# Eight Year Response to N and N+S Fertilization for the Umatilla Mixed Conifer Study in Northeast Oregon and Southeast Washington

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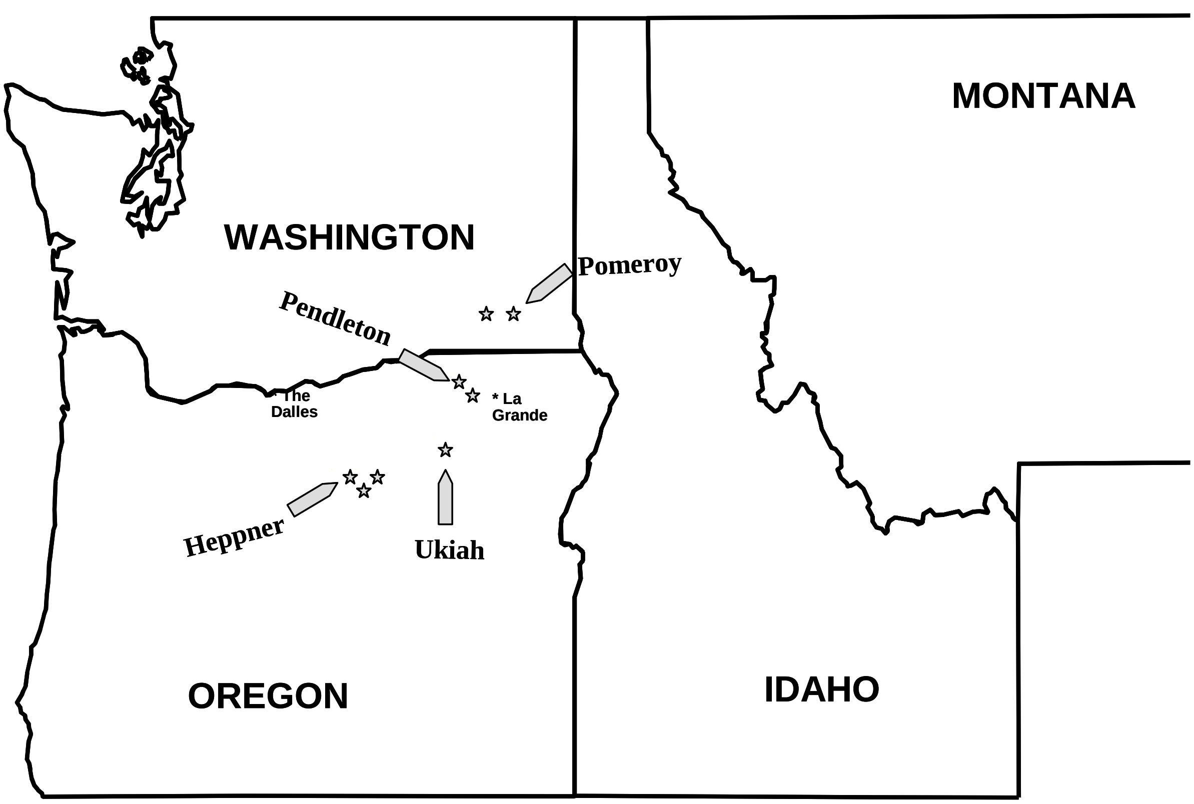
## SUMMARY

Eight study sites were established in 1991 on the Umatilla National Forest to study forest growth response to nitrogen and nitrogen-sulfur fertilization. The eight sites corresponded to four locations, Pomeroy, Pendleton, Ukiah and Heppner, which were arrayed in a linear fashion from northeast to southwest across the Forest. While this location effect was confounded with many other factors, it was an important blocking factor for analyses of fertilization growth response. However, it was difficult to identify which location factors influenced fertilization response. The more mature stands at Pomeroy and Pendleton were analyzed together, while the Ukiah and Heppner sites were analyzed separately. Overall, while both N and N+S showed positive growth responses, N+S provided the greatest eight-year volume response. This response was greatest for the mature stands at the Pomeroy and Pendleton study sites. A positive N+S response did occur at Heppner, but was only detectable in analysis of relative volume response. Ukiah did not show a significant fertilization response. Both Heppner and Ukiah were difficult to analyze and understand due to problems inherent in their small tree sizes and open-grown conditions, as well as to wide variation in initial conditions. Two-year periodic volume growth was also calculated and displayed for each of the four locations. Periodic fertilizer responses were strongest during the first two to six years of the study, and fertilizer effect has diminished to the point of being almost indiscernible during the most recent two-year period.

## Introduction

This study was established to evaluate the effects of fertilization on the growth of mixed conifer stands on the Umatilla National Forest in northeastern Oregon and southeastern Washington. The study is comprised of eight installations located in four different regions of the Forest. Two fertilization treatments were applied, one using nitrogen alone and the other using a combination of nitrogen and sulfur. Study plots were established and fertilized in the fall of 1991, and subsequent biannual measurements have been taken to detect treatment response. This report describes the methodology and the eight-year results of this study.

**Figure 1. Locations of Umatilla Mixed Conifer Study Sites**



## Methods

This study is located in the Blue Mountains of northeastern Oregon and southeastern Washington. Eight study sites were located on the Pomeroy, Pendleton, Ukiah, and Heppner ranger districts within the Umatilla National Forest. Two installations were established at each of the Pomeroy and Pendleton locations, one was established at Ukiah and three at Heppner. Geographically, these four locations are oriented in a line from northeast (NE) to southwest (SW), respectively. Figure 1 shows the locations of the study sites.

All eight installations were established in October 1991, in mixed conifer stands. The Pomeroy, Pendleton and Ukiah stands were regenerated naturally, and had been thinned 6-10 years prior to plot establishment. The three Heppner stands were planted, however the established spacing in two of these stands has been influenced by natural regeneration. Elevations range from 4500 to 5500 ft above sea level, and vegetation series are grand fir (Abies grandis) and subalpine fir (Abies lasiocarpa). Soil parent materials are basalts. Site characteristics for the eight study sites are given in Table 1.

