upper Sam unit. The Klicker stony silt loam series is an Ultic Argixeroll, moderately deep and well drained; the Anatone extremely stony loam series is a Lithic Haploxeroll, shallow and well drained. The Kamela very stony silt loam is a Dystric Xerochrept, moderately deep and well drained. All three are formed from colluvium and residuum derived dominantly from basalt, with some loess and volcanic ash in the surface layer. Plant associations found at these sites include Douglas-fir/snowberry (*Pseudotsuga menziesii/Symphoricarpos albus*) and grand fir/spiraea (*Abies grandis/Spiraea* *betulifolia*) (Johnson and Clausnitzer 1991). Soil depth varied across all units to the extent soil sampling was often difficult in the layer below 23 cm, and individual plots were not identified by specifics of soils.

Hooker was regeneration harvested during the winter 2005-2006, while both Upper and Lower Sam units were harvested during the winter 2006-2007. Hooker and Lower Sam were harvested with a fellerbuncher and rubber tired skidder while there was approximately 30 cm of snow covering the ground. Upper Sam was hand felled and harvested with a rubber tired skidder while there was also approximately 30 cm of snow covering the ground. In the spring of 2007 all residual trees that would interfere with this study were whipfelled.

### *Treatments*

Twenty-two treatments were replicated three times within each block, for a total of 66 plots. Each treatment was randomly assigned to three of the 66 plots. The treatments consisted of different herbicides, rates, application dates, and planting dates. Treatments are shown in Table 2.1 and the herbicide products used are displayed in Table 2.2. Nine treatments were applied and planted spring 2007, nine treatments were applied summer 2007 and planted spring 2008, and four of the treatments used in spring 2007 were repeated on new plots and planted spring 2008. Choices of treatment were based on knowledge of herbicide efficacy and selectivity from elsewhere, translocation processes, and need for experimentation with the relatively new herbicide aminopyralid (Milestone®). The herbicide treatments included different

Table 2.1 Treatment designations.

| # | Code | Spray Date: | Planting Date: | Chemicals and Rates |
|---|---|---|---|---|
| 1 | ou-1 | Spring 2007 | Spring 2007 | Sulfometuron @ 0.14 kg ai/ha |
| 2 | ou/gly-1 | Spring 2007 | Spring 2007 | Sulfometuron @ 0.14 kg ai/ha plus Glyphosate @ 1.68 kg ae/ha |
| 3 | ou/clo-1 | Spring 2007 | Spring 2007 | Sulfometuron @ 0.14 kg ai/ha plus Clopyralid @ 0.16 kg ai/ha |
| 4 | atr-1 | Spring 2007 | Spring 2007 | Atrazine @ 4.48 kg ai/ha |
| 5 | atr/ima-1 | Spring 2007 | Spring 2007 | Atrazine @ 4.48 kg ai/ha plus Imazapyr @ 0.14 kg ai/ha |
| 6 | ima3-1 | Spring 2007 | Spring 2007 | Imazapyr @ 0.21 kg ai/ha |
| 7 | ima6-1 | Spring 2007 | Spring 2007 | Imazapyr @ 0.42 kg ai/ha |
| 8 | hex-1 | Spring 2007 | Spring 2007 | Hexazinone @ 1.68 kg ai/ha |
| 9 | ctl-1 | Spring 2007 | Spring 2007 | Control |
| 10 | gly/ima-2 | Summer 2007 | Spring 2008 | Glyphosate @ 2.23 kg ae/ha plus Imazapyr @ 0.14 kg ai/ha |
| 11 | ou/mil-2 | Summer 2007 | Spring 2008 | Sulfometuron @ 0.14 kg ai/ha plus Aminopyralid @ 0.12 kg ai/ha |
| 12 | ou/gly-2 | Summer 2007 | Spring 2008 | Sulfometuron @ 0.14 kg ai/ha plus Glyphosate @ 2.23 kg ae/ha |
| 13 | atr/ima-2 | Summer 2007 | Spring 2008 | Atrazine @ 4.48 kg ai/ha plus Imazapyr @ 0.14 kg ai/ha |
| 14 | atr/gly-2 | Summer 2007 | Spring 2008 | Atrazine @ 4.48 kg ai/ha plus Glyphosate @ 2.23 kg ae/ac |
| 15 | Ima3-2 | Summer 2007 | Spring 2008 | Imazapyr @ 0.21 kg ai/ha |
| 16 | Ima6-2 | Summer 2007 | Spring 2008 | Imazapyr @ 0.42 kg ai/ha |
| 17 | gly-2 | Summer 2007 | Spring 2008 | Glyphosate @ 2.23 kg ae/ac |
| 18 | ctl-2 | | Spring 2008 | Control for Summer 2007 and Spring 2008 Site Prep |
| 19 | atr-3 | Spring 2008 | Spring 2008 | Atrazine @ 4.48 kg ai/ha |
| 20 | ima3-3 | Spring 2008 | Spring 2008 | Imazapyr @ 0.21 kg ai/ha |
| 21 | ima6-3 | Spring 2008 | Spring 2008 | Imazapyr @ 0.42 kg ai/ha |
| 22 | hex-3 | Spring 2008 | Spring 2008 | Hexazinone @ 1.68 kg ai/ha |

rates and various combinations of one or two products from among sulfometuron (Oust XP®), glyphosate (Accord Concentrate®), atrazine (Atrazine 4L®), imazapyr (Chopper Gen2®), hexazinone (Velpar 4L®), aminopyralid, and clopyralid

Table 2.2 Herbicide products.

| Active Ingredient | Product Name | Registration Number |
|---|---|---|
| sulfometuron | Oust XP® | 352-601 |
| glyphosate | Accord® Concentrate | 62719-324 |
| atrazine | Atrazine 4L® | 66222-36 |
| imazapyr | Chopper Gen2® | 241-430 |
| hexazinone | Velpar 4L® | 352-392 |
| aminopyralid | Milestone® | 62719-519 |
| clopyralid | Transline® | 62719-259 |

(Transline®). All of these herbicides have some degree of foliar activity, and all, with the exception of glyphosate, have some degree of soil activity (Ahrens et al. 1994). These chemicals range from being seasonally selective, such as glyphosate, to fairly selective based on the types and species that they control. These chemicals also may cause injury to conifers; for example, residues from aminopyralid, sulfometuron, or imazapyr may be toxic to Douglas-fir and hexazinone may be toxic to western larch, and the correct selectivity, rate and timing must be understood for successful plantation establishment. All these products influence processes unique to green plants. Sulfometuron and imazapyr are ALS inhibitors, glyphosate is an EPSP inhibitor, atrazine and hexazinone are photosynthesis inhibitors, and aminopyralid and clopyralid inhibit auxin production. All treatments were applied as broadcast applications with a pressurized backpack sprayer and adjustable Chapin nozzle, using the waving wand technique (Newton and Knight 1981).

### *Plot Design, Measurements, and Calculations*

Each plot was 7.3 m wide by 19.8 m long, and within each plot three rows of seedlings were planted. Each row was randomly assigned to one stock type, which included: western larch plug+1 bareroot (LB), western larch containerized 415D (LP), and Douglas-fir 2+1 bareroot (DF), and had twelve seedlings planted within it on a 1.5 m by 2.4 m spacing. Bareroot seedlings were purchased from Lava Nursery in Parkdale, OR, and containerized seedlings were purchased from PRT Pelton in Maple Ridge, BC. Seedlings were planted as soon as snow permitted access in early April 2007 and late May 2008, according to the designated treatments. A total of 7,128 seedlings were planted, 2,376 of each stock type which were measured for this experiment. Initial measurements of height, basal diameter at 15 cm above groundline, and physical damage were recorded immediately after planting each year. At the end of the growing seasons in September 2007 and 2008 all live seedlings were re-evaluated for damage, height, and diameter at 15 cm above groundline. Overtopping by shrubs, forbs, grasses, bracken fern (*Pteridium aquilinum*), and residual natural conifers was also assessed according to Howard and Newton (1984). Basal area 15 cm above groundline was calculated as:

$$BA = \pi*(bd/2)^2$$

where bd is the basal diameter at 15 cm above groundline. A seedling volume index was also calculated using the volume of a cone:

$$Vol = (ba*h)/3$$

where ba is the basal area and h is the height. First-year seedling growth was then calculated for basal area, height, and volume by subtracting the initial value at time of planting from the value at the end of the first growing season. Second-year seedling growth was calculated by subtracting the value at the end of the first-year's growing season from the value at the end of the growing season for the second-year.

In late-June/early-July 2007 and 2008 cover measurements were recorded for all plots. Cover was measured in six 1-m-radius circles (subplots) systematically located with a random starting position within each plot. Percent cover of grasses, *Carex* spp., small forbs, tall forbs, natural conifers, and shrubs by species was estimated ocularly. All species present within each subplot were also recorded. Whether pre-treatment or post-treatment cover was measured was determined by the treatment. For treatments 1-9, which were sprayed in the spring of 2007, first and second-year post-treatment data were collected. For the rest of the treatments that were either sprayed in the summer of 2007 or the spring of 2008, pre-treatment and first-year post-treatment data were collected. Grass and *Carex* cover were summed for each subplot, as were small and tall forb cover, and shrub cover by species for analysis of response to treatment by plant functional groups. All cover measurements, with the exception of coniferous cover, were also summed for each subplot for analysis of response to treatment of total non-coniferous cover.

Throughout the growing season in 2007 gravimetric soil moisture measurements were taken from 0-23 cm and 23-46 cm for the planted plots. At least three samples were collected per plot every time soil moisture was measured throughout the growing season. Representative samples were collected using Kane tube samplers and augers for each plot and oven dried in the lab at 103° C for at least 24 hours to determine net gravimetric soil moisture. Soil bulk density was determined by collecting and drying five representative samples to 46 cm at each site in June 2007. Bulk density samples were collected with a hammer driven core sampler of 7.6 cm diameter and 7.6 cm length. Throughout the 2008 field season all plots were sampled for soil moisture to 23 cm. However, only plots that were randomly selected based on low total cover and medium and high forb and shrub cover were sampled to a depth of 46 cm. From the bulk density and gravimetric soil moisture measurements volumetric soil moisture was calculated as:

$$VSM = gsm*(bd/DW)$$

where gsm is the gravimetric soil moisture, bd is the bulk density, and DW is the density of water (1.0 g/cm$^3$).

Predawn xylem water stress measurements were also recorded three times throughout the season in 2007 using a pressure bomb as described by Waring and Cleary (1967) and Scholander et al. (1965). These samples were destructive, so eight extra seedlings of each stock type were planted between the rows for the plots chosen to measure. In 2007 atr-1, ima3-1 and ctl-1 were chosen for measurement to represent the range of vegetation control. Due to poor survival and lack of correlation between treatment and first-year predawn xylem water stress the measurements were discontinued in 2008, and were not analyzed for this project. The extra seedlings were later removed to eliminate spacing bias in the event of continued measurements.

## Analysis

### *Herbicide Efficacy*

Vegetation response to chemical treatment was analyzed with analysis of variance (ANOVA) and analysis of covariance (ANCOVA), using the mixed procedure in SAS v.9.1. Response variables included average total grass cover, total forb cover, total shrub cover, and total non-coniferous cover. To determine if any block interactions with treatment existed for the ANOVA, block was treated as a fixed effect in the first model for treatments 1-9 for first and second-year post-treatment cover:

$$Y_{ijk} = \mu + B_i + T_j + (BT)_{ij} + \varepsilon_{ijk}$$

$Y_{ijk}$ response variable from above in the $i^{th}$ block and in the $j^{th}$ treatment
$\mu$ is the overall mean value of Y
$B_i$ is the fixed effect of the $i^{th}$ block, i = 1, 2, 3
$T_j$ is the fixed effect of the $j^{th}$ level of herbicide treatment, j = 1, 2, ….., 9
$(BT)_{ij}$ is the fixed effect of the interaction of block and herbicide treatment
$\varepsilon_{ijk}$ is the random effect of the plots among the treatments, within the blocks, that adds variability to the value of Y, and $\varepsilon_{ijk} \sim N(0,\sigma^2)$,
and tested at an $\alpha = 0.25$ significance level.

Using this model the assumptions of normality and homoscedascity were checked with normal probability plots and plots of the residuals versus predicted values. To meet the assumption of homoscedascity all of the first-year post-treatment response variables were transformed with the square root transformation. The arcsin sqrt transformation was not used because percentages for cover were analyzed as numbers rather than proportions due to the abundance of low percentages (0.1%). The second-year post-treatment grass, forb, and shrub cover variables were transformed with the log transformation.

Block was also treated as a fixed effect in the first model for the ANCOVA of first-year post-treatment cover for treatments 10-22 in 2008, along with a covariate of the pre-treatment cover:

$$Y_{ijk} = \mu + B_i + T_j + (BT)_{ij} + Y_{0ijk} + \varepsilon_{ijk}$$

$Y_{0ijk}$ is the covariate of the response, the pre-treatment cover level for each cover type.

Log transformations were necessary for the pre-treatment and post-treatment grass and forb cover variables based on increasing variance with increasing predicted values in plots of the residuals versus predicted values.

Once it was determined whether a block by treatment interaction existed the response variables were analyzed accordingly. For the ANOVA, no interactions existed for first-year post-treatment forb, shrub, and total non-coniferous cover, as well as all four second-year post-treatment cover variables. Block was treated as a random effect in these models:

$$Y_{ijk} = \mu + \beta_i + T_j + (\beta T)_{ij} + \varepsilon_{ijk}$$

$\beta_i$ is the random effect of block that adds variability to the value of Y, i = 1, 2, 3, and $\beta_i \sim N(0,\sigma^2_m)$

$(\beta T)_{ij}$ is the random effect of the interaction of block and herbicide treatment that adds variability to the value of Y, and $(\beta T)_{ij} \sim N(0,\sigma^2_n)$

An interaction did exist for first-year post-treatment grass cover, and each block was analyzed separately with the model:

$$Y_{jk} = \mu + T_j + \varepsilon_{jk}$$

Once the appropriate model was determined for the ANOVA, the assumptions were checked again, and the response variables were analyzed to determine if there was a significant difference between the average first-year post-treatment cover for the four common treatments for spring 2007 and spring 2008, which included atrazine at 4.48 kg ai $ha^{-1}$, imazapyr at 0.21 kg ai $ha^{-1}$, imazapyr at 0.42 kg ai $ha^{-1}$, and hexazinone at 1.68 kg ai $ha^{-1}$. They were also analyzed to determine if there was a difference between each treatment (treatments 1-8) and the control (treatment 9) for both first and second-year post-treatment cover.

For the ANCOVA, the covariate was significant and treatments interactions with blocks did exist for all of the response variables. Each block was analyzed separately with the model:

$$Y_{jk} = \mu + T_j + Y_{0jk} + \varepsilon_{jk}$$

The assumptions were checked once more, and the response variables were analyzed to determine if there was a significant difference between each treatment (treatments 10-17 and 19-22) and the control (treatment 18). For all of the analyses where log transformations were necessary the estimates and 95% confidence intervals were back transformed and graphed to illustrate the ratios of the treatment medians over the control medians. Where square root transformations were used the least squared means were back transformed and reported, along with the respective p-values for the estimates of the differences between treatments. When transformations were not necessary the estimates and their respective 95% confidence intervals were graphed to illustrate differences between treatments.

*Seedling Response to Treatment*

Seedling response to chemical treatment was also analyzed with analysis of variance in the mixed procedure. Response variables included basal area growth, height growth, and survival for the first and second growing seasons after planting. For the growth analyses all seedlings with either mechanical damage caused by slash or snow, or animal damage were removed from the sample before analyzing. The first test determined if an interaction existed for the growth analysis, with either stock type or treatment and the block variable. This test also treated block as a fixed effect in the model:

$$Y_{ijkl} = \mu + B_i + T_j + S_k + (BT)_{ij} + (BS)_{ik} + (TS)_{jk} + (BTS)_{ijk} + \gamma(BT)_{ij} + \varepsilon_{ijkl}$$

$Y_{ijkl}$ response variables from above in the $i^{th}$ block and in the $j^{th}$ treatment
$\mu$ is the overall mean value of Y
$B_i$ is the fixed effect of the $i^{th}$ block, i = 1, 2, 3
$T_j$ is the fixed effect of the $j^{th}$ level of herbicide treatment, j = 1, 2, ….., 9
$S_k$ is the fixed effect of the $k^{th}$ level of stock type, k = 1, 2, 3
$(BT)_{ij}$ is the fixed effect of the interaction of block and herbicide treatment
$(BS)_{ik}$ is the fixed effect of the interaction of block and stock type
$(TS)_{jk}$ is the fixed effect of the interaction of treatment and stock type
$(BTS)_{ijk}$ is the fixed effect of the interaction of block, treatment, and stock type
$\gamma(BT)_{ij}$ is the random effect of the plots among the treatments, within the blocks, that adds variability to the value of Y and $\gamma(BT)_{ij} \sim N(0,\sigma^2_n)$
$\varepsilon_{ijkl}$ is the random effect among the plots, that adds variability to the value of Y, and $\varepsilon_{ijkl} \sim N(0,\sigma^2)$,
and tested at an $\alpha = 0.25$ significance level.

Using this model the assumptions of normality and homoscedascity were checked with normal probability plots and plots of the residuals versus predicted values. Transformations were not necessary for the growth variables, but the arcsin(sqrt) transformation was used for first and second-year survival. Once it was determined whether a block interaction existed the response variables were analyzed accordingly. No interaction existed for second-year height growth, so block was treated as a random effect in the model:

$$Y_{ijkl} = \mu + \beta_i + T_j + S_k + (\beta T)_{ij} + (TS)_{jk} + (\beta TS)_{ijk} + \gamma(\beta T)_{ij} + \varepsilon_{ijkl}$$

$\beta_i$ is the random effect of block that adds variability to the value of Y, i = 1, 2, 3, and $\beta_i \sim N(0,\sigma^2_m)$
$(\beta T)_{ij}$ is the random effect of the interaction of block and herbicide treatment that adds variability to the value of Y, and $(\beta T)_{ij} \sim N(0,\sigma^2_o)$
$(\beta TS)_{ijk}$ is the random effect of the interaction of block, treatment, and stock type that adds variability to the value of Y, and $(\beta TS)_{ijk} \sim N(0,\sigma^2_p)$

Interactions did exist for first-year basal area growth, height growth, and survival as well as second-year basal area growth and survival, therefore each block was analyzed separately with the model:

$$Y_{jkl} = \mu + T_j + S_k + (TS)_{jk} + \varepsilon_{jkl}$$

Once the appropriate model was determined the assumptions were checked again. First-year basal area growth at Hooker, second-year basal area growth, and second-year height growth were log transformed. Then, the first-year response variables for basal area growth, height growth, and survival were analyzed to determine if there was a difference between the means of the four common treatments applied in spring 2007 and spring 2008. For both the first and second-year response variables the difference between each treatment and its respective control was also tested.

*Response to Vegetation Cover*

Volumetric soil moisture response to vegetation cover was analyzed with regression to determine the nature of the relationship between the volumetric soil moisture at the end of the growing season and vegetation cover regardless of treatment. The response variables for this analysis included the final volumetric soil moisture measurement for each year at each depth. The final extraction dates for 2007 were August 21-22, and for 2008 August 25-26. To meet the assumption of linearity each response variable was log transformed. The first step to determine the appropriate models was to run the stepwise selection method in the regression procedure with the following model for 2007:

$$Y_i = \beta_0 + \beta_1(\text{block}) + \beta_2(\text{grass}) + \beta_3(\text{forb}) + \beta_4(\text{shrub}) + \beta_5(\text{tot}) + \varepsilon_i$$

where $\varepsilon i \sim N(0,\sigma^2)$ and grass, forb, shrub, and tot are the respective percent covers in 2007.

The model for 2008 included:

$$Y_i = \beta_0 + \beta_1(\text{block}) + \beta_2(\text{grass2}) + \beta_3(\text{forb2}) + \beta_4(\text{shrub2}) + \beta_5(\text{tot}) + \beta_6(\text{tot2}) + \varepsilon_i$$

where $\varepsilon_i \sim N(0,\sigma^2)$ and grass2, forb2, shrub2, and tot2 are the respective percent covers in 2008.

Although the cover variables are not completely independent this procedure was used to narrow down the list of potential explanatory variables. Once the potential explanatory variables were determined the Akaike's Information Criteria (AIC) using the mixed procedure in SAS was used to determine which of the variables, along with any cover interactions with block, needed to be included in the final model. The assumptions of normality and homoscedascity of the final models were checked using normal probability plots and plots of the residuals versus predicted values. If more than one cover variable existed in the model their independence was checked using a variance inflation factor (VIF) of 5. VIFs above 5 were assumed to violate the independence assumption, and the next best model based on the AIC was chosen. The final models for each variable were then back-transformed and plotted against the measured values.

Seedling response to vegetation cover was analyzed with regression to determine the nature of the relationship between the seedling response and vegetation cover and its influence on survival and growth regardless of treatment. The response variables for this analysis included the first-year survival and volume growth for all the seedlings, and second-year volume growth for those seedlings that were planted in 2007. All of the seedlings with mechanical or animal damage were also removed for the growth analysis. To meet the assumption of linearity, based on plots of the response variables versus total non-coniferous cover, both volume growth variables were log transformed. The first step to determine the appropriate models was to run the stepwise selection method in the regression procedure for each stock type with the following model for first-year survival and volume growth:

$$Y_i = \beta_0 + \beta_1(\text{block}) + \beta_2(\text{y1grass}) + \beta_3(\text{y1forb}) + \beta_4(\text{y1shrub}) + \beta_5(\text{y1tot}) + \varepsilon_i$$

where $\varepsilon i \sim N(0,\sigma^2)$ and y1grass, y1forb, y1shrub, and y1tot were the respective cover types for the first-year post-treatment percent cover.

The model for second-year volume growth included:

$$Y_i = \beta_0 + \beta_1(\text{block}) + \beta_2(\text{y2grass}) + \beta_3(\text{y2forb}) + \beta_4(\text{y2shrub}) + \beta_5(\text{y1tot}) + \beta_6(\text{y2tot}) + \varepsilon_i$$

where $\varepsilon_i \sim N(0,\sigma^2)$ and y2grass, y2forb, y2shrub, and y2tot were the respective cover types for the second-year post-treatment percent cover.

Although the cover variables are not completely independent this procedure was used to narrow down the list of potential explanatory variables. Once the potential explanatory variables were determined then the Akaike's Information Criteria (AIC) using the mixed procedure in SAS was used to determine which of the variables determined by the stepwise procedure, along with whether any cover interactions with block existed, that needed to be included in the final model. The assumptions of normality and homoscedascity of the final models were checked using normal probability plots and plots of the residuals versus predicted values. If more than one cover variable existed in the model their independence was checked using a VIF of 5. VIFs above 5 were assumed to violate the independence assumption, and the next best model based on the AIC was chosen. The final models for each variable were then back-transformed if necessary and plotted against the measured values.

### *Soil Moisture Response to Treatment*

Volumetric soil moisture to 23 cm and 46 cm depth throughout both the 2007 and 2008 growing seasons were not analyzed statistically. Instead, graphs were constructed to show trends in the drawdown of soil moisture throughout each season by treatment. Also, to illustrate the drawdown in soil moisture for different levels of vegetation cover the trend in soil moisture to 46 cm in 2008 was graphed by low total cover and medium and high forb and shrub cover.

## Results

### *Herbicide Efficacy*

Mean forb, shrub, and total non-coniferous first-year post-treatment cover had differing treatment responses for at least one of the blocks for the ANOVA of the first nine treatments, i.e., there was a significant treatment interaction with block. Mean grass cover did not have differing treatment responses among blocks (Table 2.3). Mean grass, forb, shrub, and total second-year post-treatment cover did not have differing treatment responses among the blocks (Table 2.4).  For the ANCOVA the pre-treatment grass, forb, shrub, and total non-coniferous cover was significant for explaining the cover after the first growing season. For each first-year post-treatment cover there were differing treatment responses among at least one of the blocks, i.e., significant treatment interactions with block (Table 2.5).

Significant treatment effects were detected at all three blocks, indicating that at least one treatment combination was significantly different for first-year post-treatment mean grass, forb, shrub, and total non-coniferous cover, with the exception of shrub cover at US where initial cover was very low (Table 2.6). Likewise, treatment effects were detected for second-year post-treatment cover, indicating that at least one treatment combination was significantly different for grass and forb cover (Table 2.7). Significant treatment effects were detected at all three blocks, indicating that at least

Table 2.3 Tests for block interactions for first-year post-treatment cover ANOVA.

| | Block | | | Treatment | | | Block*Treatment | | |
|---|---|---|---|---|---|---|---|---|---|
| Cover | DF | F-stat | p-value | DF | F-stat | p-value | DF | F-stat | p-value |
| Grass | **2/132** | **5.08** | **0.0075** | **21/132** | **6.96** | **<0.0001** | 42/132 | 0.86 | 0.7117 |
| Forb | **2/132** | **46.47** | **<0.0001** | **21/132** | **8.60** | **<0.0001** | **42/132** | **2.30** | **0.0002** |
| Shrub | **2/132** | **48.35** | **<0.0001** | **21/132** | **4.99** | **<0.0001** | **42/132** | **1.85** | **0.0046** |
| Total | **2/132** | **3.33** | **0.0387** | **21/132** | **7.54** | **<0.0001** | **42/132** | **3.24** | **<0.0001** |

Table 2.4 Tests for block interactions for second-year post-treatment cover ANOVA.

| | Block | | | Treatment | | | Block*Treatment | | |
|---|---|---|---|---|---|---|---|---|---|
| Cover | DF | F-stat | p-value | DF | F-stat | p-value | DF | F-stat | p-value |
| Grass | **2/54** | **2.57** | **0.0858** | **8/54** | **3.70** | **0.0016** | 16/54 | 0.85 | 0.6242 |
| Forb | **2/54** | **12.12** | **<0.0001** | **8/54** | **3.31** | **0.0038** | 16/54 | 0.87 | 0.6051 |
| Shrub | **2/54** | **26.35** | **<0.0001** | 8/54 | 0.89 | 0.5342 | 16/54 | 0.99 | 0.4818 |
| Total | **2/54** | **1.69** | **0.1937** | **8/54** | **1.66** | **0.1302** | 16/54 | 0.87 | 0.6029 |

Table 2.5 Tests for block interactions for first-year post-treatment cover ANCOVA. Covariates include pre-treatment grass, forb, shrub, and total non-coniferous cover.

| | Block | | | Treatment | | | Block*Treatment | | | Covariate | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cover | DF | F-stat | p-value | DF | F-stat | p-value | DF | F-stat | p-value | DF | F-stat | p-value |
| Grass | **2/77** | **16.16** | **<0.0001** | **12/77** | **7.77** | **<0.0001** | **24/77** | **1.62** | **0.0592** | **1/77** | **21.34** | **<0.0001** |
| Forb | **2/77** | **18.77** | **<0.0001** | **12/77** | **12.99** | **<0.0001** | **24/77** | **1.46** | **0.1084** | **1/77** | **29.21** | **<0.0001** |
| Shrub | **2/77** | **21.42** | **<0.0001** | **12/77** | **10.22** | **<0.0001** | **24/77** | **2.32** | **0.0030** | **1/77** | **46.25** | **<0.0001** |
| Total | **2/77** | **17.72** | **<0.0001** | **12/77** | **8.11** | **<0.0001** | **24/77** | **2.95** | **0.0002** | **1/77** | **26.40** | **<0.0001** |

Table 2.6 Tests for treatment significance for first-year post-treatment cover ANOVA.

| | | Treatment | | |
|---|---|---|---|---|
| Cover | Block | DF | F-stat | p-value |
| Grass | All | **21/42** | **7.20** | **<0.0001** |
| | H | **21/44** | **9.05** | **<0.0001** |
| Forb | LS | **21/44** | **2.54** | **0.0046** |
| | US | **21/44** | **3.58** | **0.0002** |
| | H | **21/44** | **4.19** | **<0.0001** |
| Shrub | LS | **21/44** | **2.94** | **0.0013** |
| | US | 21/44 | 1.46 | 0.1431 |
| | H | **21/44** | **8.25** | **<0.0001** |
| Total | LS | **21/44** | **2.66** | **0.0031** |
| | US | **21/44** | **4.30** | **<0.0001** |

Table 2.7 Tests for treatment significance for second-year post-treatment cover ANOVA.

| | Treatment | | |
|---|---|---|---|
| Cover | DF | F-stat | p-value |
| Grass | **8/16** | **3.83** | **0.0107** |
| Forb | **8/16** | **3.42** | **0.0175** |
| Shrub | 8/16 | 0.94 | 0.5091 |
| Total | 8/16 | 1.17 | 0.1721 |

Table 2.8 Tests for treatment and covariate significance for cover ANCOVA. Covariates are the respective pre-treatment covers.

| | | Treatment | | | Covariate | | |
|---|---|---|---|---|---|---|---|
| Cover | Block | DF | F-stat | p-value | DF | F-stat | p-value |
| | H | **12/25** | **4.05** | **0.0015** | **1/25** | **6.37** | **0.0183** |
| Grass | LS | **12/25** | **2.81** | **0.0141** | 1/25 | 1.23 | 0.2774 |
| | US | **12/25** | **3.68** | **0.0025** | **1/25** | **24.72** | **<0.0001** |
| | H | **12/25** | **16.23** | **<0.0001** | **1/25** | **7.47** | **0.0113** |
| Forb | LS | **12/25** | **3.82** | **0.0023** | **1/25** | **22.81** | **<0.0001** |
| | US | **12/25** | **3.82** | **0.0023** | 1/25 | 0.64 | 0.4318 |
| | H | **12/25** | **4.53** | **0.0007** | **1/25** | **12.90** | **0.0014** |
| Shrub | LS | **12/25** | **5.64** | **0.0001** | **1/25** | **13.71** | **0.0011** |
| | US | 12/25 | 1.85 | 0.0937 | **1/25** | **33.69** | **<0.0001** |
| | H | **12/25** | **12.09** | **<0.0001** | **1/25** | **14.95** | **0.0007** |
| | LS | **12/25** | **5.02** | **0.0003** | **1/25** | **6.73** | **0.0156** |
| Total | US | **12/25** | **2.51** | **0.0251** | **1/25** | **8.06** | **0.0088** |

one treatment combination was significantly different for first- year post-treatment mean grass, forb, shrub, and total non-coniferous cover when pre-treatment cover was included as a covariate, with the exception of shrub cover at US (Table 2.8). Significant pre-treatment covariate effects were detected for all of the blocks, with the exception of pre-treatment grass cover at LS and pre-treatment forb cover at US.

Analysis of first-year post-treatment grass cover suggested that there was no significant difference between the common spring 2007 and spring 2008 treatments (atrazine at 4.48 kg ai $ha^{-1}$, imazapyr at 0.21 kg ai $ha^{-1}$, imazapyr at 0.42 kg ai $ha^{-1}$, and hexazinone at 1.68 kg ai $ha^{-1}$). It also suggested that there was a significant difference between percent grass cover for each of the treatments when compared to the control (Table 2.9). Analysis of first-year post-treatment forb cover suggested that for Lower Sam there was no significant difference between the common spring treatments, but there were differences for Hooker and Upper Sam. It also suggested that at Hooker there was a significant difference between percent forb cover for each of the treatments when compared to the control with the exception of atr-1, at Lower Sam there were no differences with the exception of ima3-1, and at Upper Sam there were differences with the exceptions of ou-1 and atr/ima-1, when compared to the control (Table 2.10). Analysis of first-year post-treatment shrub cover suggested that there were no significant differences between the common spring treatments at Hooker and Lower Sam, but there was a difference at Upper Sam. It also suggested that at Hooker there was no significant difference between percent shrub cover for each treatment when compared to the control, with the exceptions of ima3-1, ima6-1, and hex-1 (Table 2.11). At Lower Sam there were no significant differences, with the exceptions of atr/ima-1 and ima6-1. At Upper Sam there were no significant differences. Analysis of first-year post-treatment total non-coniferous cover suggested that there were significant differences between the common spring treatments at Hooker and Upper Sam, but not at Lower Sam (Table 2.12). It also suggested that at Hooker there was a difference between percent total non-coniferous cover for each treatment when compared to the control, with the exception of atr-1. At Lower Sam there was a significant difference between each treatment and the control, with the exceptions of ou-1, ou/clo-1, atr-1, and hex-1. At Upper Sam there was a significant difference between each treatment and the control.

Table 2.9 Back transformed least squares means and significance tests for first-year post-treatment grass cover ANOVA differences. The first column is the means for spring 2007 and each treatment. The second column is the means for spring 2008 and the control.

| Contrast | Mean | Mean | p-value |
|---|---|---|---|
| Spr. 07 - Spr. 08 | 1.4 | 1.8 | 0.4590 |
| ou-1 - ctl-1 | **3** | **14** | **<.0001** |
| ou/gly-1 - ctl-1 | **1.4** | **14** | **<.0001** |
| ou/clo-1 - ctl-1 | **3** | **14** | **<.0001** |
| atr-1 - ctl-1 | **6** | **14** | **0.0053** |
| atr/ima-1 - ctl-1 | **0.7** | **14** | **<.0001** |
| ima3-1 - ctl-1 | **0.3** | **14** | **<.0001** |
| ima6-1 - ctl-1 | **0.1** | **14** | **<.0001** |
| hex-1 - ctl-1 | **2** | **14** | **<.0001** |

Table 2.10 Back transformed least squares means and significance tests for first-year post-treatment forb cover ANOVA differences. The first column is the means for spring 2007 and each treatment. The second column is the means for spring 2008 and the control.

| Block | Contrast | Mean | Mean | p-value |
|---|---|---|---|---|
| | Spr. 07 - Spr. 08 | **14** | **8** | **0.0012** |
| | ou-1 - ctl-1 | **9** | **32** | **<.0001** |
| | ou/gly-1 - ctl-1 | **13** | **32** | **0.0005** |
| | ou/clo-1 - ctl-1 | **8** | **32** | **<.0001** |
| H | atr-1 - ctl-1 | 26 | 32 | 0.3003 |
| | atr/ima-1 - ctl-1 | **18** | **32** | **0.0142** |
| | ima3-1 - ctl-1 | **13** | **32** | **0.0004** |
| | ima6-1 - ctl-1 | **8** | **32** | **<.0001** |
| | hex-1 - ctl-1 | **11** | **32** | **0.0001** |
| | Spr. 07 - Spr. 08 | 4 | 5 | 0.6503 |
| | ou-1 - ctl-1 | 4 | 7 | 0.2623 |
| | ou/gly-1 - ctl-1 | 3 | 7 | 0.1321 |
| | ou/clo-1 - ctl-1 | 4 | 7 | 0.1794 |
| LS | atr-1 - ctl-1 | 5 | 7 | 0.3678 |
| | atr/ima-1 - ctl-1 | 5 | 7 | 0.4491 |
| | ima3-1 - ctl-1 | **1.9** | **7** | **0.0325** |
| | ima6-1 - ctl-1 | 9 | 7 | 0.5359 |
| | hex-1 - ctl-1 | 3 | 7 | 0.1183 |
| | Spr. 07 - Spr. 08 | **4** | **11** | **0.0069** |
| | ou-1 - ctl-1 | 8 | 20 | 0.0683 |
| | ou/gly-1 - ctl-1 | **5** | **20** | **0.0250** |
| | ou/clo-1 - ctl-1 | **6** | **20** | **0.0256** |
| US | atr-1 - ctl-1 | **4** | **20** | **0.0121** |
| | atr/ima-1 - ctl-1 | 13 | 20 | 0.3416 |
| | ima3-1 - ctl-1 | **5** | **20** | **0.0244** |
| | ima6-1 - ctl-1 | **4** | **20** | **0.0074** |
| | hex-1 - ctl-1 | **3** | **20** | **0.0032** |

Table 2.11 Back transformed least squares means and significance tests for first-year post-treatment shrub cover ANOVA differences. The first column is the means for spring 2007 and each treatment. The second column is the means for spring 2008 and the control.

| Block | Contrast | Mean | Mean | p-value |
|---|---|---|---|---|
| | Spr. 07 - Spr. 08 | 5 | 6 | 0.6131 |
| | ou-1 - ctl-1 | 10 | 14 | 0.4167 |
| | ou/gly-1 - ctl-1 | 9 | 14 | 0.2824 |
| | ou/clo-1 - ctl-1 | 16 | 14 | 0.7153 |
| H | atr-1 - ctl-1 | 12 | 14 | 0.7273 |
| | atr/ima-1 - ctl-1 | 14 | 14 | 0.9547 |
| | ima3-1 - ctl-1 | **3** | **14** | **0.0087** |
| | ima6-1 - ctl-1 | **3** | **14** | **0.0076** |
| | hex-1 - ctl-1 | **5** | **14** | **0.0355** |
| | Spr. 07 - Spr. 08 | 9 | 13 | 0.1467 |
| | ou-1 - ctl-1 | 17 | 19 | 0.8099 |
| | ou/gly-1 - ctl-1 | 10 | 19 | 0.1562 |
| | ou/clo-1 - ctl-1 | 16 | 19 | 0.7054 |
| LS | atr-1 - ctl-1 | 10 | 19 | 0.1694 |
| | atr/ima-1 - ctl-1 | **3** | **19** | **0.0053** |
| | ima3-1 - ctl-1 | 8 | 19 | 0.1019 |
| | ima6-1 - ctl-1 | **4** | **19** | **0.0105** |
| | hex-1 - ctl-1 | 16 | 19 | 0.6884 |
| | Spr. 07 - Spr. 08 | **1.4** | **6** | **0.0003** |
| | ou-1 - ctl-1 | 4 | 3 | 0.6432 |
| | ou/gly-1 - ctl-1 | 5 | 3 | 0.3800 |
| | ou/clo-1 - ctl-1 | 3 | 3 | 0.9619 |
| US | atr-1 - ctl-1 | 1.5 | 3 | 0.5027 |
| | atr/ima-1 - ctl-1 | 1.7 | 3 | 0.5871 |
| | ima3-1 - ctl-1 | 2 | 3 | 0.8231 |
| | ima6-1 - ctl-1 | 0.9 | 3 | 0.2899 |
| | hex-1 - ctl-1 | 1.2 | 3 | 0.3859 |

Table 2.12 Back transformed least squares means and significance tests for first-year post-treatment total non-coniferous cover ANOVA differences. The first column is the means for spring 2007 and each treatment. The second column is the means for spring 2008 and the control.

| Block | Contrast | Mean | Mean | p-value |
|---|---|---|---|---|
| | Spr. 07 - Spr. 08 | **25** | **17** | **0.0200** |
| | ou-1 - ctl-1 | **27** | **67** | **<.0001** |
| | ou/gly-1 - ctl-1 | **23** | **67** | **<.0001** |
| | ou/clo-1 - ctl-1 | **29** | **67** | **0.0002** |
| H | atr-1 - ctl-1 | 49 | 67 | 0.0880 |
| | atr/ima-1 - ctl-1 | **38** | **67** | **0.0047** |
| | ima3-1 - ctl-1 | **18** | **67** | **<.0001** |
| | ima6-1 - ctl-1 | **17** | **67** | **<.0001** |
| | hex-1 - ctl-1 | **20** | **67** | **<.0001** |
| | Spr. 07 - Spr. 08 | 17 | 22 | 0.2234 |
| | ou-1 - ctl-1 | 24 | 38 | 0.1302 |
| | ou/gly-1 - ctl-1 | **15** | **38** | **0.0091** |
| | ou/clo-1 - ctl-1 | 23 | 38 | 0.0953 |
| LS | atr-1 - ctl-1 | 24 | 38 | 0.1327 |
| | atr/ima-1 - ctl-1 | **9** | **38** | **0.0003** |
| | ima3-1 - ctl-1 | **11** | **38** | **0.0014** |
| | ima6-1 - ctl-1 | **14** | **38** | **0.0053** |
| | hex-1 - ctl-1 | 21 | 38 | 0.0576 |
| | Spr. 07 - Spr. 08 | **9** | **21** | **0.0004** |
| | ou-1 - ctl-1 | **15** | **38** | **0.0140** |
| | ou/gly-1 - ctl-1 | **15** | **38** | **0.0146** |
| | ou/clo-1 - ctl-1 | **11** | **38** | **0.0027** |
| US | atr-1 - ctl-1 | **15** | **38** | **0.0162** |
| | atr/ima-1 - ctl-1 | **15** | **38** | **0.0168** |
| | ima3-1 - ctl-1 | **9** | **38** | **0.0009** |
| | ima6-1 - ctl-1 | **5** | **38** | **<.0001** |
| | hex-1 - ctl-1 | **7** | **38** | **0.0003** |

Figure 2.1 displays the ratios of the treatment to control cover for second-year post-treatment grass, forb, and shrub cover. These are ratios of the median covers due to back transformation. A ratio of one suggests that there was no difference between

the cover of the treatment and the control. A ratio less than one suggests that the cover of the treatment was less than the cover of the control. Error bars designate back transformed 95% confidence intervals which describe the reliability of that comparison, and intervals that do not cross one indicate that cover for the treatment was significantly different than cover for the control. All of the treatments, with the exceptions of ou/clo-1 and atr-1, had significantly less grass cover than the control. None of the treatments, with the exceptions of ou-1 and hex-1, had significantly less forb cover than the control. None of the treatments had significantly different shrub cover from the control. Figure 2.2 displays the percent differences for second-year post-treatment total non-coniferous cover between each treatment and the control. A difference of zero suggests there was no difference, a difference less than zero suggests the treatment had less total cover than the control, and a difference more than zero suggests the treatment had more total cover than the control. Error bars designate 95% confidence intervals, and intervals that do not cross zero indicate a significant difference between that treatment and the control. Ou-1, ou/gly-1, ima6-1, and hex-1 had significantly less total cover than the control.

Pre-treatment cover could be used as a covariate to eliminate initial cover as a source of error in estimating effects of treatments 10-22. Gly/ima-2 at Upper Sam, ou/gly-2 at Hooker, ima3-2 at Hooker, ima6-3 at all three blocks, and hex-3 at Lower Sam and Upper Sam had significantly less first-year post-treatment grass cover than the control when pre-treatment grass cover was included as a covariate in the analysis

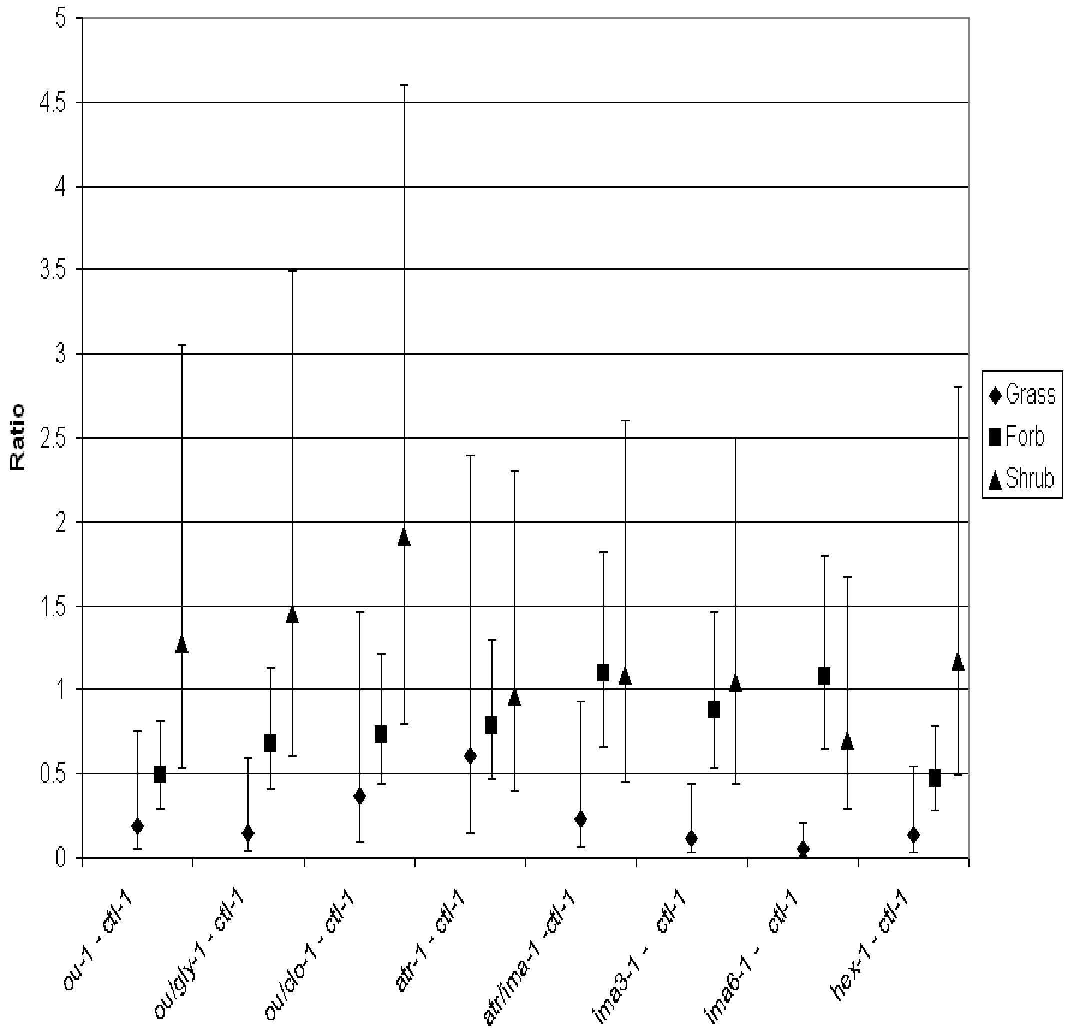


Figure 2.1 Ratio of the percent difference for second-year post-treatment grass, forb, and shrub cover between each treatment and the control. Contrasts that cross through one are not significantly different.

