AN ABSTRACT OF THE THESIS OF

Linda D. White for the degree of Master of Science in Horticulture presented on March 3, 2006.
Title: The Effect of Pre-plant Incorporation with Sawdust, Sawdust Mulch, and Nitrogen Fertilizer Rate on Soil Properties and Nitrogen Uptake and Growth of 'Elliott' Highbush Blueberry.

Abstract approved

Bernadine C. Strik

The effect of incorporated sawdust, sawdust mulch and nitrogen (N) fertilizer rate on soil nutrients and other properties, N uptake, and plant growth in a young blueberry planting on a silt loam soil type was studied in 2004 and 2005. 'Elliott' highbush blueberry plants were established on raised beds that were either constructed with the incorporation of a fir sawdust amendment, or left un-incorporated. Plots were then mulched with sawdust or left bare after planting. Nitrogen fertilizer, depleted ^{15}N ammonium sulfate, was applied at three rates, 22, 68, and 114 $kg \cdot ha^{-1}$ of N in the first year, with non-labeled N fertilizer applied in the second year at the same rates. There was a wider range in soil temperature in plots incorporated with sawdust and mulched, from -2 ºC in winter to 41 ºC in summer, than in un-mulched plots. Sawdust mulch did not appear to mitigate summer or winter soil temperatures. Incorporated plots required 5-6 times more irrigation water than non-incorporated plots during the growing season. Soil pH was reduced with higher rates of application of fertilizer N, but incorporating sawdust or mulch minimized the reduction in pH. Soil phosphorus concentration was reduced in incorporated plots. The reduction in pH and incorporating sawdust significantly lowered soil P. Pre-

plant incorporation with sawdust increased soil organic matter by ~50% the first year. Plant shoot and whip growth rate in both years was increased by mulching compared to un-mulched plots. There was a significant incorporation by mulch interaction for whip growth in 2004 and total dry weight and biomass partitioning in both years. Whip growth rate on plants in un-incorporated, mulched plots was higher than in all other treatments, peaking at 1.2 $cm{\cdot}d^{-1}$. Total plant dry weight was greatest in un-incorporated, mulched plots. Nitrogen fertilizer rate had no effect on total plant dry weight or partitioning. Total N uptake was greatest in un-incorporated plots, but the proportion of N derived from the fertilizer (NDFF) was highest in plants growing in incorporated, un-mulched plots, up to 54% NDFF. Overall, plant growth was reduced with the addition of pre-plant incorporated sawdust and no mulching in this soil type.

The Effect of Pre-Plant Incorporation with Sawdust, Sawdust Mulch, and Nitrogen Fertilizer Rate on Soil Properties and Nitrogen Uptake and Growth of ‘Elliott’ Highbush Blueberry

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APPROVED:

Major Professor, representing Horticulture

Head of the Department of Horticulture

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Linda D. White, Author

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Chapter 1: Introduction

Blueberries (*Vaccinium* sp.) have become a major crop with an estimated 36,230 ha planted worldwide in 2003 (Strik, 2005). Strong markets for processed and fresh fruit have resulted in good returns for growers and an increase in planted area. In a recent survey of North American blueberry production, the planted area of highbush blueberries was expected to increase by 31% by 2013 (Strik and Yarborough, 2005). In Oregon, 1538 ha of blueberries were harvested in 2005 with a farm gate value of $30.4 million (Anonymous, 2006).

Blueberries are perennial plants with a long fruiting life. However, although fruit production may start in the second or third year after planting, they do not reach mature production until seven or eight years after planting. A recent economic study conducted by Oregon State University found that establishment costs are $20,336 per hectare and over $300,000 in cash is required to establish 8 hectares of blueberries (Eleveld et al., 2005). A portion of this cost comes from the incorporation of soil amendments before planting and the use of sawdust mulch and fertilizers. Most growers in western North America use fir sawdust, due primarily to its ease of availability and relatively low cost. Incorporation of a sawdust amendment and nitrogen fertilizer when preparing a blueberry planting has an estimated cost of $4,069 per hectare, while sawdust mulch will add $5,632 per hectare in the establishment years (1-6) and $930 per hectare, per year, for the mature production years (Elveld et al., 2005).

Optimal growth of blueberries is achieved in soils with a high organic matter, a pH between 4.2 and 5.5, and a high water holding capacity (Eck, 1988, Strik et al., 1993). Soil amendments are commonly used before planting in mineral soils to achieve these qualities for improved plant growth. Various studies have been completed on the effects of soil amendments in blueberry production, primarily assessing the use of bark (Bollen and Glennie, 1961) or peatoss (Lareau, 1989).

However, results from studies relating specifically to the use of pre-plant incorporated sawdust amendments have been inconsistent (Cummings et al., 1981; Lareau, 1989; Moore, 1979; Townsend, 1973b).