**Table 1: Site characteristics for eight mixed conifer study sites located on the Umatilla National Forest in northeast Oregon and southeast Washington. Geographical locations are oriented from northeast (1) to southwest (4).**

| Location | Site | Elevation | Age | Veg. Series | Parent Material |
|---|---|---|---|---|---|
| 1 (NE) | Pomeroy #1 (313) | 5500 | 26 | ABLA | Grand Ronde Basalt |
| | Pomeroy #2 (314) | 5000 | 23 | ABGR | Grand Ronde Basalt |
| 2 | Pendleton #1 (315) | 4500 | 26 | ABGR | Lower Yakima Basalt |
| | Pendleton #2 (316) | 5500 | 24 | ABGR | Lower Yakima Basalt |
| 3 | Ukiah (320) | 4800 | 11 | ABGR | Upper Yakima Basalt |
| 4 (SW) | Heppner #1 (317) | 4780 | 10 | ABGR | Picture Gorge Basalt |
| | Heppner #2 (318) | 4800 | 10 | ABGR | Picture Gorge Basalt |
| | Heppner #3 (319) | 4800 | 10 | ABGR | Picture Gorge Basalt |

Each installation consists of six plots 0.1-ac in size, with surrounding buffer strips. Within each site, the plots are grouped into two blocks of three according to tree and site similarities. The three treatments applied in each block included a control (C), 200 lb/ac (225 kg/ha) nitrogen (N), and 200 lbs/ac nitrogen plus 100 lbs/ac (113 kg/ha) sulfur (N+S). Nitrogen was applied in the form of urea, and sulfur in the form of ammonium sulfate. Treatments were applied at the time of plot establishment in 1991.

Initial measurements were taken at the time of establishment, and all live trees taller than 4.5 ft (1.35 m) were tagged and measured for height, diameter and defect. Tree diameters were measured every two years, and any incidence of damage or mortality was noted at each visit. Diameter measurements occurred during the fall months of 1993, 1995, 1997, and 1999. Height measurements were taken every four years (1995 and 1999). Tree volumes were estimated using regional species-specific volume equations (Wykoff et al. 1982). Details on stand characteristics at time of establishment (1991) and at each remeasurement period are given in the appendix.

## Analysis

Each of the eight installations consists of two blocks of three plots each, in a split-plot arrangement. As can be seen in Figure 1, the eight installations occurred in four groups corresponding geographically to the four ranger districts. During the first growth response analysis performed in 1994, we found that this location grouping was an important factor explaining growth response differences. Subsequent analyses have been performed using this 'location effect' as a primary factor. For this arrangement, a split-plot design is still utilized, however blocks per location replaces blocks per installation as the experimental units. This works reasonably well for analysis, although the differing number of installations at each location leads to an unbalanced experimental design. The Pomeroy and Pendleton locations each have four blocks, whereas Ukiah has only two and Heppner has six. However a perhaps more serious problem is the number of confounding factors across the four locations, making it difficult to determine if one or a combination of factors, or something else entirely, influenced fertilization response. Geographic location effects could result from differences in rainfall or other climatic or environmental factors. In addition to these regional variables, a number of stand conditions also contribute to the possible confounding factors. Several factors which differ between the four locations are shown in Table 2.

**Table 2. Possible confounding factors described by the 'location' variable for the Umatilla mixed species fertilization study. Stand characteristics are year 0 initial conditions.**

| **Location** | **Basalt Flow** | **TPA** | **BA** | **Stand Density Index** | **Primary species composition*** |
|---|---|---|---|---|---|
| **Pomeroy** | Grande Ronde | 380-480 | 42-70 | 20-29 | wl/ gf/ pp |
| **Pendleton** | Lower Yakima | 200-330 | 53-103 | 22-34 | PP/ gf/ wl |
| **Ukiah** | Upper Yakima | 410-560 | 10-31 | 8-17 | WL/ PP |
| **Heppner** | Picture Gorge | 280-500 | 1-5 | 1-4 | DF/ PP |

*** Upper case means >40% composition, lower case means <35% composition**

In addition to the factors described above, the starting conditions within a block were different such that fertilization response was difficult to detect. This situation was particularly noticeable for the Ukiah and Heppner installations, because the trees were so small initially that the range of basal areas within a block varied by as much as 85%. The ranges of initial basal areas, quadratic mean diameters and stand density indices for each block are shown in Table 3.

**Table 3. Range of initial conditions, by block, for the Umatilla mixed conifer fertilization study.**

| **Location** | **Installation** | **Basal Area Yr 0** | **Quadratic mean** | **Stand Density** |
|---|---|---|---|---|

| | and block | | diameter Yr 0 | Index Yr 0 |
|---|---|---|---|---|
| **Pomeroy** | 313-1 | 56.8-69.6 | 5.2-5.6 | 25.0-29.5 |
| | 313-2 | 49.3-63.9 | 4.5-5.0 | 23.3-28.6 |
| | 314-1 | 42.2-45.7 | 4.2-4.7 | 20.1-21.1 |
| | 314-2 | 48.8-50.0 | 4.4-4.8 | 20.9-22.9 |
| | | | | |
| **Pendleton** | 315-1 | 83.1-100.8 | 7.8-8.8 | 28.1-34.0 |
| | 315-2 | 83.2-103.2 | 7.4-9.3 | 30.6-33.9 |
| | 316-1 | 53.2-79.8 | 5.9-7.2 | 21.9-29.7 |
| | 316-2 | 72.2-86.9 | 6.9-8.5 | 27.5-29.8 |
| | | | | |
| **Ukiah** | 320-1 | 10.8-17.7 | 1.9-2.8 | 7.8-10.6 |
| | 320-2 | 16.8-31.2 | 2.5-3.2 | 10.6-17.4 |
| | | | | |
| **Heppner** | 317-1 | 1.6-2.1 | 0.8-0.9 | 1.7-2.2 |
| | 317-2 | 2.4-4.1 | 0.9-1.3 | 2.5-3.6 |
| | 318-1 | 2.2-4.6 | 1.0-1.4 | 2.1-3.9 |
| | 318-2 | 2.2-5.3 | 1.1-1.5 | 2.0-4.3 |
| | 319-1 | 1.1-2.2 | 0.7-1.0 | 1.2-2.2 |
| | 319-2 | 2.5-3.7 | 1.3-1.6 | 2.2-3.0 |