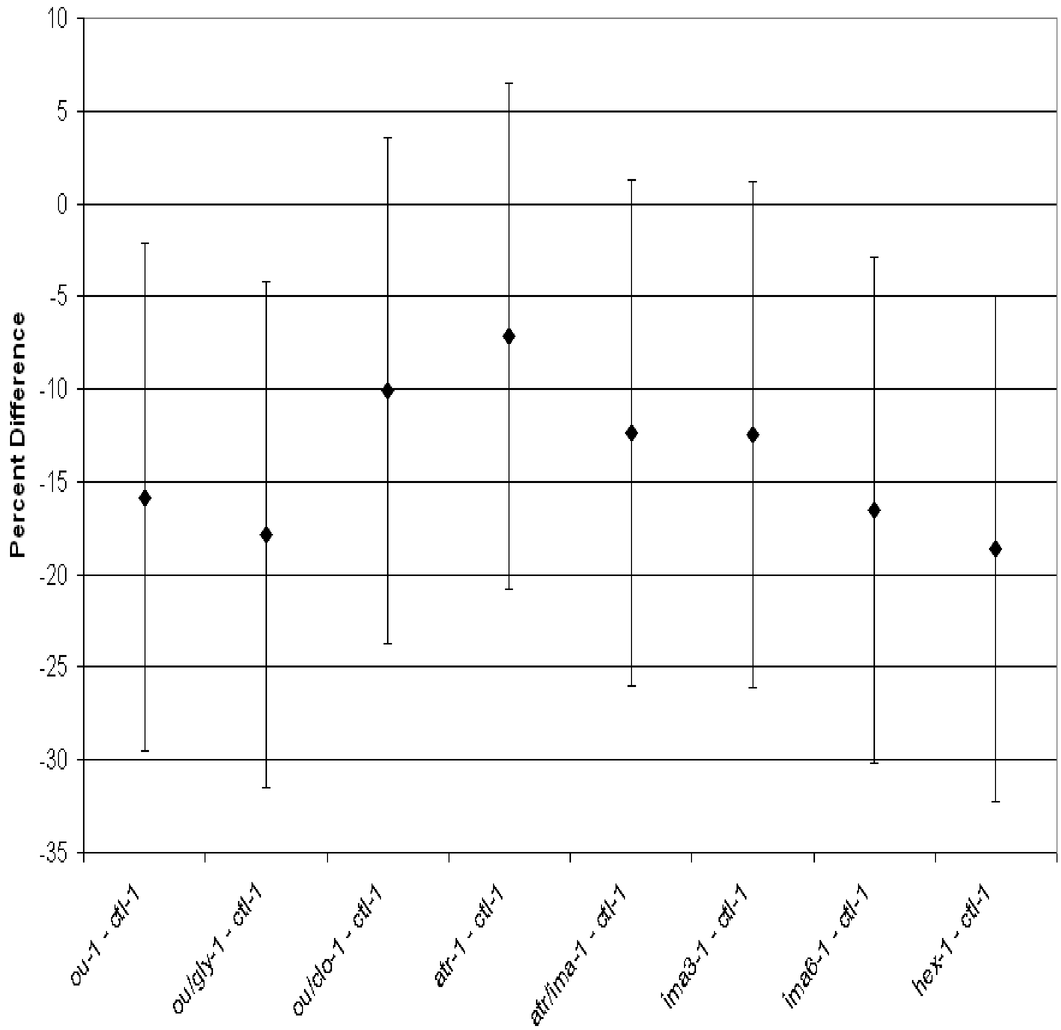


Figure 2.2 Percent difference for second-year post-treatment total cover between each treatment and the control. Contrasts that cross through zero are not significantly different.

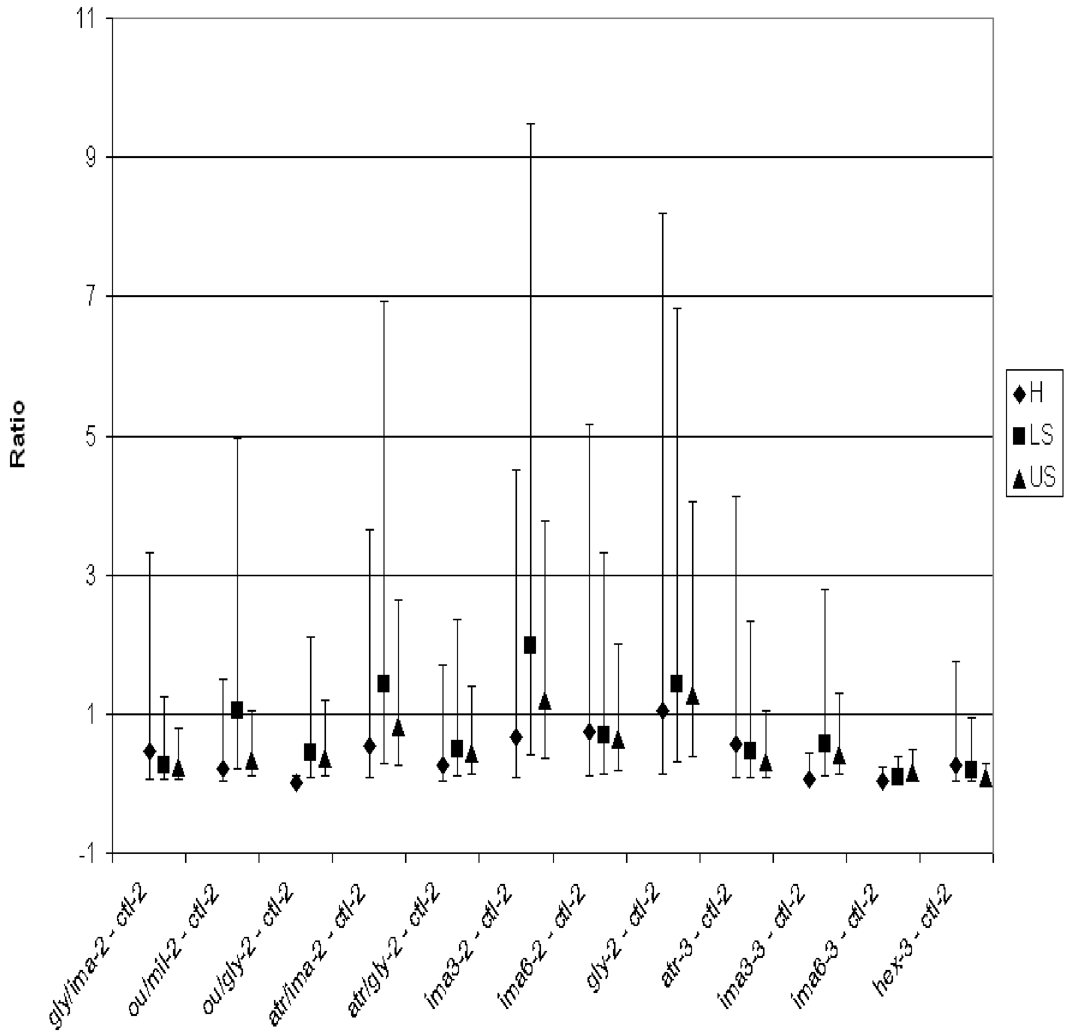


Figure 2.3 Ratio of the percent difference of first-year post-treatment grass cover with pre-treatment covariate between each treatment and the control. The covariate is pre-treatment grass cover. Contrasts that cross through one are not significantly different.

(Figure 2.3). Ou/mil-2 at all three blocks, ou/gly-2 at Hooker and Lower Sam, atr/gly-2 at Hooker, atr-3 at Hooker and Lower Sam, ima3-3 at Hooker, ima6-3 at Hooker, and hex-3 at Hooker all had significantly less first-year post-treatment percent forb cover than the control when pre-treatment forb cover was included as a covariate in the analysis (Figure 2.4). Gly/ima-2 at all three blocks, ou/gly-2 at Hooker and Lower Sam, atr/ima-2 at Upper Sam and Lower Sam, atr/gly-2 at Hooker and Lower Sam, ima3-2 at all three blocks, ima6-2 at all three blocks, gly-2 at Hooker and Lower Sam, atr-3 at Lower Sam, ima3-3 at Hooker and Lower Sam, and ima6-3 at all three blocks had significantly less first-year post-treatment percent shrub cover than the control when pre-treatment shrub cover was included as a covariate in the analysis (Figure 2.5). All treatments at Hooker, all treatments at Lower Sam, with the exception of ou/mil-2, and ou/mil-2, ima6-2, atr-3, ima6-3, and hex-3 at Upper Sam had significantly less first-year post-treatment cover of total non-coniferous vegetation than the control when pre-treatment total cover was included as a covariate in the analysis (Figure 2.6).

### *Seedling Response*

The effect of stock type on mean first and second-year survival differed among blocks. The effect of treatment on mean first-year basal area growth differed among blocks (Table 2.13). The effect of stock type on mean first-year height growth differed among blocks. The effect of treatment and stock type on mean second-year basal area growth differed among blocks.

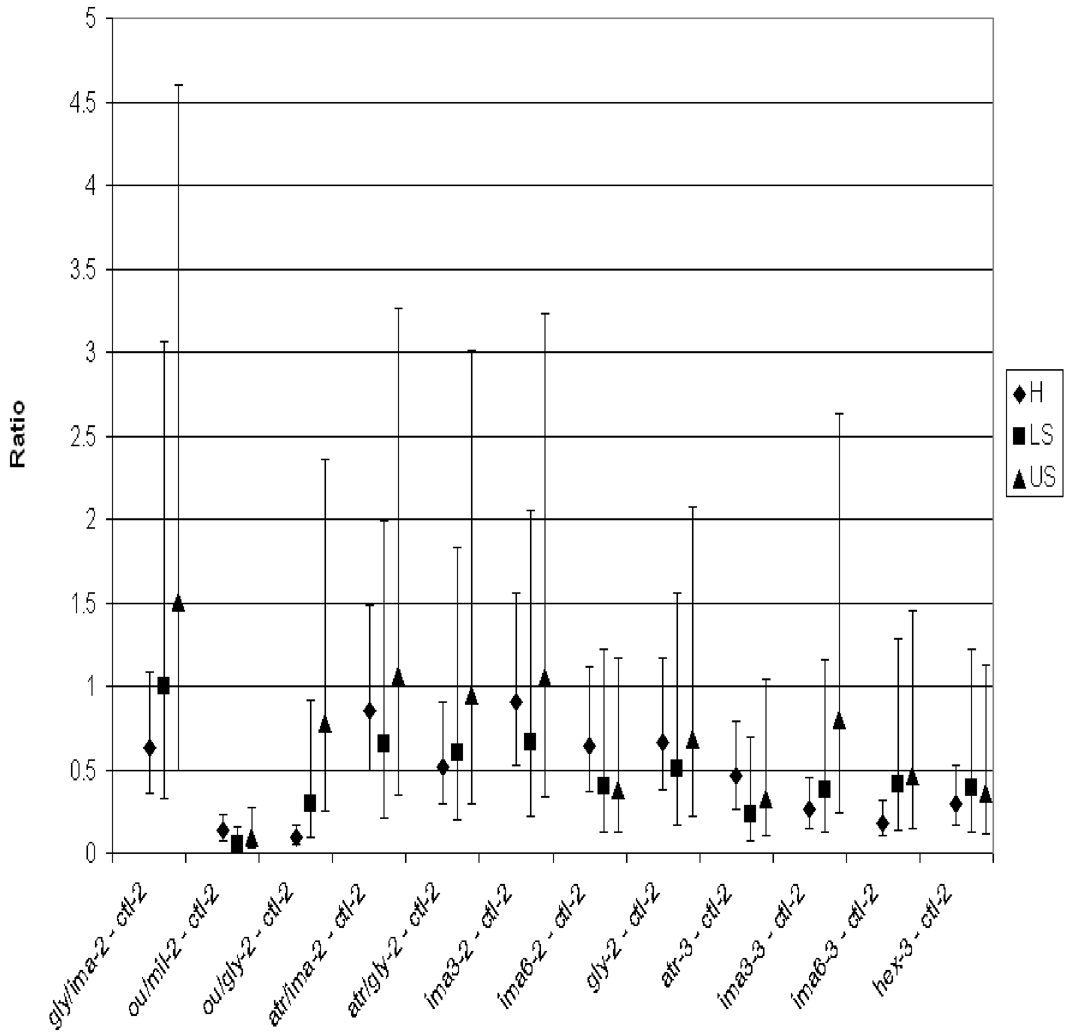


Figure 2.4 Ratio of the percent difference of first-year post-treatment forb cover with pre-treatment covariate between each treatment and the control. The covariate is pre-treatment forb cover. Contrasts that cross through one are not significantly different.

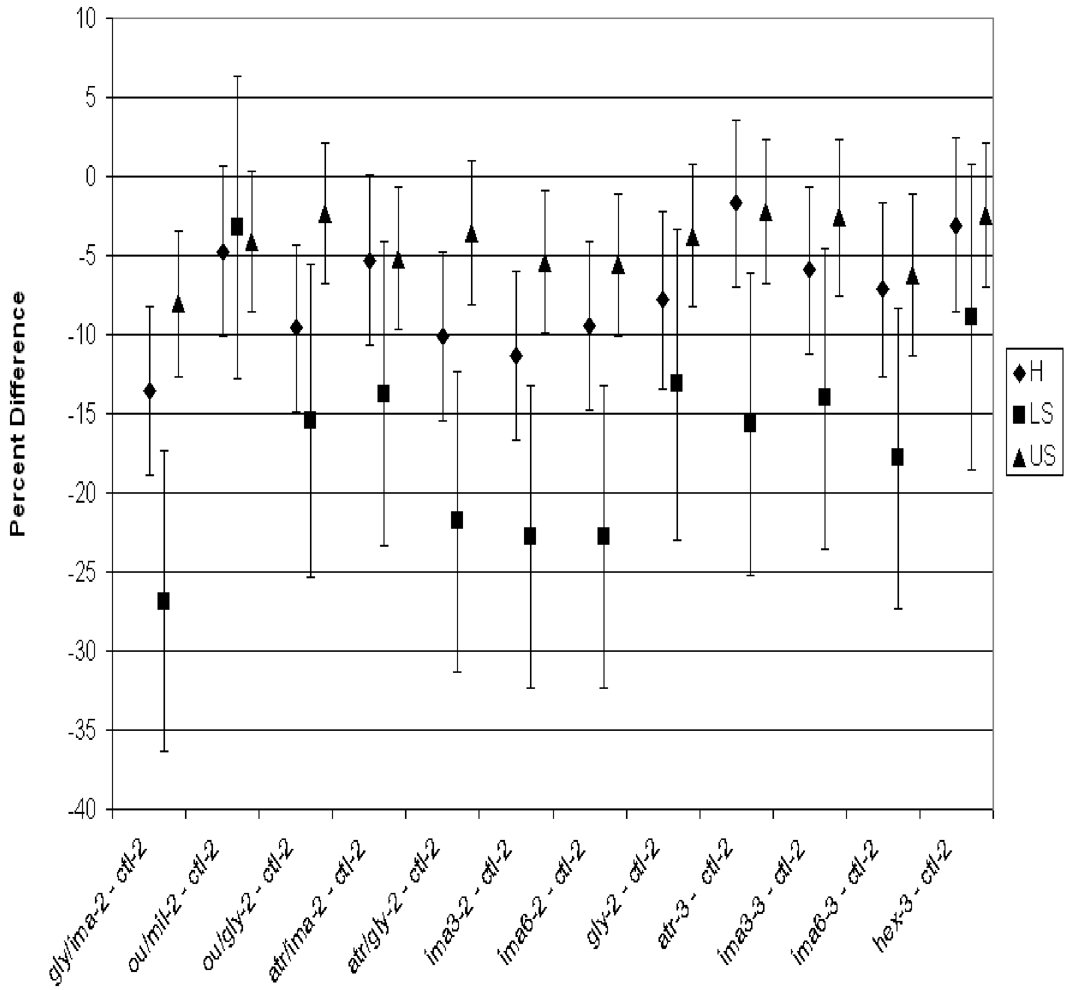


Figure 2.5 Percent difference of the first-year post-treatment shrub cover with pre-treatment covariate between each treatment and the control. The covariate is pre-treatment shrub cover. Contrasts that cross through zero are not significantly different.

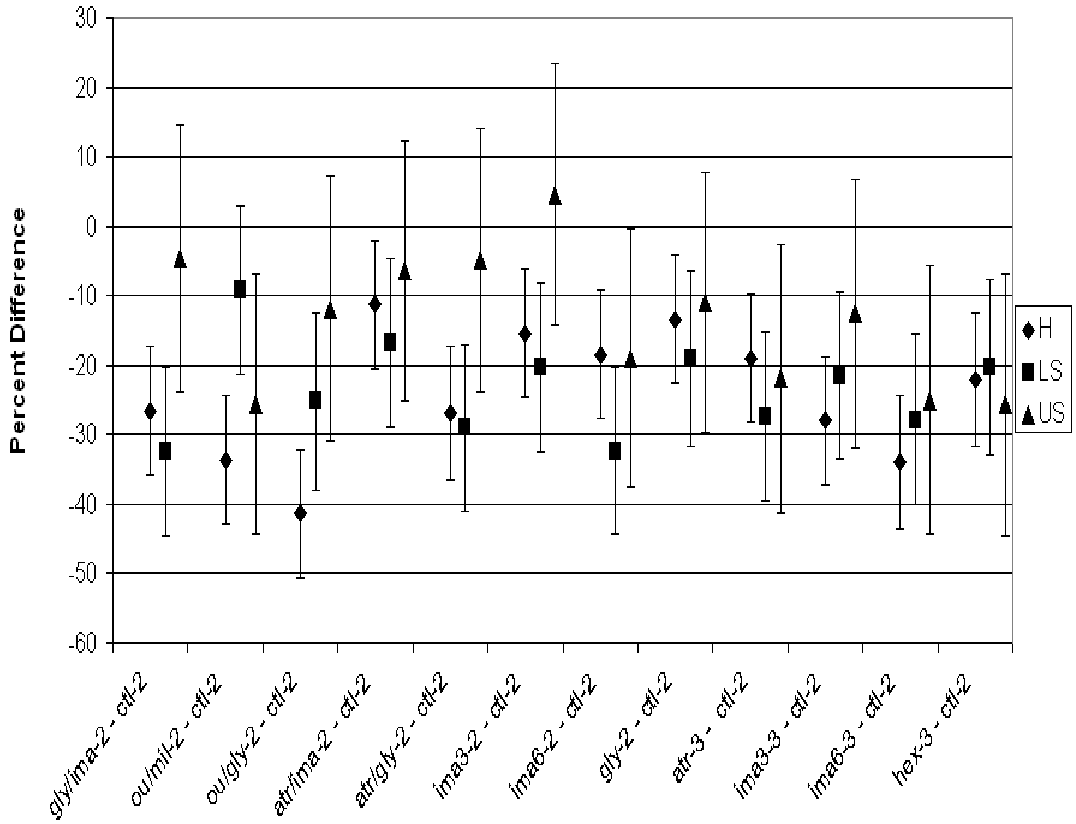


Figure 2.6 Percent difference of the first-year post-treatment total non-coniferous cover with pre-treatment covariate between each treatment and the control. The covariate is pre-treatment total non-coniferous cover. Contrasts that cross through zero are not significantly different.

Table 2.13 Tests for block interactions of seedling growth and survival response to treatment.

| | | block*trt | | | block*st | | | block*trt*st | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Response | Year | DF | F-stat | p-value | DF | F-stat | p-value | DF | F-stat | p-value |
| Survival | 1 | 42/132 | 1.16 | 0.2646 | **4/264** | **5.58** | **0.0003** | 84/264 | 1.09 | 0.3103 |
| | 2 | 16/54 | 1.00 | 0.4739 | **4/108** | **3.20** | **0.0158** | 32/108 | 0.98 | 0.5106 |
| Basal Area Growth | 1 | **42/132** | **1.32** | **0.1197** | 4/255 | 0.64 | 0.6348 | 84/255 | 0.97 | 0.5608 |
| | 2 | **16/54** | **1.35** | **0.2029** | **4/97** | **1.66** | **0.1653** | **32/97** | **1.22** | **0.2297** |
| Height Growth | 1 | 42/132 | 0.93 | 0.6036 | **4/255** | **4.75** | **0.0010** | 84/255 | 0.81 | 0.8768 |
| | 2 | 16/54 | 1.12 | 0.3589 | 4/97 | 0.31 | 0.8727 | 32/97 | 0.75 | 0.8215 |

Table 2.14 Tests for stock type interactions of seedling growth and survival response to treatment.

| | | Treatment | | | Stock Type | | | Trt*ST | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Response | Block | DF | F-stat | p-value | DF | F-stat | p-value | DF | F-stat | p-value |
| First-year Survival | H | 21/132 | 0.63 | 0.8903 | 2/132 | 0.03 | 0.9690 | 42/132 | 1.12 | 0.3086 |
| | LS | **21/132** | **1.76** | **0.0298** | 2/132 | 0.00 | 0.9989 | **42/132** | **1.81** | **0.0059** |
| | US | **21/132** | **7.30** | **<0.0001** | **2/132** | **17.53** | **<0.0001** | **42/132** | **1.66** | **0.0164** |
| Second-year Survival | H | **8/54** | **4.58** | **0.0003** | **2/54** | **18.46** | **<0.0001** | 16/54 | 1.49 | 0.1380 |
| | LS | **8/54** | **6.46** | **<0.0001** | **2/54** | **32.50** | **<0.0001** | 16/54 | 1.37 | 0.1923 |
| | US | **8/54** | **10.15** | **<0.0001** | **2/54** | **16.42** | **<0.0001** | **16/54** | **2.27** | **0.0129** |
| First-year Basal Area Growth | H | **21/131** | **6.56** | **<0.0001** | **2/131** | **38.72** | **<0.0001** | 42/131 | 1.20 | 0.2184 |
| | LS | **21/132** | **8.29** | **<0.0001** | **2/132** | **31.60** | **<0.0001** | 42/132 | 0.42 | 0.9992 |
| | US | **21/124** | **9.56** | **<0.0001** | **2/124** | **30.89** | **<0.0001** | 42/124 | 1.19 | 0.2260 |
| Second-year Basal Area Growth | H | **8/51** | **2.90** | **0.0095** | **2/51** | **26.56** | **<0.0001** | 16/51 | 0.60 | 0.8660 |
| | LS | **8/52** | **4.41** | **0.0004** | **2/52** | **36.88** | **<0.0001** | 16/52 | 1.21 | 0.2894 |
| | US | 8/48 | 1.39 | 0.2266 | **2/48** | **6.80** | **0.0025** | 16/48 | 0.43 | 0.9657 |
| First-year Height Growth | H | **21/131** | **6.55** | **<0.0001** | **2/131** | **92.30** | **<0.0001** | **42/131** | **1.49** | **0.0472** |
| | LS | **21/132** | **4.92** | **<0.0001** | **2/132** | **56.26** | **<0.0001** | 42/132 | 0.97 | 0.5298 |
| | US | **21/124** | **5.86** | **<0.0001** | **2/124** | **58.77** | **<0.0001** | **42/124** | **1.52** | **0.0412** |
| Second-year Height Growth | All | 8/16 | 1.76 | 0.1587 | **2/36** | **91.93** | **<0.0001** | **16/36** | **1.86** | **0.0600** |

The effect of stock type on mean first-year survival at Upper Sam and Lower Sam, mean second-year survival at Upper Sam, and mean first-year height growth at Hooker and Upper Sam differed among treatments (Table 2.14). Treatment effects were significant for all of the response variables, with the exceptions of first-year survival at Hooker, second-year basal area growth at Upper Sam, and second-year height growth. Stock type effects were significant for all of the response variables, with the exception of first-year survival at Hooker and Lower Sam.

Atr/ima-1, ima3-1, and ima6-1 at Hooker had significantly greater first-year survival than the control (Table 2.15). Ou/gly-1, atr-1, ima6-1, and hex-1 had significantly greater DF survival at Lower Sam (Table 2.16). The four spring treatments common to 2007 and 2008 had significantly greater LP survival in 2007 at Lower Sam. Atr-3 and hex-3 had significantly lower survival than the control for LP at Lower Sam. Gly/ima-2, ou/mil-2, ou/gly-2, atr/ima-2, ima6-2, and gly-2, as well as ima3-3, ima6-3, and hex-3 had significantly greater DF survival than the control at Upper Sam (Table 2.17). The four spring treatments common to 2007 and 2008 had significantly greater LB survival in 2007 at Upper Sam. Ima6-2 and gly-2, as well as ima6-3 had significantly greater LB survival than the control at Upper Sam.

Ima3-1 at Hooker and ou-1, ou/gly-1, atr-1, atr/ima-1, and hex-1 at Lower Sam had significantly greater second-year survival than the control for all three stock types (Table 2.18). No treatment had significantly different second-year survival than the control at Upper Sam for any stock type (Table 2.19).

Table 2.15 Back transformed least squares means and treatment differences for first-year survival at Hooker. The first column is the means for spring 2007 and each treatment. The second column is the means for spring 2008 and the control.

| Contrast | Mean | Mean | p-value |
|---|---|---|---|
| Spr. 07 - Spr. 08 | 0.93 | 0.90 | 0.4103 |
| ou-1 - ctl-1 | 0.85 | 0.79 | 0.5393 |
| ou/gly-1 - ctl-1 | 0.92 | 0.79 | 0.1225 |
| ou/clo-1 - ctl-1 | 0.88 | 0.79 | 0.3101 |
| atr-1 - ctl-1 | 0.85 | 0.79 | 0.5426 |
| atr/ima-1 - ctl-1 | **0.96** | **0.79** | **0.0226** |
| ima3-1 - ctl-1 | **0.97** | **0.79** | **0.0127** |
| ima6-1 - ctl-1 | **0.96** | **0.79** | **0.0242** |
| hex-1 - ctl-1 | 0.91 | 0.79 | 0.1753 |
| gly/ima-2 - ctl-2 | 0.83 | 0.93 | 0.2008 |
| ou/mil-2 - ctl-2 | 0.92 | 0.93 | 0.7985 |
| ou/gly-2 - ctl-2 | 0.93 | 0.93 | 0.9746 |
| atr/ima-2 - ctl-2 | 0.89 | 0.93 | 0.5298 |
| atr/gly-2 - ctl-2 | 0.95 | 0.93 | 0.7161 |
| ima3-2 - ctl-2 | 0.86 | 0.93 | 0.3713 |
| ima6-2 - ctl-2 | 0.92 | 0.93 | 0.8363 |
| gly-2 - ctl-2 | 0.87 | 0.93 | 0.4201 |
| atr-3 - ctl-2 | 0.89 | 0.93 | 0.5670 |
| ima3-3 - ctl-2 | 0.95 | 0.93 | 0.8095 |
| ima6-3 - ctl-2 | 0.94 | 0.93 | 0.9029 |
| hex-3 - ctl-2 | 0.80 | 0.93 | 0.1209 |

Table 2.16 Back transformed least squares means and treatment differences for first-year survival at Lower Sam. The first column is the means for spring 2007 and each treatment. The second column is the means for spring 2008 and the control.

| | DF | | | LB | | | LP | | |
|---|---|---|---|---|---|---|---|---|---|
| Contrast | Mean | Mean | p-value | Mean | Mean | p-value | Mean | Mean | p-value |
| Spr. 07 - Spr. 08 | 0.99 | 1.00 | 0.2672 | 0.74 | 0.69 | 0.5621 | **0.94** | **0.66** | **0.0002** |
| ou-1 - ctl-1 | 0.94 | 0.84 | 0.1971 | 0.82 | 0.56 | 0.1361 | 0.98 | 0.82 | 0.1319 |
| ou/gly-1 - ctl-1 | **0.99** | **0.84** | **0.0214** | 0.66 | 0.56 | 0.5768 | 0.94 | 0.82 | 0.3090 |
| ou/clo-1 - ctl-1 | 0.94 | 0.84 | 0.1971 | 0.42 | 0.56 | 0.4418 | 0.84 | 0.82 | 0.8856 |
| atr-1 - ctl-1 | **0.99** | **0.84** | **0.0214** | 0.73 | 0.56 | 0.3294 | 0.99 | 0.82 | 0.0826 |
| atr/ima-1 - ctl-1 | 0.96 | 0.84 | 0.1089 | 0.78 | 0.56 | 0.2108 | 0.90 | 0.82 | 0.5316 |
| ima3-1 - ctl-1 | 0.96 | 0.84 | 0.1089 | 0.58 | 0.56 | 0.8966 | 0.96 | 0.82 | 0.2179 |
| ima6-1 - ctl-1 | **1.00** | **0.84** | **0.0031** | 0.79 | 0.56 | 0.1891 | 0.94 | 0.82 | 0.3090 |
| hex-1 - ctl-1 | **1.00** | **0.84** | **0.0031** | 0.83 | 0.56 | 0.1185 | 0.82 | 0.82 | 1.0000 |
| gly/ima-2 - ctl-2 | 1.00 | 0.99 | 0.4577 | 0.79 | 0.59 | 0.2311 | 1.00 | 0.97 | 0.3705 |
| ou/mil-2 - ctl-2 | 0.99 | 0.99 | 1.0000 | 0.73 | 0.59 | 0.4074 | 0.89 | 0.97 | 0.3807 |
| ou/gly-2 - ctl-2 | 1.00 | 0.99 | 0.4577 | 0.52 | 0.59 | 0.7291 | 0.89 | 0.97 | 0.4088 |
| atr/ima-2 - ctl-2 | 1.00 | 0.99 | 0.4577 | 0.84 | 0.59 | 0.1325 | 0.89 | 0.97 | 0.4088 |
| atr/gly-2 - ctl-2 | 0.94 | 0.99 | 0.2878 | 0.87 | 0.59 | 0.0892 | 0.90 | 0.97 | 0.4712 |
| ima3-2 - ctl-2 | 0.96 | 0.99 | 0.4577 | 0.81 | 0.59 | 0.2027 | 0.94 | 0.97 | 0.7445 |
| ima6-2 - ctl-2 | 0.99 | 0.99 | 1.0000 | 0.86 | 0.59 | 0.1026 | 0.94 | 0.97 | 0.7445 |
| gly-2 - ctl-2 | 0.98 | 0.99 | 0.7454 | 0.57 | 0.59 | 0.9089 | 0.99 | 0.97 | 0.6920 |
| atr-3 - ctl-2 | 1.00 | 0.99 | 0.4577 | 0.83 | 0.59 | 0.1437 | **0.65** | **0.97** | **0.0211** |
| ima3-3 - ctl-2 | 1.00 | 0.99 | 0.4577 | 0.43 | 0.59 | 0.4161 | 0.82 | 0.97 | 0.1710 |
| ima6-3 - ctl-2 | 1.00 | 0.99 | 0.4577 | 0.75 | 0.59 | 0.3443 | 0.81 | 0.97 | 0.1532 |
| hex-3 - ctl-2 | 1.00 | 0.99 | 0.4577 | 0.70 | 0.59 | 0.5176 | **0.32** | **0.97** | **0.0002** |

Table 2.17 Back transformed least squares means and treatment differences for first-year survival at Upper Sam. The first column is the means for spring 2007 and each treatment. The second column is the means for spring 2008 and the control.

| | DF | | | LB | | | LP | | |
|---|---|---|---|---|---|---|---|---|---|
| Contrast | Mean | Mean | p-value | Mean | Mean | p-value | Mean | Mean | p-value |
| Spr. 07 - Spr. 08 | 0.99 | 0.93 | 0.1557 | **0.80** | **0.41** | **0.0062** | 0.78 | 0.65 | 0.2878 |
| ou-1 - ctl-1 | 0.99 | 0.92 | 0.4115 | 0.47 | 0.71 | 0.3987 | 0.57 | 0.78 | 0.4030 |
| ou/gly-1 - ctl-1 | 0.93 | 0.92 | 0.9304 | 0.39 | 0.71 | 0.2539 | 0.59 | 0.78 | 0.4535 |
| ou/clo-1 - ctl-1 | 0.95 | 0.92 | 0.8035 | 0.80 | 0.71 | 0.7339 | 0.93 | 0.78 | 0.4379 |
| atr-1 - ctl-1 | 0.99 | 0.92 | 0.4115 | 0.82 | 0.71 | 0.6730 | 0.84 | 0.78 | 0.7896 |
| atr/ima-1 - ctl-1 | 0.94 | 0.92 | 0.8162 | 0.53 | 0.71 | 0.5128 | 0.88 | 0.78 | 0.6459 |
| ima3-1 - ctl-1 | 0.97 | 0.92 | 0.6178 | 0.56 | 0.71 | 0.5778 | 0.66 | 0.78 | 0.6211 |
| ima6-1 - ctl-1 | 1.00 | 0.92 | 0.2202 | 0.94 | 0.71 | 0.2636 | 0.96 | 0.78 | 0.2927 |
| hex-1 - ctl-1 | 0.99 | 0.92 | 0.4115 | 0.83 | 0.71 | 0.6180 | 0.58 | 0.78 | 0.4338 |
| gly/ima-2 - ctl-2 | **0.96** | **0.47** | **0.0132** | 0.50 | 0.10 | 0.1117 | 0.53 | 0.46 | 0.7912 |
| ou/mil-2 - ctl-2 | **0.94** | **0.47** | **0.0186** | 0.58 | 0.10 | 0.0643 | 0.92 | 0.46 | 0.0550 |
| ou/gly-2 - ctl-2 | **0.89** | **0.47** | **0.0485** | 0.36 | 0.10 | 0.2647 | 0.68 | 0.46 | 0.4007 |
| atr/ima-2 - ctl-2 | **0.95** | **0.47** | **0.0178** | 0.61 | 0.10 | 0.0524 | 0.87 | 0.46 | 0.1014 |
| atr/gly-2 - ctl-2 | 0.75 | 0.47 | 0.2251 | 0.18 | 0.10 | 0.6769 | 0.51 | 0.46 | 0.8303 |
| ima3-2 - ctl-2 | 0.86 | 0.47 | 0.0772 | 0.08 | 0.10 | 0.9317 | 0.54 | 0.46 | 0.7548 |
| ima6-2 - ctl-2 | **0.93** | **0.47** | **0.0237** | **0.65** | **0.10** | **0.0372** | 0.62 | 0.46 | 0.5539 |
| gly-2 - ctl-2 | **0.99** | **0.47** | **0.0040** | **0.81** | **0.10** | **0.0085** | 0.85 | 0.46 | 0.1143 |
| atr-3 - ctl-2 | 0.78 | 0.47 | 0.1701 | 0.56 | 0.10 | 0.0758 | 0.61 | 0.46 | 0.5585 |
| ima3-3 - ctl-2 | **0.97** | **0.47** | **0.0095** | 0.07 | 0.10 | 0.8560 | 0.59 | 0.46 | 0.6307 |
| ima6-3 - ctl-2 | **0.99** | **0.47** | **0.0040** | **0.70** | **0.10** | **0.0250** | 0.85 | 0.46 | 0.1221 |
| hex-3 - ctl-2 | **0.92** | **0.47** | **0.0323** | 0.41 | 0.10 | 0.1994 | 0.54 | 0.46 | 0.7656 |

Table 2.18 Back transformed least squares means and treatment differences for second-year survival at Hooker and Lower Sam. The first column is the means for each treatment and the second column is the means for the control.

| | Hooker | | | Lower Sam | | |
|---|---|---|---|---|---|---|
| Contrast | Mean | Mean | p-value | Mean | Mean | p-value |
| ou-1 - ctl-1 | 0.66 | 0.55 | 0.4930 | **0.83** | **0.59** | **0.0284** |
| ou/gly-1 - ctl-1 | 0.83 | 0.55 | 0.0552 | **0.87** | **0.59** | **0.0103** |
| ou/clo-1 - ctl-1 | 0.64 | 0.55 | 0.5400 | 0.60 | 0.59 | 0.9031 |
| atr-1 - ctl-1 | 0.63 | 0.55 | 0.5977 | **0.84** | **0.59** | **0.0230** |
| atr/ima-1 - ctl-1 | 0.76 | 0.55 | 0.1638 | **0.85** | **0.59** | **0.0168** |
| ima3-1 - ctl-1 | **0.89** | **0.55** | **0.0168** | 0.64 | 0.59 | 0.6531 |
| ima6-1 - ctl-1 | 0.83 | 0.55 | 0.0518 | 0.79 | 0.59 | 0.0698 |
| hex-1 - ctl-1 | 0.76 | 0.55 | 0.1563 | **0.86** | **0.59** | **0.0130** |

Table 2.19 Back transformed least squares means and treatment differences for second-year survival at Upper Sam. The first column is the means for each treatment and the second column is the means for the control.

| | DF | | | LB | | | LP | | |
|---|---|---|---|---|---|---|---|---|---|
| Contrast | Mean | Mean | p-value | Mean | Mean | p-value | Mean | Mean | p-value |
| ou-1 - ctl-1 | 0.79 | 0.75 | 0.8207 | 0.41 | 0.39 | 0.9510 | 0.35 | 0.47 | 0.6842 |
| ou/gly-1 - ctl-1 | 0.50 | 0.75 | 0.1686 | 0.15 | 0.39 | 0.4374 | 0.40 | 0.47 | 0.8191 |
| ou/clo-1 - ctl-1 | 0.62 | 0.75 | 0.4470 | 0.63 | 0.39 | 0.4808 | 0.86 | 0.47 | 0.1769 |
| atr-1 - ctl-1 | 0.92 | 0.75 | 0.2120 | 0.76 | 0.39 | 0.2686 | 0.78 | 0.47 | 0.2988 |
| atr/ima-1 - ctl-1 | 0.76 | 0.75 | 0.9493 | 0.38 | 0.39 | 0.9785 | 0.75 | 0.47 | 0.3514 |
| ima3-1 - ctl-1 | 0.97 | 0.75 | 0.0785 | 0.49 | 0.39 | 0.7602 | 0.66 | 0.47 | 0.5332 |
| ima6-1 - ctl-1 | 0.86 | 0.75 | 0.4533 | 0.84 | 0.39 | 0.1723 | 0.92 | 0.47 | 0.1032 |
| hex-1 - ctl-1 | 0.96 | 0.75 | 0.0965 | 0.83 | 0.39 | 0.1793 | 0.56 | 0.47 | 0.7818 |

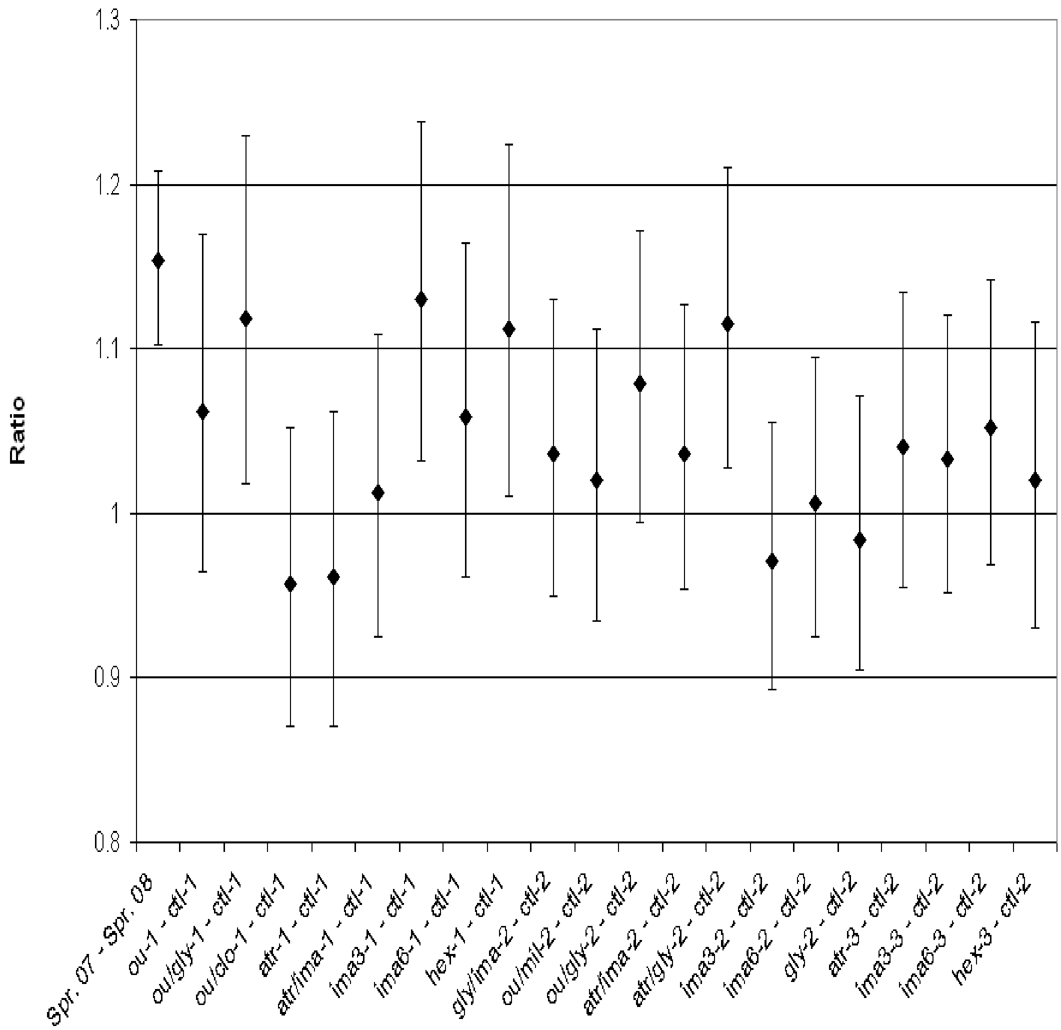


Figure 2.7 Ratio of treatment differences for first-year basal area growth at Hooker. Contrasts that cross through one are not significantly different.

The four spring treatments common to 2007 and 2008 had significantly greater first-year basal area growth in 2007 at Hooker (Figure 2.7). Ou/gly-1, ima3-1, and atr/gly-2 had significantly greater first-year basal area growth at Hooker than the control. The four spring treatments common to 2007 and 2008 had significantly greater first-year basal area growth at Lower Sam and Upper Sam in spring 2007 (Figure 2.8). Ou-1, ou/clo-1, and ima3-1 had significantly less first-year basal area growth at Lower Sam than the control. Atr/ima-1, gly/ima-2, ou/gly-2, atr/ima-2, atr/gly-2, and ima6-2, plus atr-3 and hex-3 had significantly greater first-year basal area growth than the control at Lower Sam. Ima6-1 and hex-1 had significantly greater first-year basal area growth than the control at Upper Sam.

Ou-1, ou/gly-1, ima6-1, and hex-1 had significantly greater second-year basal area growth than the control at Hooker (Figure 2.9). Ou-1 and ou/clo-1 had significantly less second-year basal area growth than the control at Lower Sam. Hex-1 had significantly greater second-year basal area growth than the control at Upper Sam.

The four spring treatments common to 2007 and 2008 had significantly greater first-year DF and LB height growth in 2007 at Hooker (Figure 2.10). Ima3-1 and ima6-1 had significantly less first-year DF height growth, while atr-3 had significantly greater first-year DF height growth than the control at Hooker. Ou-1 and ou/clo-1 had significantly less first-year LB height growth than the control at Hooker. Hex-3 had significantly greater first-year LP height growth than the control at Hooker. The four spring treatments common to 2007 and 2008 had significantly greater first-year height growth in 2007 at Lower Sam (Figure 2.11). Ou-1 and ou/clo-1, ima6-3 had

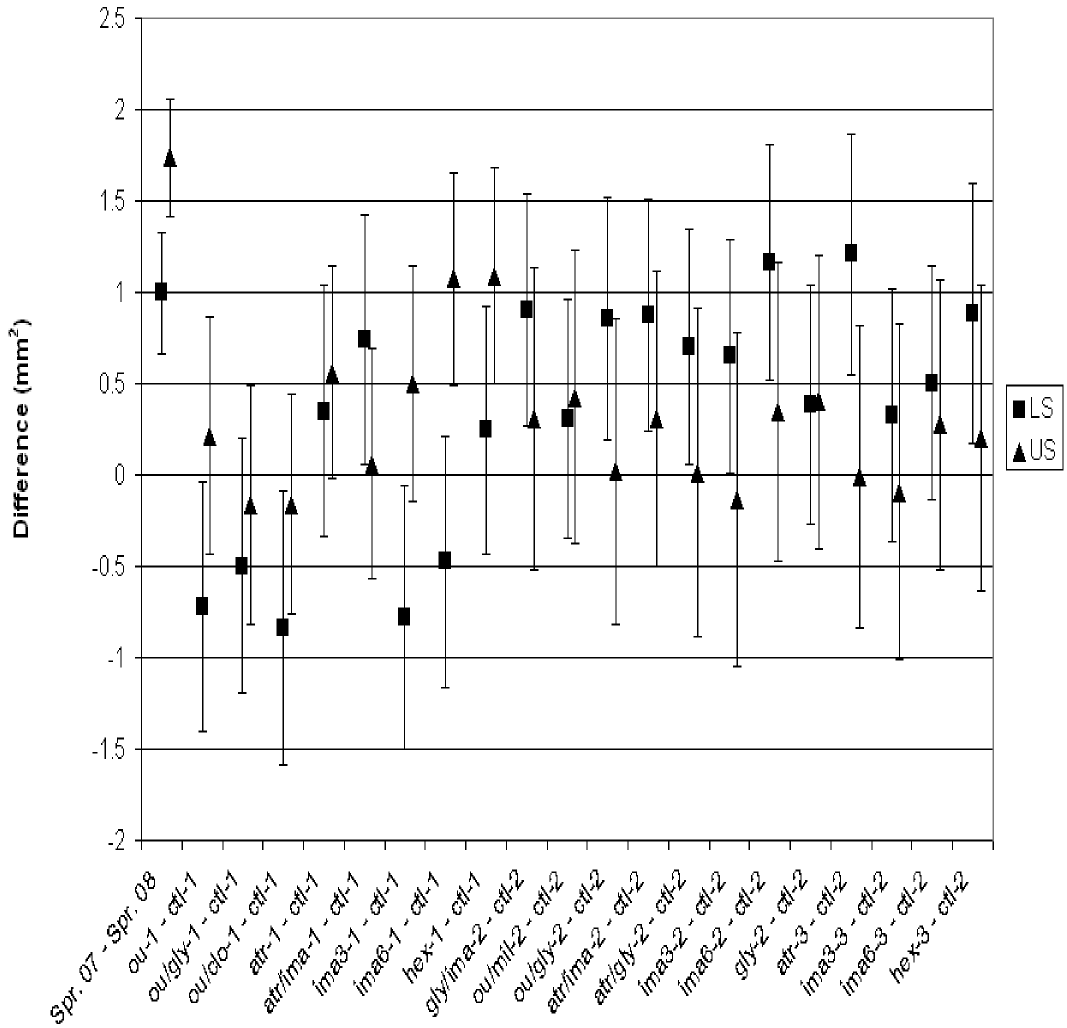


Figure 2.8 Treatment differences for first-year basal area growth at Lower Sam and Upper Sam. Contrasts that cross through zero are not significantly different.