Results on the effectiveness of surface mulches, either sawdust or other materials, have had more consistent results in blueberry. Sawdust mulch improved growth of highbush blueberry cultivars (Clark, 1991; Lareau, 1989; Moore, 1979). Use of peatmoss as a pre-plant amendment with a sawdust mulch increased soil organic matter content, the availability of iron (Fe) and manganese (Mn) and plant growth (Haynes and Swift, 1986). Spiers (1998) found that the use of pine bark mulch resulted in greater plant volume and improved yield in comparison to un-mulched plants.

Retamales and Hanson (1989) found that mature blueberry plants recovered 32% of applied nitrogen fertilizer by the end of the growing season, and that leaves and young shoots accounted for 64% of this total. In field-grown ‘Bluecrop’, N fertilizer recovery was initially slow (1-2%), but increased to 22% to 43% by the end of the growing season, depending on in-row spacing and N rate (Bañados et al, 2006). In lowbush blueberries, Eaton and Patriquin (1990) found that 45-64% of fertilizer N was recovered within 16 months. In newly established ‘Bluecrop’, N rate affected plant dry weight, total N content, percent nitrogen derived from the fertilizer (NDFF) and fertilizer recovery. By October, plants fertilized with 50 $kg{\cdot}ha^{-1}$ of N had the largest dry weight and N accumulation and fertilizer recovery reached its maximum of 10% with 60% NDFF (Bañados at al, 2006).

No work has been reported to date on the combined effects of pre-plant incorporated sawdust, mulch and N fertilizer rate on soil properties, nor the effects on blueberry plant growth and N uptake, when establishing a new blueberry field.

The objectives of this study were to evaluate the effects of pre-plant incorporated fir sawdust, fir sawdust mulch, and nitrogen fertilizer rate on two factors – 1) soil properties, including nutrient content, pH and organic matter, moisture content, and temperature; and 2) plant effects, including N uptake and partitioning, and growth and biomass partitioning of ‘Elliott’ blueberry plants in the first two years of establishment.

Chapter 2:The Effect of Pre-plant Incorporation with Sawdust, Sawdust Mulch, and Nitrogen Fertilizer Rate on Soil Nutrient Content, Moisture, and Other Properties in A Newly Established 'Elliott' Blueberry Planting

Abstract

The effect of incorporated sawdust amendment, mulch and nitrogen (N) fertilizer rate on soil nutrients and other properties, N uptake, and plant growth in a young blueberry planting on a silt loam soil type was studied in 2004 and 2005. 'Elliott' highbush blueberry plants were established on raised beds that were either constructed with the addition of an incorporated fir sawdust amendment, or left un-incorporated. Plots were then mulched with sawdust or left bare after planting. Nitrogen fertilizer, depleted ^{15}N ammonium sulfate, was applied at three rates, 22, 68, and 114 kg·ha^{-1} of N in the first year with non-labeled N fertilizer applied in the second year at the same rates. There was a wider range in soil temperature in plots incorporated with sawdust and mulched, from -2 ºC in winter to 41 ºC in summer at 0.15 m, than other plots, particularly un-mulched treatments. Sawdust mulch did not appear to mitigate summer or winter soil temperatures. Incorporated plots required 5-6 times more irrigation water than non-incorporated plots during the growing season. Soil pH was reduced with higher rates of application of fertilizer N, but incorporating sawdust before planting or adding mulch minimized the reduction in pH. Phosphorus levels were higher in mulched plots, where pH was generally higher. Pre-plant incorporation with sawdust and use of a mulch increased organic matter by ~50% the first year. The C:N ratio of the sawdust mulch declined during this study, especially in plots fertilized with high rates of N. Sawdust mulch had from 30% to 52% of nitrogen derived from the fertilizer (NDFF) in Oct. 2004. Soil in plots that had sawdust incorporated, had no mulch, and received high fertilizer N had the greatest NDFF in 2004 and 2005 with the NDFF in these plots dropping to about half by Oct. 2005. Incorporating sawdust before planting could be detrimental to blueberry growth, so soil type and properties should be considered closely before deciding whether this is a necessary production practice.

Introduction

Blueberries are perennial plants, with a long fruiting life. However, although fruit production may start in the second or third year after planting, they do not reach mature production until seven or eight years after planting. A recent economic study conducted by Oregon State University found that establishment costs are $20,336 per hectare and over $300,000 in cash is required to establish 8 ha of blueberries (Eleveld et al., 2005). A portion of this cost comes from the incorporation of soil amendments before planting and the use of sawdust mulch and fertilizers. While compost and manure may be used as soil amendments, most growers in western North America use fir sawdust, due primarily to its ease of availability and relatively low cost. Incorporation of a sawdust amendment and nitrogen fertilizer when preparing a blueberry planting has an estimated cost of $4,069 per hectare while use of a sawdust mulch will add $5,632 per hectare in the establishment years (1-6) and $930 per hectare per year, on average, for the mature production years including labor (Eleveld et al., 2005).