Due to the wide tree size differences across installations, we decided to divide the four location groupings into three sets of analyses for the current (year 8) report. The first included the Pomeroy and Pendleton large-tree installations. The second grouping included the three small-tree Heppner installations. Finally, due to its dissimilarity to any of the other stands, Ukiah was analyzed separately. This solved several problems for the larger trees. The data were now balanced with two installations at each of the two locations. Furthermore, the starting conditions were much more similar and within-block differences smaller than for the other two locations. However for the smaller trees at Ukiah and Heppner, differences in initial conditions remained. Several data adjustments and analytical approaches were undertaken. For both sites, the plot-level values for all independent variables were recalculated using only those trees which were greater than or equal to 6.5 ft in height at the time of plot establishment (1991). This was done to eliminate the variation caused by 'ingrowth' of small trees which were close to the 4.5 ft height limit for measurement trees. Relative eight-year volume growth, which is eight-year growth expressed as a percentage of initial volume, was calculated for the Heppner sites. For the Ukiah, Heppner and the Pomeroy/ Pendleton groups, absolute volume growth, absolute basal area growth, and absolute height growth were analyzed. Gross and net results were similar, so only the results for gross response are provided in this report. Dependent variables used for each of the three sets of analysis are summarized in Table 4.

**Table 4. Variables used during analyses of growth response to fertilization**

| **Dependent Variable** | **Calculation of Variable** |
|---|---|
| ***Pomeroy (313, 314) and Pendleton (315, 316)*** | |
| Absolute 8-year Volume Increment | Volume8 - Volume0 |
| Absolute 8-year Basal Area Increment | BA8 - BA0 |
| Absolute 8-year Height Increment | Height8 - Height0 |
| | |
| ***Heppner (317, 318, 319)*** | |
| Relative 8-year Volume Increment | (Volume8-Volume0) / Volume0 * 100 |
| Absolute 8-year Volume Increment | Volume8 - Volume0 |
| Absolute 8-year Basal Area Increment | BA8 - BA0 |
| Absolute 8-year Height Increment | Height8 - Height0 |
| | |
| ***Ukiah (320)*** | |
| Absolute 8-year Volume Increment | Volume8 - Volume0 |
| Absolute 8-year Basal Area Increment | BA8 - BA0 |
| Absolute 8-year Height Increment | Height8 - Height0 |

The Pomeroy/ Pendleton and Heppner analyses were performed using a mixed-model split-block factorial design. The Pomeroy and Pendleton analysis used the following model statement:

$$\mathbf{Y_{ijk} = \mu + \alpha_j + \pi_{i(j)} + \beta_k + (\alpha\beta)_{jk} + (\beta\pi)_{ki(j)} + \varepsilon_{ijk}}$$

*Where*

$Y_{ijk}$ = value in each block for each location and treatment combination

$\mu$ = grand mean

$\alpha_j$ = location effect (fixed)

$\pi_{i(j)}$ = block effect for block within location (random)

$\beta_k$ = fertilization treatment effect (fixed)

$(\alpha\beta)_{jk}$ = location by treatment interaction

$(\beta\pi)_{ki(j)}$ = treatment by block interaction

$\varepsilon_{ijk}$ = error term

The Heppner analysis was performed using the model statement:

$$\mathbf{Y_{ijk} = \mu + \alpha_j + \pi_{i(j)} + \beta_k + (\alpha\beta)_{jk} + (\beta\pi)_{ki(j)} + \varepsilon_{ijk}}$$

*Where*

$Y_{ijk}$ = value in each block for each installation and treatment combination

$\mu$ = grand mean

$\alpha_j$ = installation effect (random)

$\pi_{i(j)}$ = block effect for block within installation (random)

$\beta_k$ = fertilization treatment effect (fixed)

$(\alpha\beta)_{jk}$ = installation by treatment interaction

$(\beta\pi)_{ki(j)}$ = treatment by block interaction

$\varepsilon_{ijk}$ = error term

Since the Ukiah location was represented by only one installation, the data were analyzed as a simple randomized block design. The model statement for this analysis was:

$$\mathbf{Y_{ijk} = \mu + \alpha_j + \pi_i + \varepsilon_{ijk}}$$

*Where*

$Y_{ijk}$ = value in each block for each treatment

$\mu$ = grand mean

$\alpha_j$ = treatment effect (fixed)

$\pi_{i(j)}$ = block effect (random)

$\varepsilon_{ijk}$ = error term

For all basal area and volume analyses, initial basal area ($BA_0$) was included as a covariate. Height growth analyses used no covariate. All analyses were performed using the analysis of variance procedures in the general linear models module of SAS (SAS Institute Inc. 1985).

## Results and Discussion

Pomeroy and Pendleton

Eight-year volume, basal area and height results for the four installations at Pomeroy and Pendleton showed that the treatment effects were significant for volume (p=.0080), marginally significant for basal area (p=.1010), and non-significant for height (p=.2041). Examination of least squares means for volume showed significantly greater growth on both the N and N+S plots than on the control plots. Basal area tended towards greater growth for the N treatments and showed significantly greater growth on the N+S treatments. Height growth was significantly greater on the N treatments, and tended to be greater on the N+S treatments.