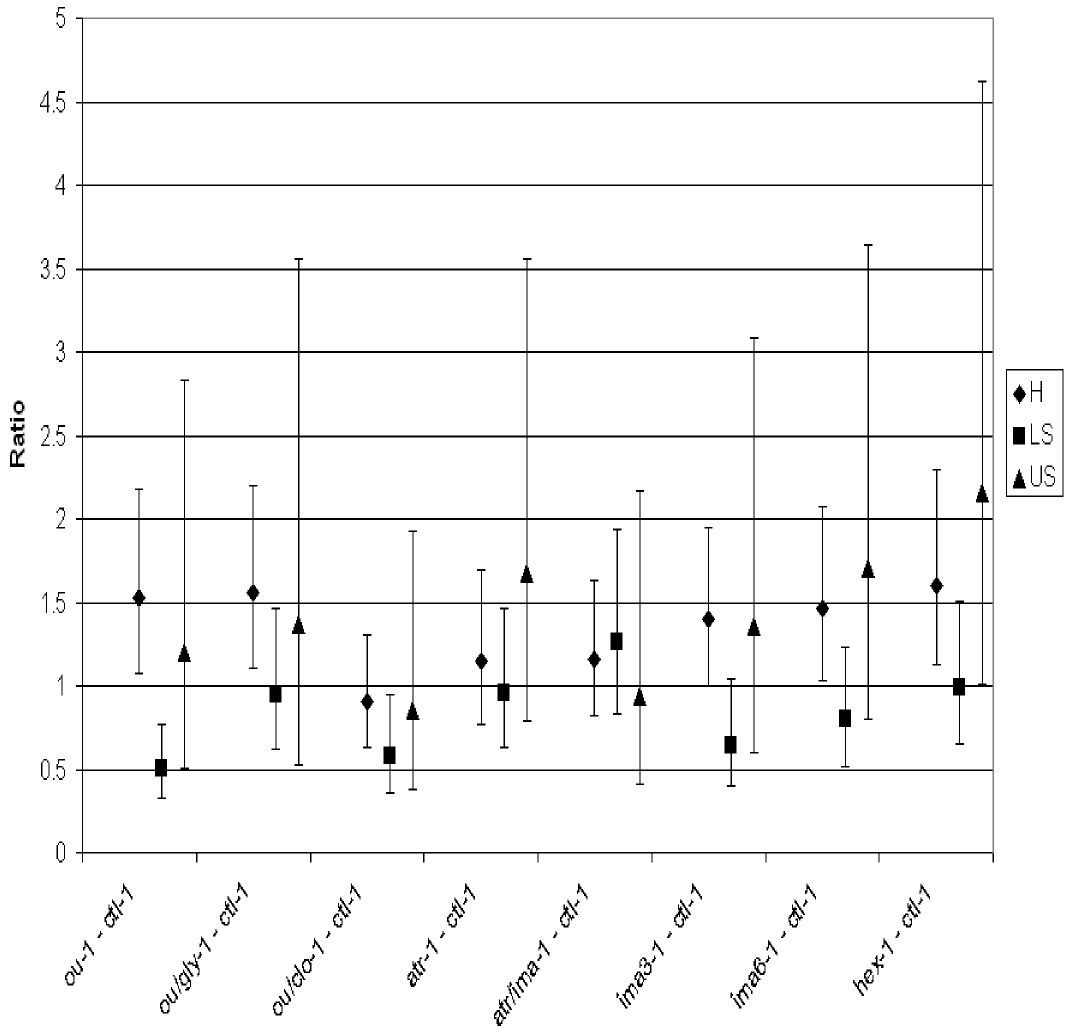


Figure 2.9 Ratio of treatment differences for second-year basal area growth. Contrasts that cross through one are not significantly different.

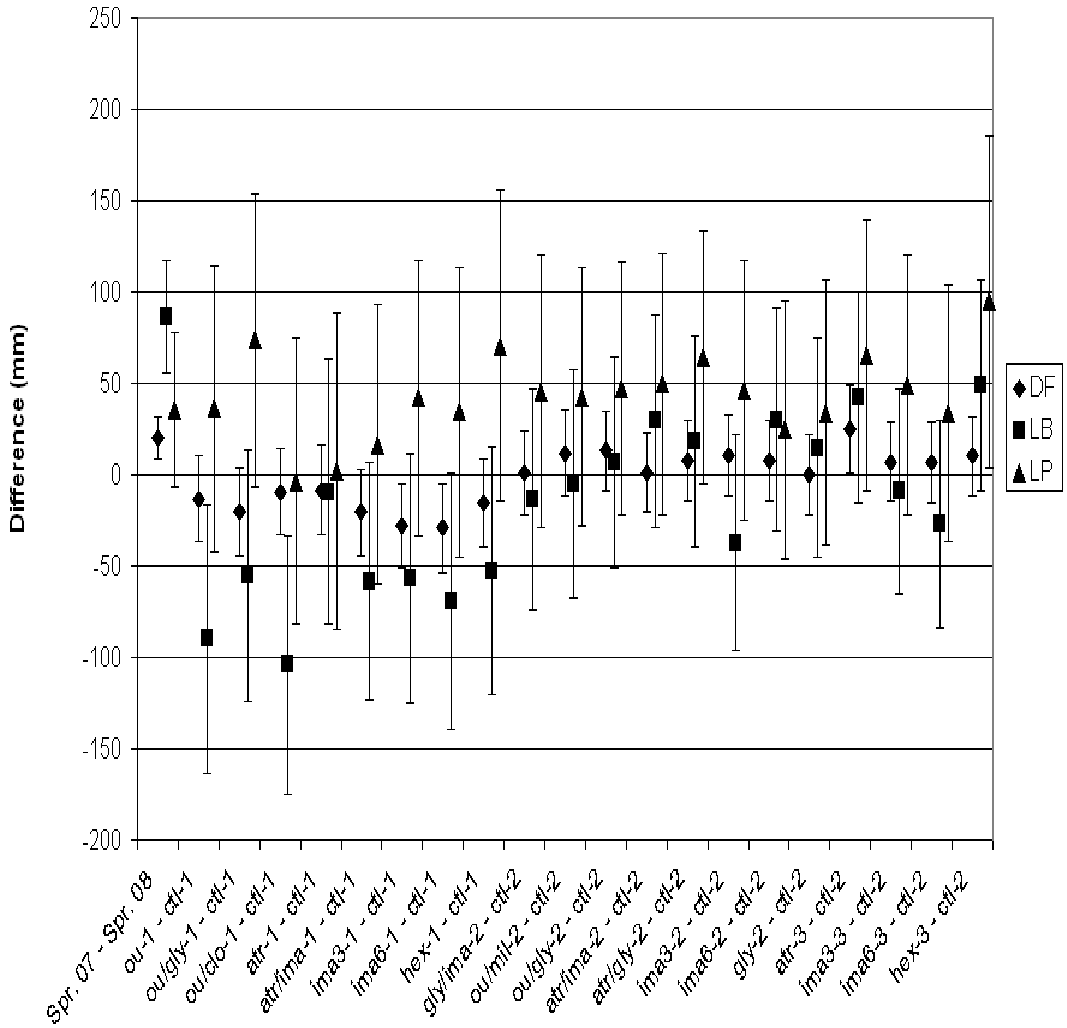


Figure 2.10 Treatment differences for first-year height growth at Hooker. Contrasts that cross through zero are not significantly different.

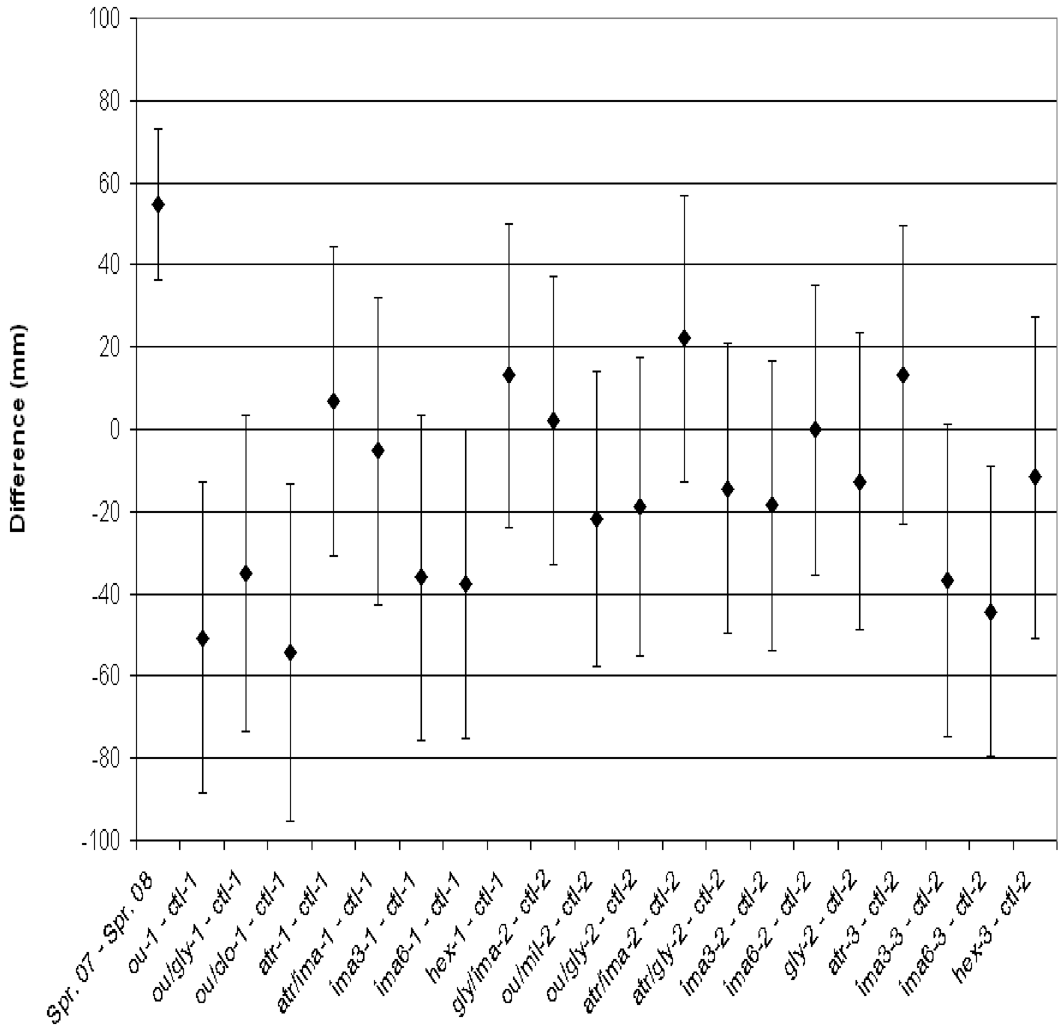


Figure 2.11 Treatment differences for first-year height growth at Lower Sam. Contrasts that cross through zero are not significantly different.

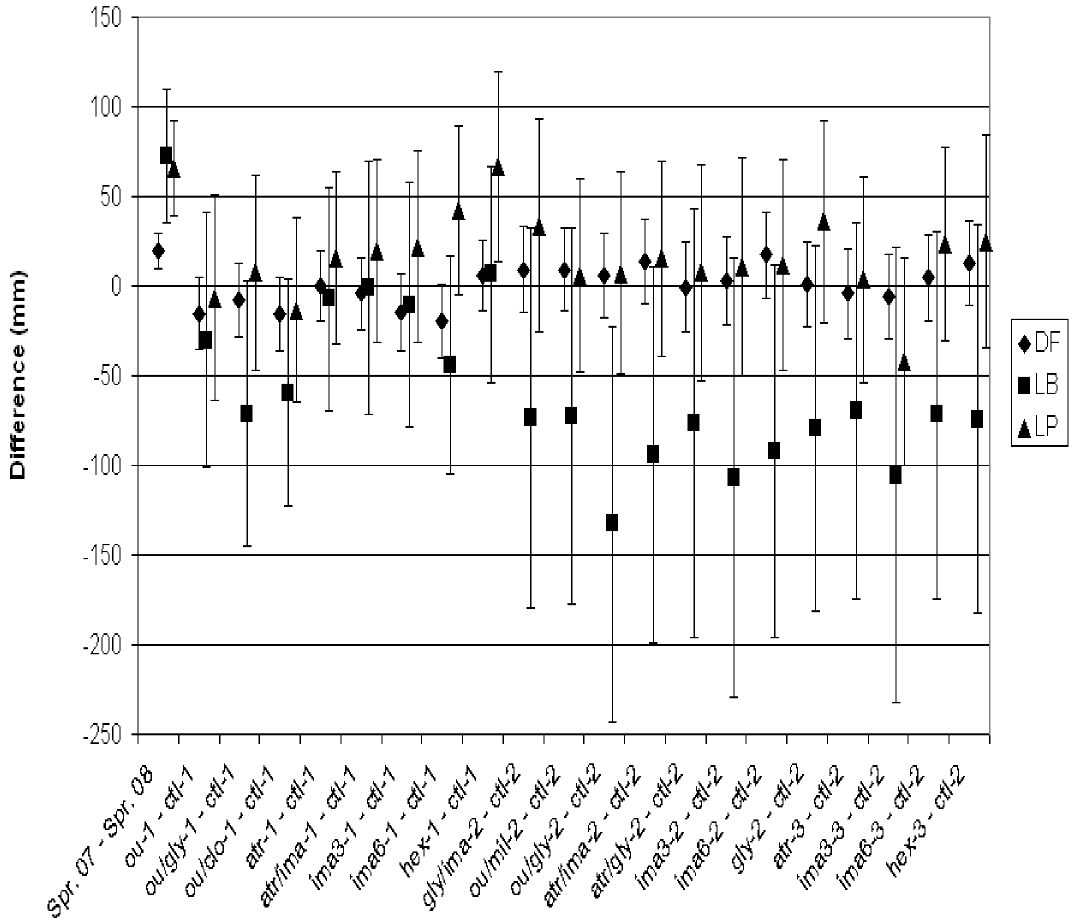


Figure 2.12 Treatment differences for first-year height growth at Upper Sam. Contrasts that cross through zero are not significantly different.

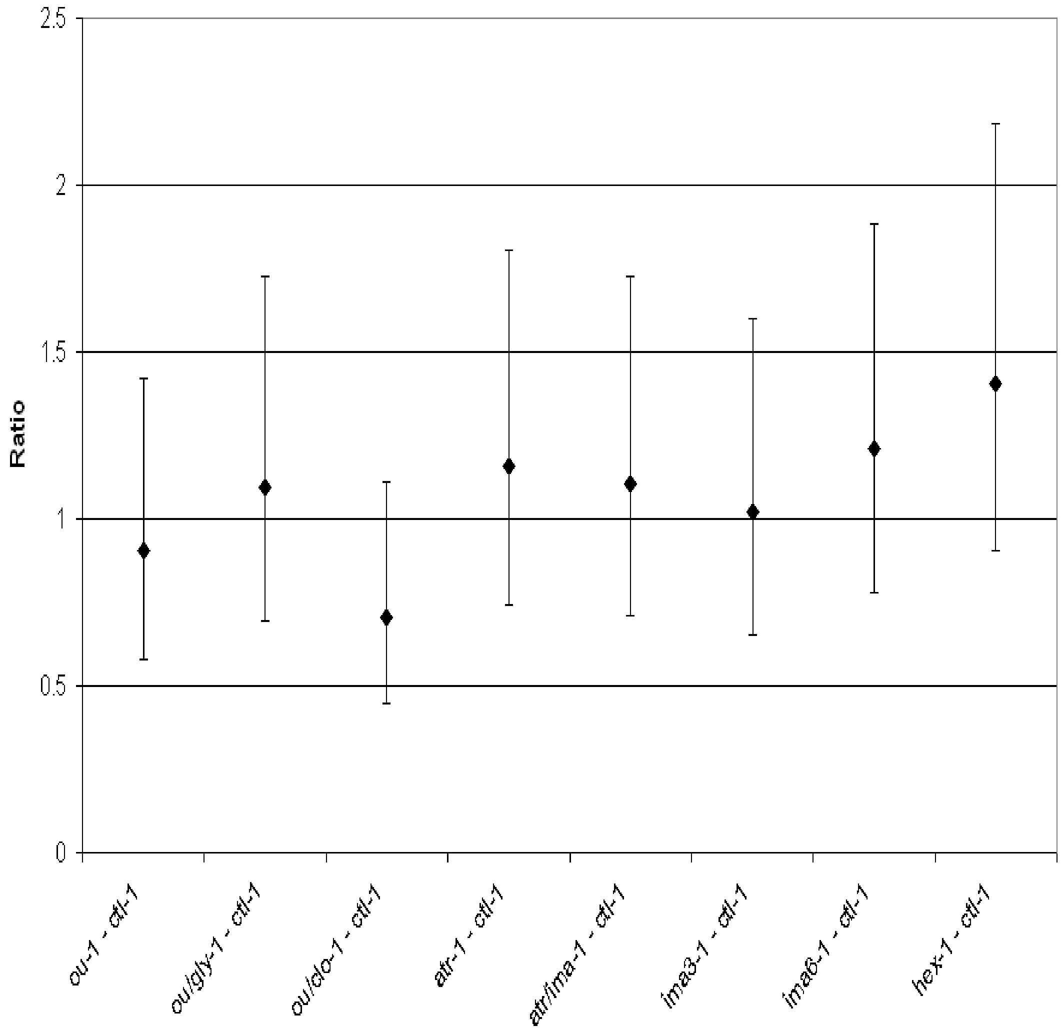


Figure 2.13 Ratio of treatment differences for second-year height growth. Contrasts that cross through one are not significantly different.

significantly less first-year height growth than the control at Lower Sam. The four spring treatments common to 2007 and 2008 had significantly greater first-year height growth in 2007 for all three stock types at Upper Sam (Figure 2.12). DF first-year height growth was not significantly different from the control for all treatments at Upper Sam. Ou/gly-2 had significantly less first-year LB height growth than the control and hex-1 had significantly greater first-year LP height growth at Upper Sam. Second-year height growth did not differ significantly from the control for any stock type of treatment (Figure 2.13).

### *Response to Vegetation Cover*

The relationship between final volumetric soil moisture and vegetation cover for each year and at each depth is negative exponential, which means that volumetric soil moisture at the end of the growing season decreases exponentially with increasing vegetation cover. Total non-coniferous cover was the most significant variable in 2007 at both sampling depths. Total grass and total non-coniferous cover were the most significant variables in 2008 at 23 cm depth, and total non-coniferous cover was the most significant variable at 46 cm depth (Table 2.20 and Figures 2.14-2.17).

There is a negative relationship between DF, LB, and LP first-year survival in 2007 and 2008 and percent cover (Table 2.21). However, the relationship between first and second-year volume growth for DF, LB, and LP is negative exponential. DF survival in 2007 was significantly related to both first-year post-treatment grass and forb cover (Figure 2.18), LB survival was significantly related to first-year post-treatment grass cover (Figure 2.19), and LP survival was significantly related to first

Table 2.20 Formulas for final volumetric soil moisture (VSM) regressed on percent cover.

| Response | Year | Depth (cm) | Block | Formula |
|---|---|---|---|---|
| Final VSM | 2007 | 23 | H | $= e^{(-0.9506 - 0.01334(tot))}$ |
| Final VSM | 2007 | 23 | LS | $= e^{(-0.9381 - 0.01334(tot))}$ |
| Final VSM | 2007 | 23 | US | $= e^{(-1.1554 - 0.01334(tot))}$ |
| Final VSM | 2007 | 46 | ALL | $= e^{(-0.9172 - 0.01635(tot))}$ |
| Final VSM | 2008 | 23 | H | $= e^{(-0.9276 + 0.005298(shrub2) - 0.01026(tot2))}$ |
| Final VSM | 2008 | 23 | LS | $= e^{(-1.11652 + 0.005298(shrub2) - 0.01026(tot2))}$ |
| Final VSM | 2008 | 23 | US | $= e^{(-1.137 + 0.005298(shrub2) - 0.01026(tot2))}$ |
| Final VSM | 2008 | 46 | ALL | $= e^{(-0.7475 - 0.01636(tot2))}$ |

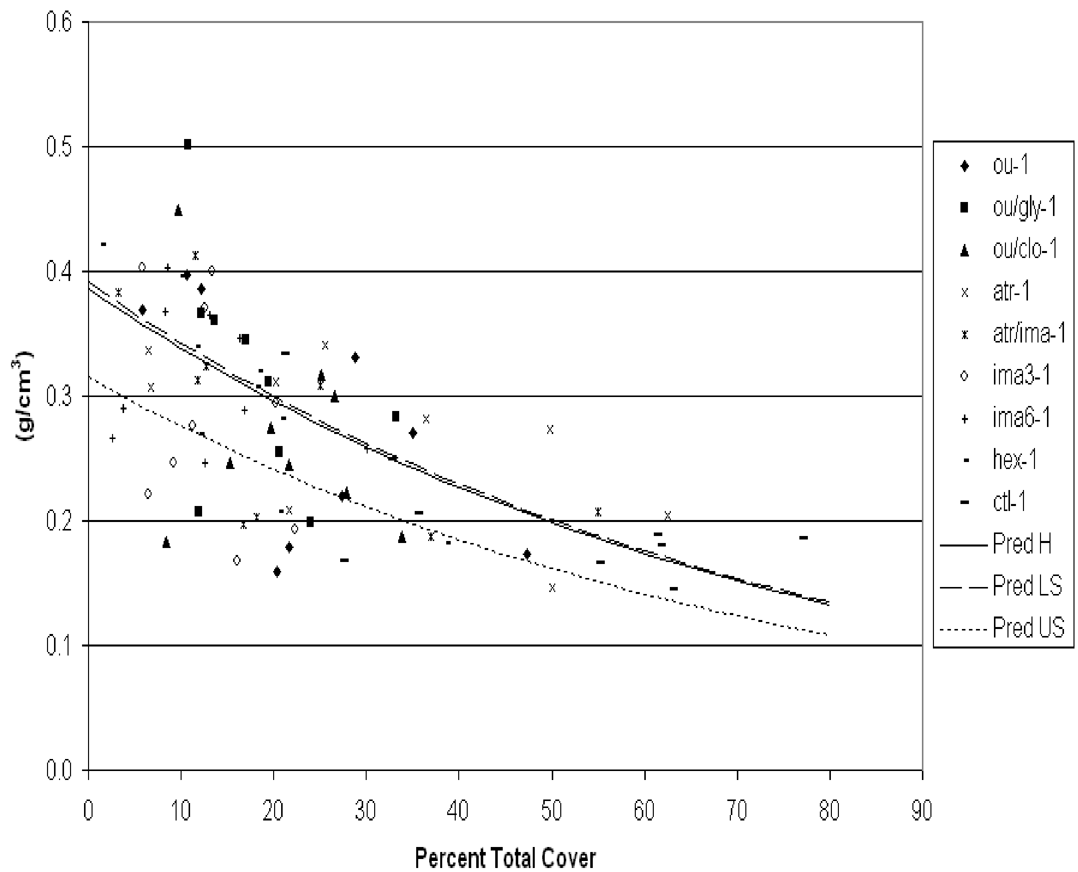


Figure 2.14 Predicted vs. measured values for volumetric soil moisture (VSM g/cm$^3$) to 23 cm depth in 2007 regressed on percent total cover. This is final VSM collected at the end of the growing season in late August.

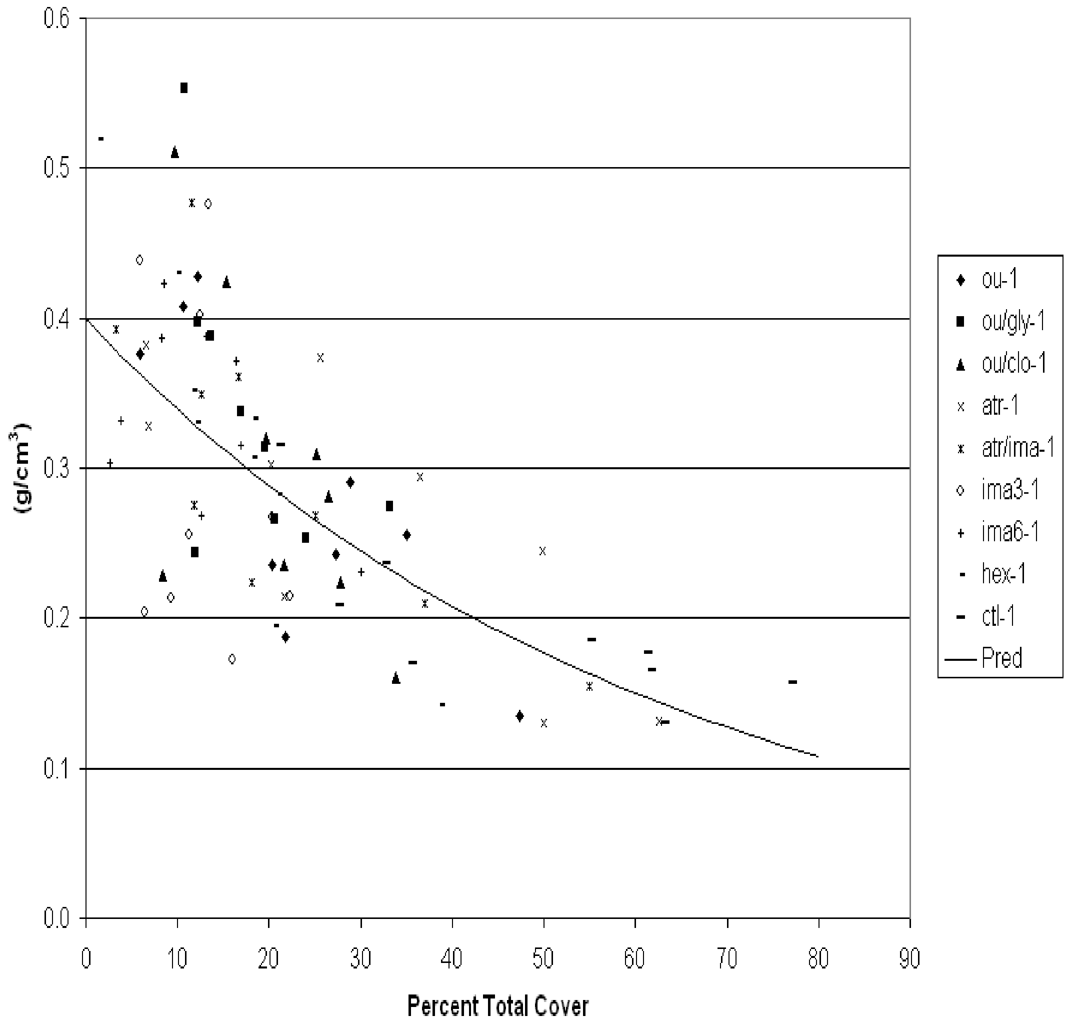


Figure 2.15 Predicted vs. measured values for volumetric soil moisture (VSM g/cm$^3$) to 46 cm depth in 2007 regressed on percent total cover. This is final VSM collected at the end of the growing season in late August.

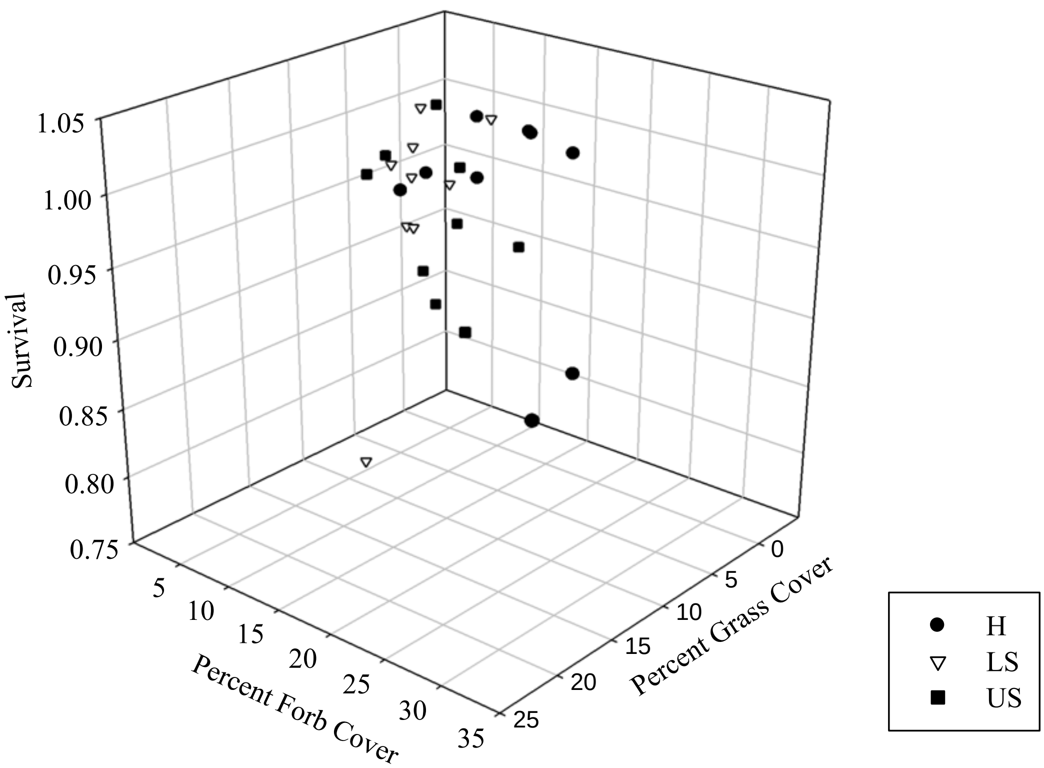


Figure 2.16 Measured values for volumetric soil moisture (VSM g/cm3) to 23 cm depth in 2008 regressed on percent shrub and total cover. This is final VSM collected at the end of the growing season in late August.

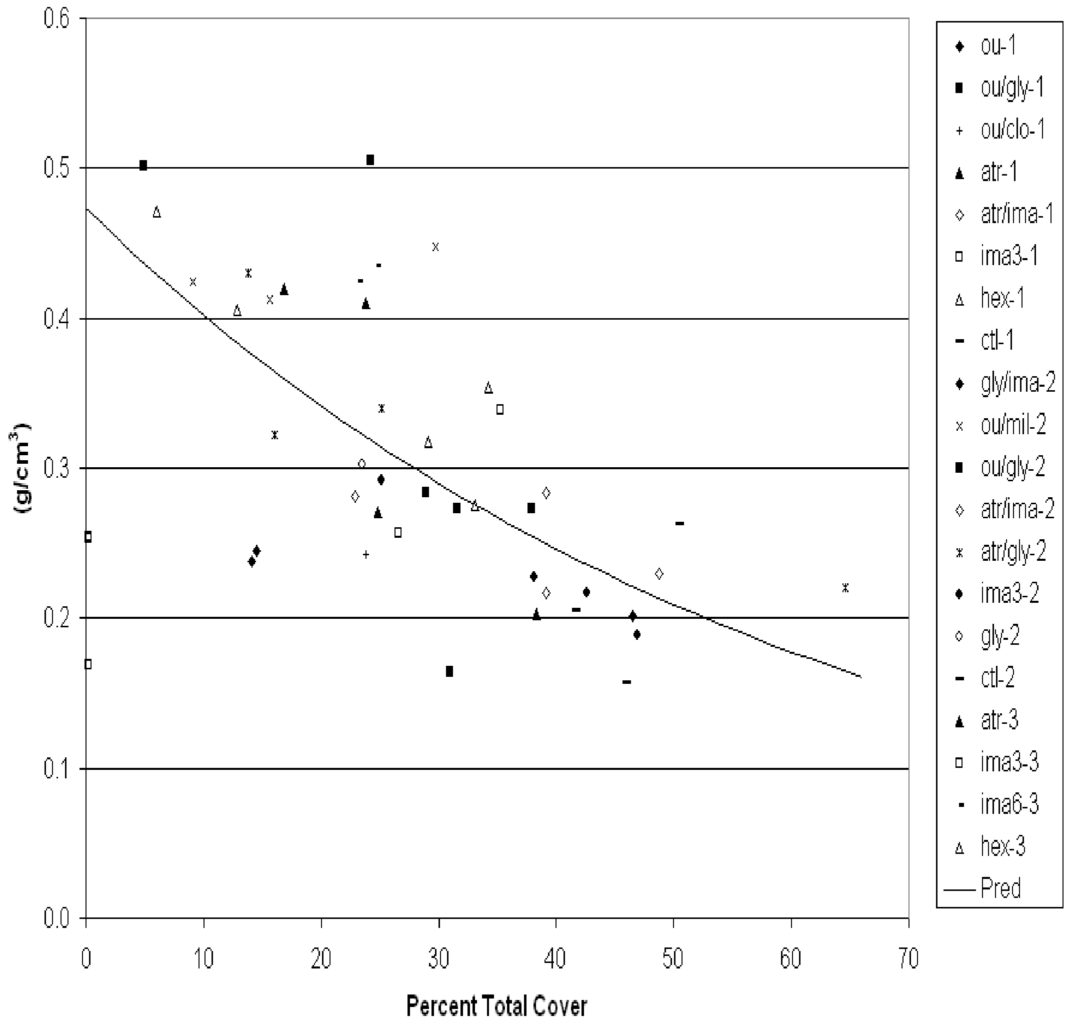


Figure 2.17 Predicted vs. measured values for volumetric soil moisture (VSM g/cm$^3$) to 46 cm depth in 2008 regressed on percent total cover. This is final VSM collected at the end of the growing season in late August.

Table 2.21 Formulas for seedling survival and growth regressed on percent cover. The first survival and volume equations are for treatments 1-9, and the second survival and volume equations are for treatments 10-22.

| Resp. | Year | ST | Block | Formula |
|---|---|---|---|---|
| Surv. | 2007 | DF | H | = 1.0088 - 0.004051(y1grass) - 0.001115(y1forb) |
| Surv. | 2007 | DF | LS | = 1.01755 - 0.008889(y1grass) - 0.01107(y1forb) |
| Surv. | 2007 | DF | US | = 0.9759 + 0.004529(y1grass) - 0.0073(y1forb) |
| Surv. | 2007 | LP | ALL | = 0.8598 - 0.00313(y1tot) |
| Surv. | 2007 | LB | H | = 0.8791 - 0.01624(y1grass) |
| Surv. | 2007 | LB | LS | = 0.722382 - 0.01624(y1grass) |
| Surv. | 2007 | LB | US | = 0.7138 - 0.01624(y1grass) |
| Vol. | 2007 | DF | ALL | no variables are significant |
| Vol. | 2007 | LP | ALL | $= e^{(8.9105 - 0.022(y1tot))}$ |
| Vol. | 2007 | LB | H | $= e^{(8.5793 - 0.0084(y1shrub))}$ |
| Vol. | 2007 | LB | LS | $= e^{(8.95384 - 0.0372(y1shrub))}$ |
| Vol. | 2007 | LB | US | $= e^{(8.9738 - 0.2395(y1shrub))}$ |
| Vol. | 2008 | DF | ALL | $= e^{(10.0831 - 0.02106(y2forb) - 0.0202(y2tot))}$ |
| Vol. | 2008 | LP | H | $= e^{(11.4435 - 0.04463(y2tot))}$ |
| Vol. | 2008 | LP | LS | $= e^{(12.1926 - 0.04463(y2tot))}$ |
| Vol. | 2008 | LP | US | $= e^{(11.4435 - 0.04463(y2tot))}$ |
| Vol. | 2008 | LB | H | $= e^{(11.5342 - 0.03312(y2tot))}$ |
| Vol. | 2008 | LB | LS | no variables are significant |
| Vol. | 2008 | LB | US | $= e^{(12.0737 - 0.05737(y2tot))}$ |
| Surv. | 2008 | DF | H | = 0.99542 - 0.001205(y1forb) |
| Surv. | 2008 | DF | LS | = 0.981 - 0.000368(y1forb) |
| Surv. | 2008 | DF | US | = 0.9487 - 0.00673(y1forb) |
| Surv. | 2008 | LP | ALL | = 0.8418 - 0.00713(y1forb) |
| Surv. | 2008 | LB | H | = 0.80272 - 0.021604(y1grass) + 0.00181(y1tot) |
| Surv. | 2008 | LB | LS | = 0.77896 - 0.003084(y1grass) - 0.002795(y1tot) |
| Surv. | 2008 | LB | US | = 0.7674 + 0.00666(y1grass) - 0.01254(y1tot) |
| Vol. | 2008 | DF | ALL | $= e^{(7.4623 - 0.01715(y1tot))}$ |
| Vol. | 2008 | LP | H | $= e^{(8.3962 - 0.02961(y1tot))}$ |
| Vol. | 2008 | LP | LS | $= e^{(8.1949 - 0.02961(y1tot))}$ |
| Vol. | 2008 | LP | US | $= e^{(7.9369 - 0.02961(y1tot))}$ |
| Vol. | 2008 | LB | ALL | $= e^{(8.0153 - 0.01397(y1tot))}$ |

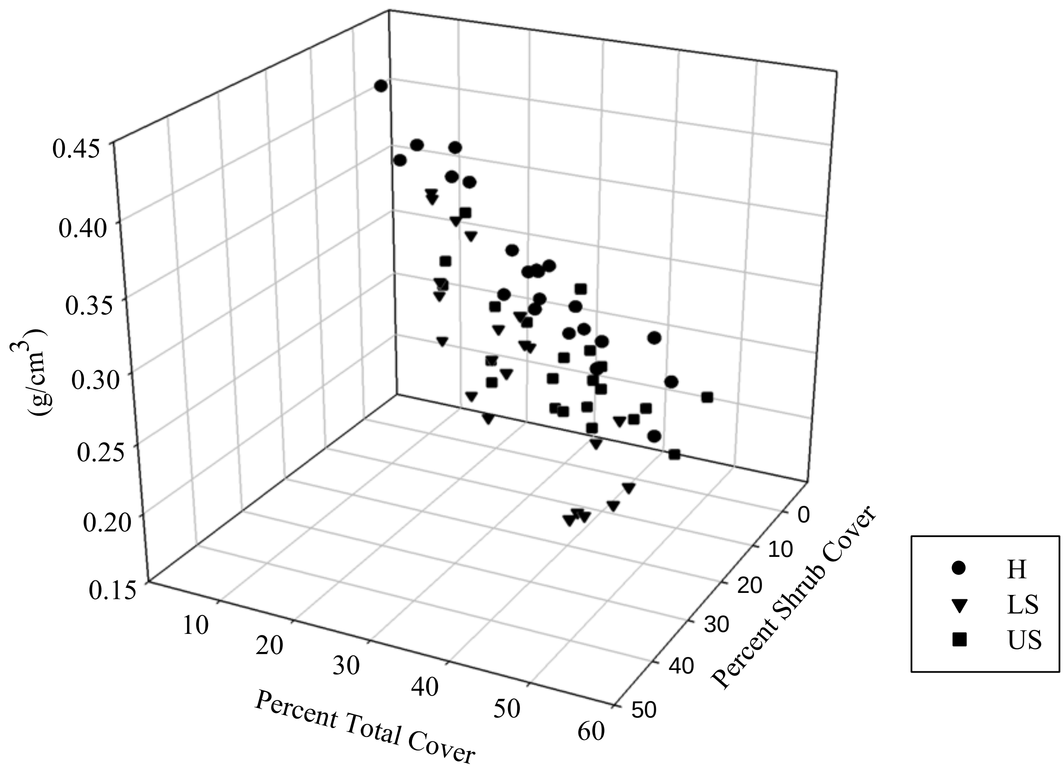


Figure 2.18 Measured values for Douglas-fir first-year percent survival in 2007 regressed on percent grass and forb cover.

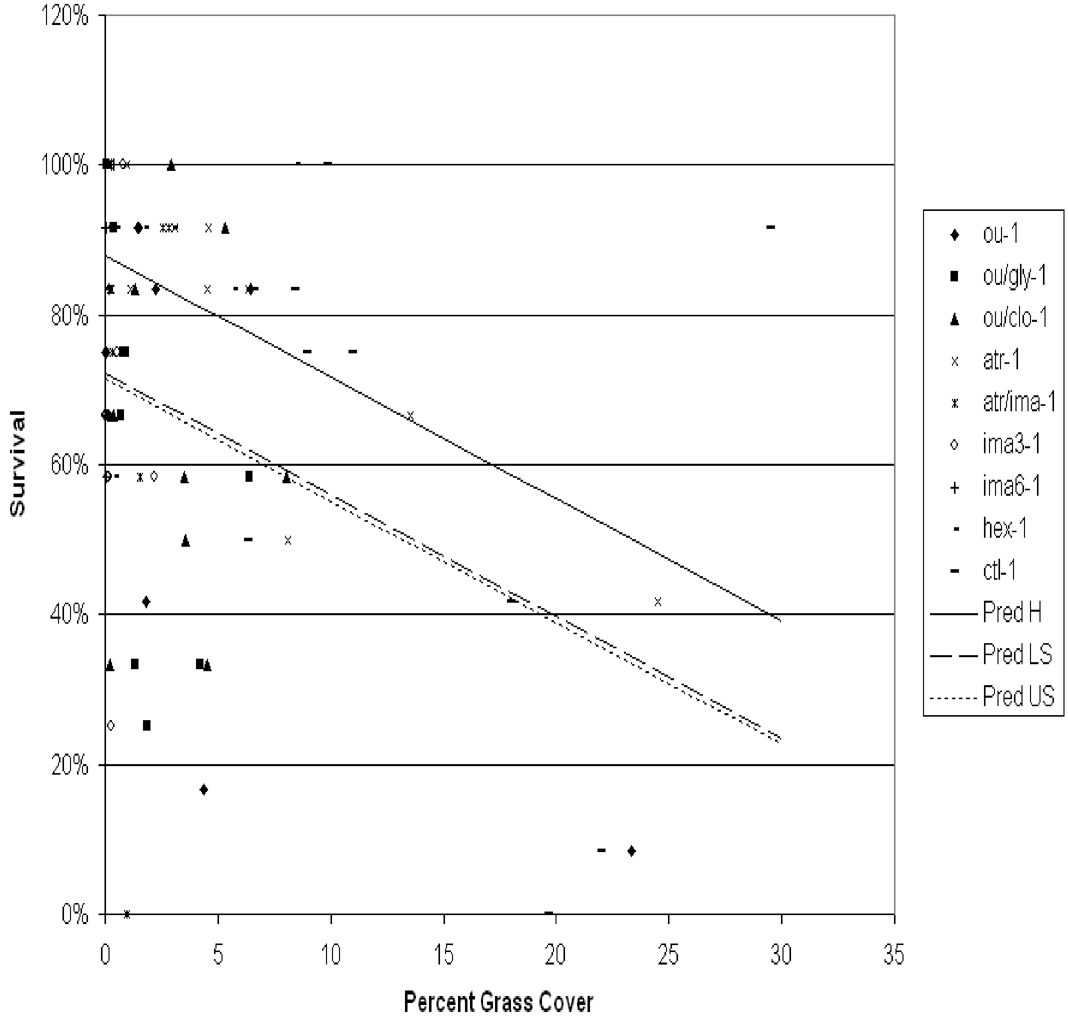


Figure 2.19 Predicted vs. measured values for larch bareroot first-year percent survival in 2007 regressed on percent grass cover.

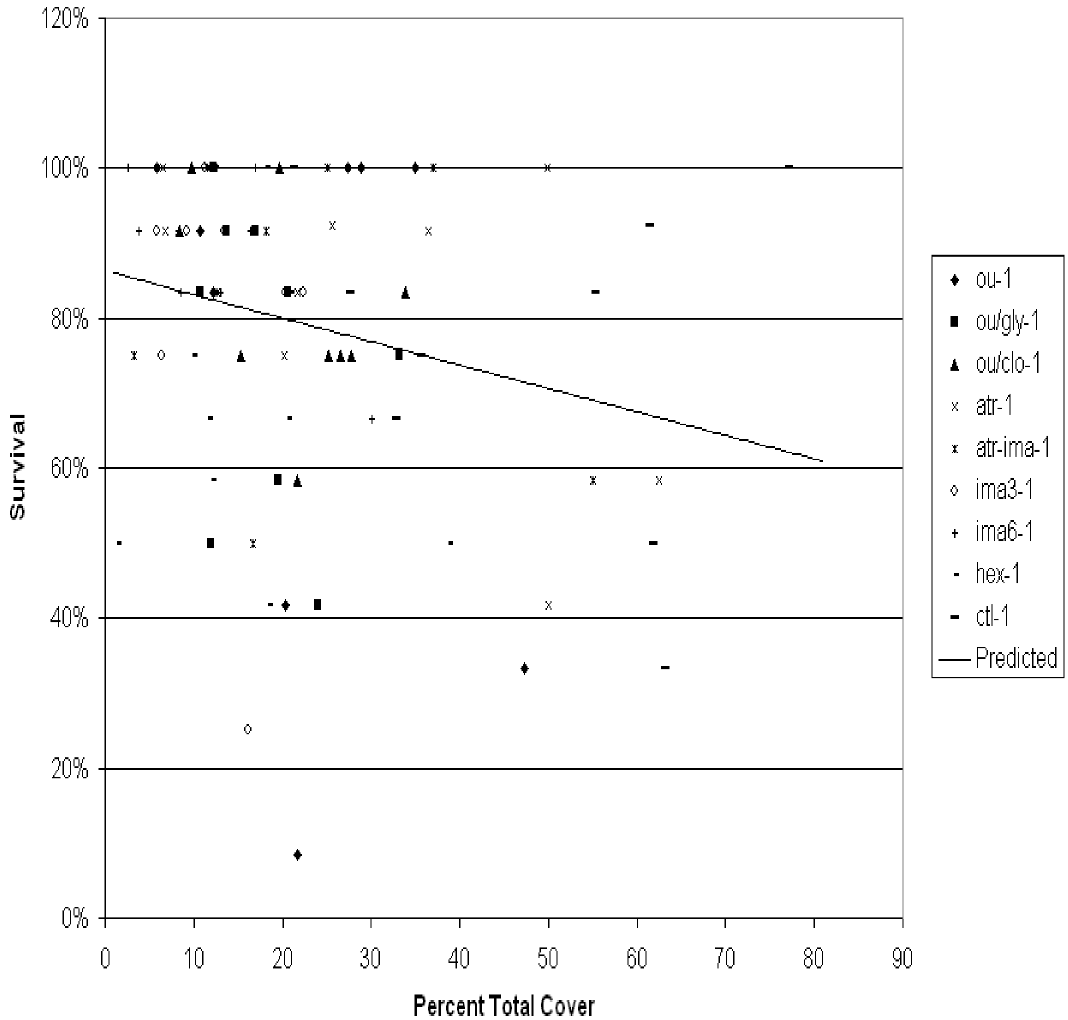


Figure 2.20 Predicted vs. measured values for larch plug first-year percent survival in 2007 regressed on percent total cover.