Optimal growth for highbush blueberries is achieved in soils with a high organic matter, a pH between 4.2 and 5.5, and in soils with a high water holding capacity (Eck, 1988; Strik et al., 1993). Amendments are commonly used before planting in mineral soils to achieve these qualities for improved plant growth. Various studies have been completed on the effects of soil amendments in blueberry production; most have used bark (Bollen and Glennie, 1961) or peatmoss (Lareau, 1989). The effects of pre-plant incorporation on blueberry plant growth have been inconsistent (Cummings et al., 1981; Lareau, 1989; Moore, 1979; Townsend, 1973b).

Research on the effect of surface mulches, either sawdust or other materials, has had more consistent results in blueberry usually improving growth (Clark, 1991; Lareau, 1989; Moore, 1979; Spiers, 1998). Use of peatmoss as a pre-plant amendment and sawdust mulch increased soil organic matter content, the availability of iron (Fe) and manganese (Mn), and plant growth (Haynes and Swift, 1986).

No work has been reported to date on the combined effects of pre-plant soil amendment, mulch, and N fertilizer rate on soil properties when establishing a new blueberry field. The objectives of this study were to evaluate the effects of pre-plant incorporation with fir (*Pseudotsuga menziesii* Mirbel) sawdust, use of fir sawdust as a mulch, and nitrogen fertilizer rate on soil nutrient content, pH, organic matter, moisture content, and temperature.

Materials and Methods

Experimental site and design

In Oct. 2003, a field of 'Elliott' northern highbush blueberry (*Vaccinium corymbosum* L.) was established at the North Willamette Research and Extension Center, Aurora, Ore., USA (lat. 45°17 ′N, long. 122°45 ′ W) on a Willamette soil (fine-silty, mixed, mesic pachic ultic argixerolls), having a 5.4 pH, 127 $mg \cdot kg^{-1}$ Bray-P, and 270 $mg \cdot kg^{-1}$ K (ammonium acetate). Nitrogen and organic matter content were 0.08% and 4-6%, respectively. Plants were established on raised beds approximately 0.30 m high with 0.75 m between plants in the row and 3.1 m between rows. Plants were two-year-old in 3.8 L containers and were purchased from a commercial nursery. Each treatment plot consisted of 20 plants with a 3 m un-planted buffer zone between plots.

The study encompassed 16 treatments relating to incorporation or mulching with sawdust and nitrogen (N) fertilization rate. The experimental design was a split plot with sawdust incorporation as the main plot effect (2 levels) and combinations of surface mulching with sawdust (2 levels) and N fertilization rate (3 levels) as the sub-plot effects. There were four replications.

Incorporation. Rows received pre-plant incorporation with fir sawdust or were not incorporated before planting. Sawdust was incorporated by applying a strip of sawdust, (60% 2 mm finer; C:N 790:1), 0.1 m deep and 0.4 m wide centered down the length of each incorporated row. Nitrogen fertilizer (16-16-16) was added to each incorporated row at a rate of 45 $kg \cdot ha^{-1}$ of N to help facilitate decomposition of sawdust, a standard commercial practice (Eleveld et al., 2005; Strik et al., 1993). The sawdust and fertilizer were incorporated into the existing soil using a rototiller. Raised beds were constructed on incorporated and non-incorporated rows using a bed shaper. Rows without incorporated sawdust received the same rate of P and K as incorporated rows.

Surface mulch. In mulched treatments, sawdust was applied after planting to the top and sides of the raised beds to a depth of 5-8 cm using a sawdust spreader. Sawdust mulch was not re-applied during the course of this two-year study.

Nitrogen fertilization rate. Plants were fertilized with 22, 68, or 114 $kg \cdot ha^{-1}$ of N (low, medium, or high), the equivalent of 5.1, 15.8, or 26.5 $g \cdot plant^{-1}$, respectively. The total N rate was split into thirds and applied on 8 Apr., 13 May, and 23 June 2004 (and on similar dates in 2005) by hand to the soil surface covering the area from the base of the plant outward to the drip-line of the bush in a circular area. All fertilizer was applied in the form of granular ammonium sulfate (21-0-0) with overhead irrigation used after application. Depleted ^{15}N fertilizer (0.01 atom % ^{15}N, Icon Isotopes, Summit, N.J.) was applied in 2004 at the rates described above. In 2005, only un-labeled fertilizer was applied. Three plants at the end of each plot receiving 22 $kg \cdot ha^{-1}$ of N were left un-fertilized for comparison purposes.

All treatment plots were fertilized with 35 $kg \cdot ha^{-1}$ of P and 66 $kg \cdot ha^{-1}$ of K each spring and were otherwise maintained according to standard commercial practice (Strik et al., 1993).