Growth estimates for each location were adjusted to the average initial basal area per location (53 $ft^2$/ac for Pomeroy and 82 $ft^2$/ac for Pendleton). Average growth estimates over both locations were adjusted to the overall $BA_0$ of 67 $ft^2$/ac. Using these adjusted estimates, fertilization response was also calculated, using the following equation:

Response = (Fertilized Growth - Control Growth)/Control Growth * 100

Growth increments and responses for the Pomeroy and Pendleton sites are summarized in Table 5.

**Table 5: Absolute volume, basal area and height growth by treatment across the Pomeroy and Pendleton locations for Umatilla mixed conifer study in northeast Oregon and southeast Washington. Treatments include control (C), 200#/ac nitrogen (N), and 200#/ac nitrogen plus 100#/ac sulfur (N+S).**

**Absolute Volume Growth**

| Location | Treatment | Absolute Volume Growth (ft3/ac) | Response Contrast | Percent Response # |
|---|---|---|---|---|
| Pomeroy | Control | 1052 | | |
| | N | 1188 | N-Control | 12.9* |
| | N+S | 1265 | NS-Control | 20.2** |
| | | | NS-N | 6.5 |
| | | | | |
| Pendleton | Control | 1695 | | |
| | N | 1797 | N-Control | 6.0 |
| | N+S | 1843 | NS-Control | 8.7** |
| | | | NS-N | 2.5 |
| | | | | |
| Overall | Control | 1374 | | |
| | N | 1492 | N-Control | 8.6** |
| | N+S | 1554 | NS-Control | 13.1** |
| | | | NS-N | 4.1 |

**Absolute Basal Area Growth**

| Treatment | Absolute Basal Area Growth (ft2/ac) | Response Contrast | Percent Response # |
|---|---|---|---|
| Control | 49 | | |
| N | 56 | N-Control | 13.7* |
| N+S | 58 | NS-Control | 17.0** |
| | | NS-N | 2.9 |
| | | | |
| Control | 68 | | |
| N | 70 | N-Control | 3.1 |
| N+S | 72 | NS-Control | 6.0 |
| | | NS-N | 2.9 |
| | | | |
| Control | 59 | | |
| N | 63 | N-Control | 7.6 |
| N+S | 65 | NS-Control | 10.7** |
| | | NS-N | 2.9 |

**Absolute Height Growth**

| Location | Treatment | Absolute Height Growth (ft) | Response Contrast | Percent Response # |
|---|---|---|---|---|
| Pomeroy | Control | 11.2 | | |
| | N | 11.4 | N-Control | 1.7 |
| | N+S | 11.5 | NS-Control | 2.9 |
| | | | NS-N | 1.1 |
| | | | | |
| Pendleton | Control | 13.6 | | |
| | N | 14.2 | N-Control | 3.9 |
| | N+S | 14.4 | NS-Control | 5.4 |
| | | | NS-N | 1.4 |
| | | | | |
| Overall | Control | 12.4 | | |
| | N | 12.8 | N-Control | 2.9 |
| | N+S | 12.9 | NS-Control | 4.2* |
| | | | NS-N | 1.3 |

**# : * Indicates significance at p=.10;  ** Indicates significance at p=.05**

The results shown in Table 5 indicate that for the mature stands at Pomeroy and Pendleton, the application of both N and N+S resulted in significant increases in volume growth during the eight year study period. The Pomeroy sites showed the greatest percentage response, with significant 12.9 and 20.2% increases to N and N+S respectively. The Pendleton response was lower, with a 6% response to N and a significant 8.7% response to N+S. For both Pendleton and Pomeroy, response was greater following N+S fertilization than N-only, however the difference between responses was not significant. Overall, the 13.1% volume response to N+S was greater than the 8.7% response to N-only, and both responses were significant.

Basal area (BA) response for the northeast group to N+S was also positive and significant, with an overall 10.7% increase in BA growth during the eight-year measurement period. The response to N-only, while not significant, did show a positive trend of 7.6% during the measurement period. The Pomeroy installations showed significant positive responses of 13.7% and 17% to N and N+S fertilization respectively. The Pendleton responses of 3% and 6% were not significant at p=.10. The Pomeroy sites not only responded better than the Pendleton sites to fertilization, but they responded so strongly as to drive the overall significance for the combined sites.

Height growth showed a significant overall increase of 4.2% to N+S fertilization. While both locations showed greater height growth following N+S than N-only fertilization, these responses were not significant at p=.10. However it is interesting to note that while BA growth tended to be greater at Pomeroy than Pendleton, height growth tended to be greater at Pendleton than at Pomeroy. According to Table 2, basal area conditions and stand density index were generally greater for Pendleton than for Pomeroy. These higher densities may cause the trees to respond to fertilization by increasing height growth rather than diameter growth, which may explain the differences in both height and BA growth between the two locations. By implication this also affects overall volume response, as basal area is more important in volume determination than is height. These results also offered evidence that lower-density stands responded better to fertilization, highlighting the importance of density management in addition to fertilization as an important nutrient management activity.

<u>Heppner</u>

The three installations at Heppner were analyzed for absolute volume, relative volume, absolute BA and absolute height growth. Results of volume analyses are shown in Table 6a, while basal area and height results are shown in Table 6b.

**Table 6(a): Absolute and relative volume growth by treatment across the Heppner installations for Umatilla mixed conifer study in northeast Oregon. Treatments include control (C), 200#/ac nitrogen (N), and 200#/ac nitrogen plus 100#/ac sulfur (N+S).**

**Absolute Volume Growth**

| Installation | Treatment | Absolute Volume Growth (ft3/ac) | Response Contrast | Percent Response # |
|---|---|---|---|---|
| 317 | Control | 515 | | |
| | N | 393 | N-Control | -23.7 |
| | N+S | 462 | NS-Control | -10.3 |
| | | | NS-N | 17.6 |
| | | | | |
| 318 | Control | 373 | | |
| | N | 376 | N-Control | 0.9 |
| | N+S | 389 | NS-Control | 4.3 |
| | | | NS-N | 3.3 |
| | | | | |
| 319 | Control | 355 | | |
| | N | 331 | N-Control | -6.8 |
| | N+S | 389 | NS-Control | 9.4 |
| | | | NS-N | 17.4 |
| | | | | |
| Overall | Control | 414 | | |
| | N | 367 | N-Control | -11.5 |
| | N+S | 413 | NS-Control | -0.3 |
| | | | NS-N | 12.6 |