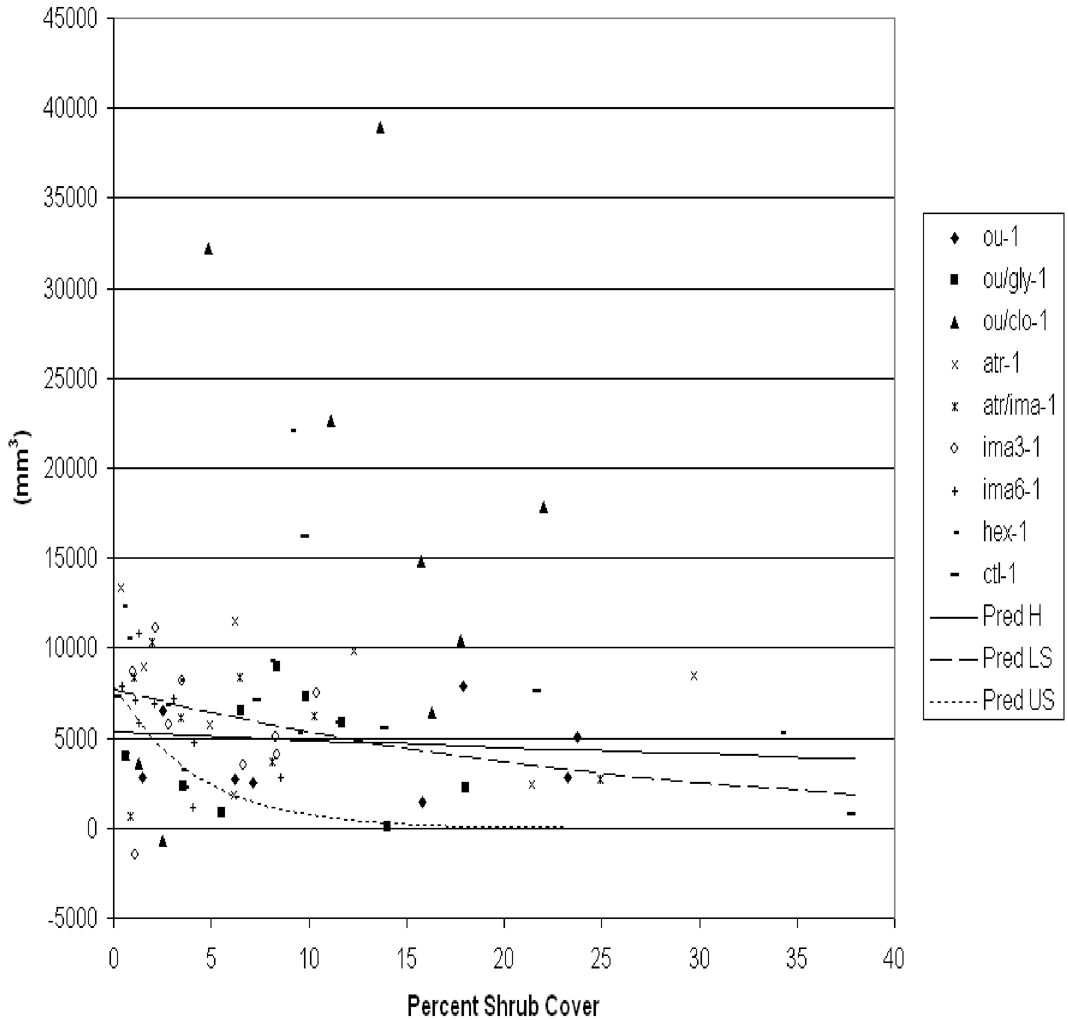


Figure 2.21 Predicted vs. measured values for larch bareroot first-year volume growth ($mm^3$) in 2007 regressed on percent shrub cover.

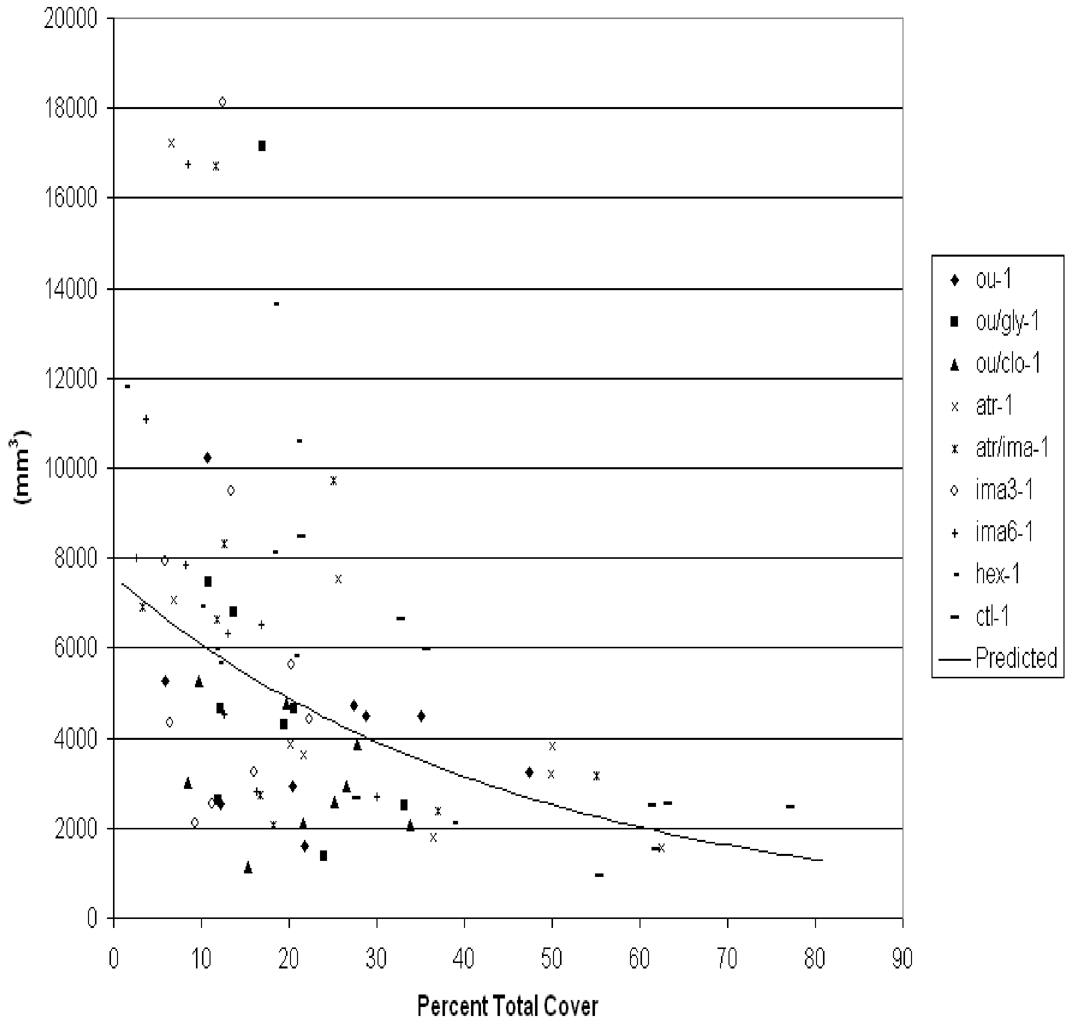


Figure 2.22 Predicted vs. measured values of larch plug first-year volume growth ($mm^3$) in 2007 regressed on percent total cover.

year post-treatment total non-coniferous cover (Figure 2.20). No cover variables were significant for predicting first-year DF volume growth in 2007, but first-year post-treatment shrub and total non-coniferous cover were significant for LB (Figure 2.21) and LP (Figure 2.22), respectively. The ou/clo-1 treatment exhibited a concentration of the greatest LB volume growth. Second-year DF volume growth was significantly related to both second-year post-treatment forb and total non-coniferous cover (Figure 2.23), and LB (Figure 2.24) and LP (Figure 2.25) were significantly related to second-year post-treatment total non-coniferous cover. DF (Figure 2.26) and LP (Figure 2.27) survival in 2008 were significantly related to first-year post-treatment forb cover, and LB survival was significantly related to both first-year post-treatment grass and total non-coniferous cover (Figure 2.28). DF, LB, and LP first-year volume growth were consistently related to first-year post-treatment total non-coniferous cover (Figures 2.29-2.31). Treatments of atrazine and hexazinone had consistently better first-year DF volume growth than predicted (Figure 2.29).

### *Soil Moisture Response to Treatment*

Trends in volumetric soil moisture by treatment were plotted for 23 and 46 cm depth for both the 2007 and 2008 growing seasons. By the end of the 2007 growing season, the control at all three blocks for both 23 and 46 cm depth had the lowest volumetric soil moisture. However, treatments were clustered, and the treatment with the greatest volumetric soil moisture at the end of the growing season was not always the same. Differences in soil moisture often sorted out early in the summer and persisted where cover was reduced regardless of treatment. At Hooker ima6-1 and

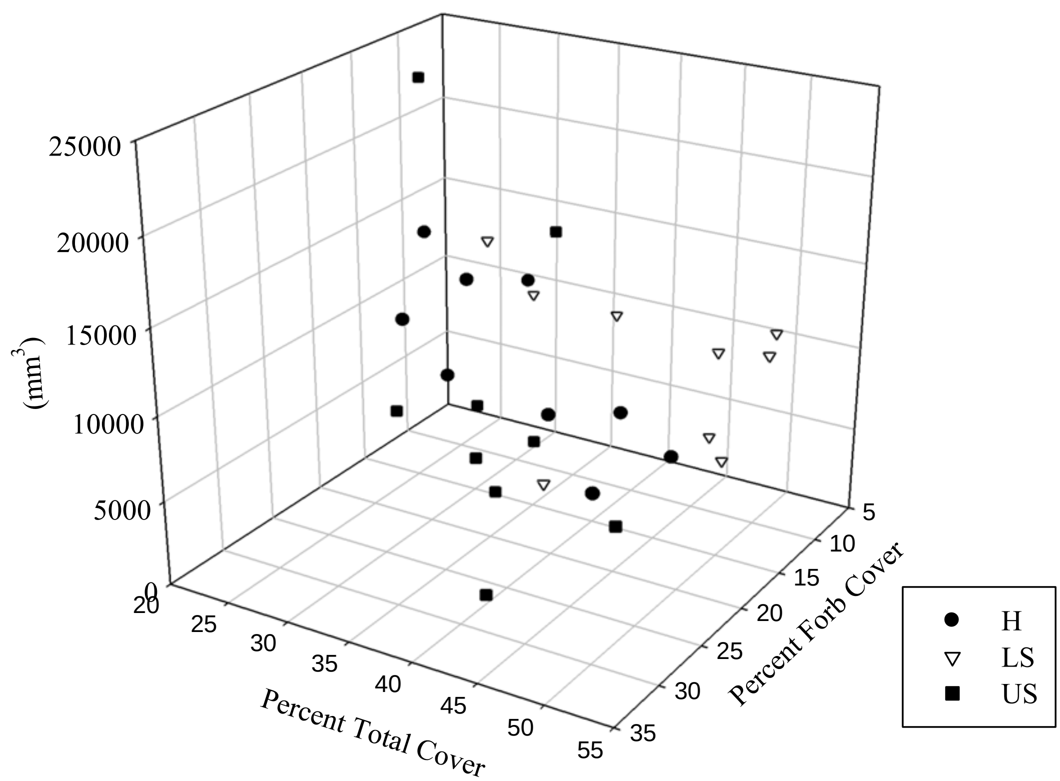


Figure 2.23 Measured values of Douglas-fir second-year volume growth (mm$^3$) in 2008 regressed on percent forb and total cover.

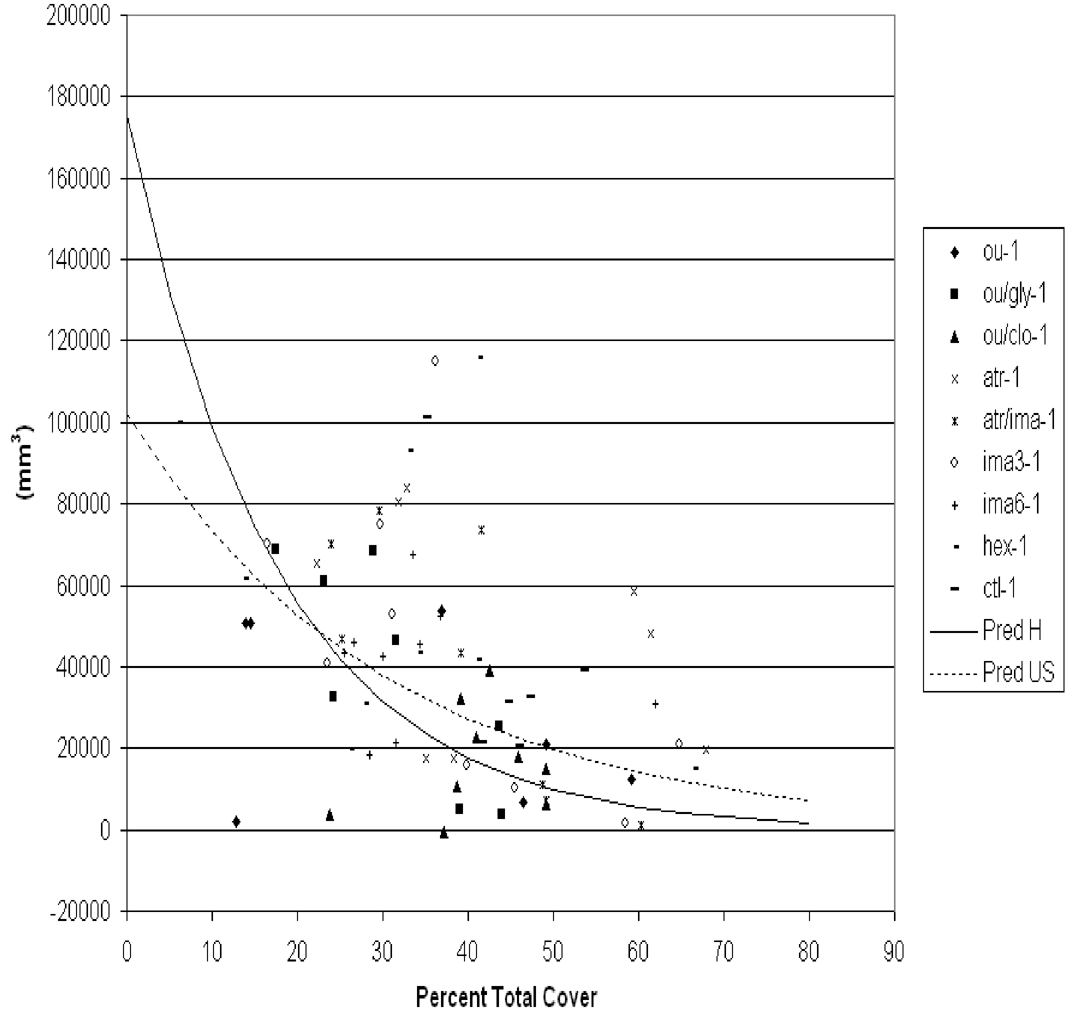


Figure 2.24 Predicted vs. measured values for larch bareroot second-year volume growth ($mm^3$) in 2008 regressed on percent total cover.

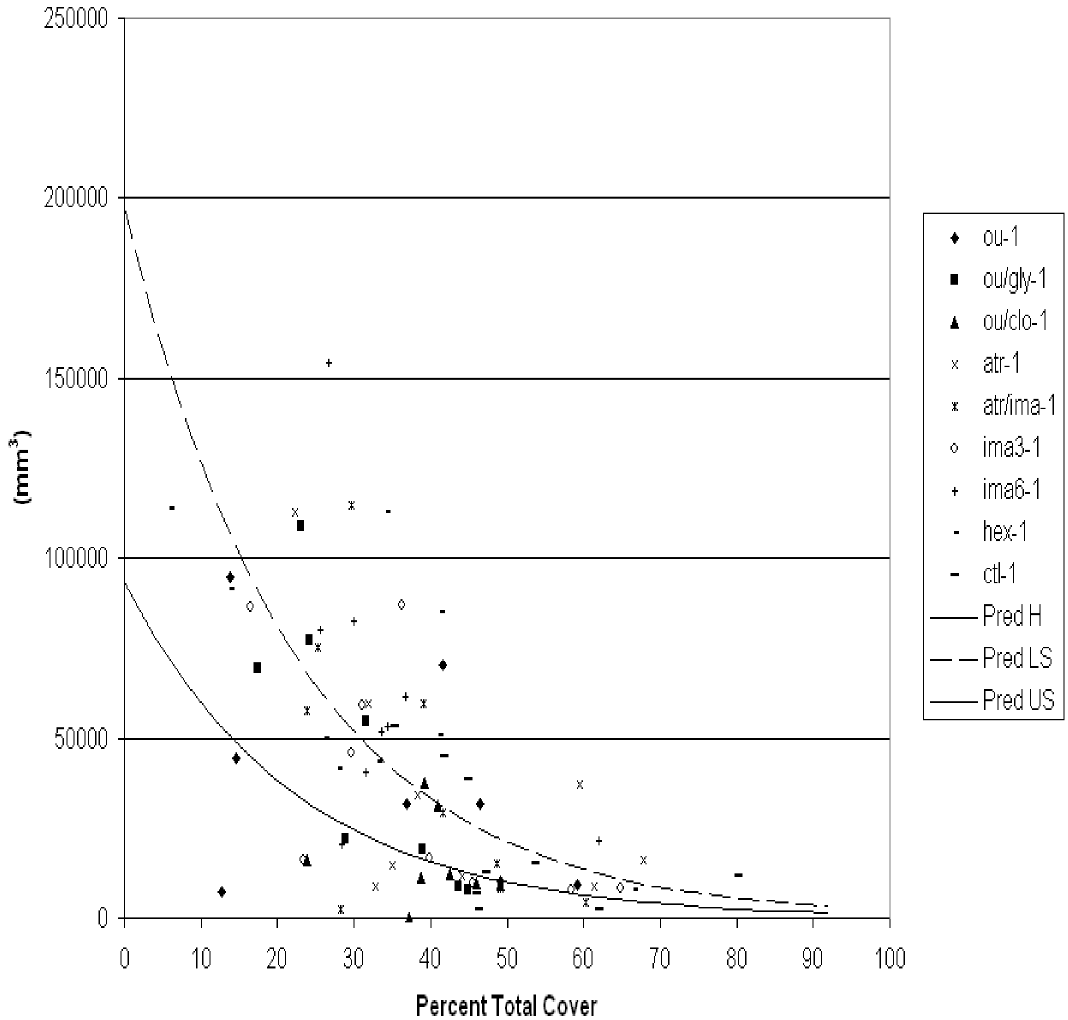


Figure 2.25 Predicted vs. measured values for larch plug second-year volume growth ($mm^3$) in 2008 regressed on percent total cover.

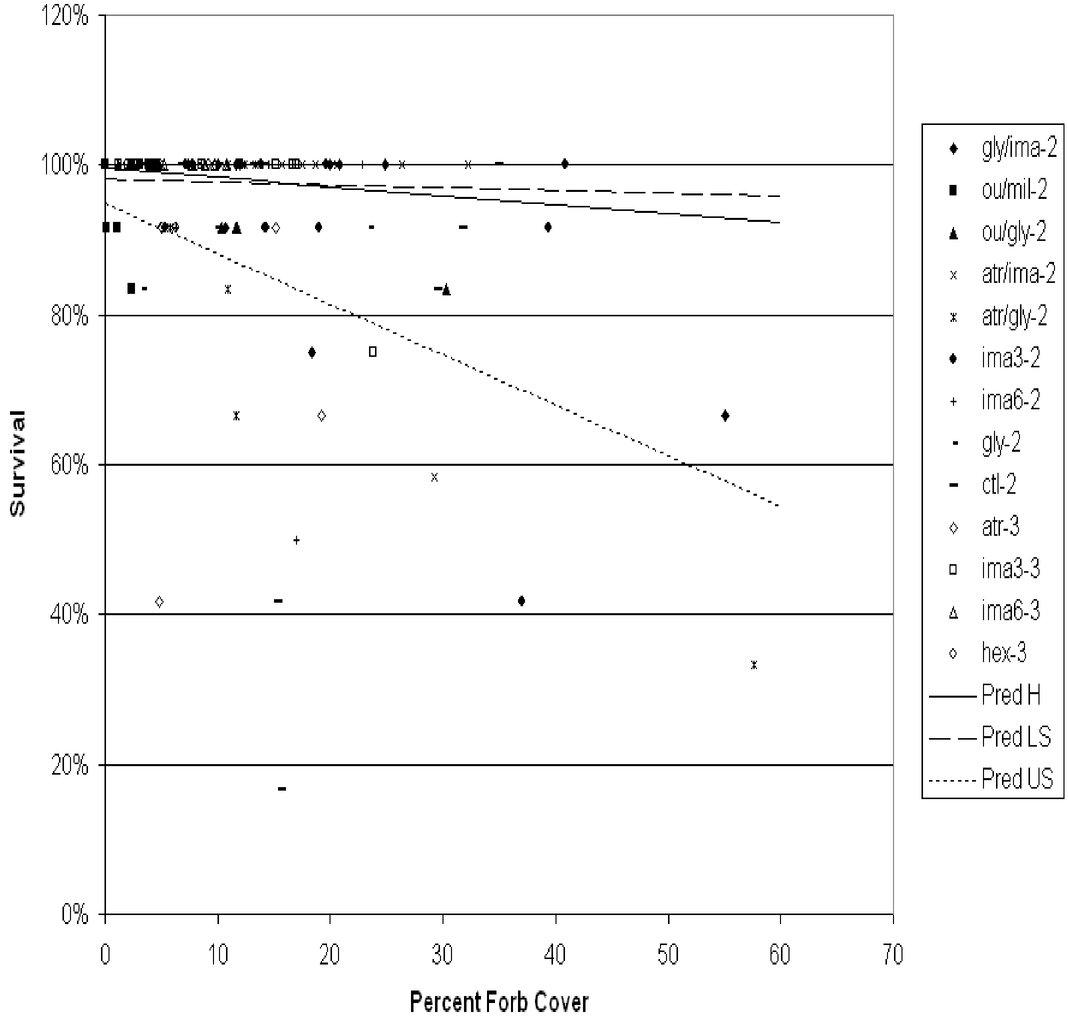


Figure 2.26 Predicted vs. measured values for Douglas-fir first-year percent survival in 2008 regressed on percent forb cover.

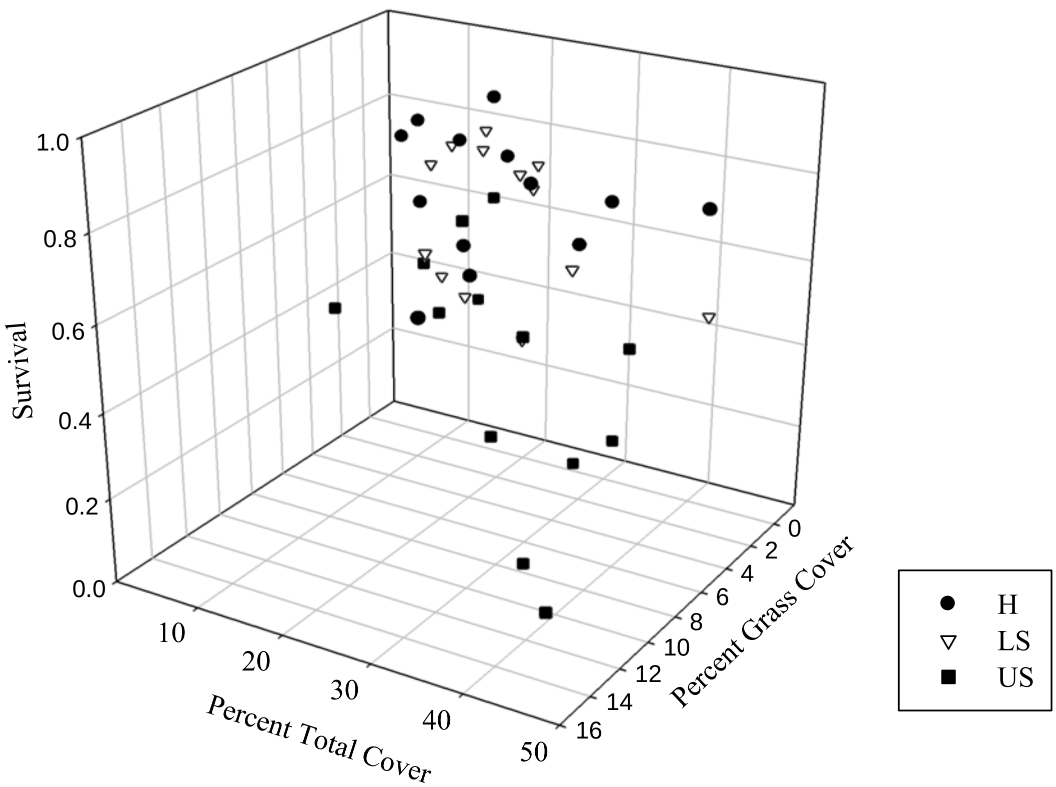


Figure 2.27 Measured values for larch bareroot first-year percent survival in 2008 regressed on percent grass and total cover.

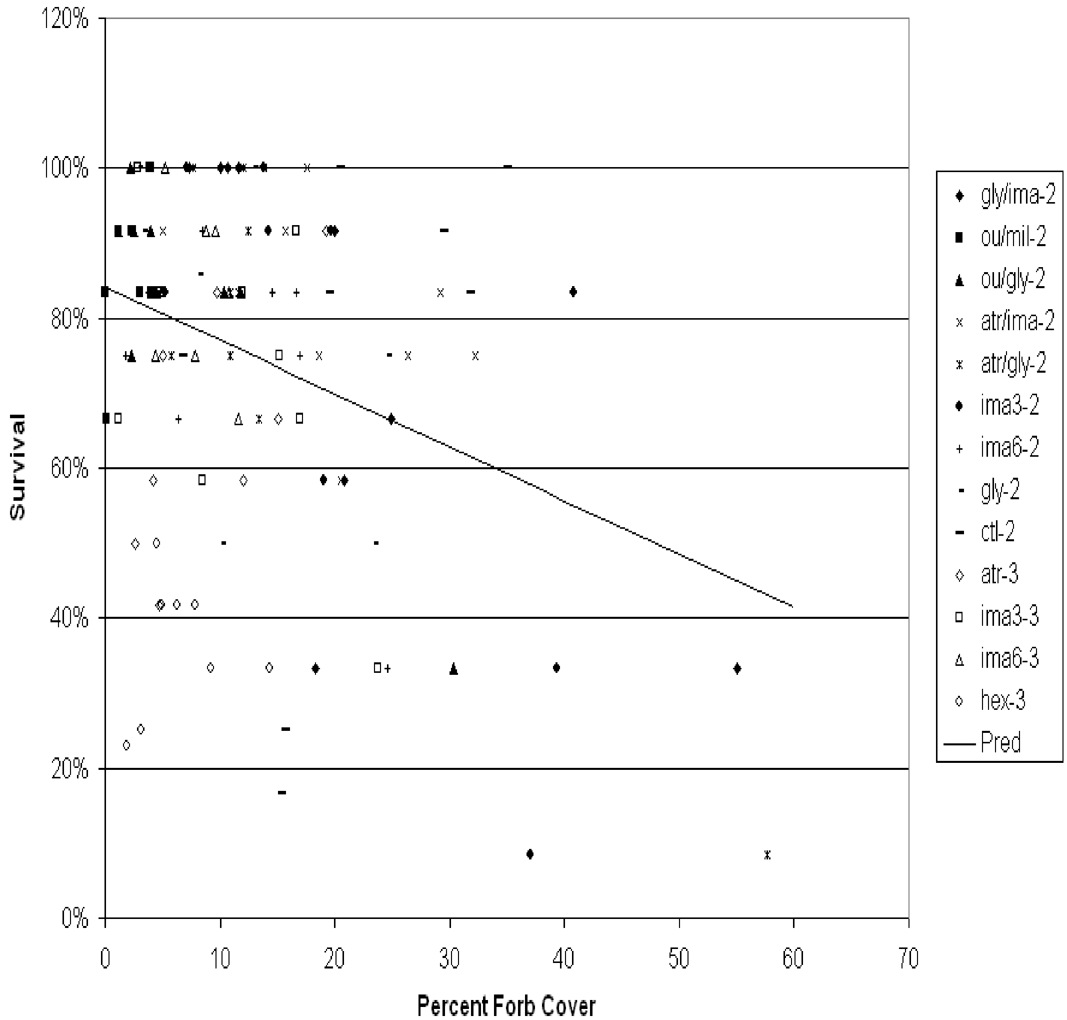


Figure 2.28 Predicted vs. measured values for larch plug first-year survival in 2008 regressed on percent forb cover.

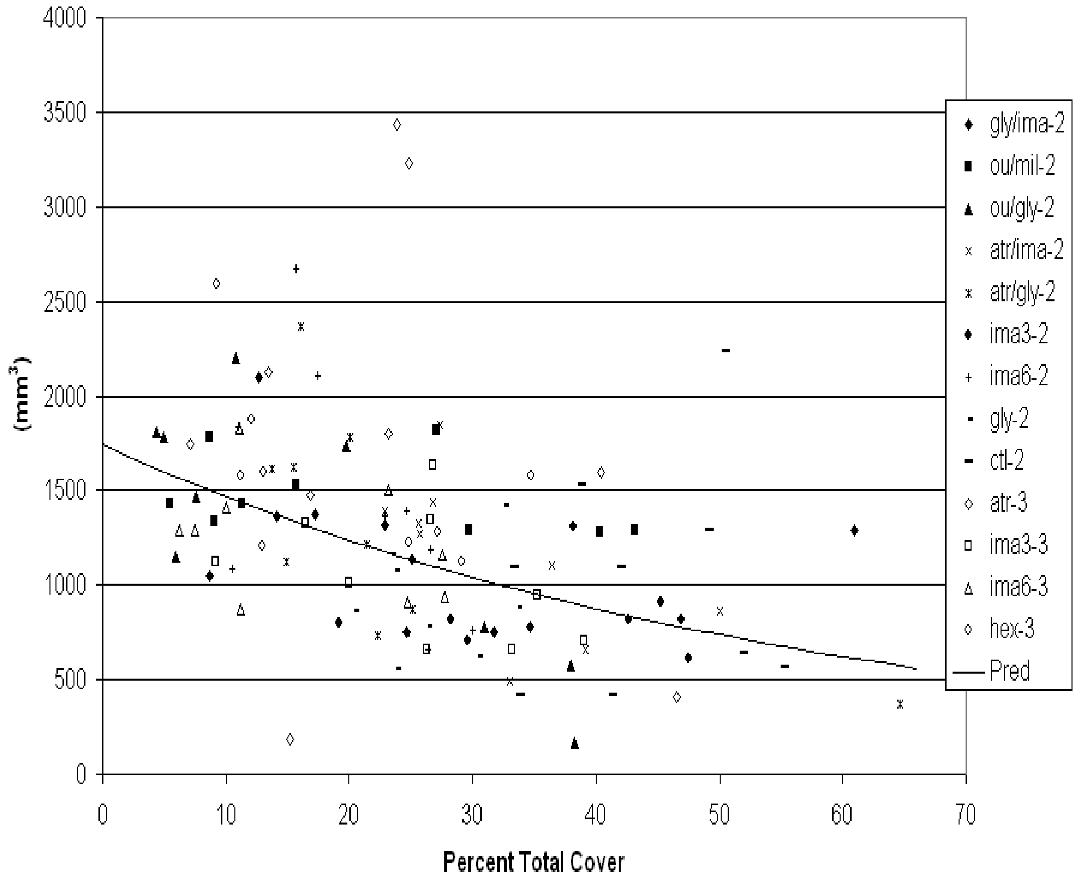


Figure 2.29 Predicted vs. measured values for Douglas-fir first-year volume growth ($mm^3$) in 2008 regressed on percent total cover.

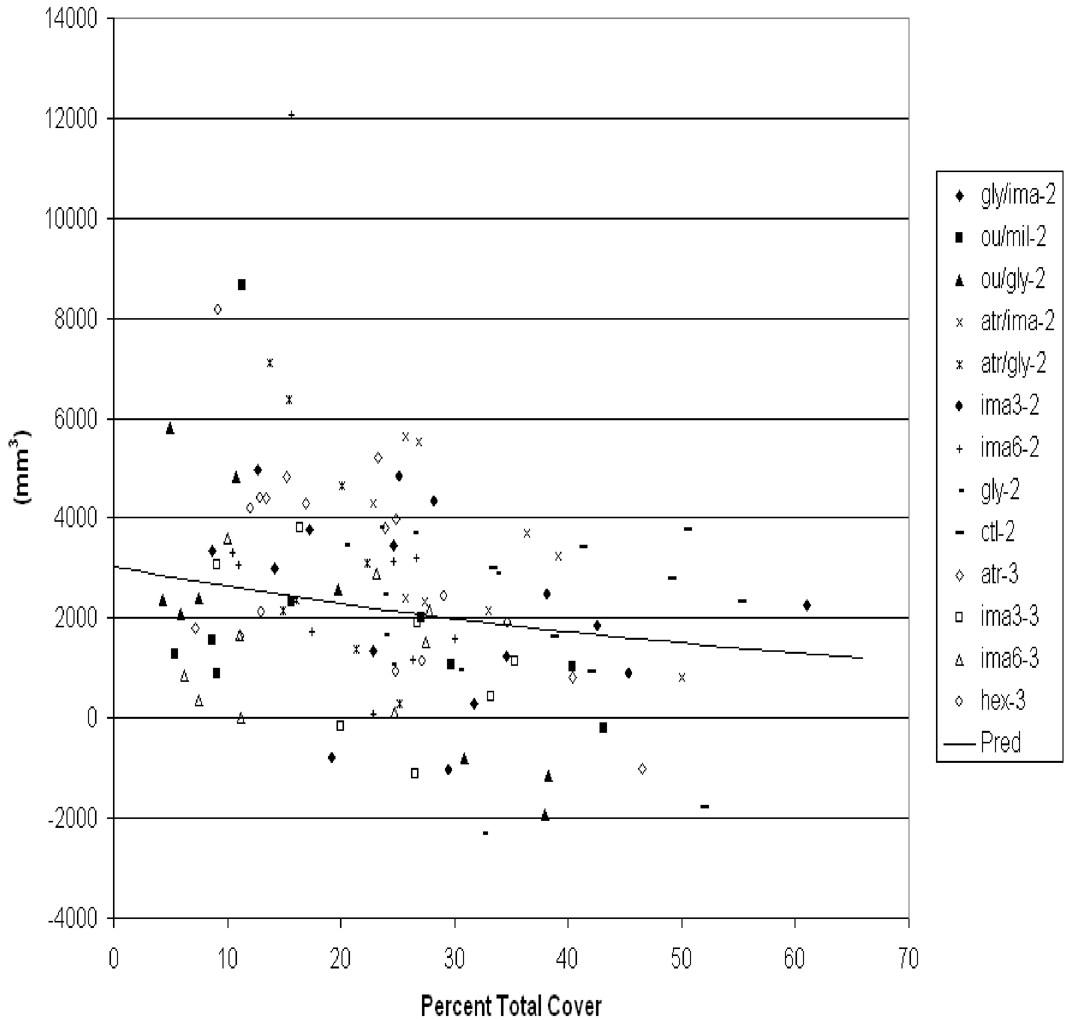


Figure 2.30 Predicted vs. measured values for larch bareroot first-year volume growth ($mm^3$) in 2008 regressed on percent total cover.

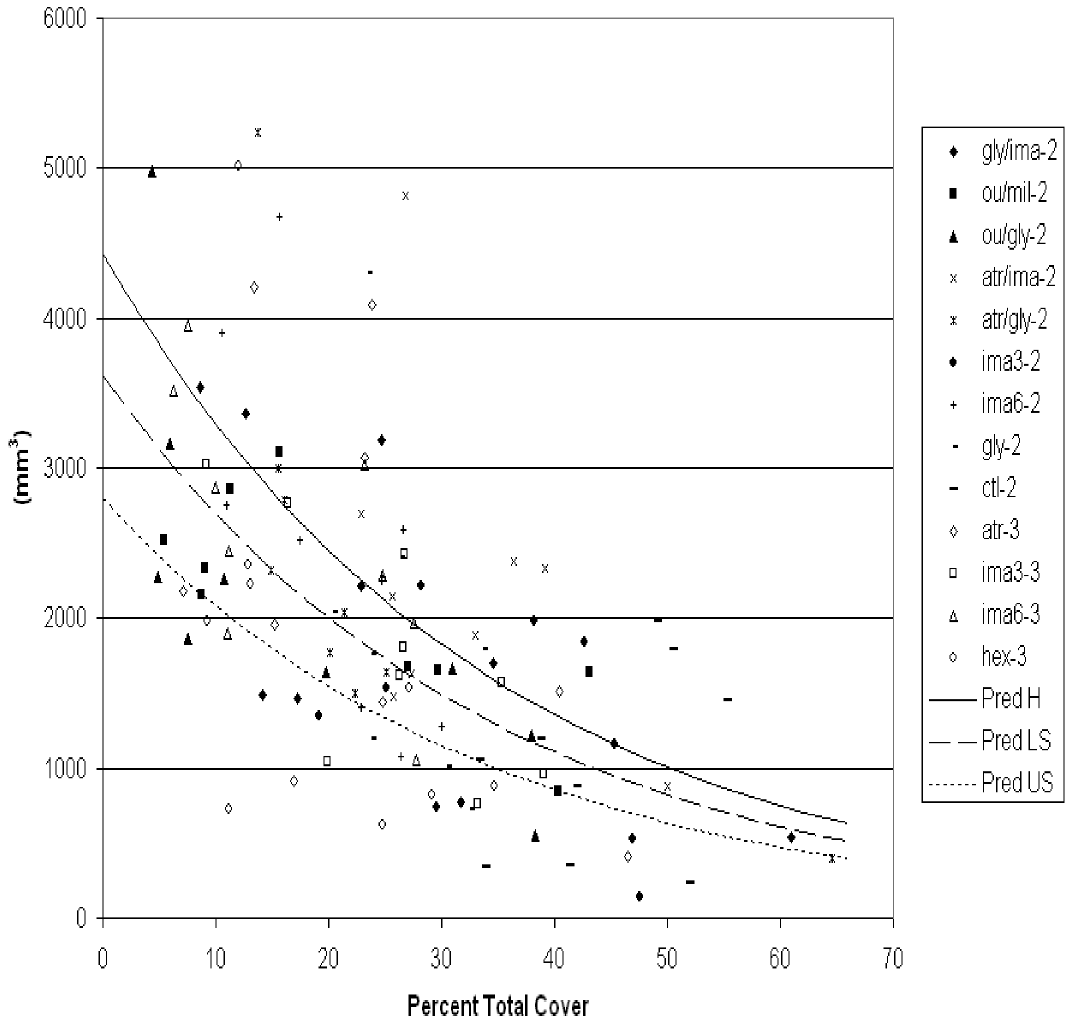


Figure 2.31 Predicted vs. measured values for larch plug first-year volume growth ($mm^3$) in 2008 regressed on percent total cover.

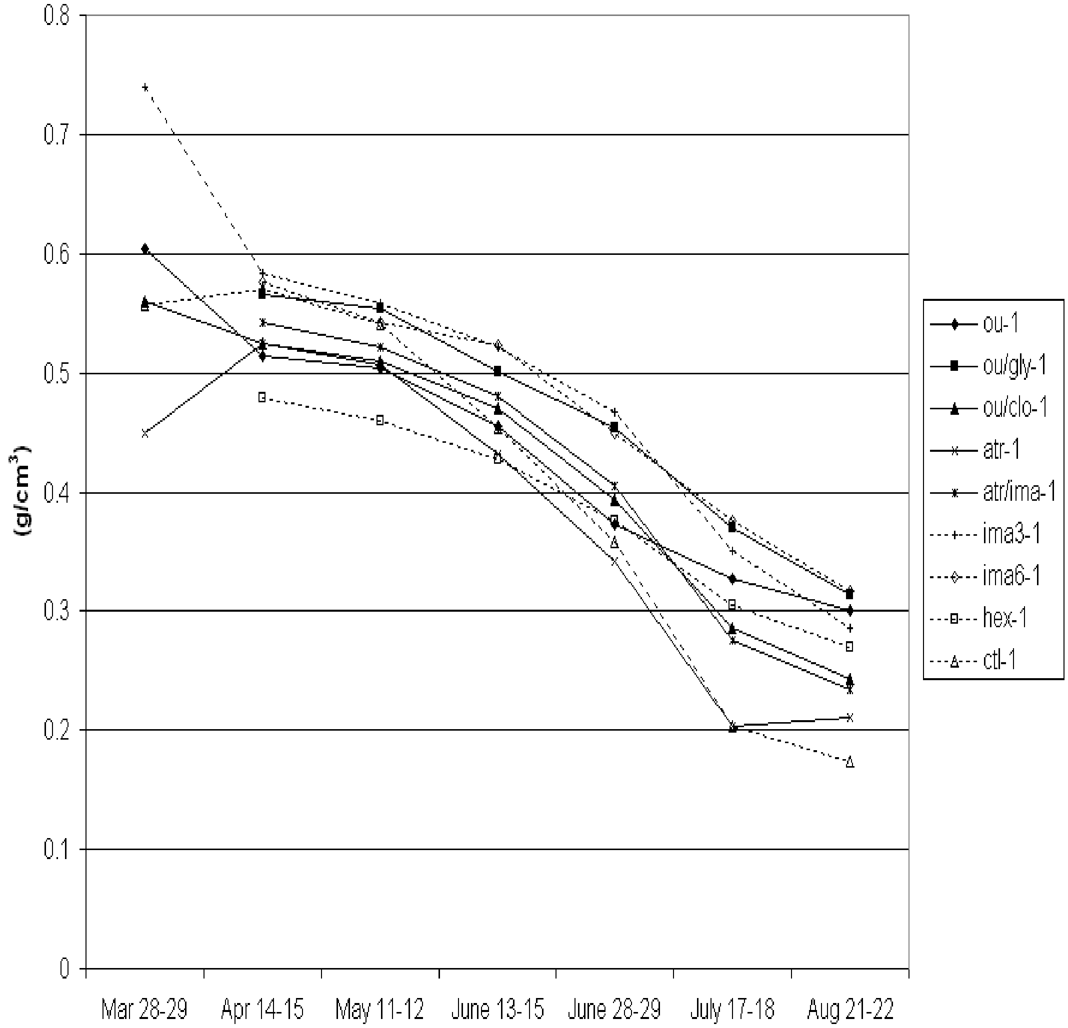


Figure 2.32 Trend in volumetric soil moisture (VSM g/cm$^3$) to 23 cm depth at Hooker throughout the 2007 growing season.

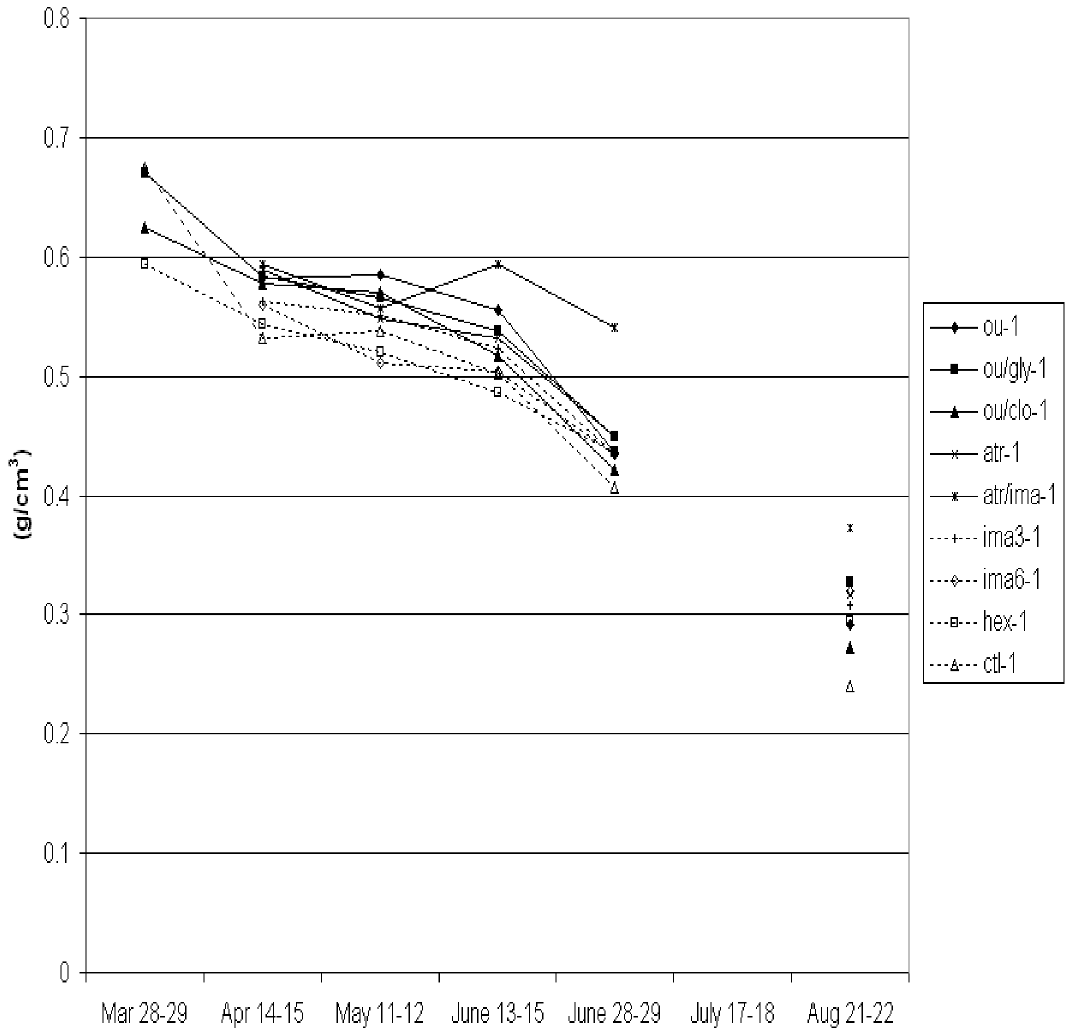


Figure 2.33 Trend in volumetric soil moisture (VSM g/cm$^3$) to 23 cm depth at Lower Sam throughout the 2007 growing season.