Irrigation and soil moisture

Plants were irrigated until Aug. 2004, with an overhead sprinkler system to supply ~6 cm of water per week, when rainfall was inadequate. In Aug. 2004, drip irrigation was installed and utilized so that both incorporated and non-incorporated plots received adequate water. The drip irrigation line contained 3.8 $L \cdot h^{-1}$ emitters placed 0.15 m on either side of the base of the plant. The emitters were installed with spaghetti tubing attached, the end of which was inserted into the soil, taking into account any sawdust mulch, at a depth of about 6 cm. Inserting the tubing into the soil slightly, alleviated the problem of water run-off from the raised beds. During the 2004 season, incorporated rows received 14 h of drip irrigation per week in August (106 L·plant^{-1}) and 10.5 h of drip irrigation per week in September (80 L·plant^{-1}). Rows without incorporated sawdust received approximately 2 h of drip irrigation per week (15 L·plant^{-1}) through this same time period. In 2005, incorporated rows received ~14 h of irrigation per week (53 L·plant^{-1}) and rows without incorporation received ~2 h of irrigation per week (15 L·plant^{-1}) during the irrigation season.

Soil moisture content was monitored using TDR (time domain reflectometry, Trase System, Soil Moisture Equipment Corp., Santa Barbara, Cal.). Soil moisture was monitored at three depths, 0.15, 0.30, and 0.45 m. Wavelength guides (0.45 m) were buried 0.10 m from the base of a plant, and remained in the soil for the term of the study. Only plots receiving 68 kg·ha^{-1} of N were monitored. To measure soil moisture at 0.15 and 0.30 m, wavelength guides were inserted into the soil halfway between the base of the plant and the dripline when readings were taken.

<u>Soil and sawdust sampling</u>

Soil and sawdust samples were collected from each treatment plot in Oct. 2004 and 2005 to determine the amount of plant-available soil N and fertilizer ^{15}N. Soil samples were also analyzed for P, K, Ca, Mg, B, Zn, Mn, Cu, Fe, C, pH, and organic matter. Six sub-samples per plot were taken using a standard soil probe to the depth of 0.30 m. Samples were collected from each plot from within the baseline of plants fertilized with ^{15}N. In treatments with sawdust mulch, a small area of mulch was removed, for separate analysis, prior to taking the soil sample. Soil and sawdust samples were homogenized and analyzed for total N concentration and atom percent ^{15}N by mass spectrometry at Isotope Services (Los Alamos, N.M.). Atom percent values were converted to the proportion of the N derived from fertilizer (NDFF), using standard conversions (Hauck and Bremner, 1976). The ^{15}N natural abundance was assumed equal to 0.366 atom percent. All other analyses previously mentioned were completed at Central Analytical Laboratory (Oregon State University, Corvallis, Ore.). Soil bulk density was calculated in Oct. 2004. Soil samples were taken with an impact corer soil sampler and then dried for 24 h at 40ºC.

Soil temperature was monitored in one plot representing each of the following treatments: with incorporated sawdust and mulch; with incorporated sawdust, but without mulch; no incorporation with mulch; and no incorporation or mulch. The temperature at three soil depths (0.02, 0.15, and 0.30 m) in each of the treatment sites was monitored using HOBO 8K 4-channel industrial outdoor data loggers (Onset Corporation, Bourne, Mass.). Data were recorded hourly from Mar. 2004 through Oct. 2005. Daily averages were calculated from the hourly data. In mulched plots, depth was measured from the soil/mulch interface. Air temperature was recorded at an Agrimet weather station located less than 0.5 km from the research planting.

Statistical Analysis

The experimental design was a split plot with four replications. Analysis of treatment effects, using the low, medium, and high N rate treatments in combination with incorporation and mulching was performed using the PROC MIXED procedure in SAS (SAS Institute, Inc., 1999). Treatment means were compared using LSMeans procedure with a Bonferroni adjustment. Un-fertilized treatments were used for observational purposes only and were not included in any analyses.

Results and Discussion

Soil temperature

In all treatments, soil temperature at all depths increased from spring to mid-summer and then declined to the lowest level in winter (Figure 2-1). The soil temperature at 0.2 m in plots without mulch was very similar to the air temperature (Figure 2-1). Plots that had surface mulch, with or without pre-plant incorporation, had a lower average soil temperature in the winter at all depths measured. Plots that were incorporated with sawdust and had mulch had higher soil temperatures in the summer months. Soil temperature increased faster in the spring in mulched plots than other treatments, but soil in mulched plots did not cool faster than the other treatments in the fall (Figure 2-1). Soil temperature at 0.3 m showed slightly less fluctuation or extremes over the course of both years.

While we observed that plots without incorporation with mulch did not show an increase in soil temperature during the summer, neither did we see a cooling effect of the mulch compared to plots without mulch (Figure 2-1). This is counter to previous work (Gough, 1994; Tukey and Schoff, 1963) where mulch was found to lower soil temperature in summer and increase temperature in winter compared to un-mulched plantings. The lack of soil temperature mitigation in our study may have been attributable to the raised bed design.