**Relative Volume Growth**

| Treatment | Relative Volume Growth (% of initial volume) | Response Contrast | Percent Response # |
|---|---|---|---|
| Control | 2484 | | |
| N | 2051 | N-Control | -17.4 |
| N+S | 2770 | NS-Control | 11.5 |
| | | NS-N | 35.1 |
| | | | |
| Control | 2113 | | |
| N | 2142 | N-Control | 1.4 |
| N+S | 2448 | NS-Control | 15.9 |
| | | NS-N | 14.3 |
| | | | |
| Control | 2124 | | |
| N | 2101 | N-Control | -1.1 |
| N+S | 2668 | NS-Control | 25.6 |
| | | NS-N | 27.0 |
| | | | |
| Control | 2240 | | |
| N | 2098 | N-Control | -6.4 |
| N+S | 2628 | NS-Control | 17.3 |
| | | NS-N | 25.3* |

**# : * Indicates significance at p=.10;  ** Indicates significance at p=.05**

**Table 6(b): Absolute basal area and height growth by treatment across the Heppner installations for Umatilla mixed conifer study in northeast Oregon. Treatments include control (C), 200#/ac nitrogen (N), and 200#/ac nitrogen plus 100#/ac sulfur (N+S).**

**Absolute Basal Area Growth**

| Installation | Treatment | Absolute Basal Area Growth (ft2/ac) | Response Contrast | Percent Response # |
|---|---|---|---|---|
| 317 | Control | 43 | | |
| | N | 34 | N-Control | -20.5 |
| | N+S | 41 | NS-Control | -5.0 |
| | | | NS-N | 19.5 |
| | | | | |
| 318 | Control | 39 | | |
| | N | 39 | N-Control | 0.4 |
| | N+S | 41 | NS-Control | 5.4 |
| | | | NS-N | 5.0 |
| | | | | |
| 319 | Control | 34 | | |
| | N | 31 | N-Control | -6.5 |
| | N+S | 36 | NS-Control | 6.2 |
| | | | NS-N | 13.5 |
| | | | | |
| Overall | Control | 38 | | |
| | N | 35 | N-Control | -9.3 |
| | N+S | 39 | NS-Control | 1.8 |
| | | | NS-N | 12.3 |

**Absolute Height Growth**

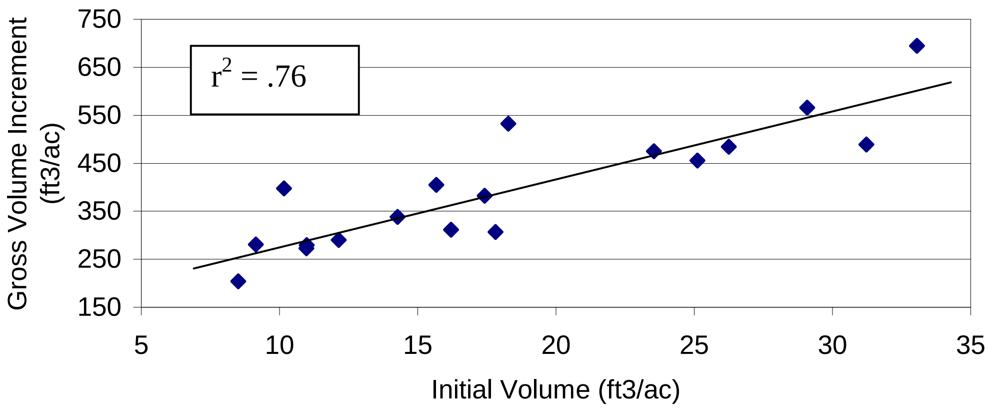
| Treatment | Absolute Height Growth (ft) | Response Contrast | Percent Response # |
|---|---|---|---|
| Control | 15.9 | | |
| N | 14.8 | N-Control | -7.1 |
| N+S | 15.0 | NS-Control | -5.7 |
| | | NS-N | 1.6 |
| | | | |
| Control | 13.3 | | |
| N | 14.2 | N-Control | 6.8 |
| N+S | 14.7 | NS-Control | 10.7 |
| | | NS-N | 3.6 |
| | | | |
| Control | 14.2 | | |
| N | 13.9 | N-Control | -1.7 |
| N+S | 15.4 | NS-Control | 8.6 |
| | | NS-N | 10.5 |
| | | | |
| Control | 14.5 | | |
| N | 14.3 | N-Control | -1.0 |
| N+S | 15.0 | NS-Control | 3.6 |
| | | NS-N | 4.6 |

**# : * Indicates significance at p=.10; ** Indicates significance at p=.05**

Absolute volume growth (Table 6a) showed an overall negative response to N fertilization and almost no response to N+S fertilization. In other words, the fertilized plots grew less than the control plots. However these results are related more to initial tree size and density conditions than to fertilization itself. A review of Table 3 indicates that at the time of initial plot establishment and fertilization, the Heppner sites generally displayed very low basal areas and very low stand density. These were very small trees experiencing open-grown conditions. The growth rate of trees under these conditions is more dependent on individual tree characteristics such as size and crown than on site resources such as nutrients and water.  The following figure illustrates the relationship between initial tree size and eight-year volume increment for the eighteen plots at the three Heppner installations:

**Figure 2: Eight-Year Volume Increment vs. Initial Volume**

**Heppner Installations**




This figure shows the strong relationship between initial tree size and current volume growth. Essentially, the bigger the trees were to start with, the greater the volume increment.  Had all the plots started out with the exact same size and density conditions, we may have been able to detect a fertilizer response.  Unfortunately, differences in initial conditions between plots, combined with the strong relationship between initial tree size and eight-year volume growth, make it very difficult to detect fertilizer response.