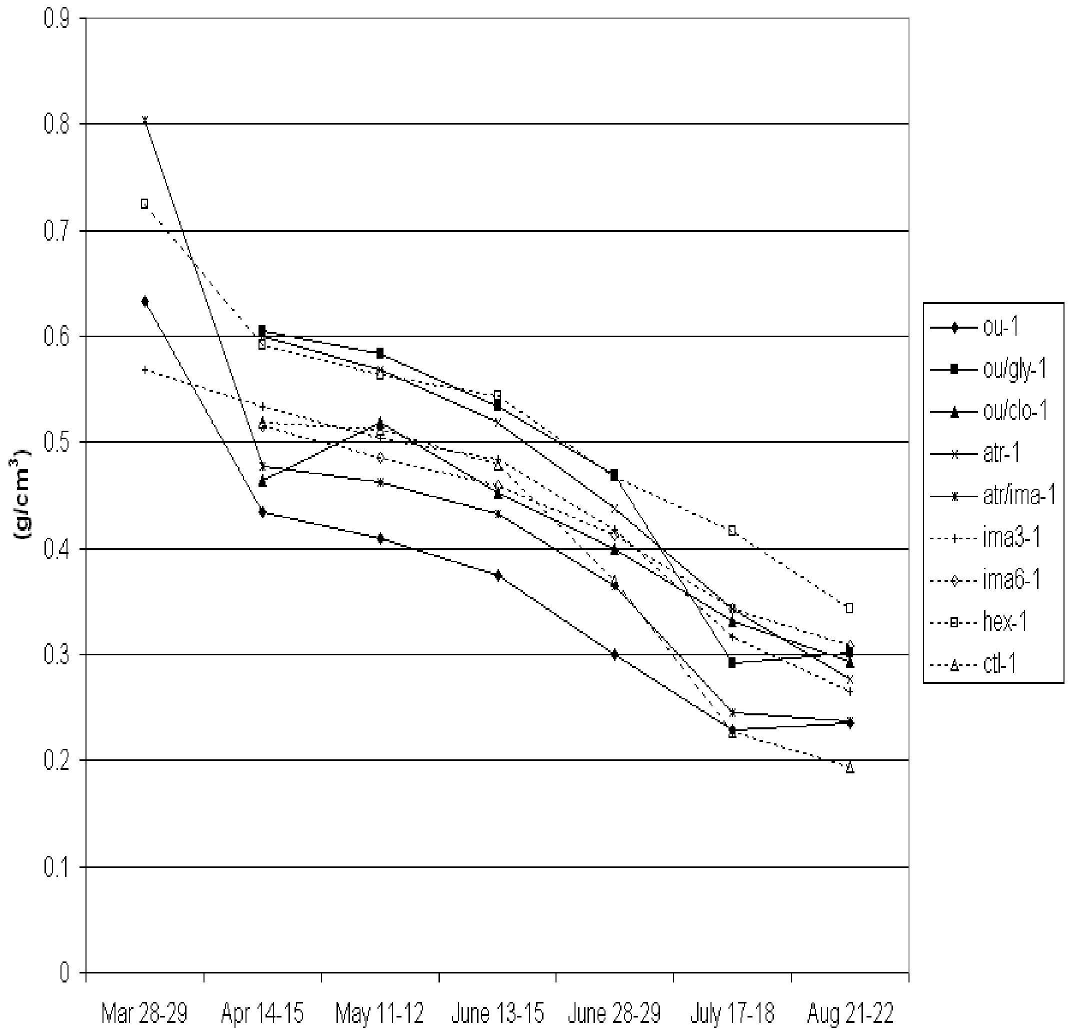


Figure 2.34 Trend in volumetric soil moisture (VSM g/cm$^3$) to 23 cm depth at Upper Sam throughout the 2007 growing season.

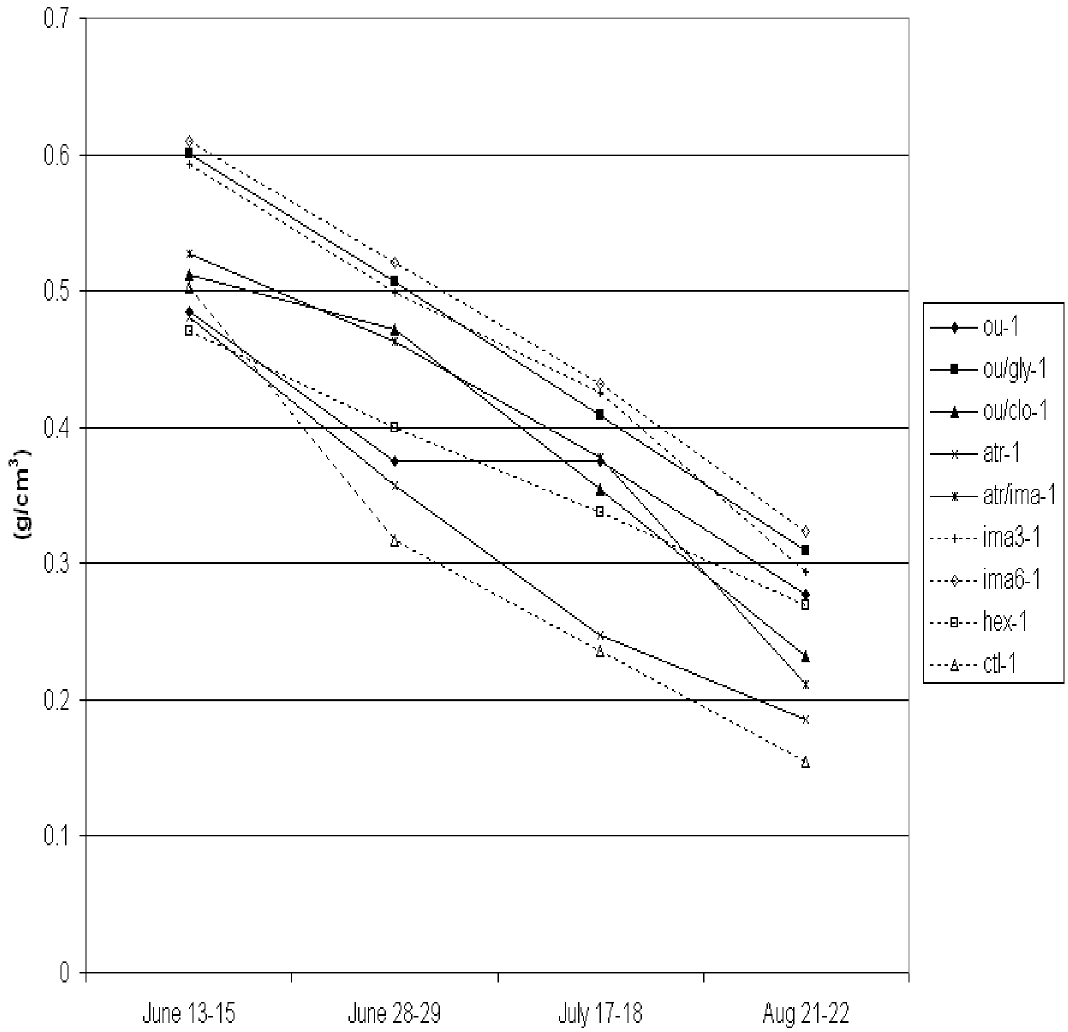


Figure 2.35 Trend in volumetric soil moisture (VSM g/cm$^3$) to 46 cm depth at Hooker throughout the 2007 growing season.

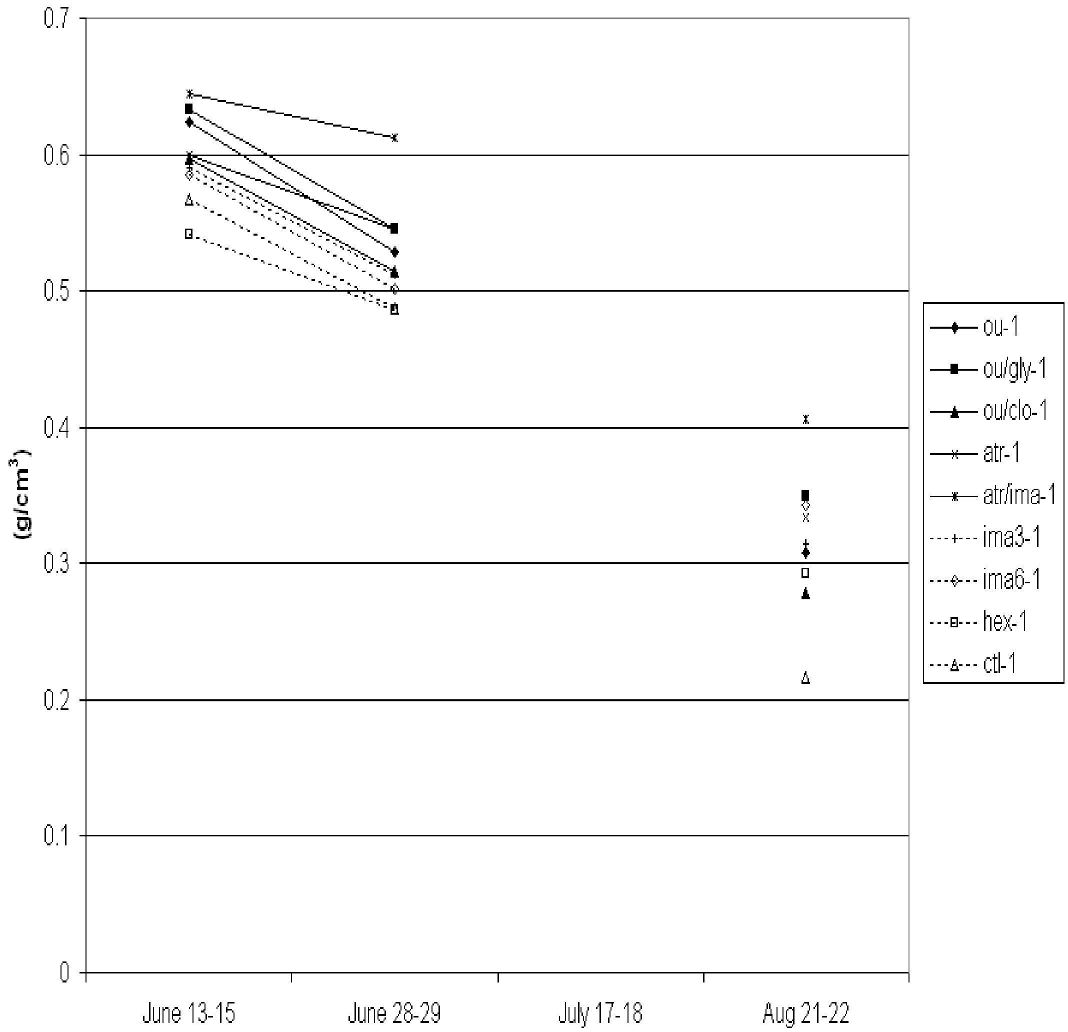


Figure 2.36 Trend in volumetric soil moisture (VSM g/cm$^3$) to 46 cm depth at Lower Sam throughout the 2007 growing season.

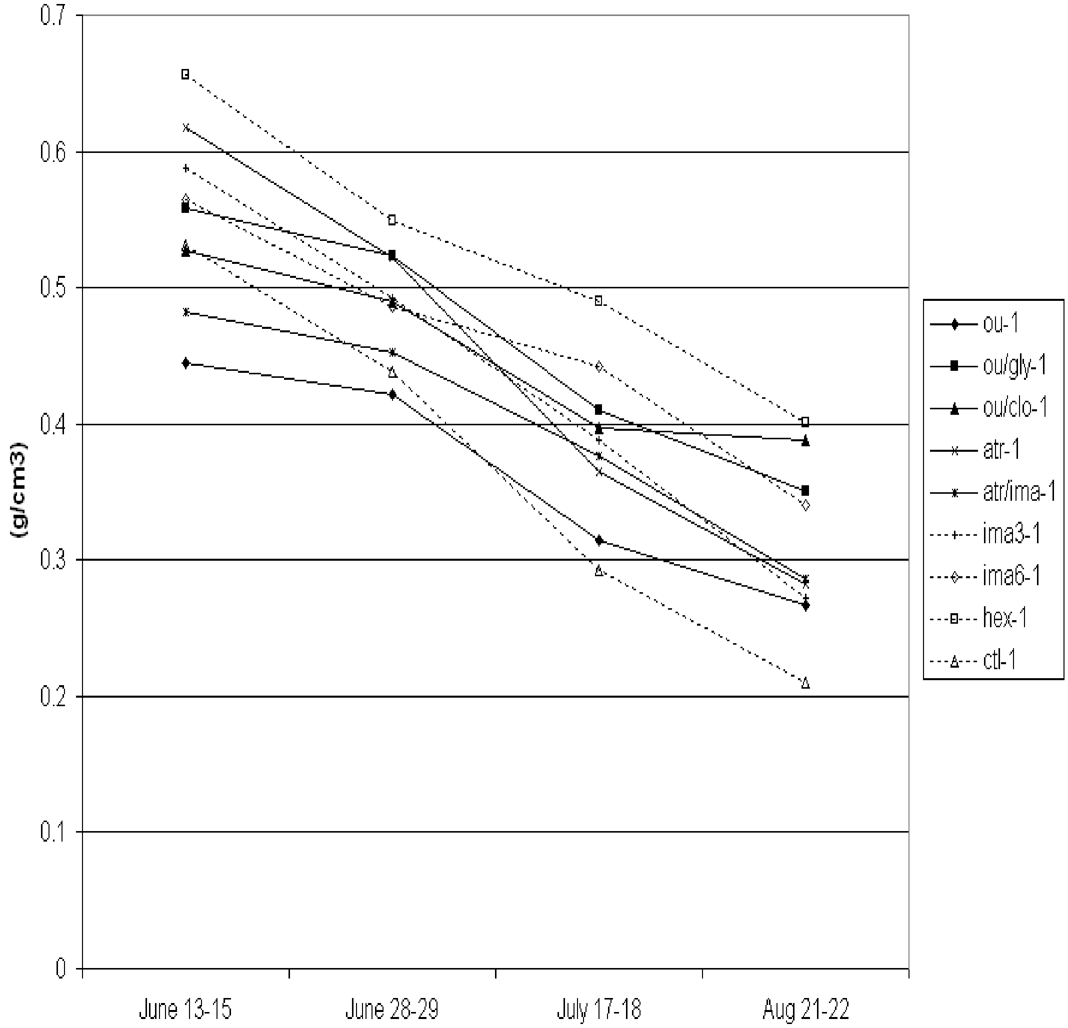


Figure 2.37 Trend in volumetric soil moisture (VSM g/cm$^3$) to 46 cm depth at Upper Sam throughout the 2007 growing season.

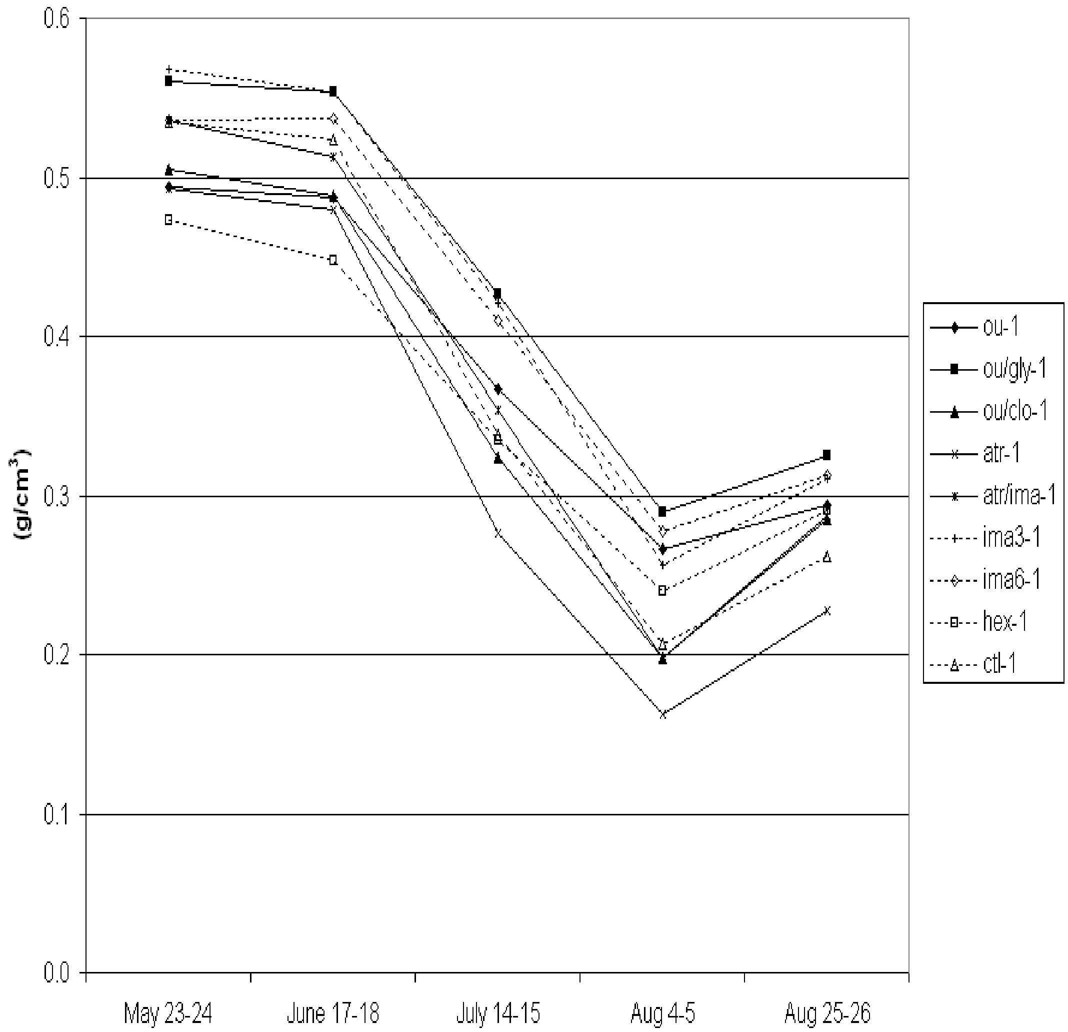


Figure 2.38 Trend in volumetric soil moisture (VSM g/cm$^3$) to 23 cm depth for treatments 1-9 at Hooker throughout the 2008 growing season.

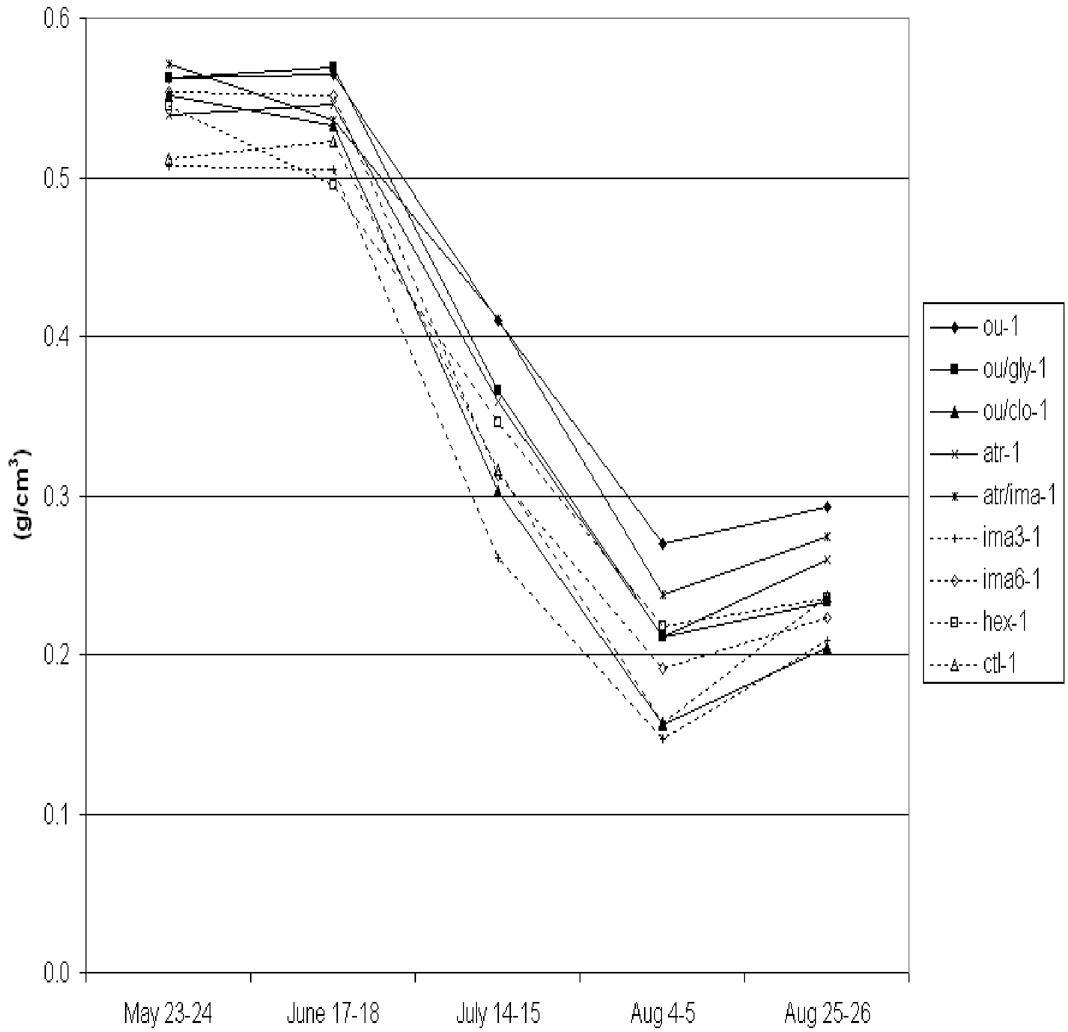


Figure 2.39 Trend in volumetric soil moisture (VSM g/cm$^3$) to 23 cm depth for treatments 1-9 at Lower Sam throughout the 2008 growing season.

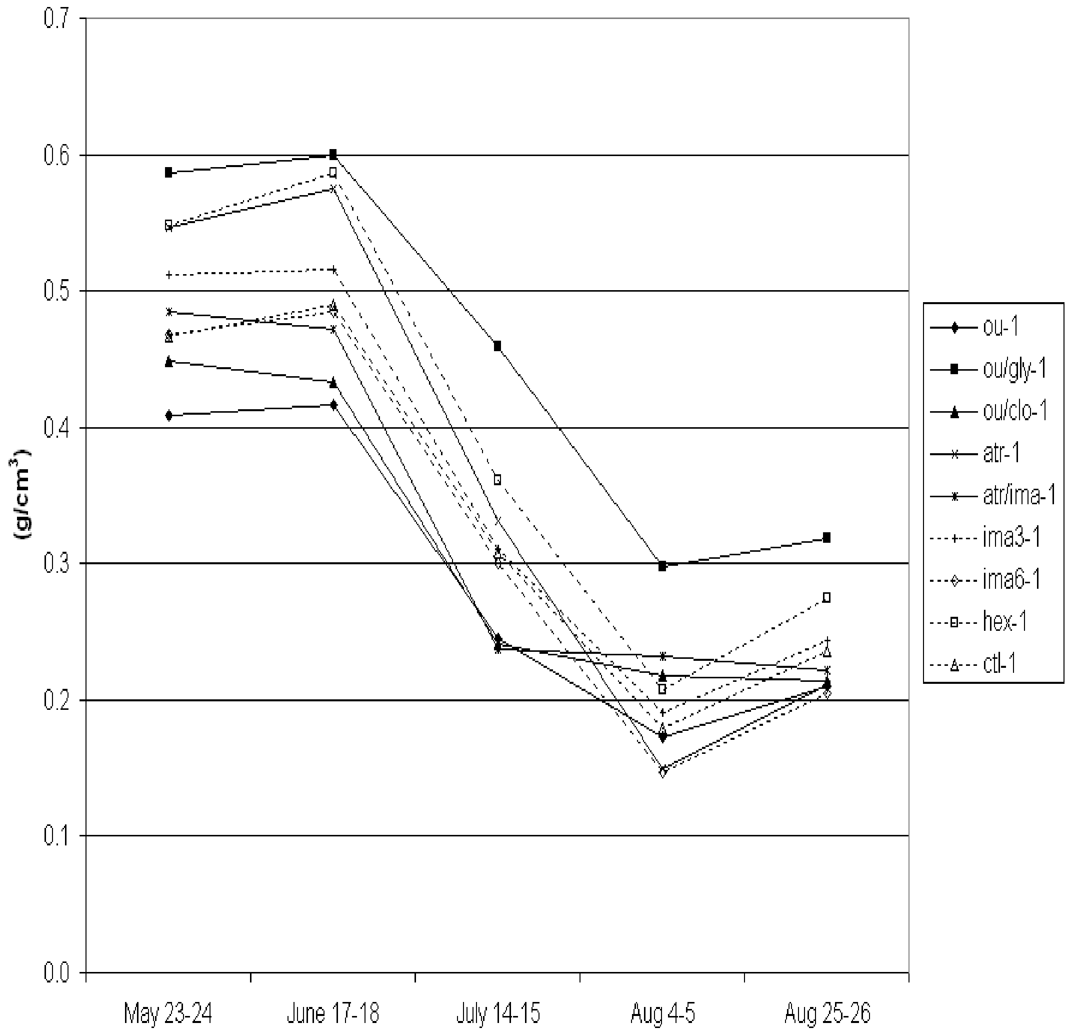


Figure 2.40 Trend in volumetric soil moisture (VSM g/cm$^3$) to 23 cm depth for treatments 1-9 at Upper Sam throughout the 2008 growing season.

ou/gly-1 had the greatest volumetric soil moisture at 23 cm and 46 cm depth (Figures 2.32 and 2.35). At Lower Sam atr/ima-1 had the greatest volumetric soil moisture at both depths (Figures 2.33 and 2.36). At Upper Sam hex-1 had the greatest soil moisture at both depths (Figures 2.34 and 2.37).

In 2008 the control did not consistently have the lowest soil moisture at 23 cm depth by the end of the growing season, but it was among the lower treatments. For the treatments that were sprayed and planted in spring 2007 (1-9) atr-1 and ou/clo-1 had the lowest soil moisture, while the ou-1 and ou/gly-1 had the greatest soil moisture (Figures 2.38-2.40). For the treatments that were sprayed in summer 2007 and planted spring 2008, the control, gly-2, and ima3-2 had the lowest volumetric soil moisture at the end of the growing season, while ou/gly-2 and ou/mil-2 had the greatest soil moisture (Figures 2.41-2.43). For the treatments that were sprayed and planted in spring 2008 (18-22) the control and atr-3 had the lowest volumetric soil moisture at the end of the growing season, while all four chemical treatments had the greater soil moisture than the control (Figures 2.44-2.46).

In 2008 volumetric soil moisture to 46 cm depth was sampled by cover class instead of treatment (Figures 2.47-2.49). For these cover classes low total vegetation cover consistently had the highest volumetric soil moisture at the end of the growing season for all three blocks, with the exception of Lower Sam where high shrub cover had slightly higher soil moisture. High forb cover also consistently had the lowest soil moisture at the end of the growing season, but high shrub cover at Hooker and Upper Sam and medium forb cover at Lower Sam also had low soil moisture.

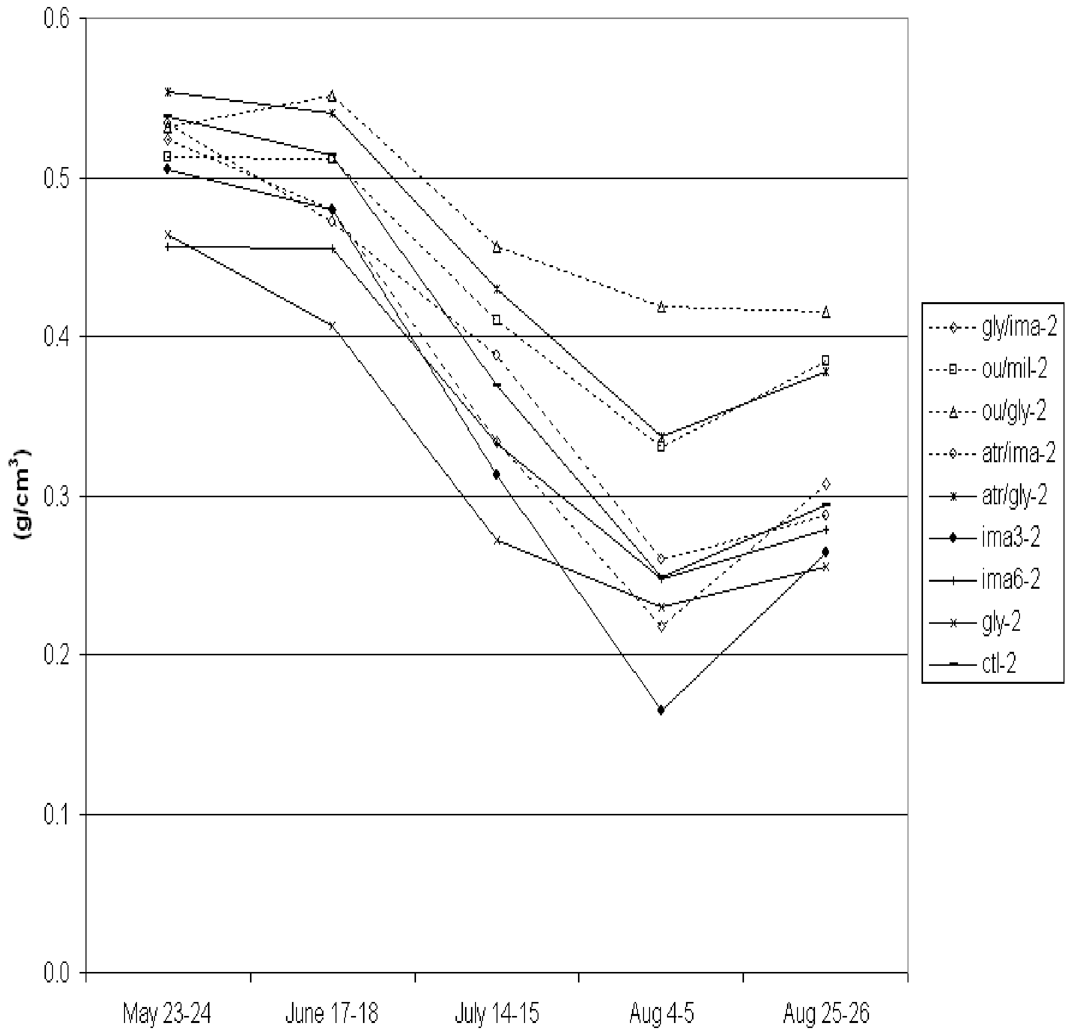


Figure 2.41 Trend in volumetric soil moisture (VSM g/cm$^3$) to 23 cm depth for treatments 10-18 at Hooker throughout the 2008 growing season.

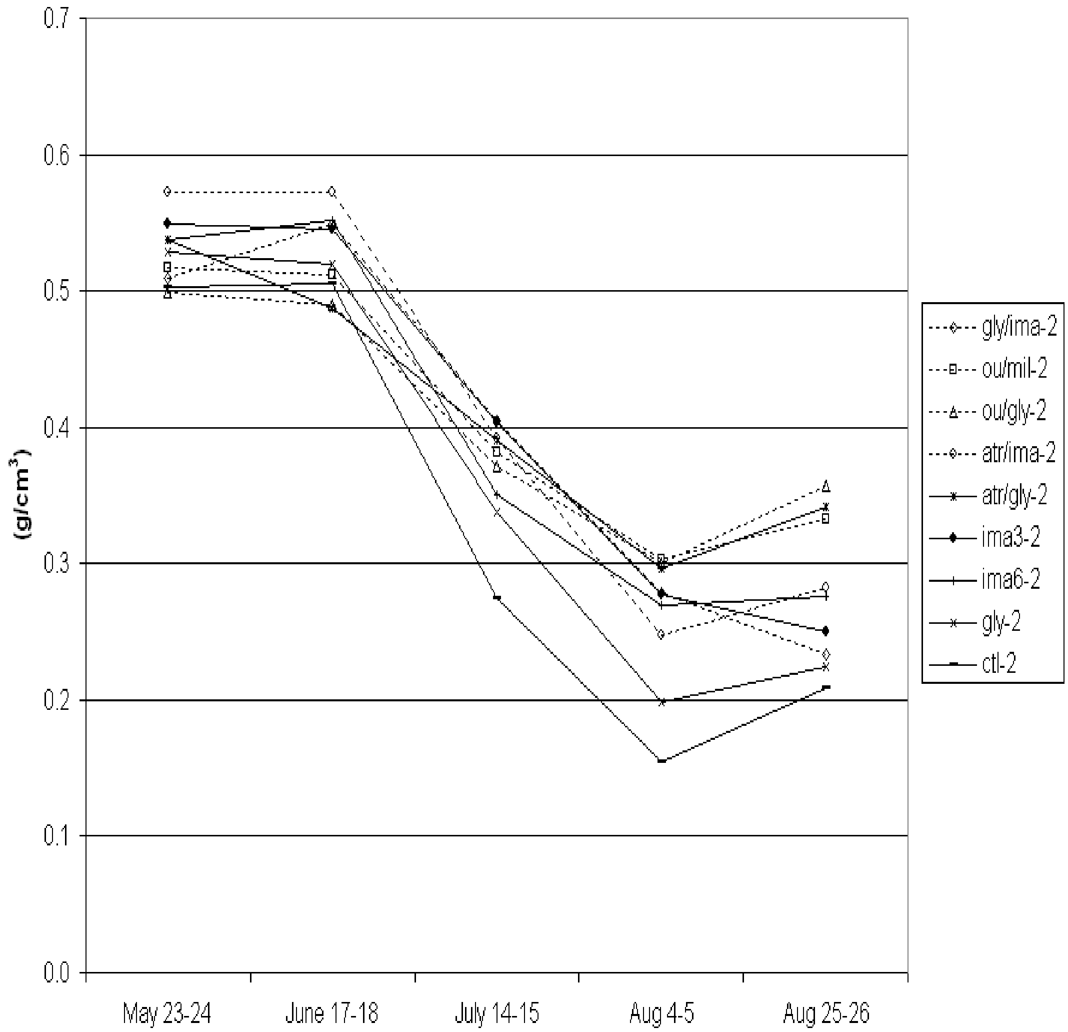


Figure 2.42 Trend in volumetric soil moisture (VSM g/cm$^3$) to 23 cm depth for treatments 10-18 at Lower Sam throughout the 2008 growing season.

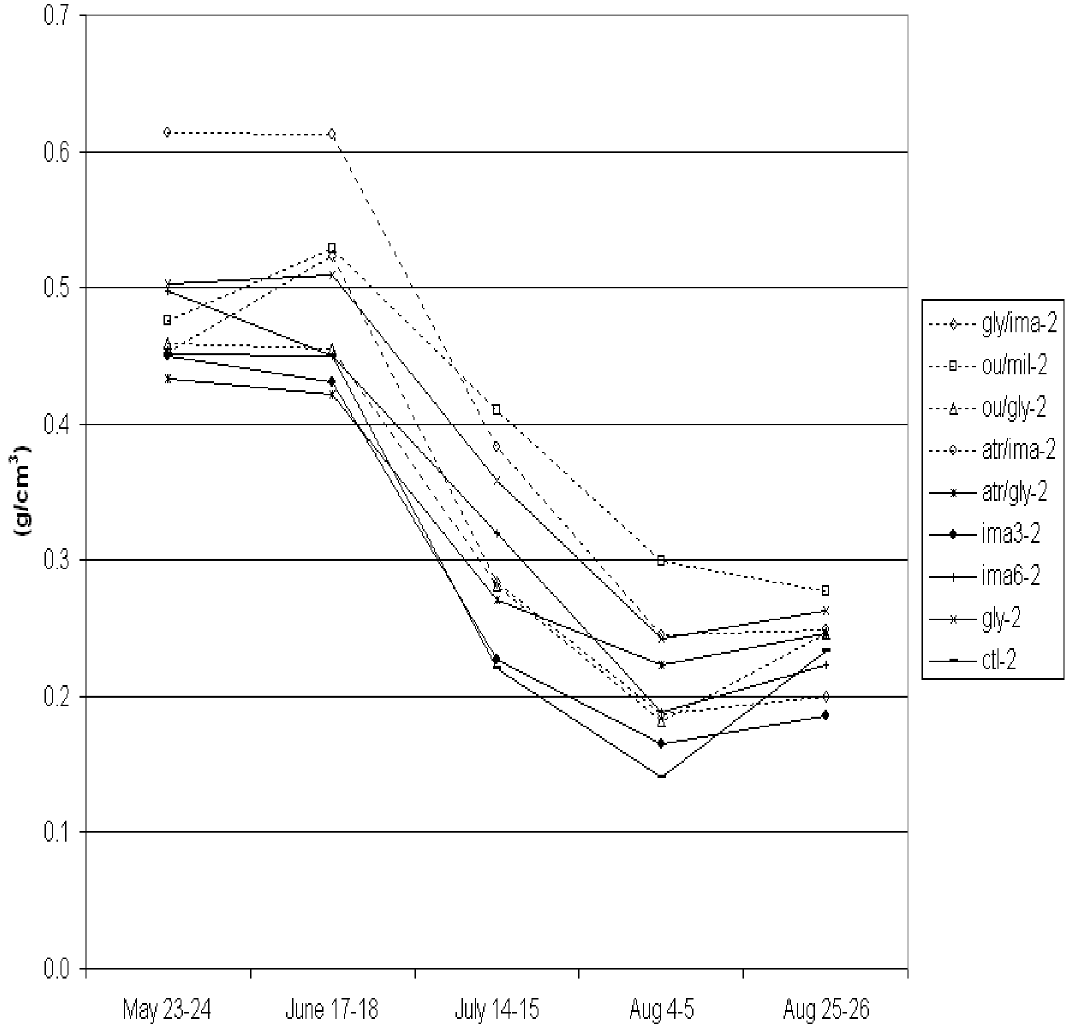


Figure 2.43 Trend in volumetric soil moisture (VSM g/cm$^3$) to 23 cm depth for treatments 10-18 at Upper Sam throughout the 2008 growing season.

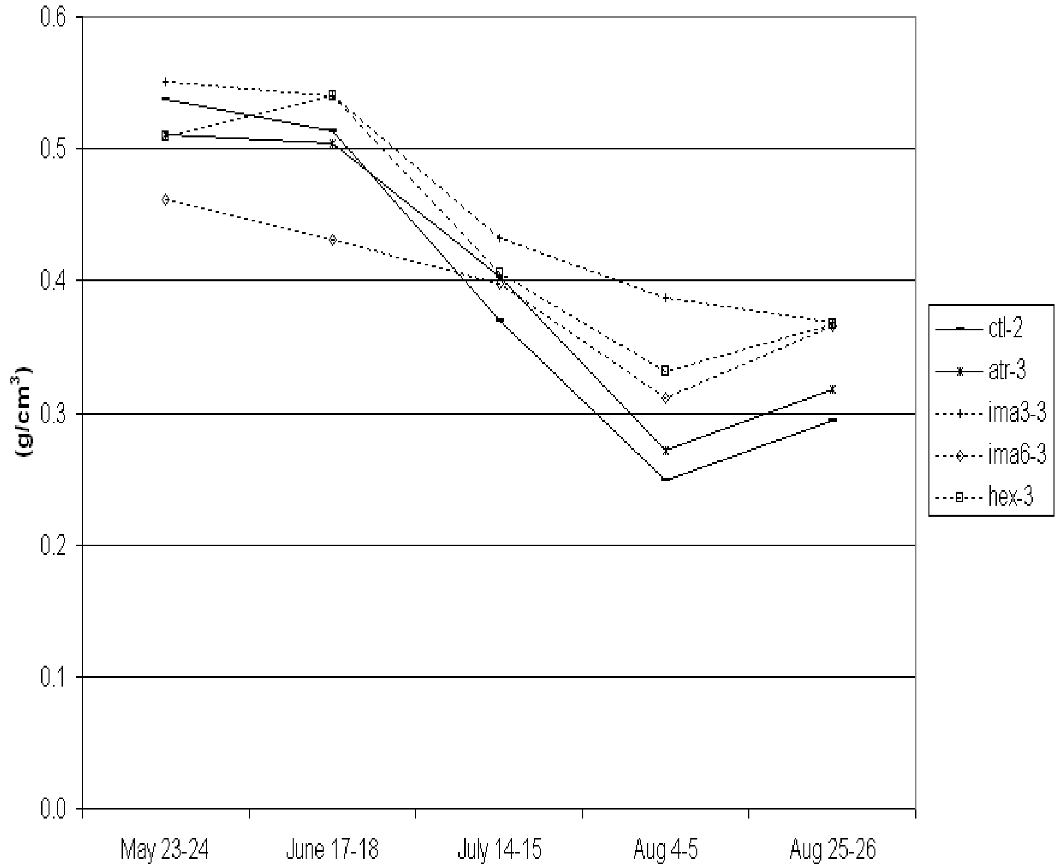


Figure 2.44 Trend in volumetric soil moisture (VSM g/cm$^3$) to 23 cm depth for treatments 18-22 at Hooker throughout the 2008 growing season.

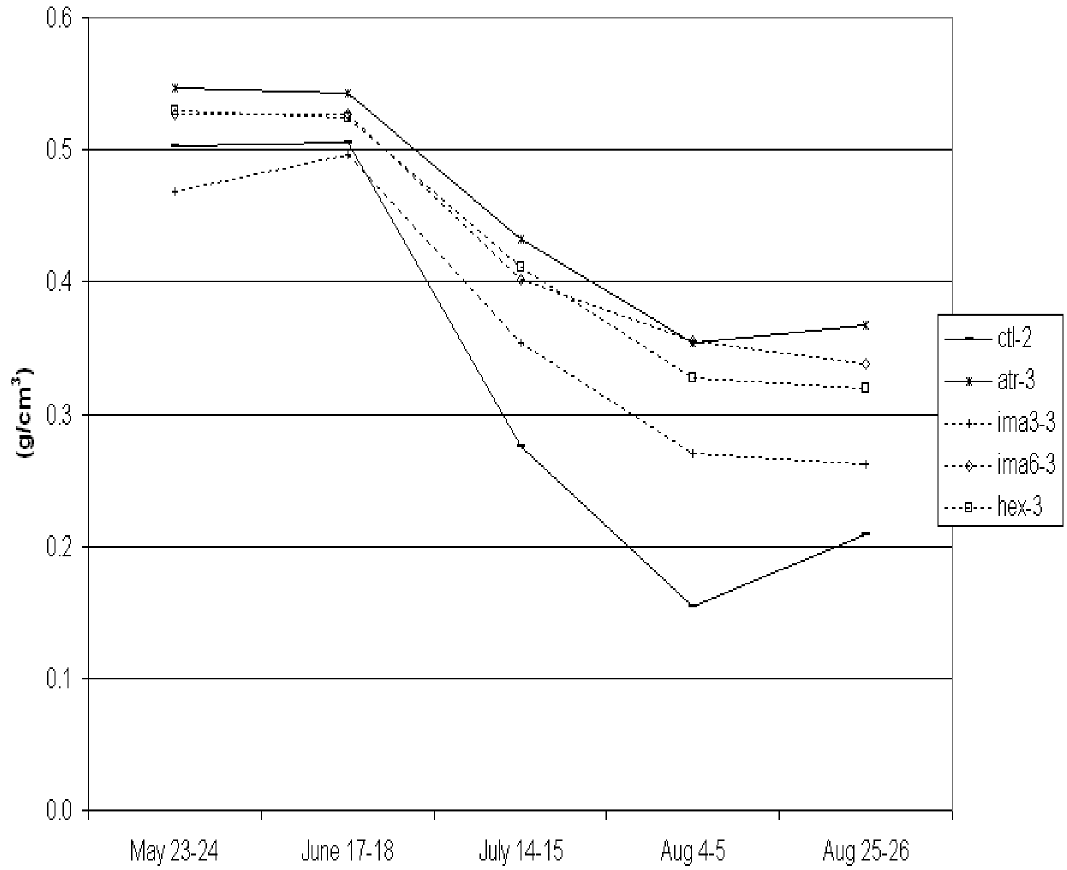


Figure 2.45 Trend in volumetric soil moisture (VSM g/cm$^3$) to 23 cm depth for treatments 18-22 at Lower Sam throughout the 2008 growing season.

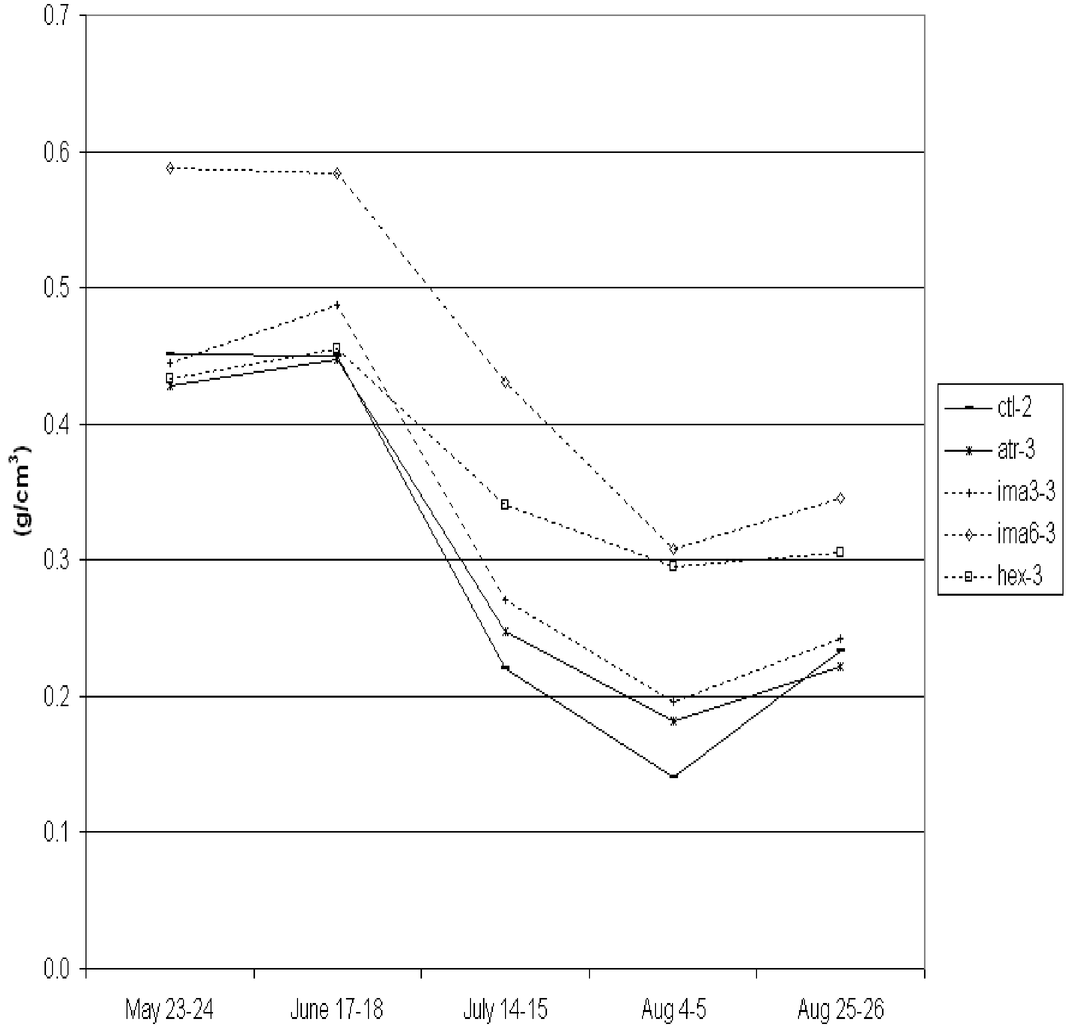


Figure 2.46 Trend in volumetric soil moisture (VSM g/cm$^3$) to 23 cm depth for treatments 18-22 at Upper Sam throughout the 2008 growing season.