The greatest fluctuation in soil temperature occurred in the plots incorporated with sawdust and with a mulch, from an average low in winter of -2°C to a summer high of 41°C at 0.15 m. While some of these extremes could have been due to the raised bed design, the sawdust incorporated within the bed may have increased soil pore space and thus capacity to heat and cool more quickly, with the mulch layer acting as an insulator. Webster and Adamson (1960) found that incorporating sawdust into soil increased soil temperature over mulched plots, especially under low soil water conditions. Hourly temperature changes within our experiment agree with this work, and the differences in our study, which were more extreme, may be due to the mulch being applied over incorporated plots. Data for a sunny summer day and an overcast summer day were compared (Appendix). Within these time periods, incorporated plots, either with or without mulch, attained higher daily temperature than un-incorporated plots. . Another potential issue is that the data loggers could have been less precise under high or low soil moisture conditions in the height of summer or winter, respectively. While individual temperature data may be incorrect, the relative differences seen between treatments are real.

Soil moisture

Pre-plant incorporation with sawdust had a significant effect on soil moisture content at all probe depths; 0.15 m 0.30 m, 0.45 m, ($p<0.001$), ($p<0.01$) and ($p<0.01$), respectively. In both years, incorporated rows required 5-6 times more water than non-incorporated rows to maintain a desirable soil moisture content for plant growth of not less than 15%. Figure 2 illustrates soil moisture content at three depths from 1 to 25 h after drip irrigation in Aug. 2004; results for 2005 were similar (data not shown). It was difficult maintaining adequate soil moisture in the upper 0.15 m of soil, particularly in incorporated plots (Figure 2-2). Within 7 h after irrigation, water had moved into deeper soil depths or had been taken up by the plants (Figure 2-2). Water content at 0.30 m was generally 18% higher than at the 0.15 m depth, but was significantly affected by incorporation ($p<0.001$). In contrast, soil moisture at 0.45 m was significantly affected by the interaction of incorporation and mulch at 1 h ($p<0.01$) and at 25 h ($p<0.01$). However, at 7 h after irrigation there were no significant treatment effects. Incorporation with mulch plots had the lowest soil moisture content, 15%, at both 1h and 25 h after irrigation (Figure 2-2).

Incorporating sawdust as a pre-plant amendment decreased soil bulk density from 1.2 $g{\cdot}cm^{-3}$ to 0.82 $g{\cdot}cm^{-3}$, due to an increase in soil pore space. The increase in porosity in incorporated plots caused water to flow through the soil at a faster rate. Blueberries, with their shallow, fibrous root system, require moist, well-drained soil and would likely be more difficult to maintain in a production system with sawdust incorporated into the soil before planting and raised beds. Spiers (1998) found that both high irrigation and low bed height significantly improved the growth of rabbiteye blueberry.

pH, organic matter, and soil nutrients

In 2004, pH was affected by N fertilization rate, incorporation, mulch and there was a significant interaction between incorporation and mulch ($p<0.05$; Table 1) whereas in 2005, only the main effects of incorporation, mulch, and N rate were significant (Table 2-2). Main effects are shown in Tables 1 and 2 for clarity with any significant interactions discussed.

Soil pH was lowest in plots without incorporation or mulch and fertilized with the highest N rate, averaging pH 4.9 and 4.5 in 2004 and 2005, respectively. The soil pH of non-incorporated plots was 7% lower than in the incorporated plots, and in non-incorporated plots mulch increased pH 6% compared to plots without mulch.

Plots with incorporated sawdust had the greatest change from baseline readings of soil nutrient availability and organic matter (OM) content by the end of the study. Soil P was significantly lower in incorporated plots than in non-incorporated plots, both years (Table 2-1 and 2-2). Conversely, in 2004 and 2005, Mg levels were higher in plots with incorporated sawdust. The Mn and B soil content were higher in incorporated plots and Fe was affected by the incorporation and mulch interaction, with incorporated, un-mulched plots having the highest level of Fe. Neither total N nor Zn was significantly affected by treatment in either 2004 or 2005 (Table 2-1 and 2-2).

There was a significant interaction of incorporation and mulching on OM in 2004, with the highest OM content in incorporated plots with mulch (8.7%) which contained ~50% more OM than non-incorporated plots without sawdust (51%). In 2005, OM continued to be higher in incorporated plots with mulch ($p<0.01$). Nitrogen fertilization rate had no significant effect on soil OM content (Table 2-1 and 2-2).