One method of accounting for initial size differences in an analysis is to determine relative volume growth, which expresses volume growth as a percentage of initial volume. Relative volume growth is also shown in Table 6a.   For the Heppner plots, since the trees were so small initially, relative growth ranged well over 2000 percent.  However, this analysis did show 17.3% greater growth following N+S fertilization compared to the controls.  For each individual installation, a positive response to N+S fertilization was detected, though none of the responses were significant at p=.10. Nitrogen-only fertilization responses tended to be negative to none, both on an individual installation basis and overall.

Absolute basal area and height growth for the Heppner installations were quite similar to the results for absolute volume (Table 6b). Since these attributes are both reflected in the previously discussed volume response, basal area and height fertilization responses will not be further discussed.

Ukiah

The single installation at Ukiah was analyzed for absolute volume, basal area, and height growth. Results are shown in Table 7:

**Table 7: Absolute volume, basal area and height growth by treatment at the Ukiah installations for Umatilla mixed conifer study in northeast Oregon. Treatments include control (C), 200#/ac nitrogen (N), and 200#/ac nitrogen plus 100#/ac sulfur (N+S).**

**Absolute Volume Growth**

| Location | Treatment | Absolute Volume Growth (ft3/ac) | Response Contrast | Percent Response # |
|---|---|---|---|---|
| Ukiah | Control | 781 | | |
| | N | 576 | N-Control | -26.2 |
| | N+S | 682 | NS-Control | -12.6 |
| | | | NS-N | 18.4 |

**Absolute Basal Area Growth**

| Treatment | Absolute Basal Area Growth (ft2/ac) | Response Contrast | Percent Response |
|---|---|---|---|
| Control | 51 | | |
| N | 45 | N-Control | -12.2 |
| N+S | 46 | NS-Control | -10.1 |
| | | NS-N | 2.3 |

**Absolute Height Growth**

| Location | Treatment | Absolute Height Growth (ft) | Response Contrast | Percent Response # |
|---|---|---|---|---|
| Ukiah | Control | 16.2 | | |
| | N | 12.3 | N-Control | -24.0 |
| | N+S | 15.4 | NS-Control | -4.6 |
| | | | NS-N | 25.5 |

Growth estimates for Ukiah were adjusted to the initial average basal area of 19 $ft^2$/ac. In spite of this basal area adjustment, the results in Table 7 show negative volume, basal area and height growth responses to fertilization at Ukiah. None of these responses was significant at p=.10. As with Heppner, the negative responses are likely due to initial conditions rather than to fertilization. Ukiah results were affected by the same problems as Heppner, in that the stand was comprised of small trees with low densities at study initiation. However for Ukiah, the differences in initial conditions between treatments was so great and the sample size so small that we were not able to make statistical adjustments to overcome this problem. The following table shows initial basal areas and volumes as well as the unadjusted eight-year volume growth for the Ukiah site:

**Table 8. Mensurational information for Ukiah fertilization test site**

| Treatment / Attribute | Basal Area Yr 0 ($ft^2$/ac) | Volume Yr 0 ($ft^3$/ac) | Unadjusted Eight Year Volume Increment ($ft^3$/ac) |
|---|---|---|---|
| Control | 24 | 169 | 840 |
| N Fertilization | 14 | 84 | 497 |
| N+S Fertilization | 21 | 145 | 702 |

To further illustrate the tree size problem, the relationship of eight-year volume growth to initial tree size for the six Ukiah plots was plotted in Figure 3. Table 8 and Figure 3 both indicate that the initial conditions at Ukiah were the controlling factor in determining eight year growth response. Had the plots been better matched for initial stand conditions, we might have been able to detect a fertilizer effect. However, until crown-closure occurs and stand dynamics begin to control growth of these young stands, we should probably not expect to see fertilizer effects.

**Figure 3: Eight-Year Volume Increment vs. Initial Volume**

**Ukiah Installation**

$r^2 = .96$

Periodic Growth

Periodic volume growth was analyzed for all four locations, using two-year increments. The analysis was performed using a repeated measures statement in the general linear models module of SAS (SAS Institute Inc. 1985). The analysis was performed separately for the three installation groups (Pomeroy/Pendleton, Heppner, Ukiah). The change in growth over time was significant for all three groups, while treatment and its interaction with time were non-significant.

Two-year volume increment was plotted for each location and treatment, with the volume increments calculated as shown in Table 9. In each case, means were calculated for each location and treatment, and were adjusted to the basal area per location at the start of that period. The results for the four locations are shown in Figures 4 through 7.

**Table 9.** Calculation of periodic volume increment

| **Variable** | **Calculation** | **Adjustment Factor** |
|---|---|---|
| Periodic volume increment 2 | $Volume_2$ - $Volume_0$ | Basal Area Year 0 |
| Periodic volume increment 4 | $Volume_4$ - $Volume_2$ | Basal Area Year 2 |
| Periodic volume increment 6 | $Volume_6$ – $Volume_4$ | Basal Area Year 4 |
| Periodic volume increment 8 | $Volume_8$ – $Volume_6$ | Basal Area Year 6 |