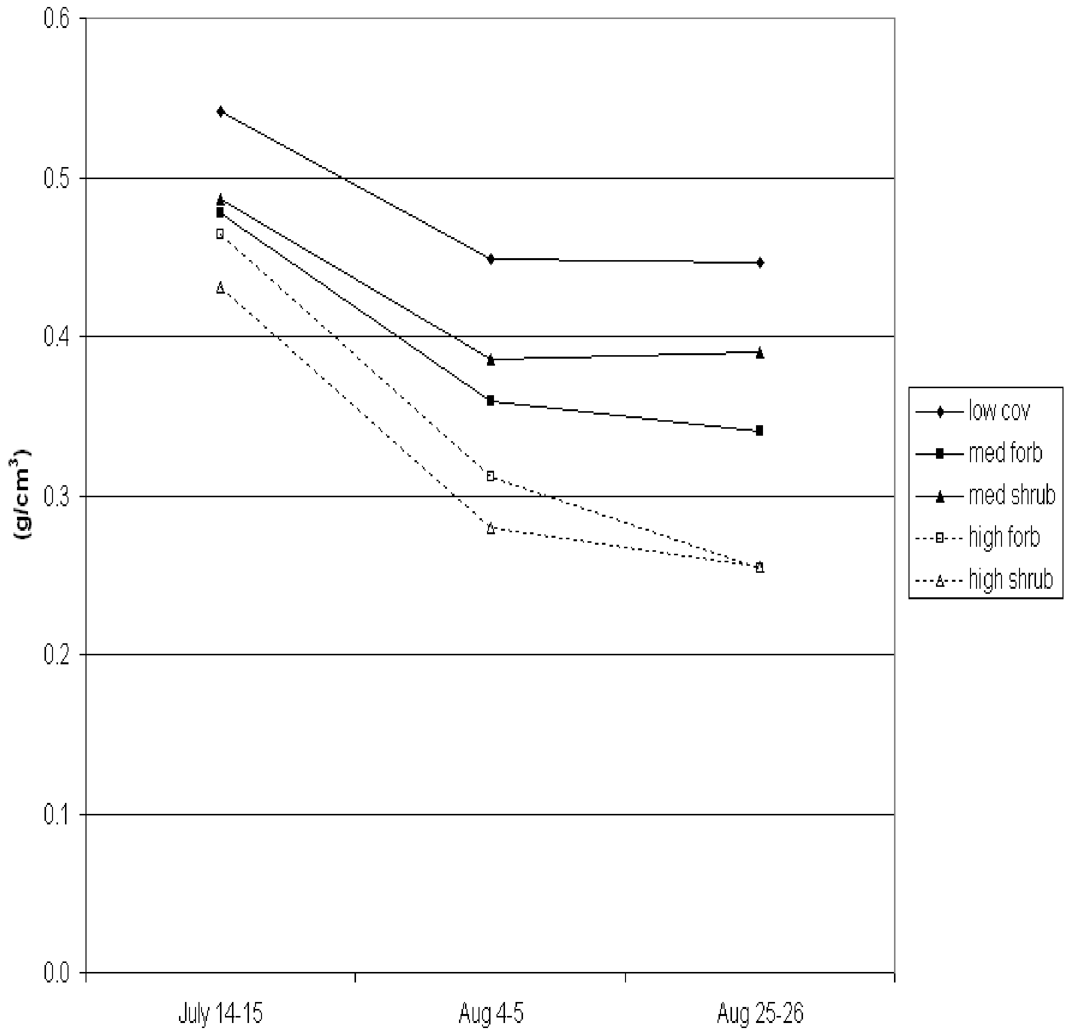


Figure 2.47 Trend in volumetric soil moisture (VSM g/cm$^3$) to 46 cm depth for five cover classes at Hooker throughout the 2008 growing season.

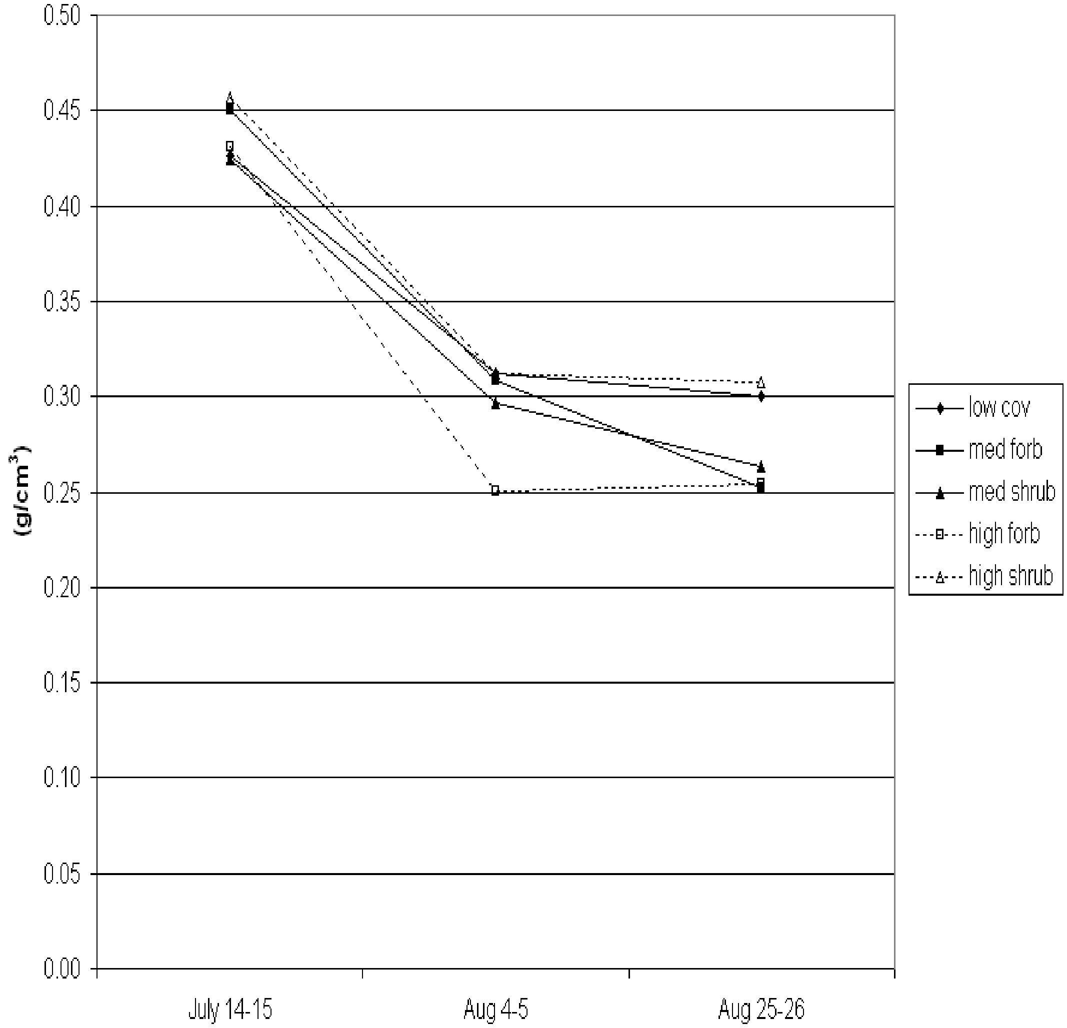


Figure 2.48 Trend in volumetric soil moisture (VSM g/cm$^3$) to 46 cm depth for five cover classes at Lower Sam throughout the 2008 growing season.

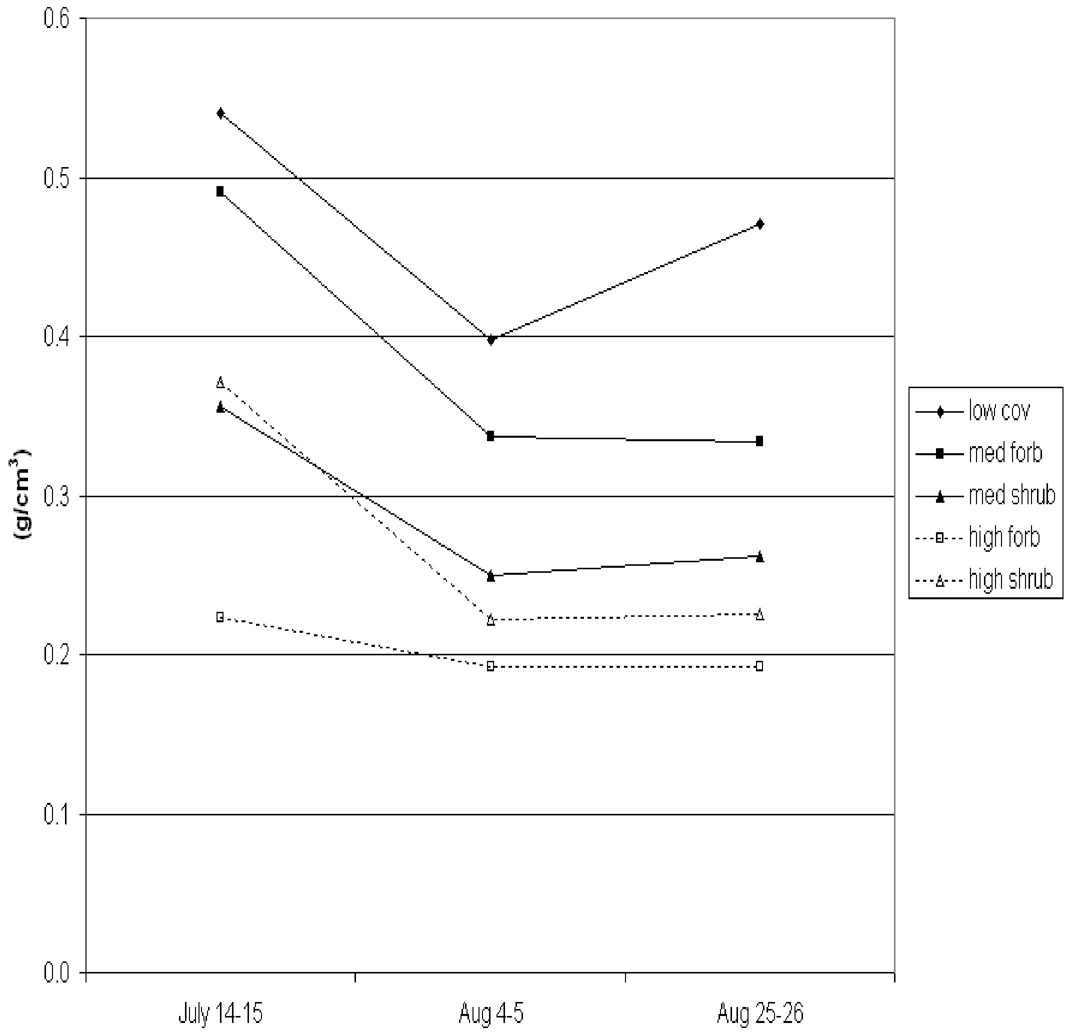


Figure 2.49 Trend in volumetric soil moisture (VSM g/cm$^3$) to 46 cm depth for five cover classes at Upper Sam throughout the 2008 growing season.

## Discussion

### *Vegetation Cover*

Spring chemical treatments seemed to reduce grass cover the most consistently, when compared to summer treatments (Figure A.1). The imazapyr and hexazinone treatments consistently reduced grass cover when compared to the control. However, grass cover was low at all of the blocks, so only small differences were realized. These results are consistent with Newton and Cole (1989) who report that, when multiple treatments, were compared hexazinone reduced grass cover the most on the southern Oregon Coast. White et al. (1986) similarly reported that treatments with hexazinone significantly decreased grass cover in Christmas tree plantations in western Oregon. All of the spring 2007 treatments, with the exceptions of ou/clo-1 and atr-1 had control that persisted to the second-year post-treatment. These results are not consistent with Newton and Overton (1973) who report that atrazine had persistent effects on annual grasses. However, most of the grasses in this study were perennial, which may explain this consistency. Many grasses are physiologically active early in the spring, so greater effectiveness in spring seems reasonable. These results support the principle that spring site preparation treatments for units that have high grass cover may be more effective at controlling the competing grass cover than summer treatments.

Spring chemical treatments also seemed to reduce forb cover the most consistently, when compared to summer treatments (Figure A.2).Treatments varied in reduction of forbs at different blocks and for different years when compared to their respective controls. Forb cover at Lower Sam averaged only 7%, and given the high variability among plots it is not surprising that treatments did not significantly differ from the control, which also included some bare spots. The greatest level of control appears to be at Hooker, which had the highest level of forb cover. The ou/mil-2 treatment consistently reduced forb cover to less than approximately 5% (Figure A.2). This appears to be a function of aminopyralid, or the combination of aminopyralid and sulfometuron. The hexazinone treatment was the only one that appeared to have strong forb control in the second year (Figure A.6).

Spring chemical treatments did not appear to reduce shrub cover any more consistently than summer treatments (Figure A.3).Control of shrub cover did not persist for more than one year, but the reduction of first-year shrub cover when compared to the control was strong, and also consistent, especially for any treatment that contained glyphosate, atrazine, or imazapyr, regardless of season or year of treatment (Figures 2.5, A.3 and A.7). The general lack of control at Upper Sam may be due to low shrub cover (<3%). Adequate control of shrubs with glyphosate was also reported by Newton (1978b) and with glyphosate and imazapyr by Cole and Newton (1990). All treatments had less percent total cover than the control for both first and second-year post-treatment, even though they were not all statistically significant (Figures 2.6, A.4 and A.8). Ou-1, ou/gly-1, ima6-1, and hex-1 all show possible residual effects for controlling vegetation past the first-year post-treatment. Persistent control with hexazinone has been documented (Newton 1978). Polhill and McLaughlan (1998) reported that site preparation with hexazinone at 3.5 kg ai $ha^{-1}$ in

Canada lasted for three years, and Boyd et al. (1995) reported 2-10 years of control in the Northern Rocky Mountains. One cannot be certain, though, whether such persistence of control relates to failure to re-colonize or failure of damaged plants to recover.

Differences in vegetation cover were apparent among the blocks. These influenced comparisons between treatments and controls such that the range of possible effects varied widely. In general, Upper Sam had predominantly grass and forb cover; control plots had so little shrub cover that comparisons with treatments at such low levels were nearly meaningless. Lower Sam had the greatest shrub cover, offering the best opportunity to evaluate treatment effects on shrubs, and Hooker had the most diversity of species, with high grass, forb and shrub cover for evaluating general effectiveness on total cover. Hooker also had the largest population of large forbs (mullein (*Verbascum thapsis*), thistle (*Cirsium* spp.), and hounds tongue (*Cynoglossum officinale*)) that were still green even at the end of the growing season. One reason for this may be that Hooker had one year longer between harvesting and the initiation of this study, allowing competing vegetation to recover and reestablish on this site. Variability within blocks was also high. Each block had areas where percent vegetation cover was relatively high, and areas where percent vegetation cover was relatively low despite the fact that it had not been treated with any chemical. Treatments seemed to have the largest impact at reducing vegetation cover at sites where the vegetation of interest was abundant before treatment and in the control plots.

*Seedling Survival and Growth*

Most treatments increased DF (Figure A.9), LB (Figure A.10), and LP (Figure A.11) first-year survival across blocks when compared to the control, even though not all treatments were significant and these patterns were not seen at all blocks. Exceptions to this include DF and LP at Lower Sam in 2008, and survival at Hooker in 2008. DF survival was generally always high when compared to LB and LP. At Lower Sam and Upper Sam LP survival was generally higher than LB, and western larch survival was generally higher in 2007 than 2008. Spring hexazinone treatments reduced LP survival for both years across blocks (Figure A.11) even though tests between the controls were rarely significant because of low survival in the controls as well. Exceptions to this include survival at Lower Sam in 2007 and at Upper Sam in 2008. In general, treatment increased second-year survival of all the stock types across blocks when compared to the control, even though they were rarely significant. For both DF (Figure A.12) and LB (Figure A.13) the ima6-1 and hex-1 had the greatest second-year survival, and for LP (Figure A.14) ima6-1 had the greatest. These results are consistent with Oester (2005) who reported that at the end of the second year, weed control with sulfometuron in eastern Oregon improved both Douglas-fir and western larch plug seedling survival when compared to the control, but not significantly.

In general, treatment increased first-year basal area growth. The four common treatments in spring 2007 had greater first-year basal area growth than the four common spring 2008 treatments. Exceptions to the increase of basal area growth with treatment included spring 2007 sulfometuron treatments for LB (Figure A.15), with the exception of Hooker, and ou/clo-1 for LP (Figure A.16). Spring atrazine and hexazinone treatments improved DF basal area growth the most, when compared to the control (Figure A.14). This is consistent with Boyd et al. (1995) who reported that 5-6 years after treatment hexazinone improved Douglas-fir plantation growth index the most (PGI = survival x stem volume). Imazapyr at 0.42 kg ai $ha^{-1}$ for all years and seasons improved LP basal area growth the most; besides controlling cover, this implies the safety of herbicide residues when applied immediately before planting. Most treatments are not significantly different from the control for second-year basal area growth; however, ou/clo-1 almost always decreased growth when compared to the control. Hex-1 always had the greatest growth for each stock type across blocks, but looking at the blocks across stock types did not have the greatest growth at Lower Sam. Ou/gly-1 and atr-1 exhibited good growth for DF and LB, and ima6-1 exhibited good growth for LP.

First-year height growth showed mixed results for treatments. The four common treatments in spring 2007 had greater first-year height growth than the four common spring 2008 treatments, reflecting earlier planting in 2007. Most treatments decreased LB first-year height growth when compared to the control, and many decreased DF height growth. However, spring atrazine and hexazinone treatments consistently had the greatest height growth for DF and LP, as well as atr/ima-2 and ima6-2 for DF, and atr/ima-2 and gly/ima-2 for LP. Overall, each treatment with the exceptions of ou-1 and ou/clo-1 increased second-year height growth when compared to the control. Recently Oester (2008) found that ten years after treatment with sulfometuron that western larch had six to eight times the growth of the control, but Douglas-fir seedlings showed little, if any difference. Hex-1 had the greatest height growth for all three stock types across blocks (Figures A.18-A.20), and atr-1 and ima6-1 had high height growth for DF and LP, respectively.

### *Regression Relationships*

Despite the lack of consistent treatment response for vegetation cover and seedling growth, seedling and soil moisture response to vegetation cover illustrates a moderately strong, consistent relationship. Whether linear or exponential, seedling and soil moisture response to vegetation cover was consistently negative, meaning that as vegetation cover increased soil moisture at the end of the growing season decreased, as did seedling survival and growth. Similar trends for seedling survival and growth were reported by Rose et al. (2006) and Wagner et al. (1989). These results were fairly consistent in form with the concept of competition thresholds (Wagner et al. 1989), which illustrate seedling response to competition decreases as competition increases. Seedling volume growth decreased exponentially with increasing vegetation cover, as illustrated by the threshold concept. However, survival decreases linearly with increasing competition, while other thresholds demonstrate survival not decreasing substantially until high levels of cover occur. Our results indicate that small amounts of vegetation cover could have a larger detrimental impact to plantation establishment in hot, dry regions than where water is more abundant.

While seedling response to soil moisture was not analyzed directly, we can speculate that due to their moderately strong, consistent relationships with vegetative cover, there would be a positive relationship between soil moisture and seedling survival and growth. Soil water depletion is largely attributable to transpiration. Therefore, an abundance of forb, grass, and/or shrub leaf area increases transpiration, depletes soil water faster, and has the impact of shortening the growing season with suppressive or lethal outcomes (Newton 1981).

### *Stock Type Variability*

Treatment differences may not be more apparent due to the many sources of local environmental and operational influences that create variability within this study. One example is initial seedling size. At planting it was evident for both 2007 and 2008 that initial differences in the seedling size between the stock types existed. More importantly, it was also evident that differences between 2007 and 2008 for each stock type existed. To display these differences the mean basal area, height, and volumes of the seedlings for each stock type were calculated (Table 2.22). It is evident that in 2007 DF seedlings had the largest mean BA but the lowest mean HT. DF seedlings in 2008 were smaller than in 2007, and were still the shortest of the three stock types. In 2007 LB seedlings were of medium mean BA, but were the tallest, and LP seedlings were of medium mean HT but had the smallest mean BA. In 2008 the LB seedlings had larger mean BA and HT, and the LP had smaller mean BA and HT than in 2008. For both years the LB had the greatest mean Vol, followed by DF and LP.

Table 2.22 Mean initial seedling size by stock type.

| ST | 2007 BA ($mm^2$) | 2007 HT (mm) | 2007 Vol ($mm^3$) | 2008 BA ($mm^2$) | 2008 HT (mm) | 2008 Vol ($mm^3$) |
|---|---|---|---|---|---|---|
| DF | 32.7 | 326.5 | 3760.1 | 24.7 | 272.6 | 2385.0 |
| LB | 27.2 | 530.5 | 5138.6 | 44.8 | 667.0 | 10187.9 |
| LP | 12.9 | 462.4 | 2039.9 | 9.0 | 357.8 | 1116.4 |

Mean survival, basal area, height, and volume at the end of each growing season and for each stock type are displayed in Table 2.23. Regardless of planting date or year, DF had the greatest mean survival and LB had the lowest mean survival. The positive relation between seedling diameter and subsequent growth has been summarized by Rose and Ketchum (2003) and Rosner and Rose (2006). Rosner and Rose (2006) reported that gains from larger seedling diameters and weed control were multiplicative; and that volume returns with the best weed control were increased with larger seedlings of the same species. The results from Rose (2006) did not hold true for this study when comparisons were made across stock types. Observations suggest that even though the LB seedlings were larger at planting, in the best weed control treatments the LP seedlings were comparable in size after the first growing season in 2007. Also, by the end of the second growing season, mean volume of the LP seedlings (43,791 $mm^3$) was essentially the same as the mean volume of the LB seedlings (44,565 $mm^3$), and nearly three times the volume of the DF seedlings (15,741 $mm^3$). LP seedlings may have grown better due to ease of planting plugs when compared to bareroots, possible seedling shock during lifting bareroot seedlings, and the plug medium itself which provides for nutrient reserves and moisture at the time of planting. This suggests that selecting the appropriate stock type is more important for increasing seedling growth than seedling size at planting.

Table 2.23 Mean seedling size and survival by stock type at the end of each growing season.

| Response | Year | Growing Season | Stock Type DF | LB | LP |
|---|---|---|---|---|---|
| Survival | 2007 | 1 | 95% | 71% | 79% |
| | 2008 | 1 | 93% | 64% | 75% |
| | 2008 | 2 | 82% | 59% | 67% |
| Basal Area ($mm^2$) | 2007 | 1 | 49.7 | 47.8 | 35.1 |
| | 2008 | 1 | 32.4 | 52.6 | 19.3 |
| | 2008 | 2 | 90.7 | 131.1 | 126.9 |
| Height (mm) | 2007 | 1 | 389.1 | 632.5 | 600.7 |
| | 2008 | 1 | 318.8 | 702.2 | 455.3 |
| | 2008 | 2 | 468.0 | 816.7 | 825.8 |
| Volume ($mm^3$) | 2007 | 1 | 6811.9 | 10957.4 | 7458.8 |
| | 2008 | 1 | 3637.5 | 12625.2 | 3104.1 |
| | 2008 | 2 | 15740.7 | 44564.7 | 43791.1 |

### *Environmental Variability*

Differences in the weather prevailed in the two years. The winter of 2006-2007 was generally mild, and the snow was off the plots by mid-March. Owing to early snow melt, spraying occurred March 28-29, 2007 and seedlings were planted about two weeks later on April 13. The summer of 2007 was generally hot and dry, with a few thunderstorms that provided rain throughout the growing season. Heavy snowfall accumulated during the winter of 2007-2008, covering the plots until early-May. Climatalogical data for La Grande, OR, the closest active weather station reports that snowfall between November and March was approximately four times the amount in the winter 2007-2008 (61.0 cm) than the winter 2006-2007 (15.7 cm) (National Climatic Data Center 2008). This prevented us from spraying until May 13, 2008, and planting only one week later on May 22. The summer of 2008 was hot and dry, although personal observations noted not as hot and dry as 2007, with a few thunderstorms that provided rain throughout the growing season.

The difference in time between spraying and planting for 2008 when compared to 2007 may be influential on potential chemical damage to the seedlings, especially LP. In general, when the mean survival of the four common spring treatments was compared, survival was lower for 2008 than 2007, although this was only significantly different at Lower Sam (p-value = 0.0002). Mean basal area and height growth of the four common spring treatments, however, were significantly greater in 2007 than in 2008 for all blocks. A time difference of one week between spraying and planting and late planting in 2008 may have allowed fewer residues to incorporate into the soil, making chemicals more available for uptake by seedling roots or attachment to plug soil mediums. Late planting in 2008 may have also been detrimental to LB growth, due to extended cold storage and the observation that the LB seedlings were already breaking bud at the time of planting. Although late planting did not seem to decrease mean LB survival between the two years, it did seem to decrease mean basal area and height growth. We observed that at the end of the 2008 growing season, many of the LB planted that spring had top dieback.

Large variances in seedling performances among sites and within sites was clearly related to variability within and among the stock types, between the weather for both years and within and among the three blocks with respect to soil depth, texture, compaction, and water retention. Upper Sam had the greatest surface disturbance, hence possible compaction, the shallowest ash/loess layer, and the most surface water flow during snowmelt. Ash depth at Upper Sam seemed to vary with position on slope, and at the bottom of the unit, residual, rocky soil was apparent within the first 23 cm. Within blocks the same patterns for compaction and soil water retention seemed to persist. Compaction in skid roads and early season soil water retention increased going down the slope. Plots with high woody debris cover also appeared to retain more soil moisture throughout the growing season.

### *Herbicide Injury*

Planted seedlings respond to several environmental and operational factors in their initial years after planting. This study shows that chemical treatment of competing vegetation increases seedling survival and growth by increasing moisture available for seedlings, while negative effects to seedlings can show up as visible herbicide damage or simple stunting in negating response to moisture. LP seedlings that were treated with hexazinone in the spring had the poorest first-year survival across blocks for each year (approximately 66% in 2007 and 41% in 2008; Figure A.11). However, they also had some of the greatest first-year basal area and height growth across blocks for both years (Figures A.16 and A.20). This suggests that hexazinone has an acutely toxic effect on western larch containerized seedlings, but if seedlings survive for a month or two they can respond to better soil moisture conditions. Boyd et al. (1995) found that western larch was the most susceptible conifer to damage from hexazinone in the northern Rocky Mountains. McLeod and Mandzak (1990) also reported high toxicity to naturally regenerated western larch seedlings. Granular products may possibly be safer than broadcast sprays. Applications in the fall before spring planting, may lead to soil binding, hence prove safer while providing relief from competition.

Sulfometuron, widely regarded for suppression of grasses, has been described as chronically toxic to Douglas-fir to the extent that growth suppression is proportional to dosage, and persists past the first growing season (Newton and Cole, 1989). Oester (2005) reported that sulfometuron may have some negative growth effects on Douglas-fir seedlings. Sulfometuron may cause root damage, inhibiting growth or possibly even killing the roots of Douglas-fir seedlings (Personal communications, Allen Heimgorthey Green Diamond Resources, Tillamook, OR). Despite other studies that suggest sulfometuron may have negative growth effects on Douglas-fir seedlings, our results did not indicate this effect. Lack of evidence may partially be due to the variability throughout this study, and revisiting this study in five to ten years, or repeating sulfometuron plots over more homogeneous soil and cover conditions, may show evidence of reduced growth. Evidence of harm from aminopyralid to Douglas-fir was not detected either.

Evidence of herbicide injury to seedlings, like any toxic substance, is necessarily a dose-related phenomenon. Imazapyr did not display damage at 0.42 kg $ha^{-1}$ and led to some of the highest observed growth rates. Treatments at 0.21 kg ai $ha^{-1}$ had consistently low LB survival in 2007 and 2008 for both spring and summer treatments; it is prudent to seek other explanations for damage. This treatment at both rates consistently decreased vegetation cover, with respect to the control, presumably leading to increased moisture availability. The evidence of residual damage from imazapyr elsewhere demands continued research to examine the factors that may be associated with enhancing effectiveness while reducing risk.

### *Scope of Inference*

The scope of inference for this study is limited to the first two years of seedling establishment analyzed for these and similar sites characterized by the same plant associations, soils, and climate. Our results are generally consistent with treatment responses and relationships in the Intermountain West and other regions of Oregon, and it's reasonable to expect similar results on dry, mid-elevation site in the Intermountain West. This study was not designed for long-term monitoring of tree survival and growth without major modification of tree spacing. Other studies are needed that narrow down the list of herbicide treatments and that track through rotation age. This will give managers a better understanding of not only how western larch and Douglas-fir trees respond to initial site preparation, but also how the effects of intra-specific competition influences longer-term patterns of competing vegetation and its influence on planted conifers.

## Conclusion

General patterns of seedling response and soil moisture to vegetation control were demonstrated in this study for northeastern Oregon. Treatment responses were not always statistically significant, and sometimes were even negative. Survival and growth responses depended on stock type, site characteristics, chemicals and rates, season and year of application, and combinations of those. In determining site preparation and plantation establishment practices in northeastern Oregon many factors will need to be determined. Christie (1995) recommends that site characteristics need to be determined along with vegetation management to maximize productivity of a forest stand. We suggest that chemicals, rates, season of application and selection of planting stock types may require comprehensive prescription guides for achieving maximum benefits per unit of expense in establishing productive stands. This requires extensive planning following the acquisition of sound data pertaining to site and plant cover. These experiments are a first step in that process.

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## CONCLUSION

Chemical control of competing vegetation has shown to be effective at reducing vegetation cover and increasing seedling survival and growth of ponderosa pine, western larch, and Douglas-fir in northeastern Oregon. However, on dry sites vegetation management does not always guarantee high seedling survival and growth, but with no vegetation management few seedlings survive through rotation age. Also, some chemicals damage seedlings, decreasing survival and growth. High variability among sites, years, species, stock types, and seasons of application make determining the prescription to maximize growth and yield highly complicated. Maximizing productivity will take extensive knowledge of existing vegetation, herbicide translocation processes, tree species, and stock types, as well as their interactions. Prescriptions will need to consider all of these factors, possibly making them different among years and even sites. The magnitude of increase of economic returns at the end of a rotation caused by herbicide treatment at seedling establishment still needs to be determined. Evaluation of these studies, as well as other studies that are better designed for long-term monitoring are needed.

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# APPENDIX

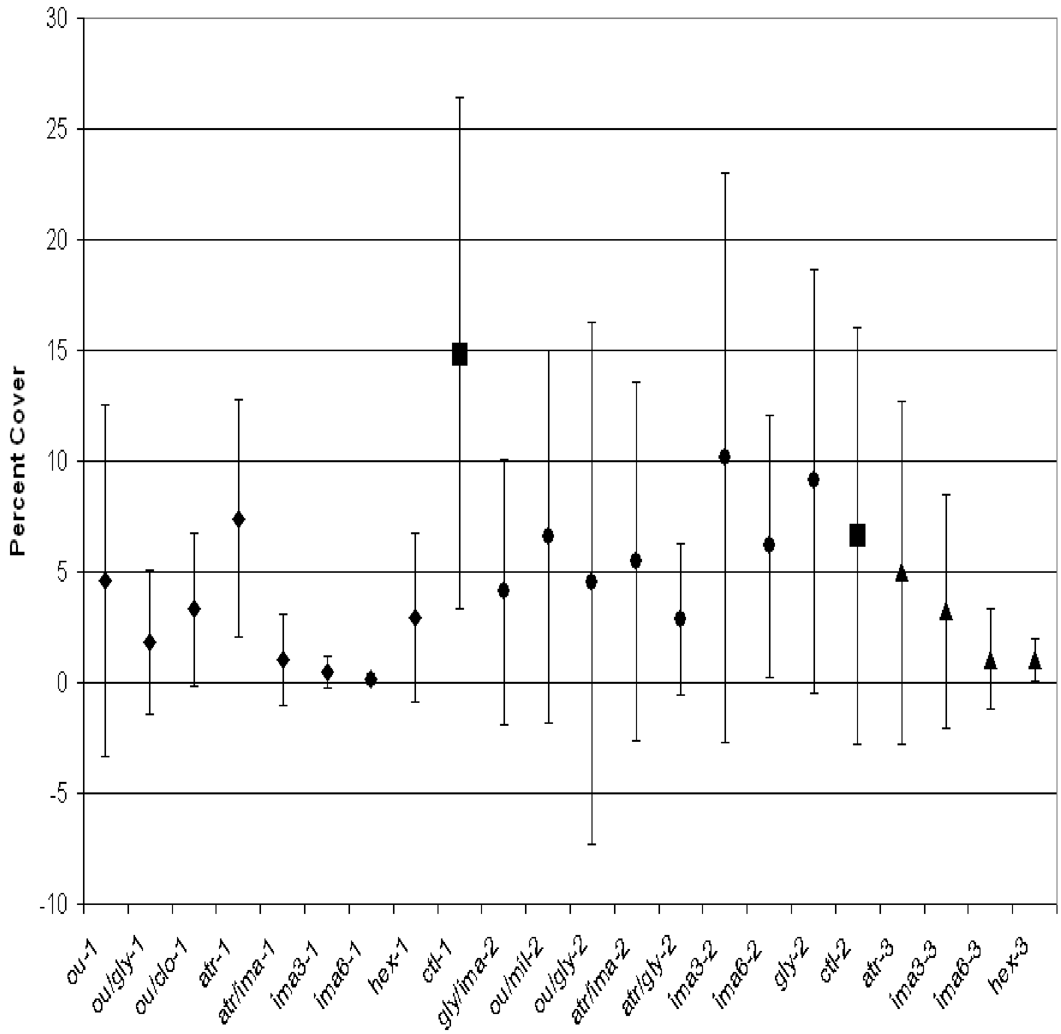



Figure A.1 First-year post-treatment percent grass cover.

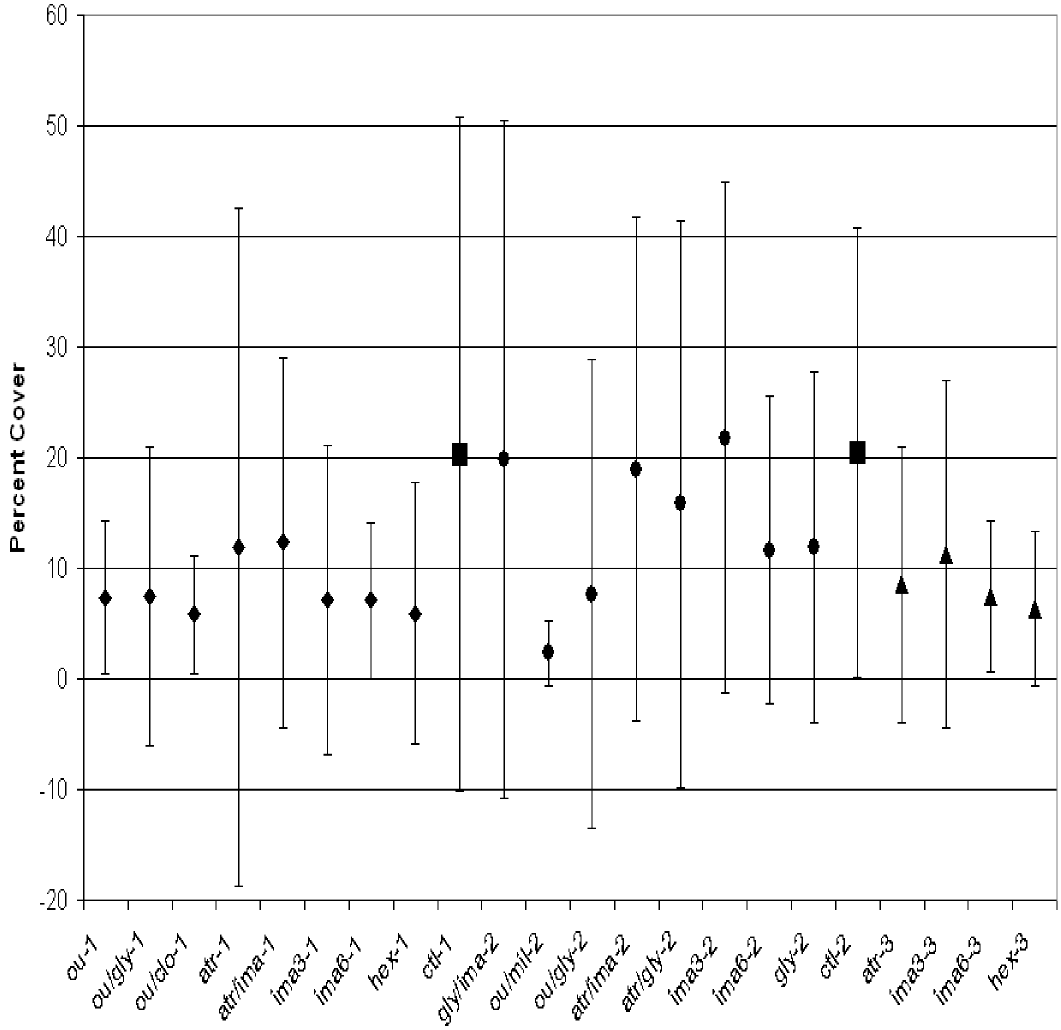



Figure A.2 First-year post-treatment percent forb cover.

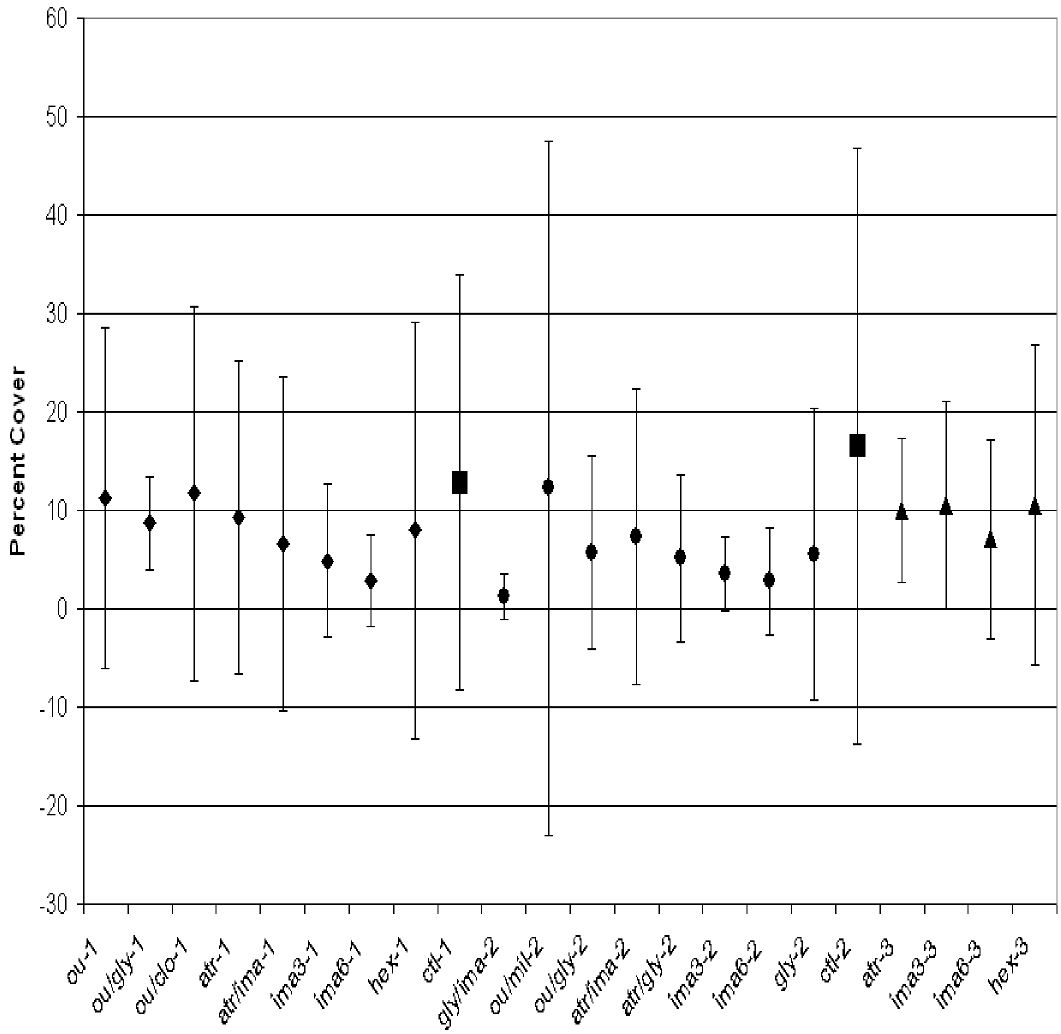



Figure A.3 First-year post-treatment percent shrub cover.

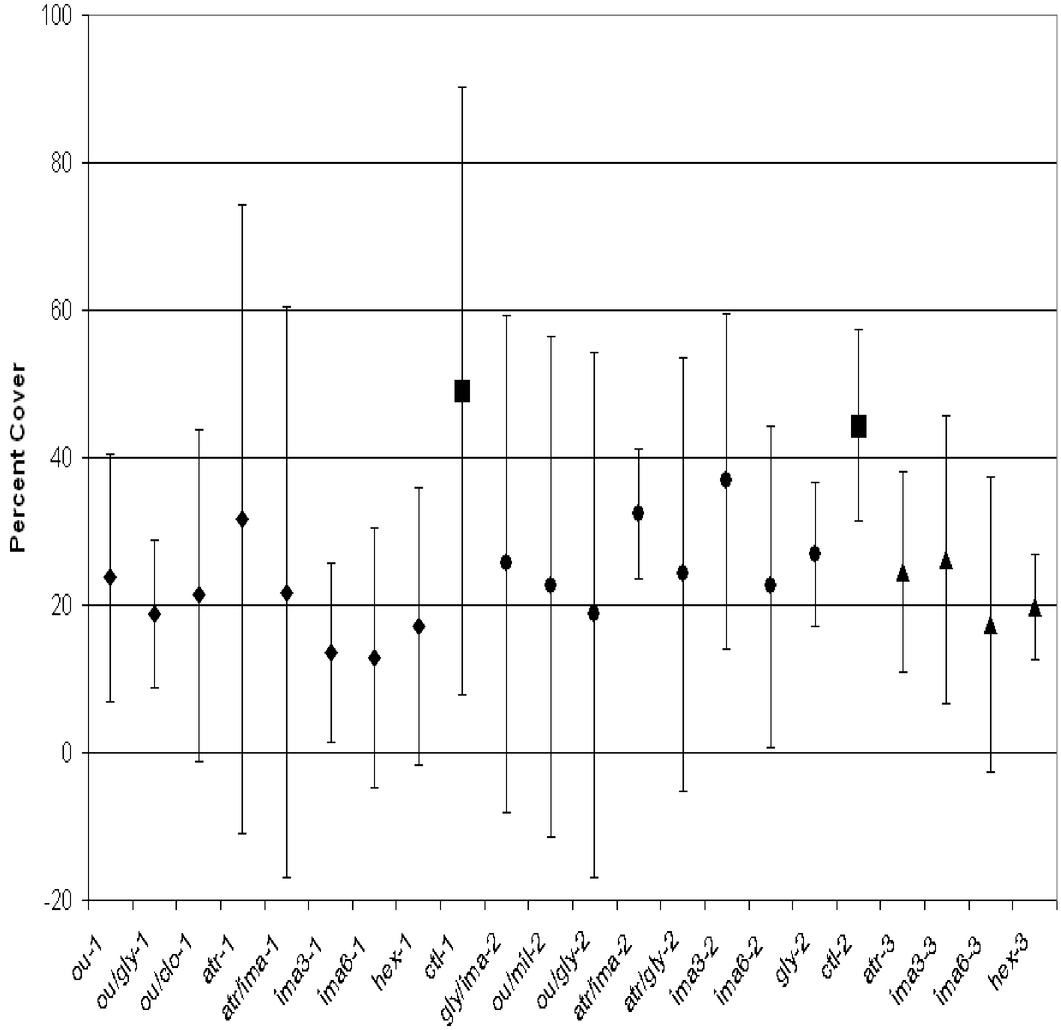
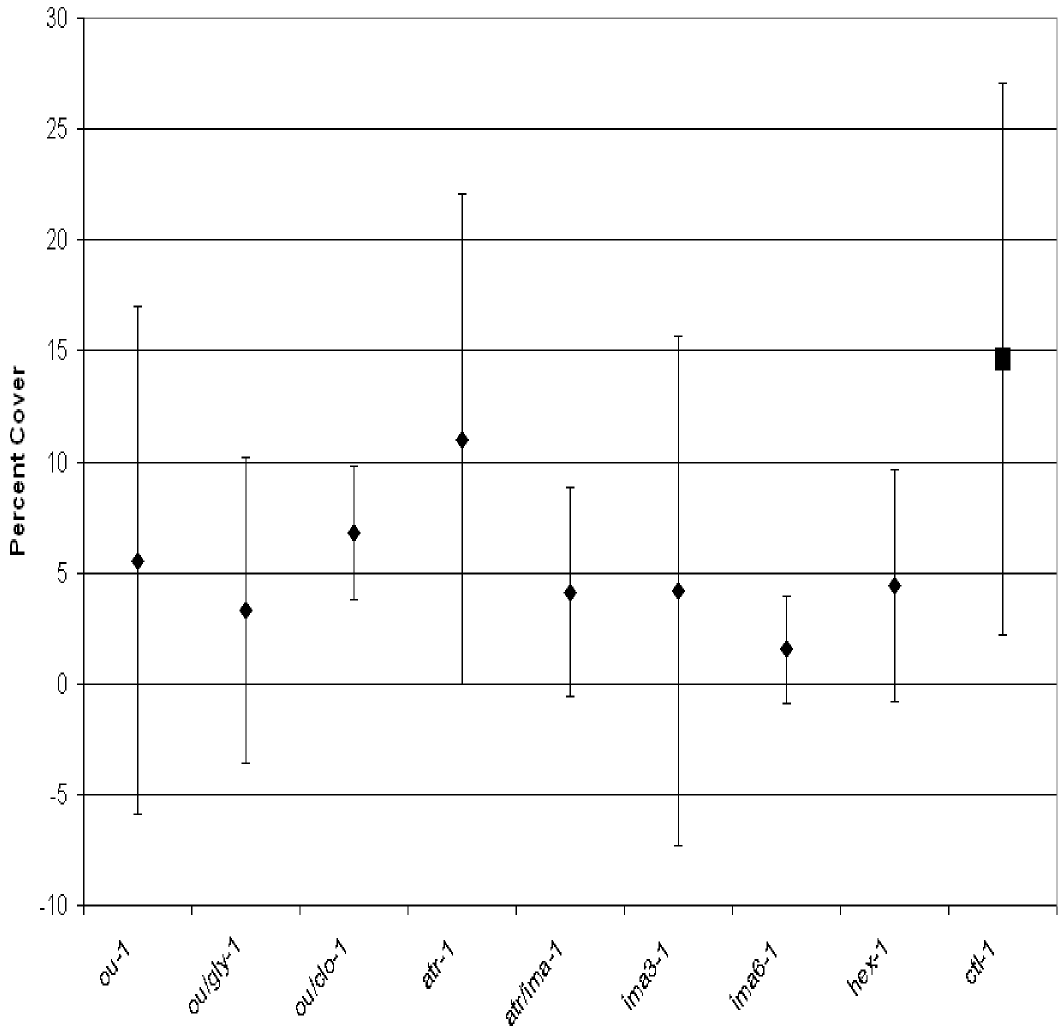



Figure A.4 First-year post-treatment percent total non-coniferous cover.