Soil pH is reduced with application of ammonium sulfate fertilizer (Townsend, 1973a) and the availability of many of the soil nutrients can be directly correlated to the pH level. Phosphorus levels were higher in mulched plots, where pH was generally higher, because P is less available below pH 6.0. With Fe the opposite effect occurred, with Fe being more readily available at lower pH and in treatments with a higher OM. The increased soil OM in the incorporated, mulched plots also affected soil B and Mg levels. Organic matter has an electrical conductivity 2-30 times greater than clay particles, so cations such as B, K and Mg will bind to soil OM and be more easily exchangeable.

<u>Sawdust mulch NDFF and C:N ratio</u>

In 2004, there was a significant N rate and incorporation by N rate interaction on the amount of fertilizer N (NDFF) remaining within the sawdust mulch layer

(Table 2-3). There was no significant treatment effect on sawdust NDFF in 2005. In Oct. 2004, the highest NDFF in mulch was found in the incorporated plots receiving the high rate of N fertilizer (Table 2-3). Non-incorporated plots receiving the high N rate retained the greatest amount of NDFF in the sawdust mulch. The lowest NDFF levels in mulch were found in incorporated plots with the low N rate. In 2005, the NDFF of sawdust mulch in incorporated and non-incorporated plots receiving the high rate of N fertilizer dropped to an average of 12% (Table 2-3).

Fertilizer N rate had a significant effect on the C:N ratio of sawdust mulch in 2004 with a trend in 2005 (p=0.0523; Table 3). By the end of 2004, the C:N ratio of the sawdust mulch had decreased from 790:1 to 281:1 in unfertilized treatments (data not shown). In plots fertilized with N, the greatest drop in C:N ratio occurred with the medium rate of N, 205:1 (Table 2-3). By the end of 2005, C:N ratio had further decreased in all treatments (Table 2-3).

Sawdust mulch immobilizes available N due to its high C:N ratio. Microorganisms will break down the sawdust carbon, however, on average, for every 8 parts of carbon that an organism can break down, 1 part of N is needed, and mined from the existing soil or media. As the C:N ratio reaches ~20:1 a balance is attained between C, N and microorganism levels such that N is no longer mined due to a lack of C supply. With the decrease in available C, soil microorganisms die and release the bound N (Brady and Weil, 1996). In this study, the higher rates of fertilizer N provided greater amounts of available N, resulting in a faster decline in the C:N ratio.

Soil NDFF

The NDFF of soil in 2004 was significantly affected by mulch, N fertilizer rate, and the interaction of incorporation and mulch (Table 2-4). In 2005, the interaction between incorporation, mulch, and N rate had a significant effect on soil NDFF. Soil in plots that were incorporated, had no mulch, and received the high rate of fertilizer N had the greatest NDFF in 2004 and 2005 (Table 2-4); the NDFF in these plots dropped by approximately 50% between 2004 and 2005. Soil from the incorporated treatments likely had the greatest NDFF due to their higher OM content, which would bind the fertilizer N more readily.

In the present study, blueberry plants within plots that had sawdust incorporated grew less than plants in non-incorporated plots (Chapter 3). This was perhaps due to insufficient available water in the root zone and increased soil temperature, primarily in mulched plots. Also, fertilizer N may have been less available to plants in incorporated, mulched plots, being immobilized in the mulch layer or the soil organic matter. Our findings agree with previous work stating that mulch is the most effective method, in mineral soils, of adding organic matter to the soil without causing detrimental effects to plant growth (Eck, 1966; Mercik and Smolarz, 1995). The results from this study suggest that incorporating with sawdust, even with adequate N fertilization, may be detrimental to blueberry growth. In this study, the experimental site was on a silt-loam soil, high in organic matter and with a good water holding capacity. Results, particularly on the effects of incorporating sawdust, could have been different, however, if the soil type had been a heavier clay or if a flat-ground planting had been utilized. The increased permeability and OM content from additions of incorporated sawdust could enhance plant growth over un-incorporated soils. Mulching with sawdust, however, while immobilizing some N fertilizer, will slowly increase soil OM without the adverse effect of decreasing soil water availability.