**Figure 4.** Pomeroy Periodic Volume Increment

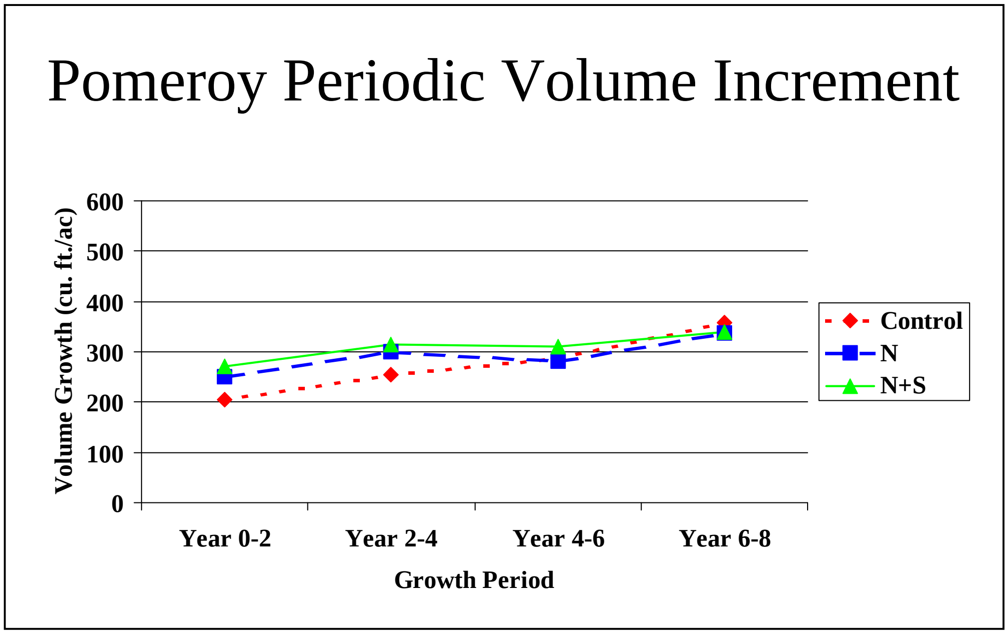



**Figure 5.** Pendleton Periodic Volume Increment

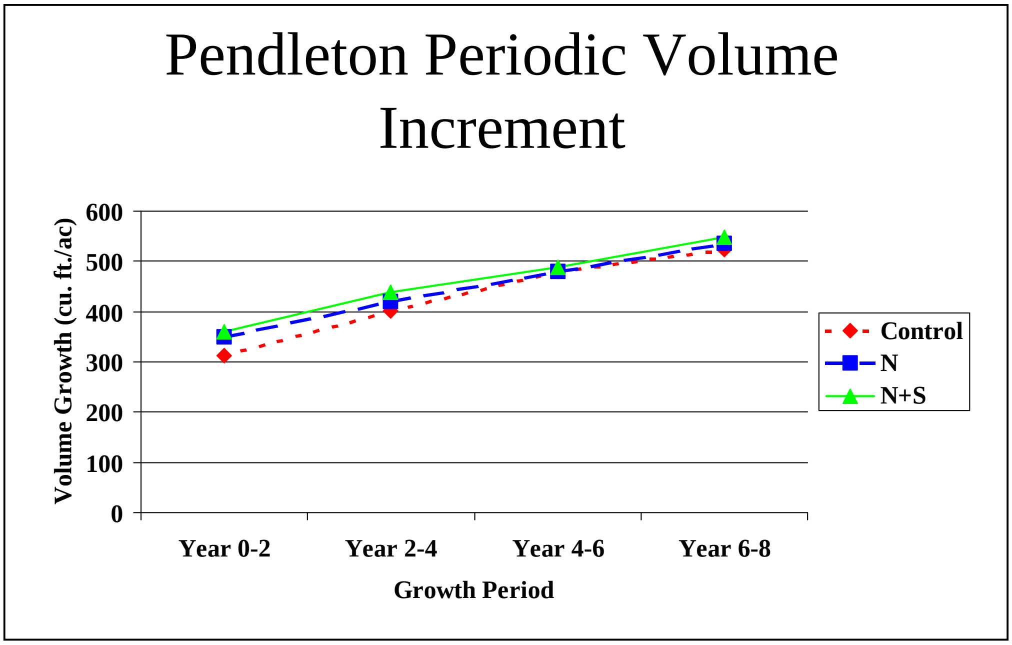



Figure 4 illustrates that at Pomeroy, N and N+S fertilization both showed greater two-year volume increments than the control plots during the first two periods. During the third and fourth periods, volume increments on the fertilized plots were about the same as the control plots. Figure 5 shows similar trends for Pendleton, in that both N and N+S fertilization showed good initial response, but that by the third and fourth periods, growth on the fertilized plots was about the same as control plots. The eight-year volume results for Pomeroy and Pendleton, discussed earlier, indicated that over the entire eight year study period, the N+S treatments resulted in significantly greater growth than the control plots, and fertilization with N-alone also tended to show greater growth. The periodic results shown here indicate the growth responses occurred primarily during the first four to six years of the study. We might therefore expect to see the fertilizer effect continue to decline over time, unless additional nutrient amendments are applied.

For the Heppner installations, periodic growth is displayed in relative terms since relative growth was a better indicator of fertilizer response than absolute growth for the eight-year analysis. Growth for each two-year period is presented as a percentage of the initial volume for that period for calculation of periodic response. Since initial volumes were larger at each successive time period, relative growth decreased, even as absolute growth continued to increase. Figure 6 shows that volume growth during the first two periods was greatest following N+S fertilization, compared to both the control and N-only treatments. The control plots showed somewhat better growth than the N-fertilized plots, however by the third and fourth periods of the study, there was almost no difference in two-year volume increment between any of the three treatments. This may be interpreted in a similar fashion as Pomeroy and Pendleton in that the fertilization effect declined by the $6^{th}$ and $8^{th}$ year of the study. Furthermore, the N+S response reported during the eight-year analysis occurred primarily during the first four to six years of the study.