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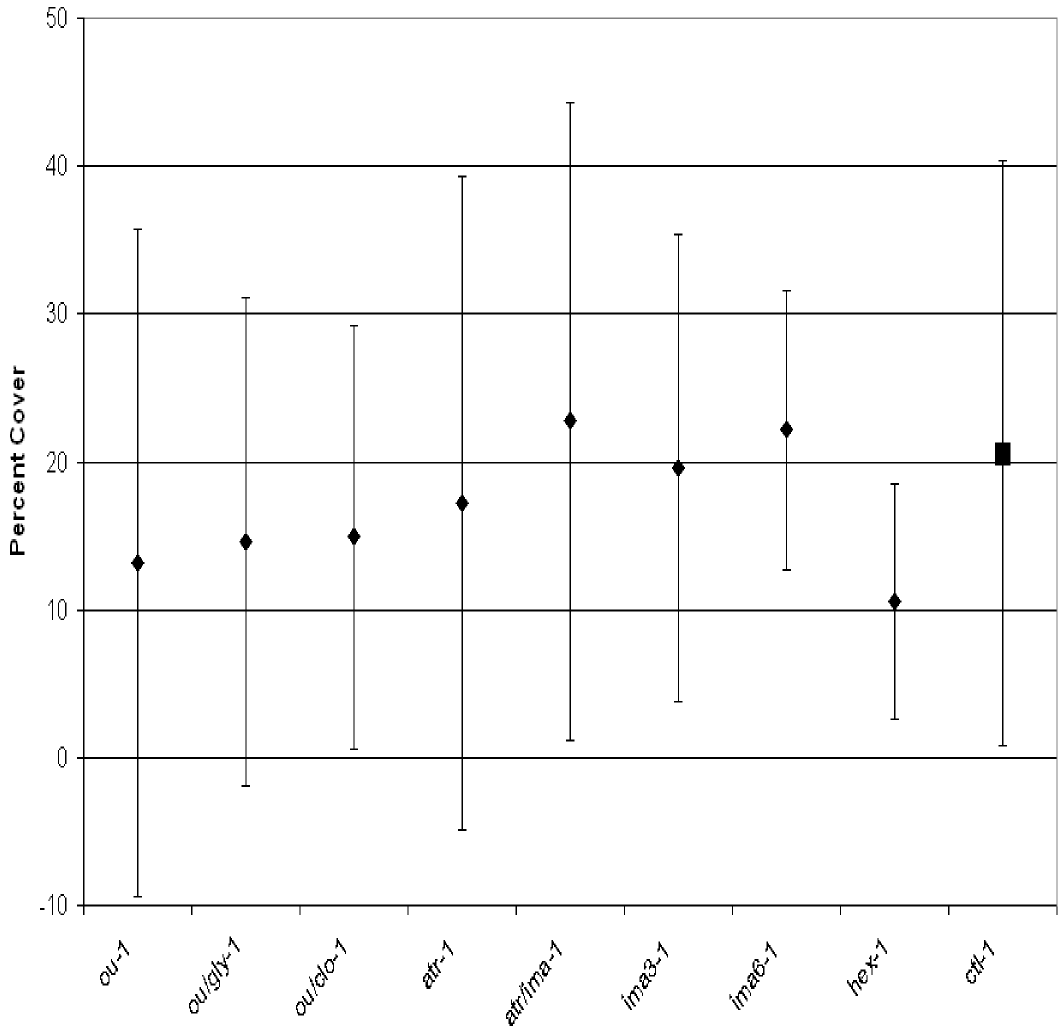


Figure A.6 Second-year post-treatment percent forb cover.

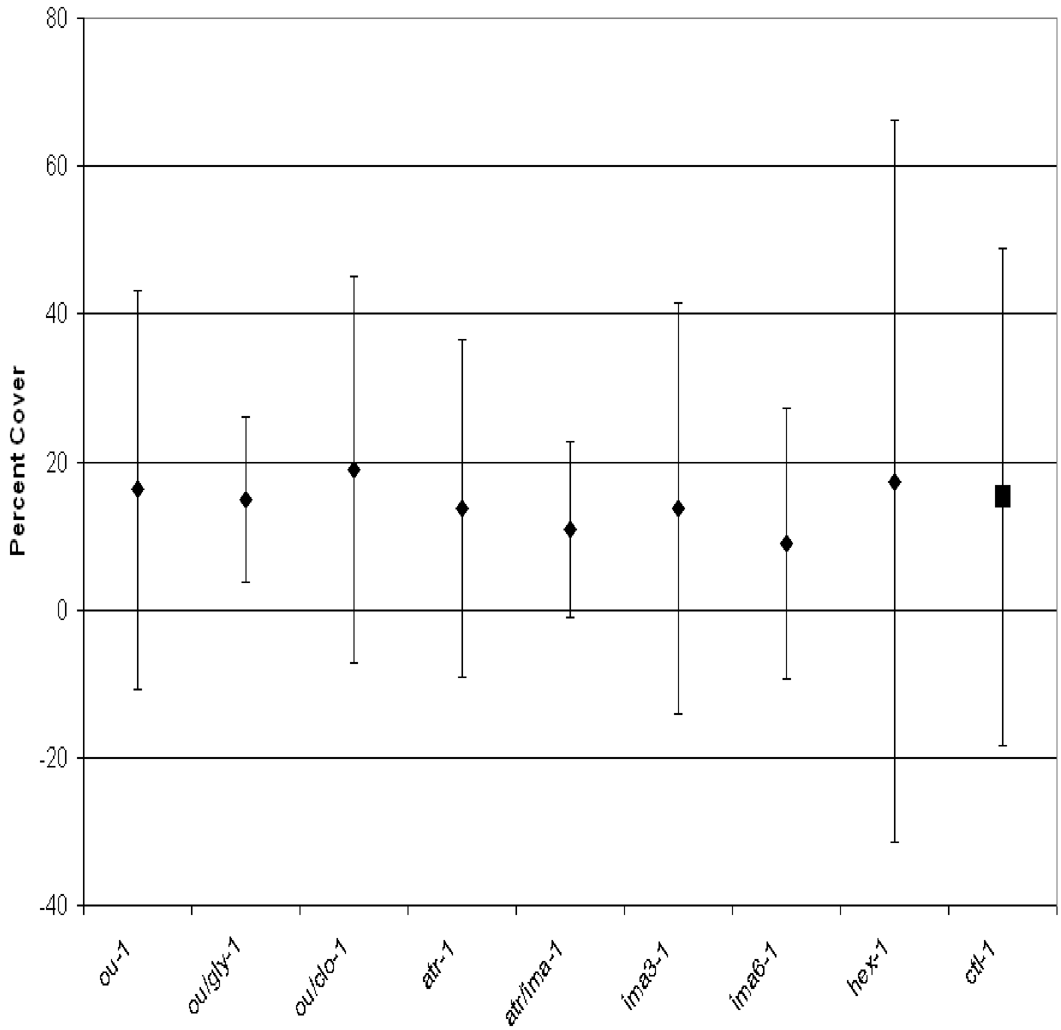


Figure A.7 Second-year post-treatment percent shrub cover.

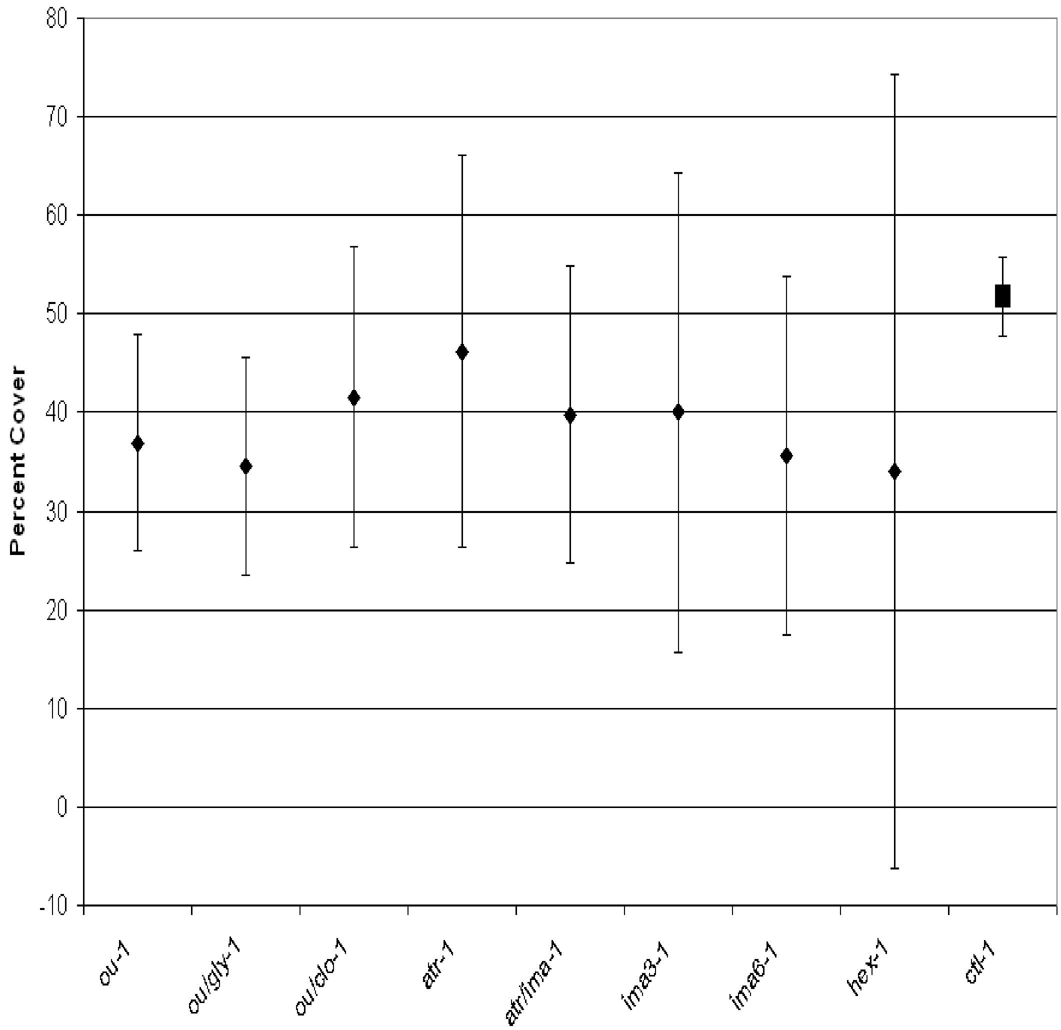


Figure A.8 Second-year post-treatment percent total non-coniferous cover.

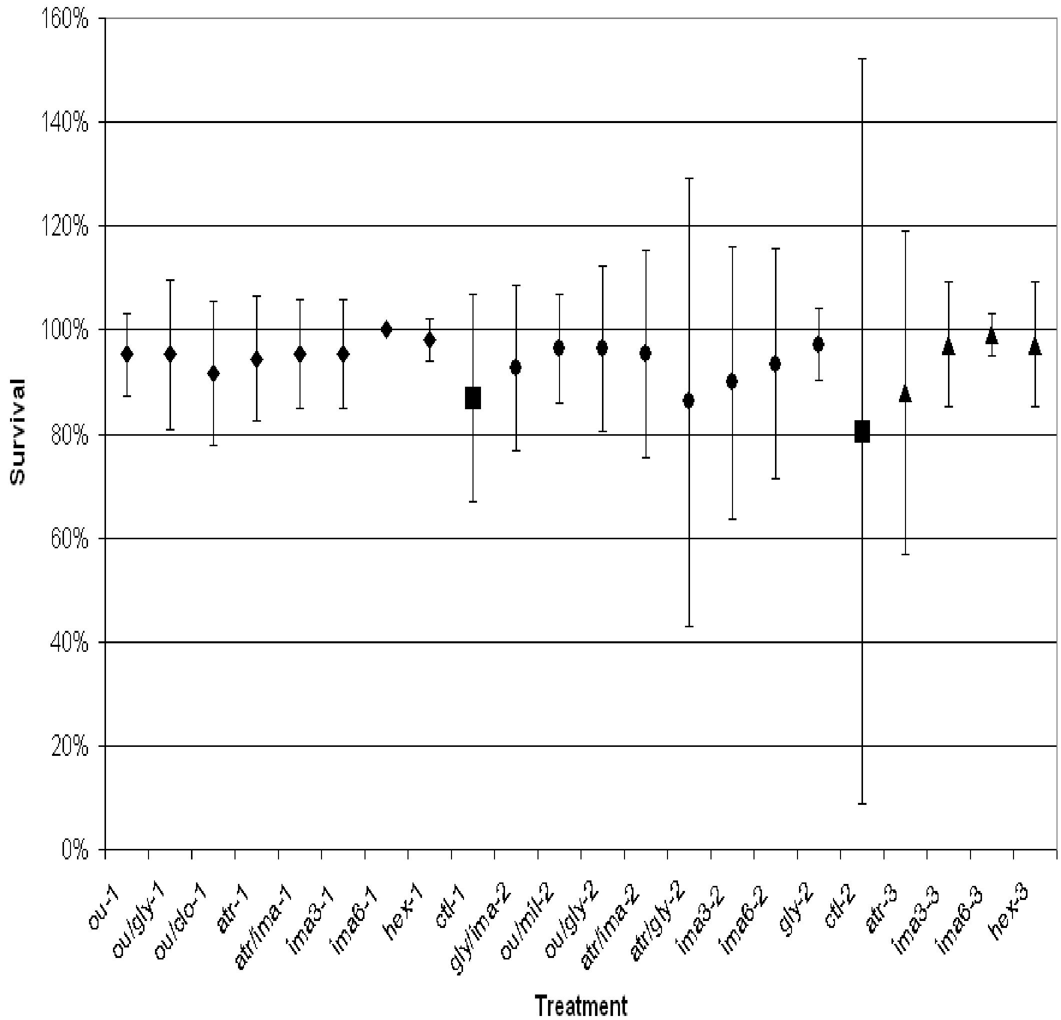


Figure A.9 First-year Douglas-fir survival.

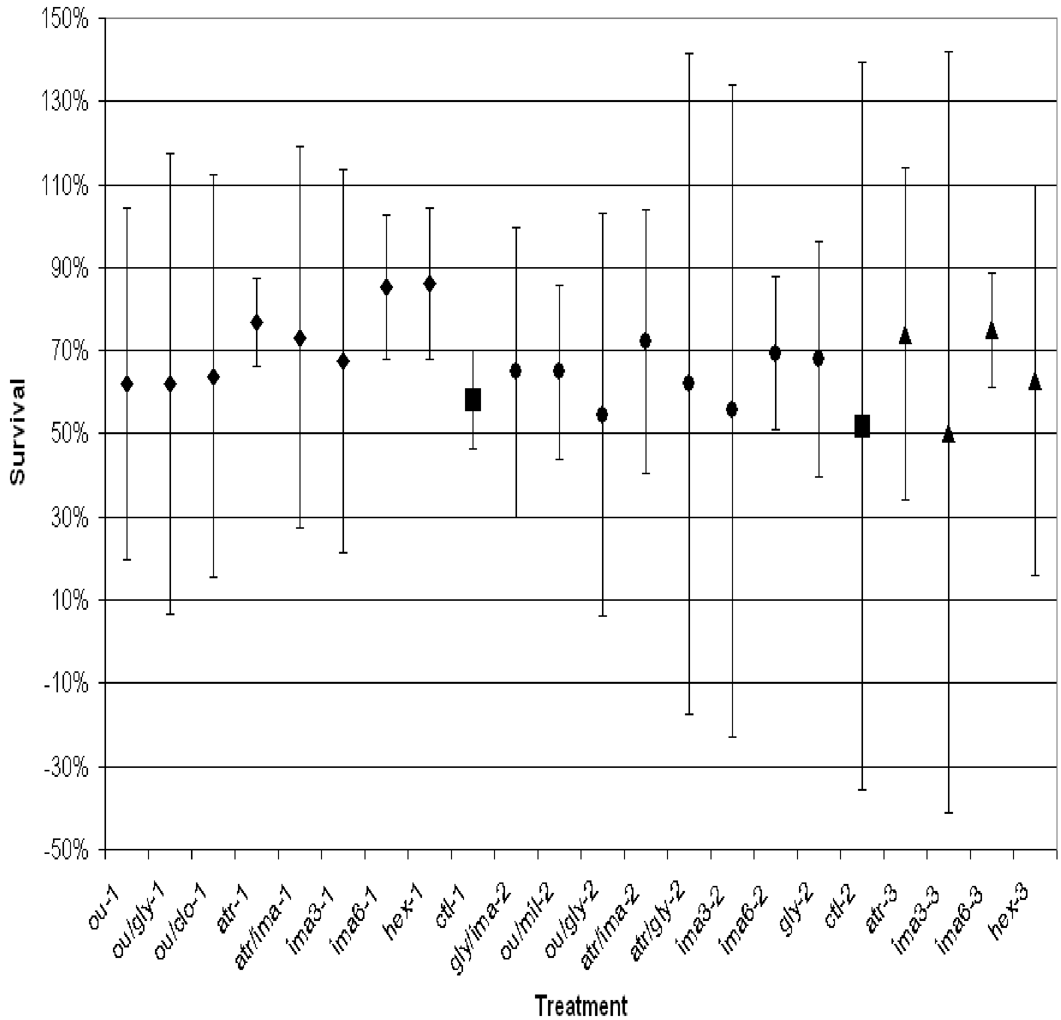


Figure A.10 First-year larch bareroot survival.

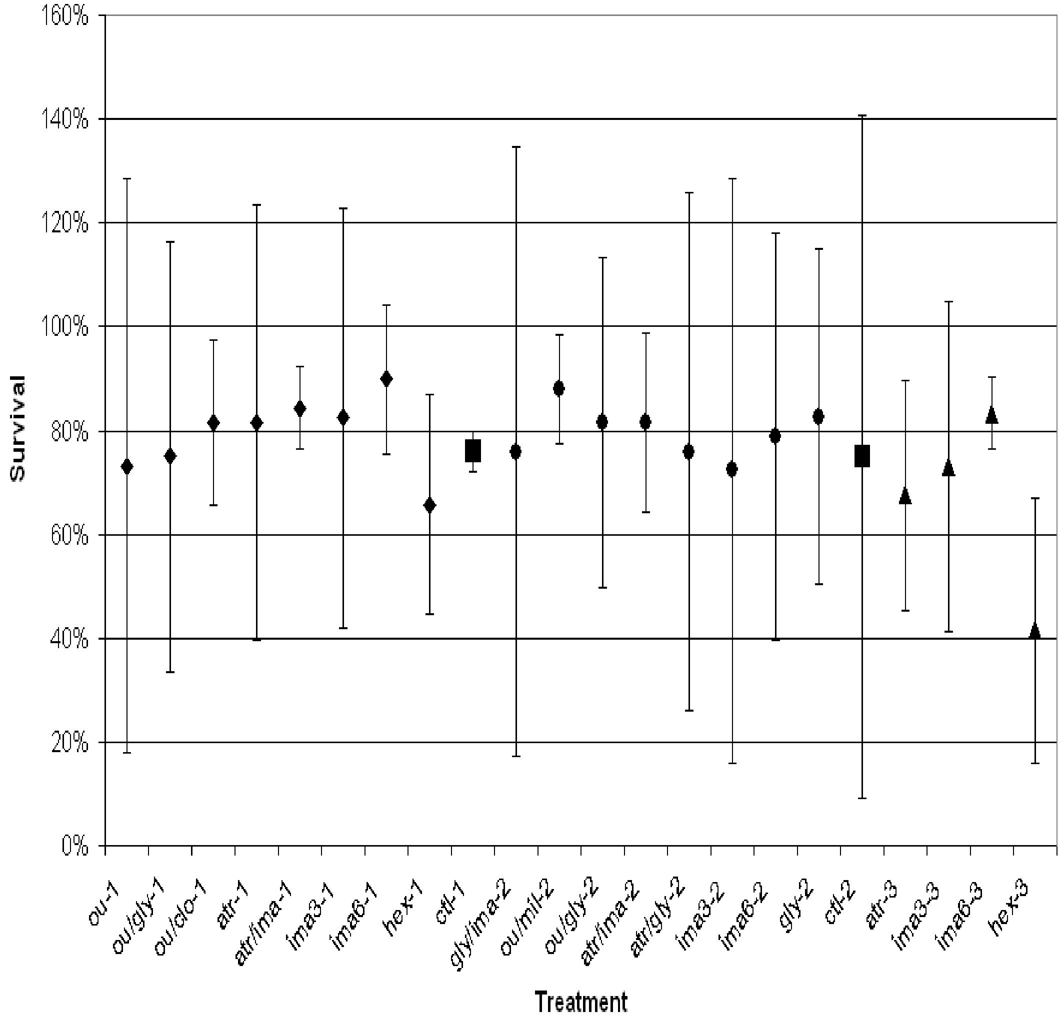


Figure A.11 First-year larch plug survival.

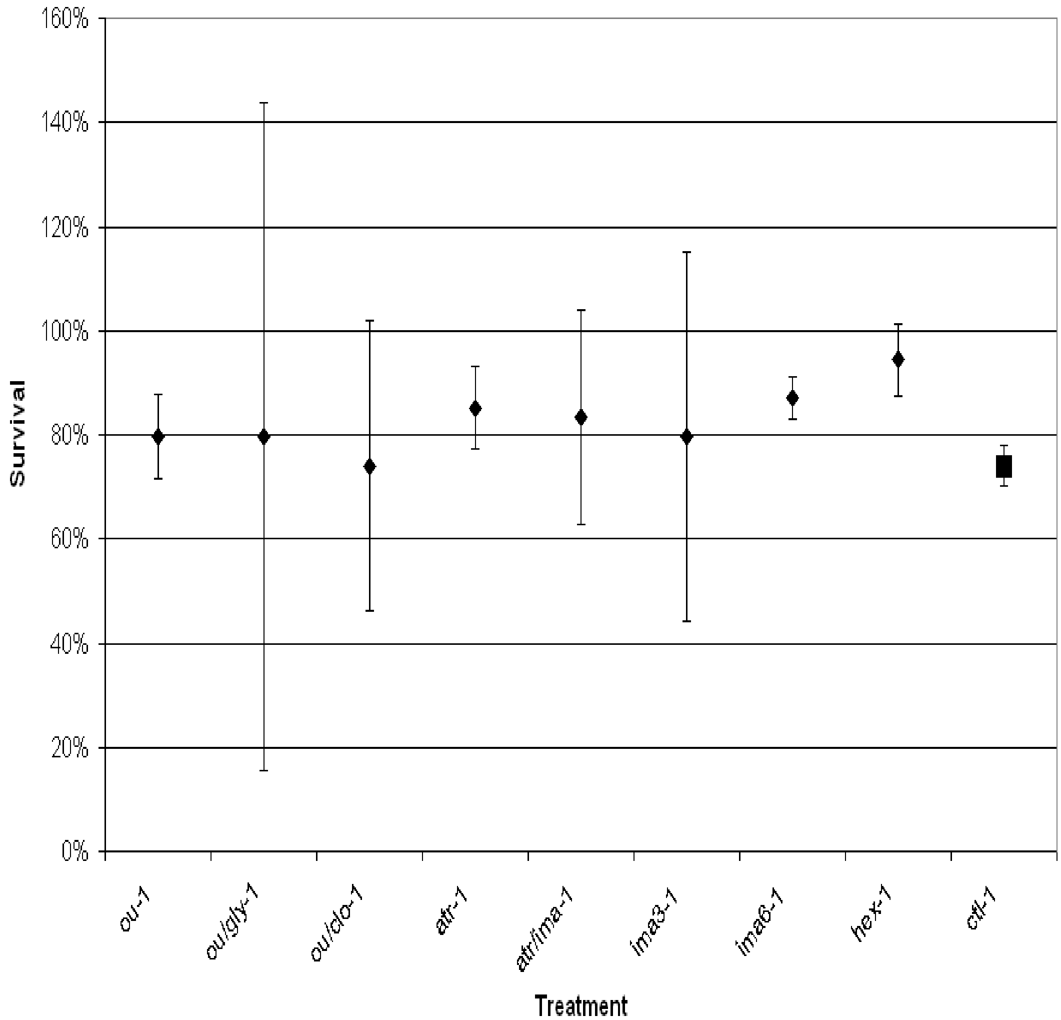


Figure A.12 Second-year Douglas-fir survival.

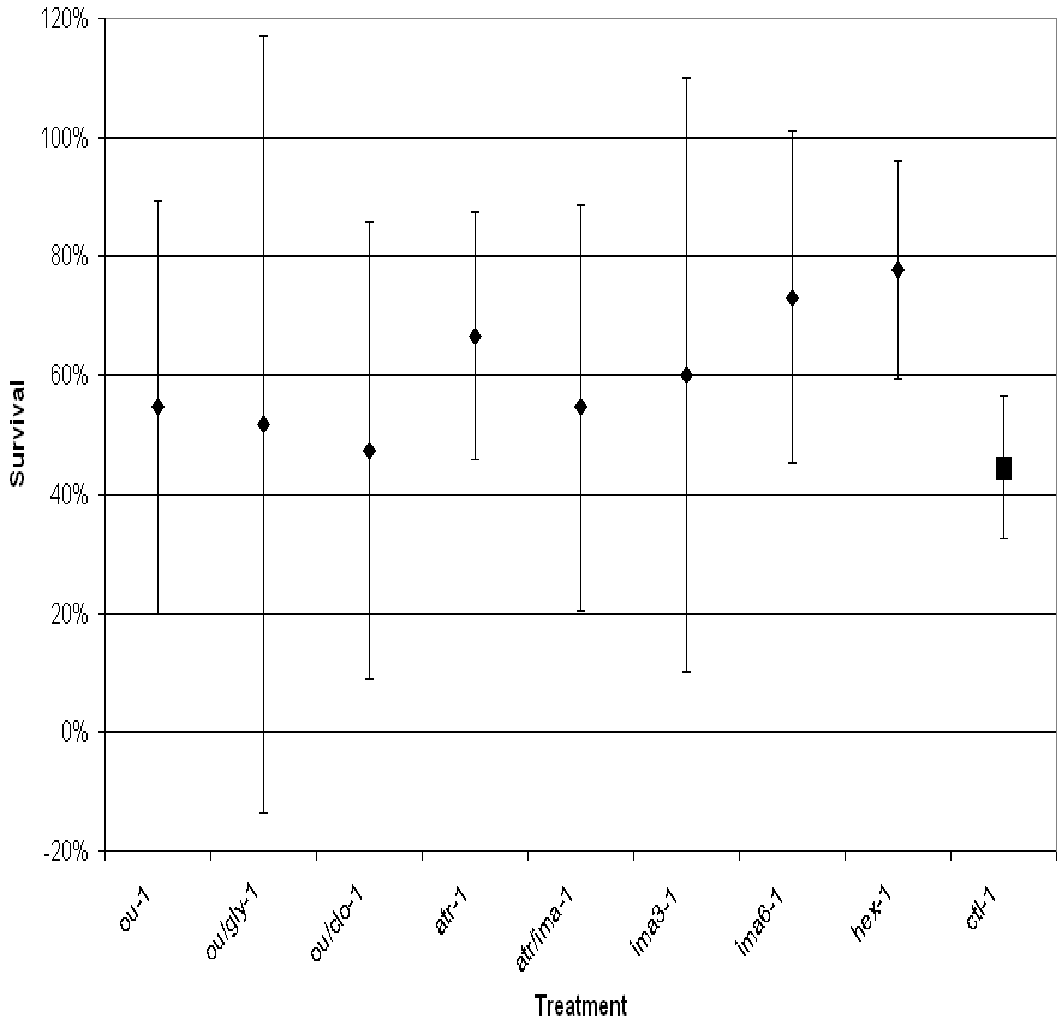


Figure A.13 Second-year larch bareroot survival.

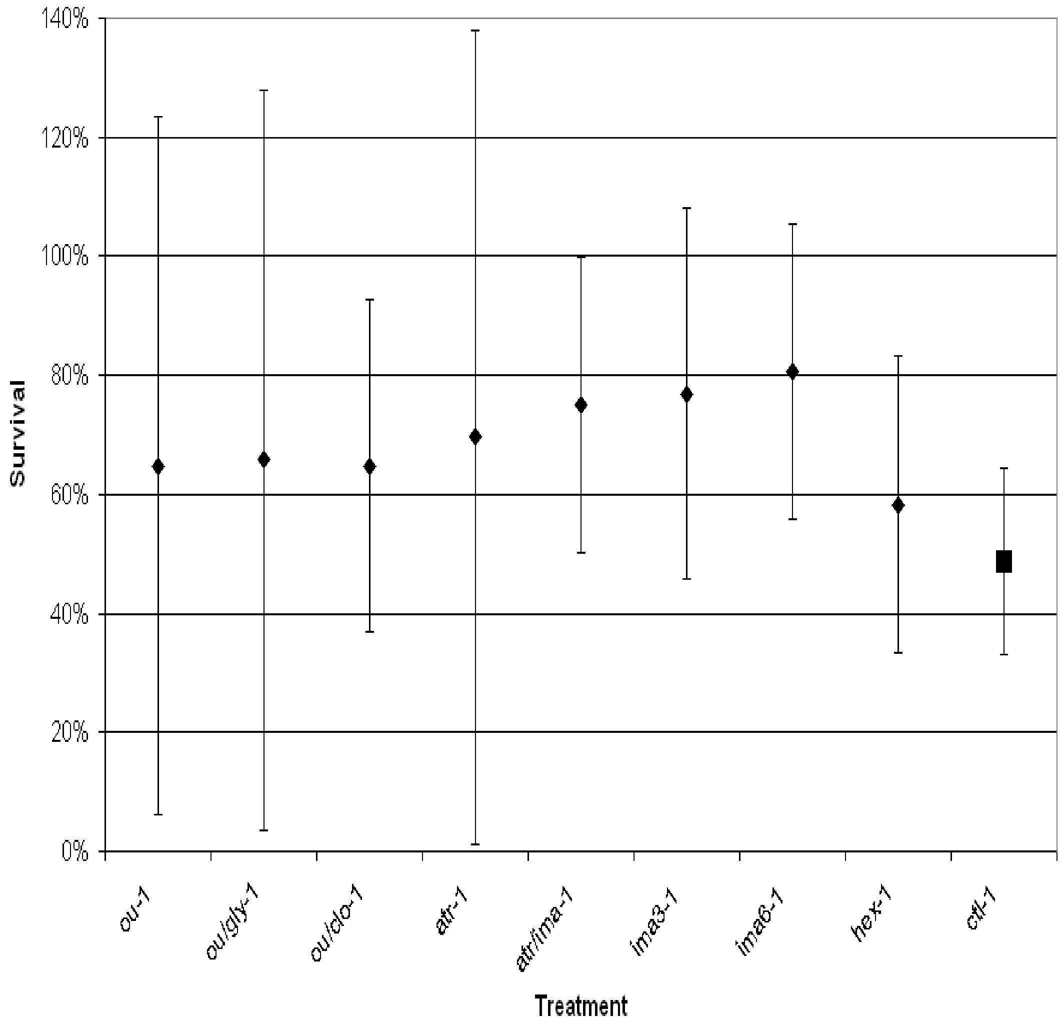


Figure A.14 Second-year larch plug survival.

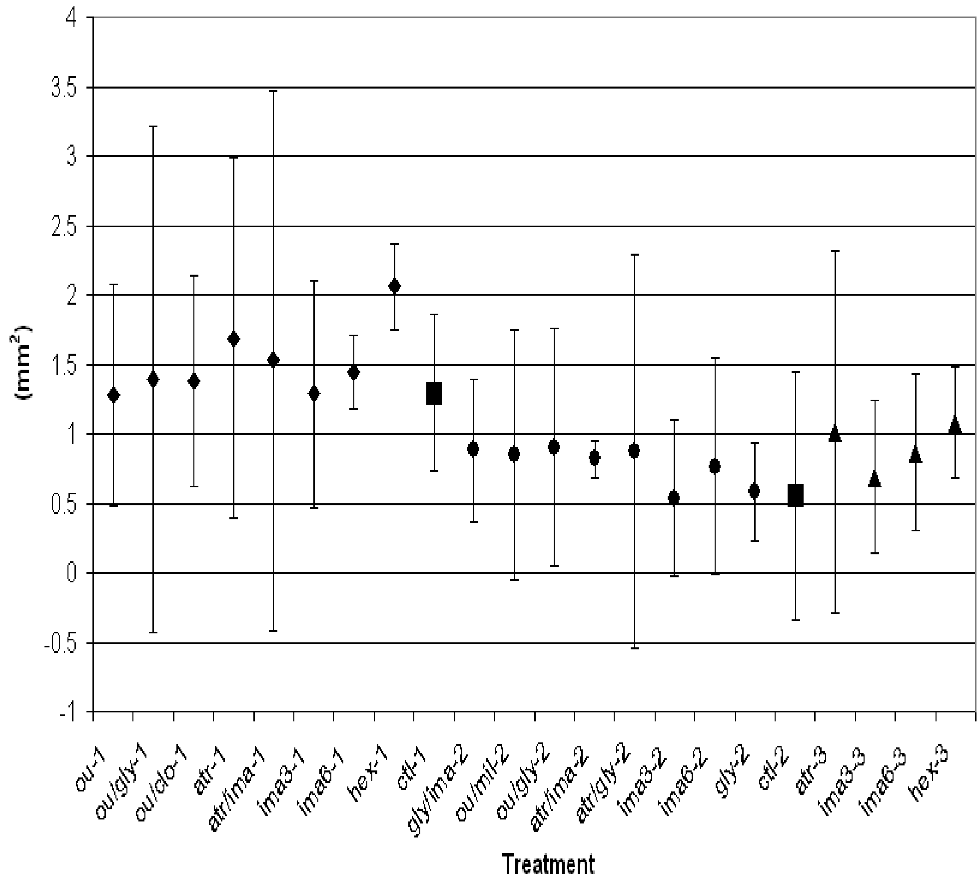


Figure A.15 First-year Douglas-fir basal area growth ($mm^2$).

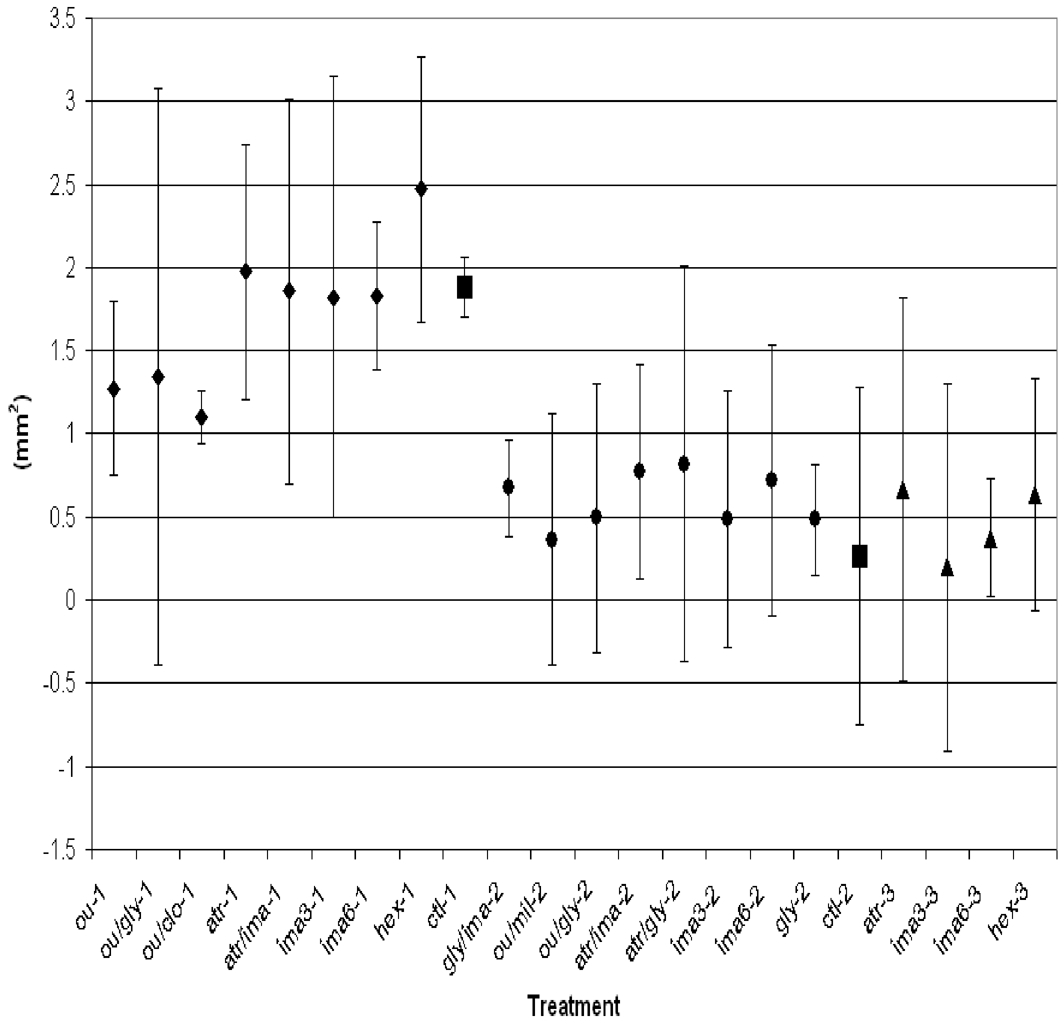


Figure A.16 First-year larch bareroot basal area growth ($mm^2$).

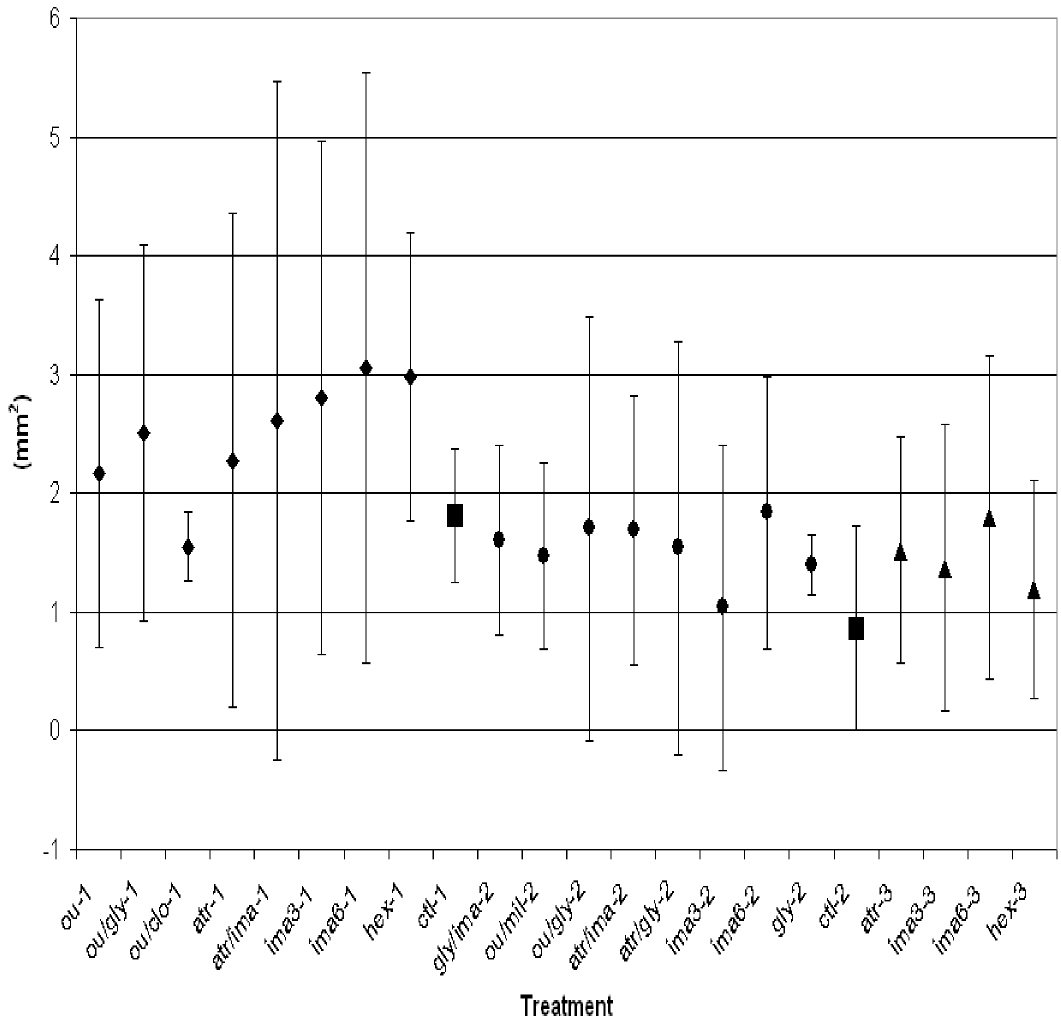


Figure A.17 First-year larch plug basal area growth ($mm^2$).

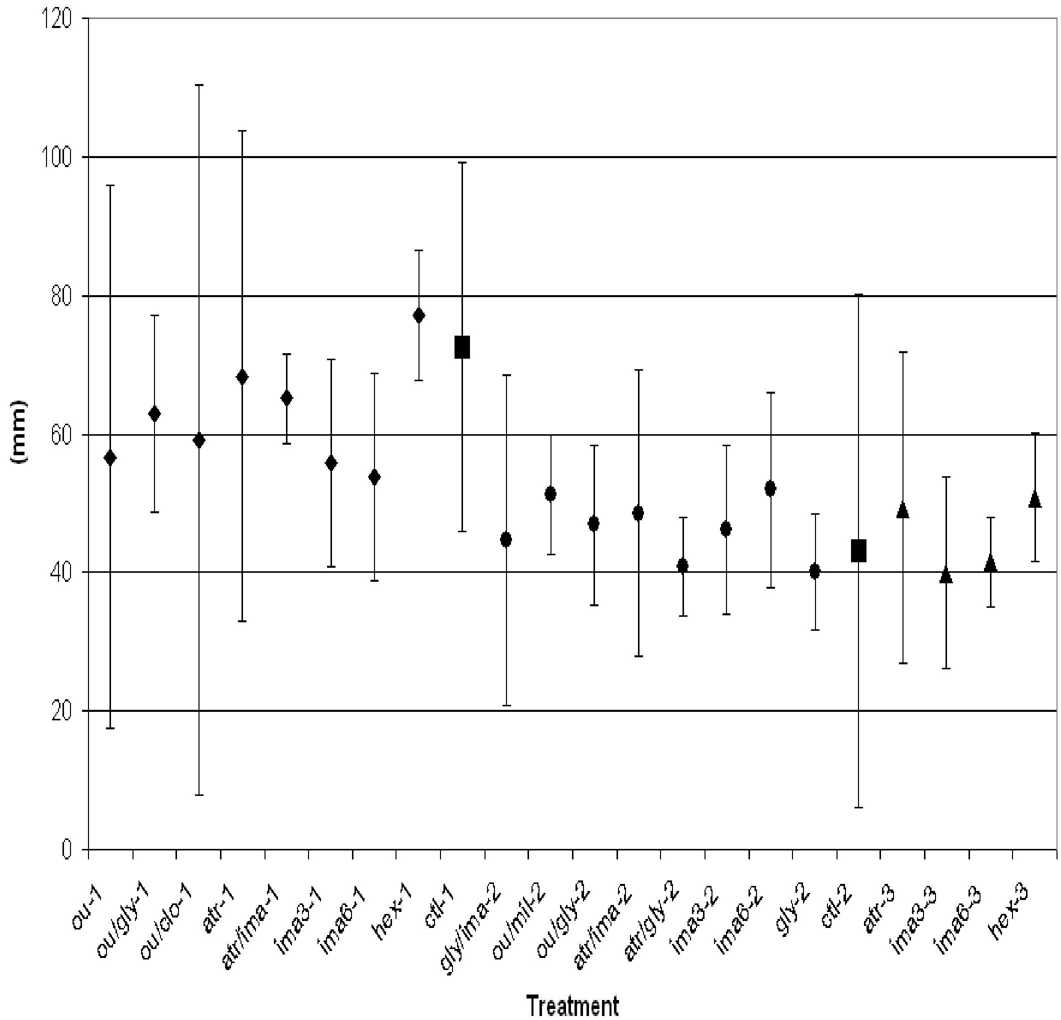


Figure A.18 First-year Douglas-fir height growth (mm).

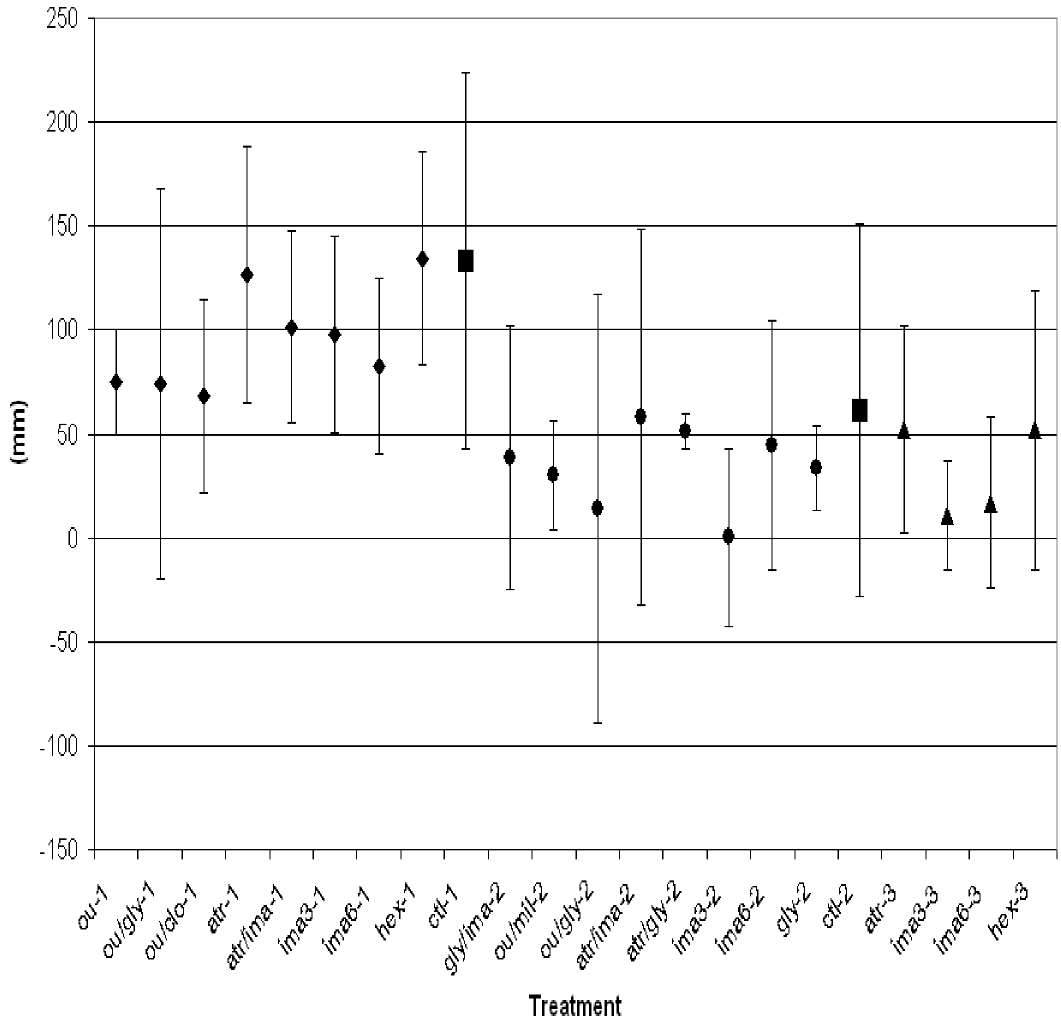


Figure A.19 First-year larch bareroot height growth (mm).