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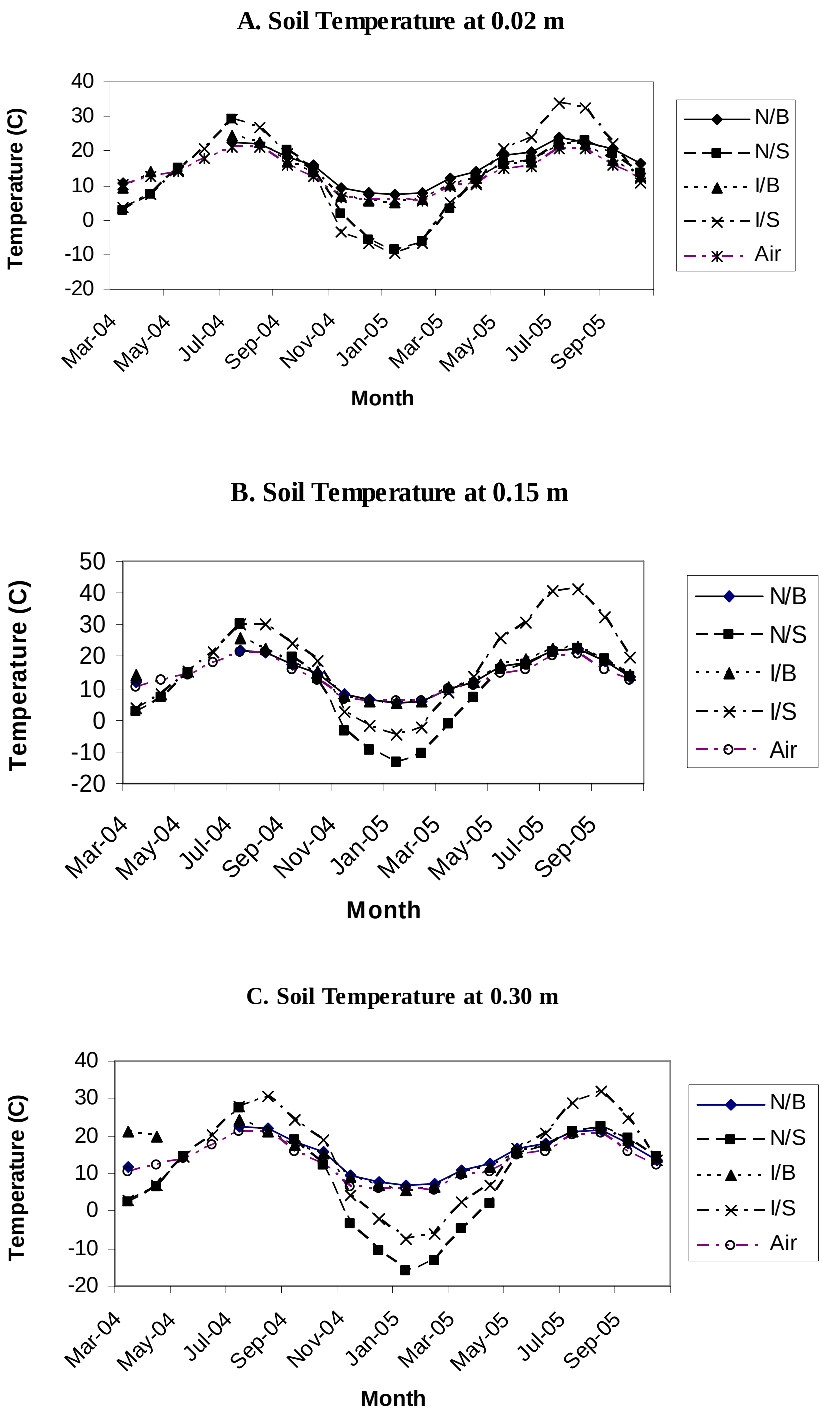

Figure 2-1. The effect of incorporation with sawdust and sawdust mulch on soil temperature at, A) 0.02 m; B) 0.15 m; C) 0.30 m, soil depth.
Legend; N/B=No incorporation, no mulch; N/S=No incorporation with mulch; I/B= Incorporated, no mulch; I/S=Incorporated, with mulch.