**Figure 6.** Heppner Periodic Relative Volume Increment

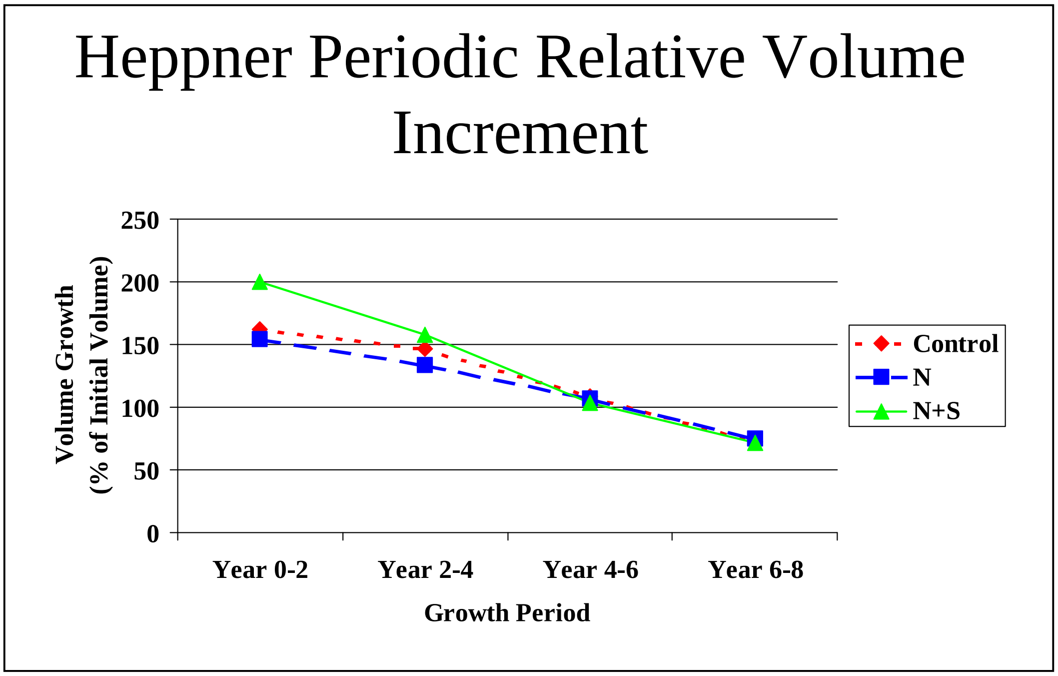
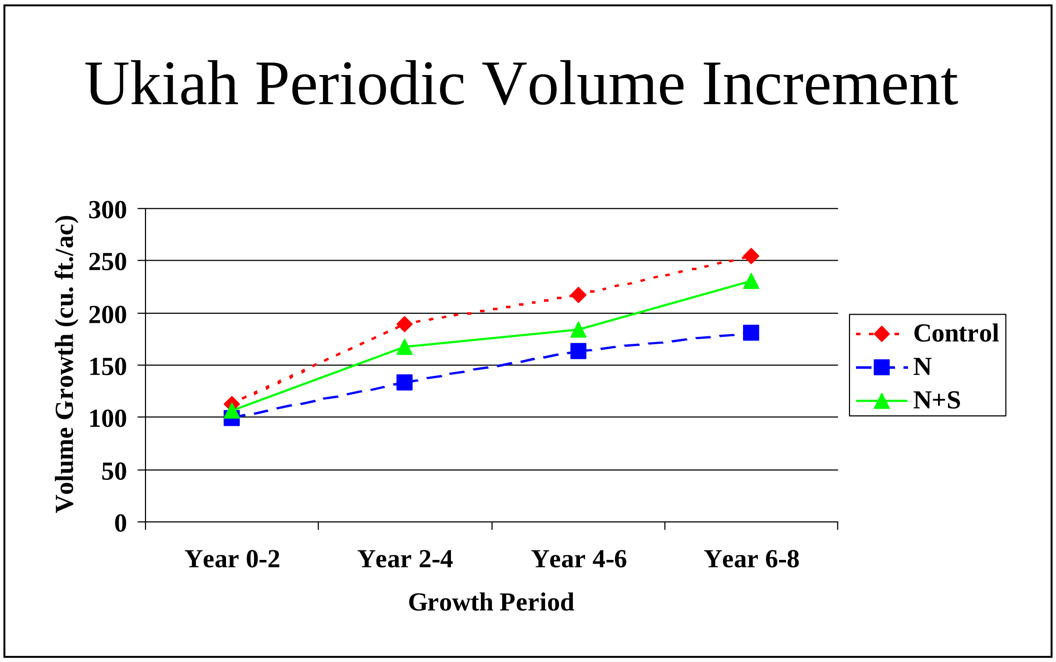



Figure 7 shows two-year periodic growth increments for the Ukiah installation. This figure supports results from the absolute eight-year response, discussed earlier. Growth trends did not seem to respond to fertilization, but rather to initial size and density conditions. While the fertilized plots did show growth over the eight year period, their growth did not differ significantly from control plot growth. The control plots had a greater initial volume than the fertilized plots, and this pattern continued through the four growth periods.

**Figure 7.** Ukiah Periodic Volume Increment




## Conclusions

Eight-year volume increment following fertilization on the Umatilla National Forest indicated that overall, the stands responded best to N+S fertilization, but also did well following application of N only. Basal area and height growth showed results similar to the volume analyses. The Pomeroy and Pendleton stands were the most straightforward to analyze due to mature stand conditions. Heppner and Ukiah were more challenging to analyze and understand due to the problems intrinsic to the measurement and analysis of small trees in open-grown stands. Pomeroy, Pendleton and Heppner all showed stronger responses to N+S than to N-only. The Ukiah response was controlled by initial tree size and density conditions rather than fertilization, and did not show any significant fertilization response. Periodic growth for the four locations indicated that the significant eight-year results were driven primarily by strong responses during the first two to six years of the study. In all cases, the fertilizer effect declined as of the most recent measurement period, and was essentially the same as control growth. Generally speaking, N+S fertilization would likely produce more growth response than N-only fertilization in mixed-conifer stands on fir sites with basalt parent materials in northeastern Oregon and southeastern Washington.

## Literature Citations

SAS Institute Inc., 1985. SAS User's Guide: Statistics, Version 5 Edition. SAS Institute Inc., Cary NC pp 433-506.

Wykoff, W.R., N.L. Crookston and A.R. Stage, 1982. User's guide to the Stand Prognosis Model. USDA For. Serv. Gen. Tech. Rep. INT-133.