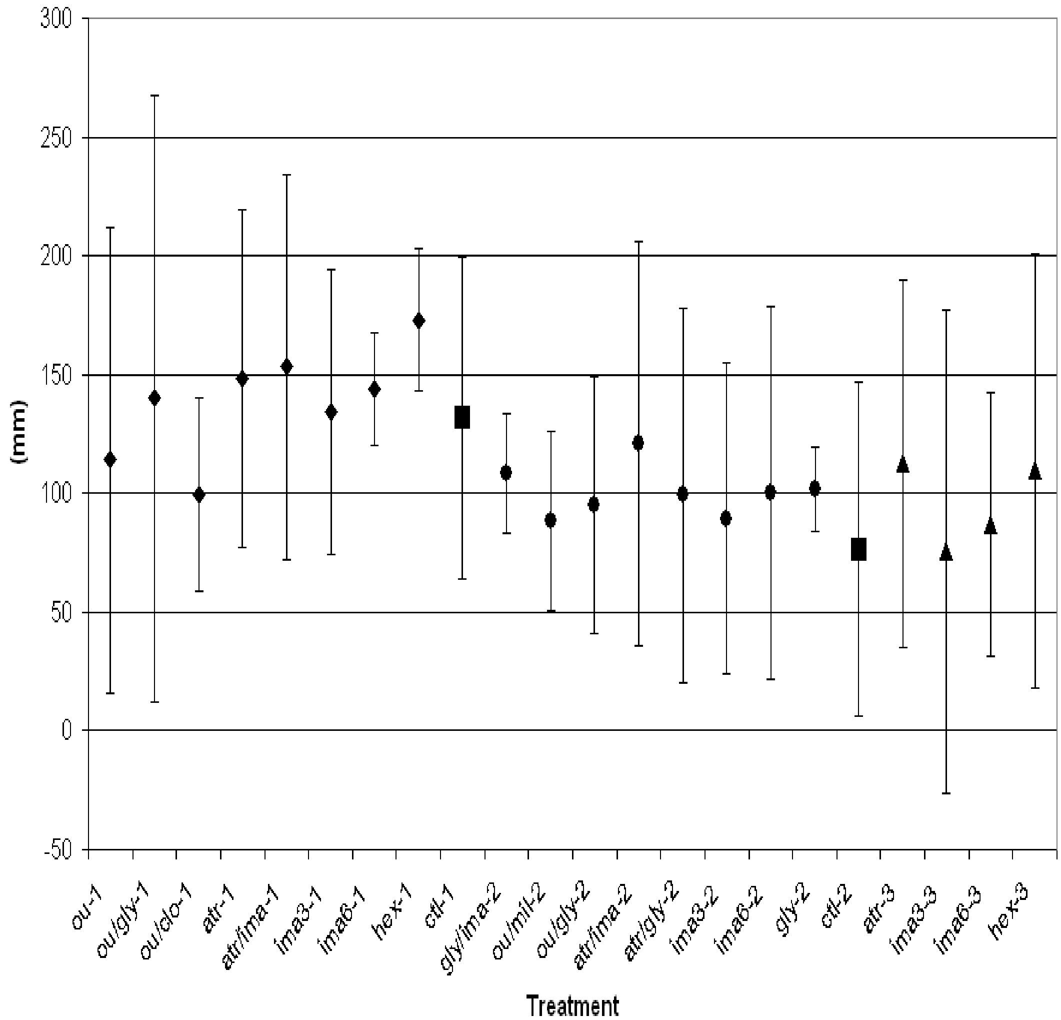


Figure A.20 First-year larch plug height growth (mm).

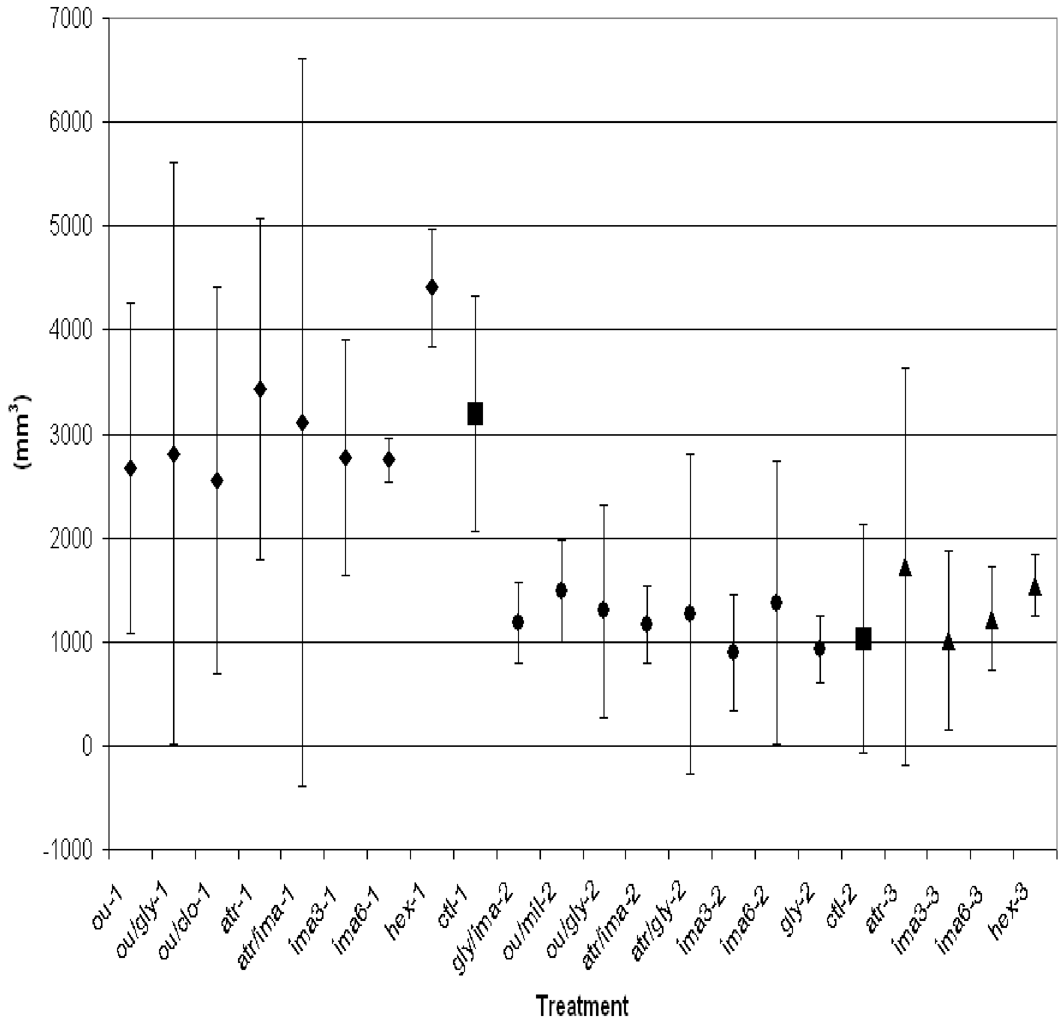


Figure A.21 First-year Douglas-fir volume growth ($mm^3$).

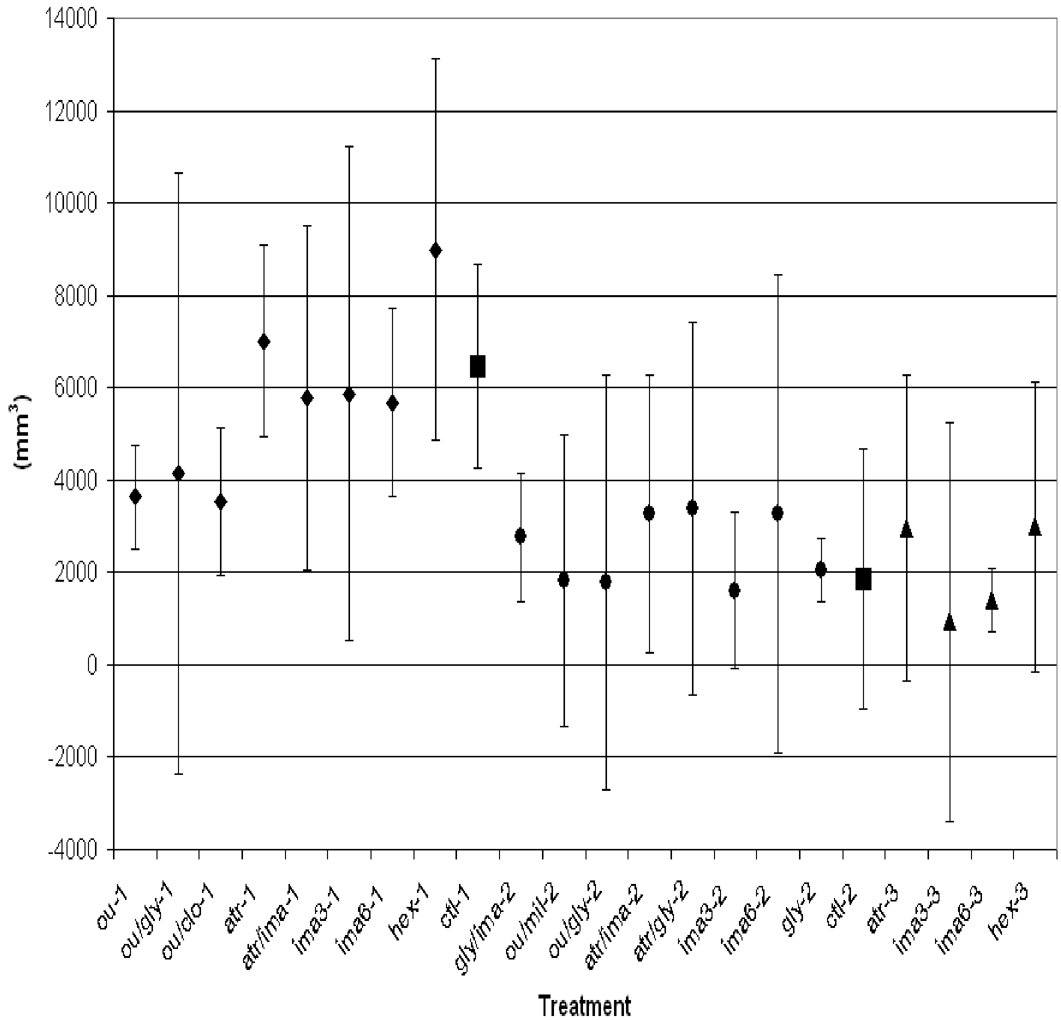


Figure A.22 First-year larch bareroot volume growth ($mm^3$).

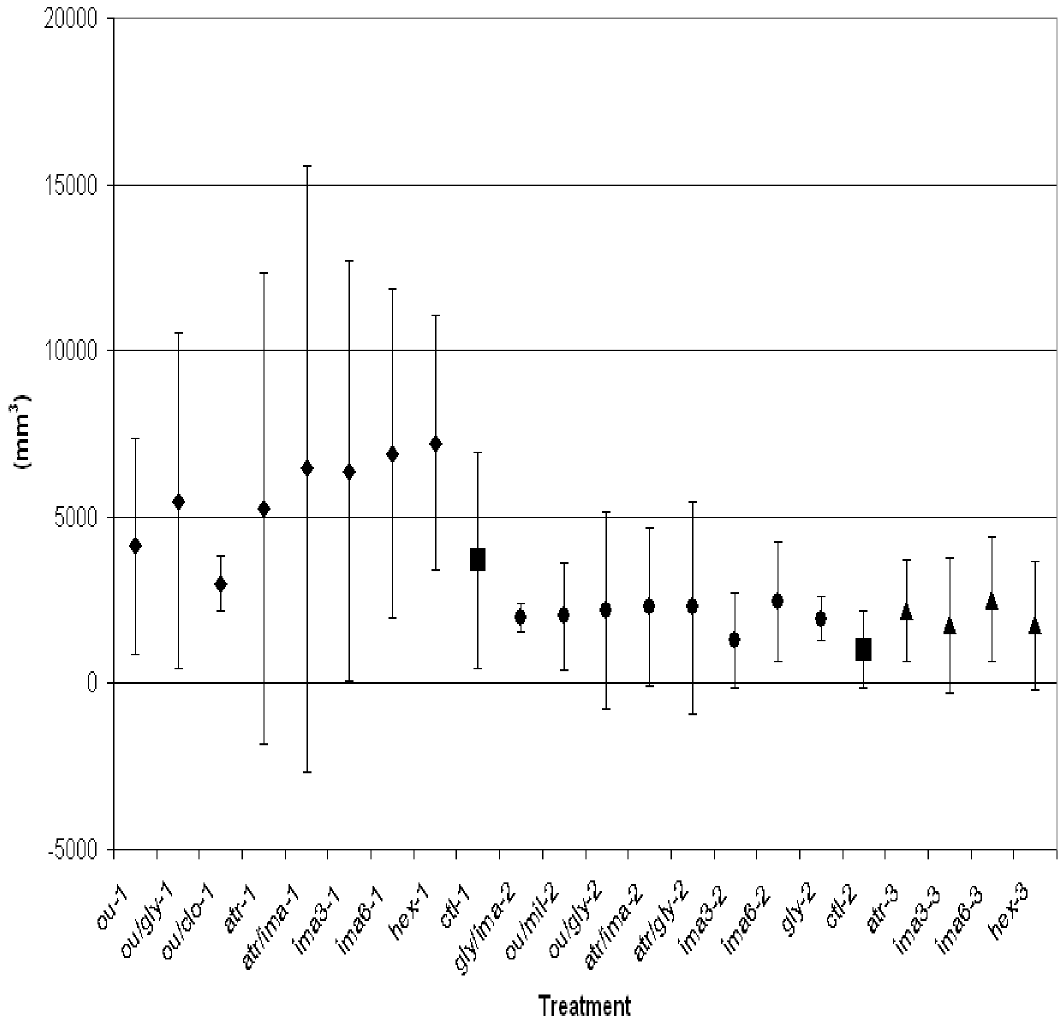


Figure A.23 First-year larch plug volume growth ($mm^3$).

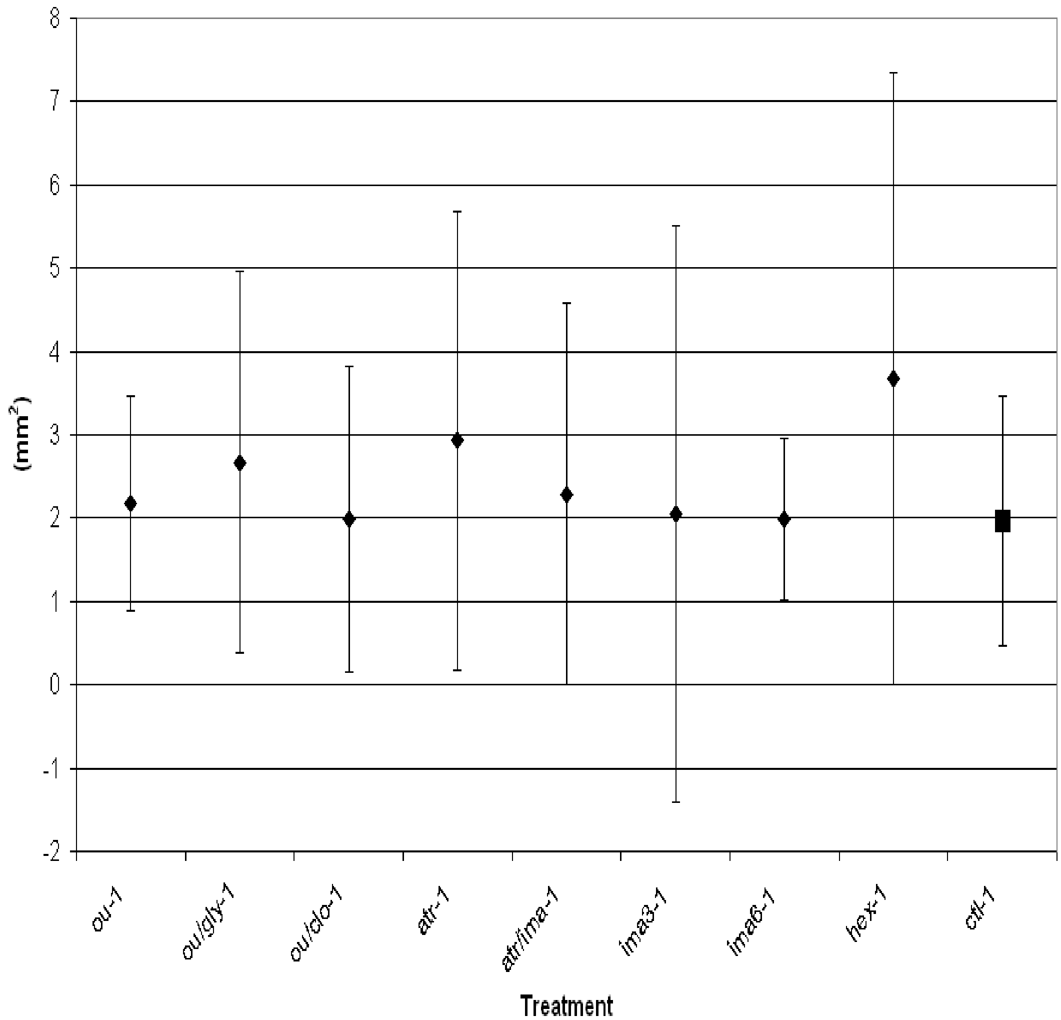


Figure A.24 Second-year Douglas-fir basal area growth ($mm^2$).

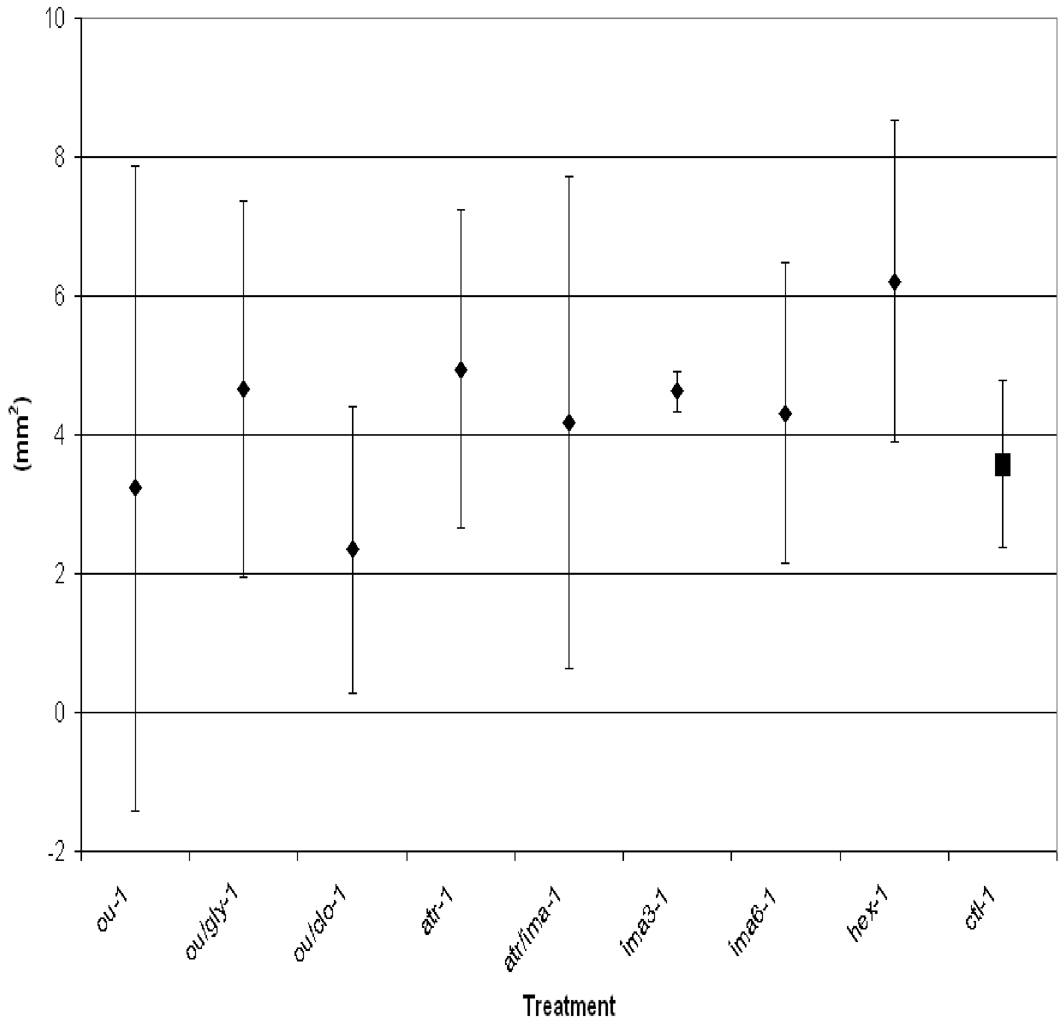


Figure A.25 Second-year larch bareroot basal area growth (mm$^2$).

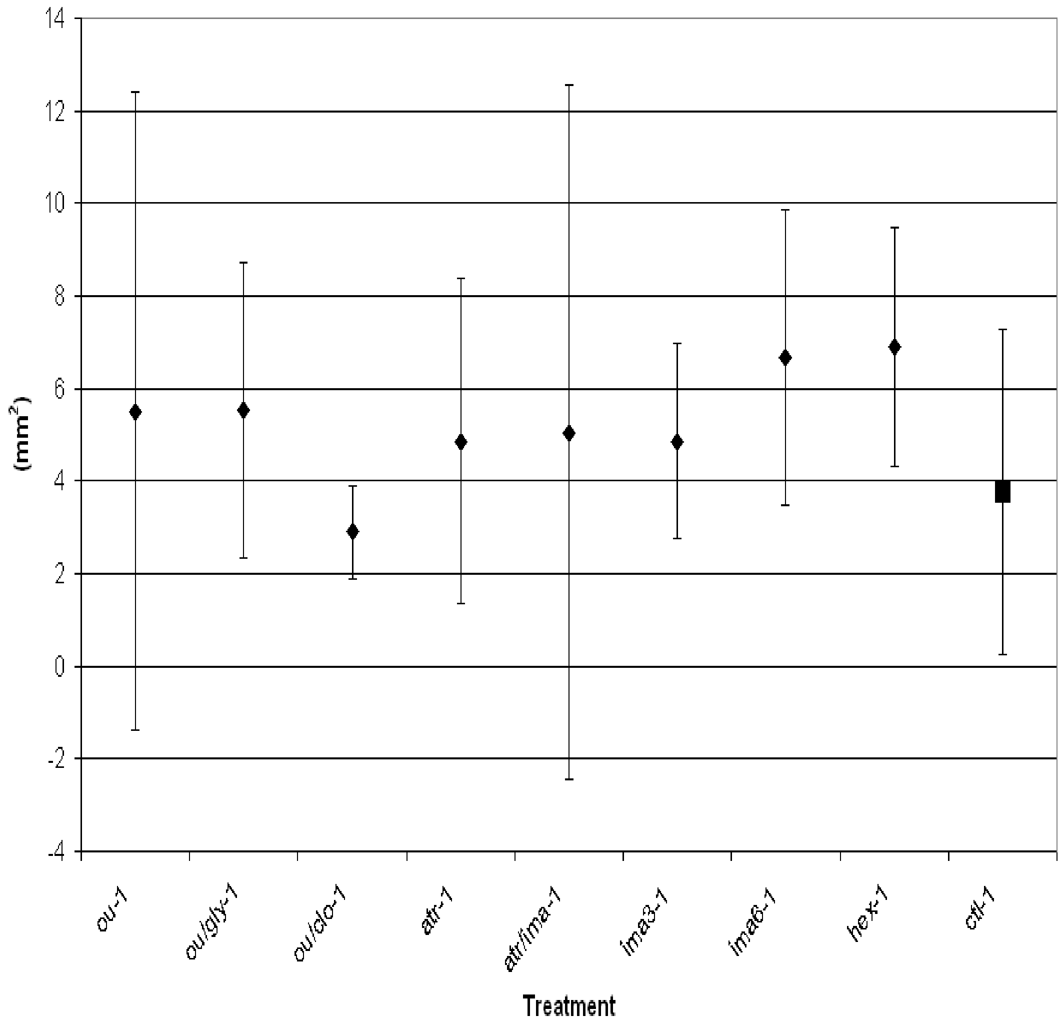


Figure A.26 Second-year larch plug basal area growth ($mm^2$).

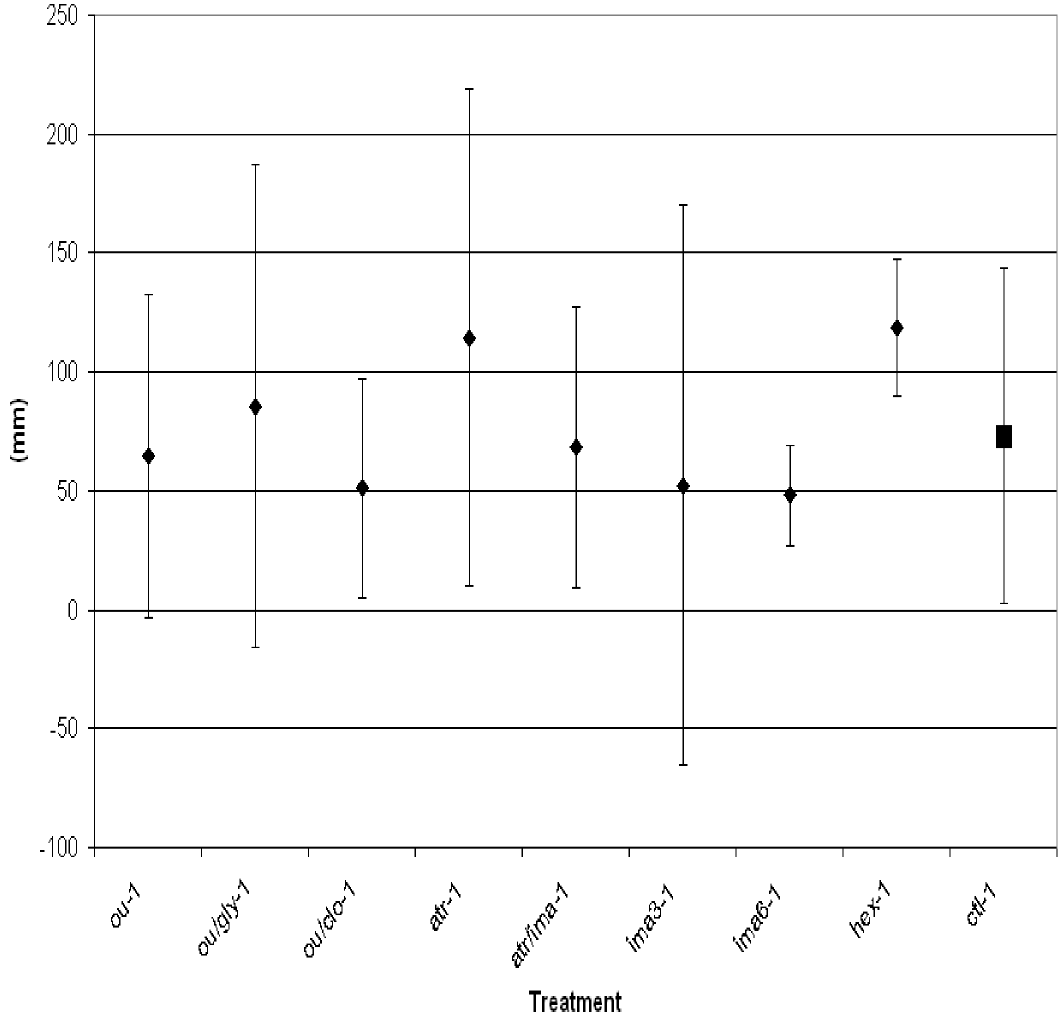


Figure A.27 Second-year Douglas-fir height growth (mm).

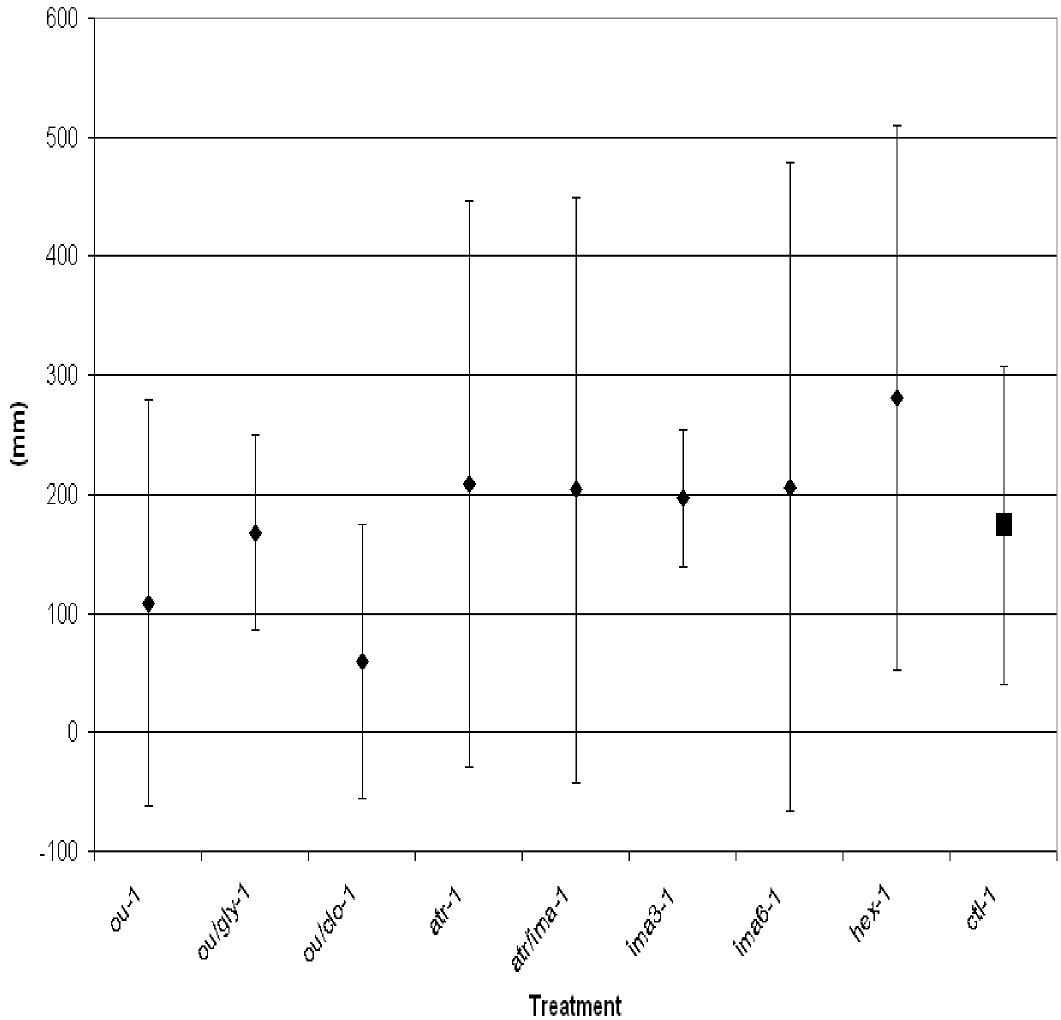


Figure A.28 Second-year larch bareroot height growth (mm).

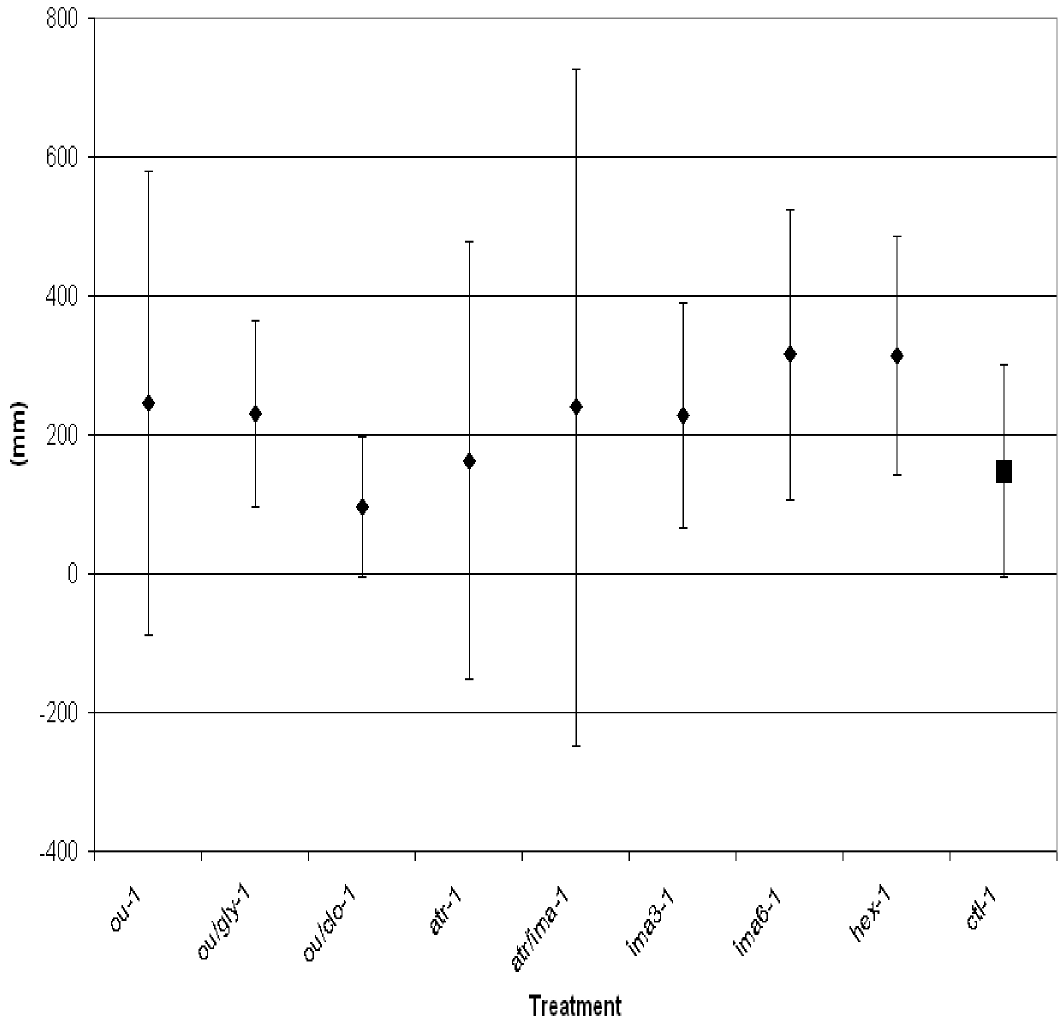


Figure A.29 Second-year larch plug height growth (mm).

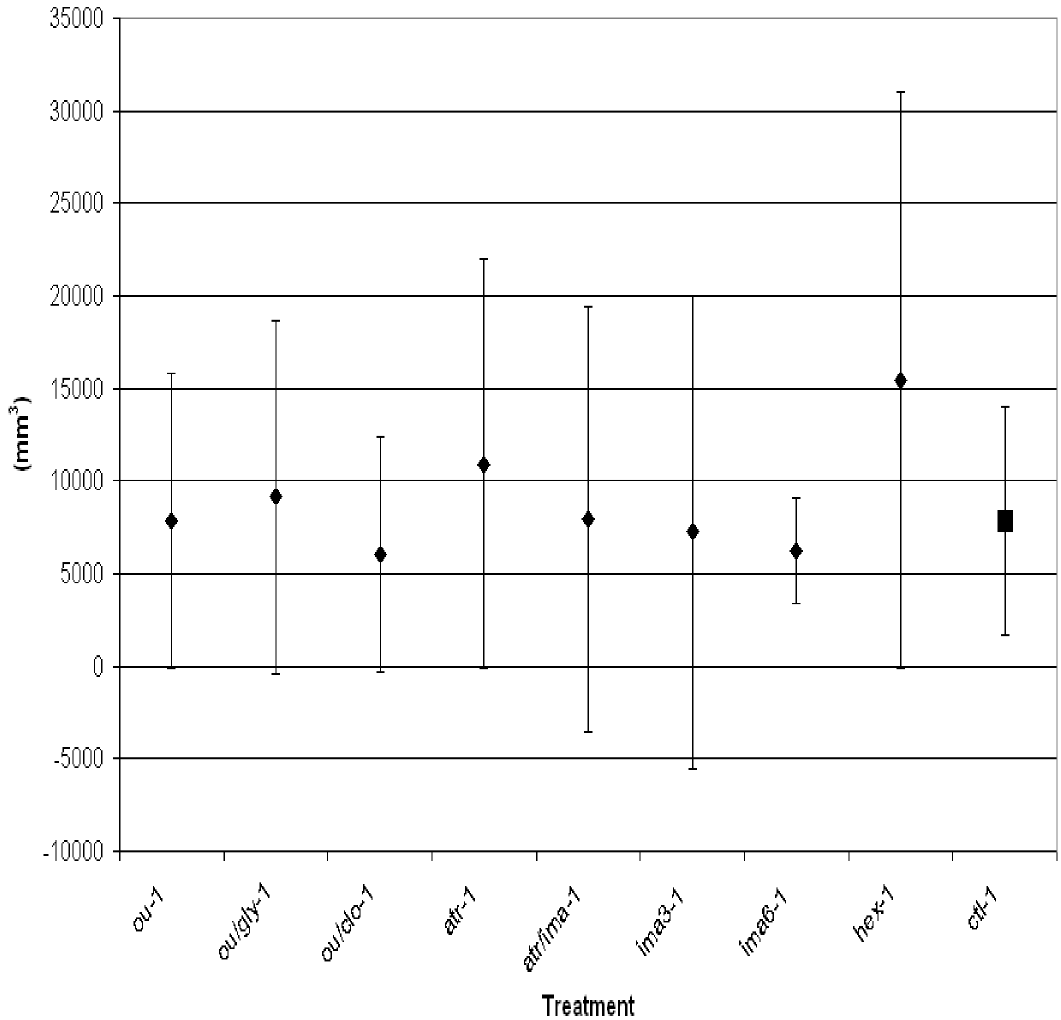


Figure A.30 Second-year Douglas-fir volume growth ($mm^3$).

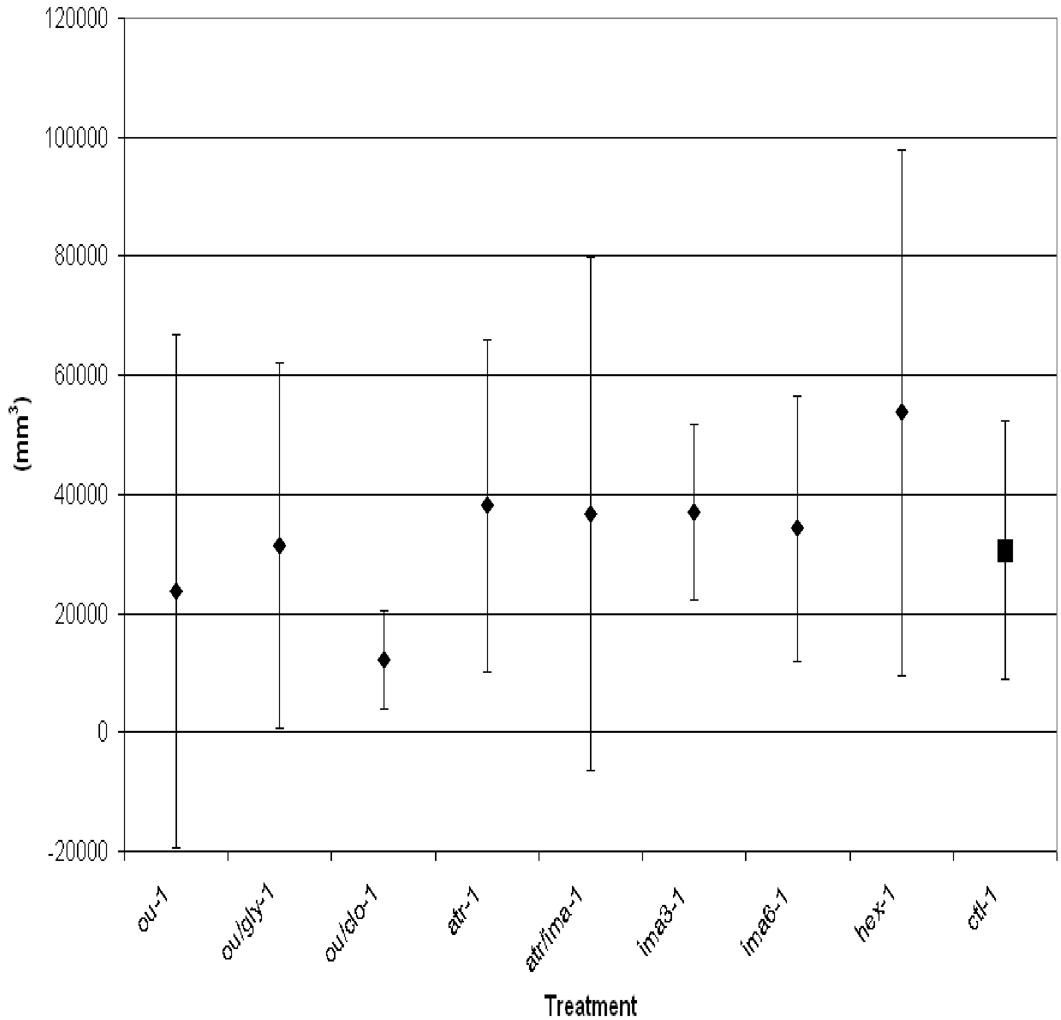


Figure A.31 Second-year larch bareroot volume growth ($mm^3$).

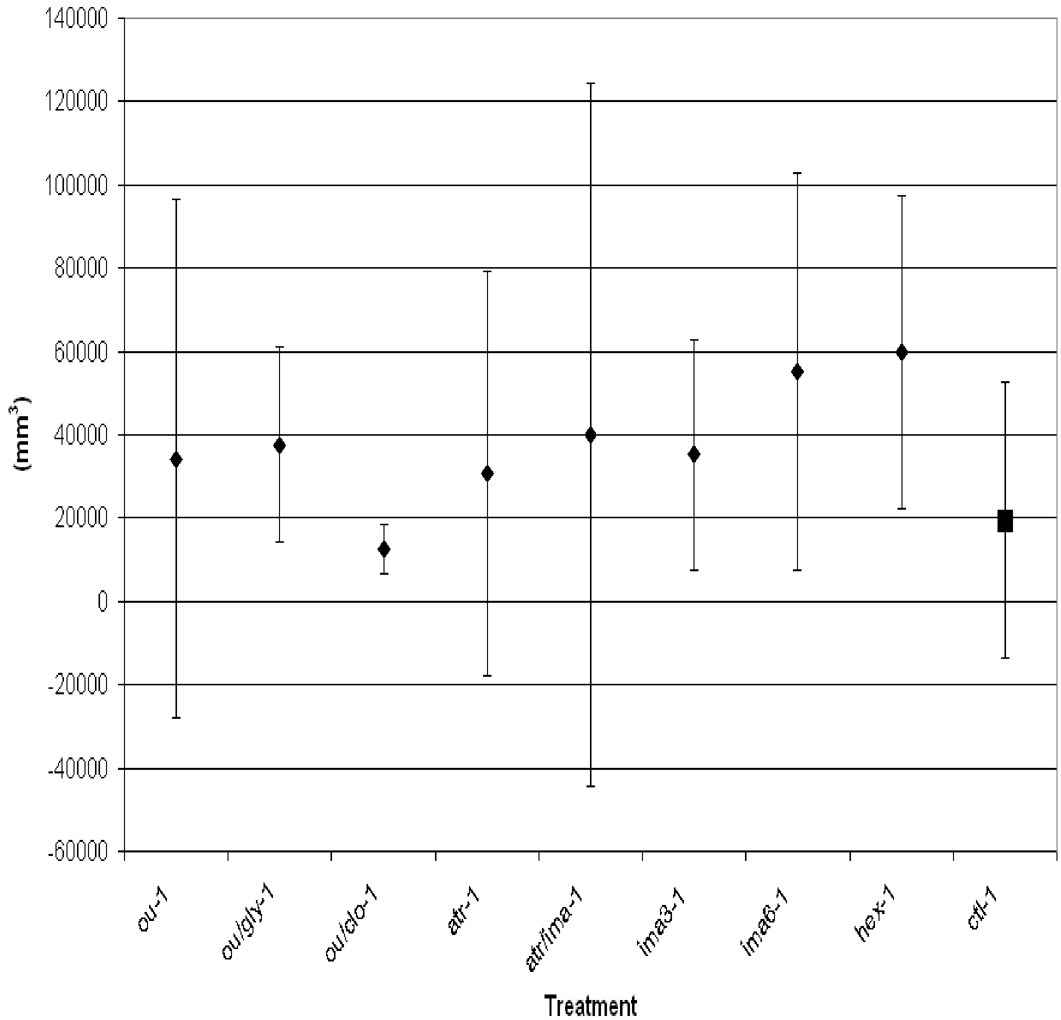


Figure A.32 Second-year larch plug volume growth ($mm^3$).