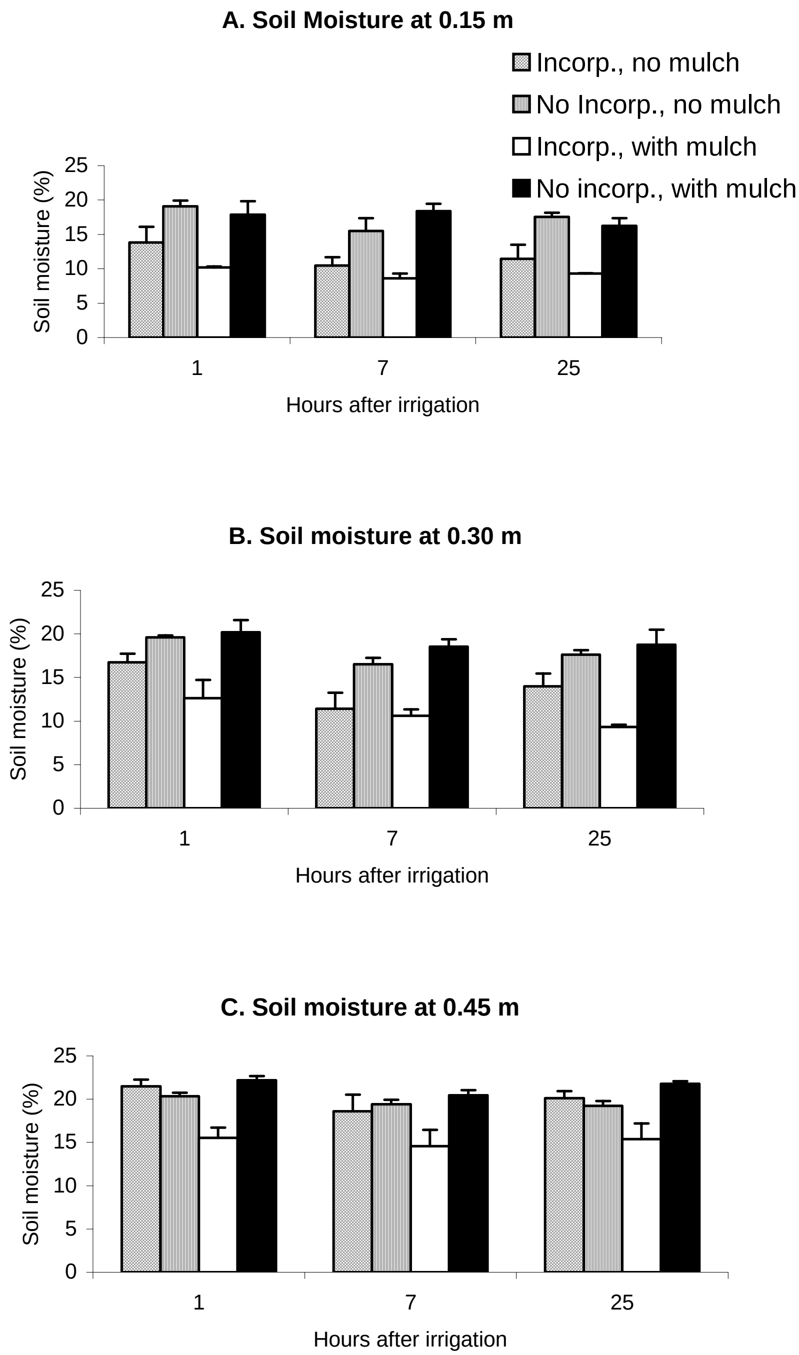

Figure 2-2. The effect of incorporation with sawdust and sawdust mulch on percent soil moisture at three depths, A) 0.15 m; B) 0.30 m; C) 0.45 m; 1 to 25 h after irrigation on August 2, 2004 (n=3, mean ± SE).

Table 2-3. The effect of nitrogen fertilization rate on nitrogen derived from the fertilizer (NDFF) and the C:N ration in sawdust mulch in incorporated and non-incorporated plots (n=4) on 26 Oct. 2004 and 12 Oct. 2005.

Rate of Fertilizer N (kg N·ha^{-1})	Incorporation (yes/no)	2004		2005	
		NDFF (%)	C:N	NDFF (%)	C:N
22	yes	30.7±0.7	250:1	10.5±1.1	112:1
	no	40.3±4.0	281:1	13.4±1.5	107:1
68	yes	45.4±1.6	219:1	11.6±0.8	85:1
	no	48.5±2.8	193:1	13.7±0.3	84:1
114	yes	52.6±2.8	265:1	11.9±1.4	72:1
	no	47.1±3.5	275:1	12.1±1.7	65:1
Significance[z]					
Incorporation		ns	ns	ns	ns
Nitrogen rate		***	**	ns	ns
Incorporation*Nitrogen rate		*	ns	ns	ns

[z]*Significant at P=<0.05; **significant at P=<0.01; ***significant at P=<0.001; ns=not significant.

Table 2-2. Soil nutrient analyses for the main effects of sawdust incorporation (n=24), mulch (n=24), and rate of nitrogen fertilization (n=16), Oct. 2005.

	Macronutrients					Micronutrients						
Rate of N fertilizer ($kg \cdot ha^{-1}$)	N (%)	P (ppm)	K (ppm)	Ca (meq/100g)	Mg (meq/100g)	Fe (ppm)	B (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)	pH	OM[y] (%)
22	0.1	100	221	4.1	1.6	123	0.08	1.4	25	1.1	5.0	6.8
68	0.1	95	201	3.6	1.4	135	0.08	1.4	36	1.0	4.7	6.7
114	0.1	98	197	3.3	1.31	138	0.09	1.4	38	1.10	4.6	7.1
Significance[z]	ns	ns	*	**	*	ns	ns	ns	*	ns	***	ns
Incorporation	0.1	93	218	4.3	1.7	144	0.09	1.5	42	1.1	5.1	7.9
No incorporation	0.1	105	208	3.3	1.2	109	0.08	1.3	15	1.0	4.8	5.6
Significance	ns	*	ns	***	***	***	***	**	***	ns	*	**
Mulch	0.1	94	217	3.9	1.5	122	0.08	1.5	26	1.0	5.1	7.0
No mulch	0.1	105	210	3.7	1.4	130	0.09	1.3	31	1.1	4.8	6.5
Significance	ns	ns	ns	*	ns	ns	ns	*	ns	ns	***	ns

[z]*Significant at P=<0.05; **significant at P=<0.01; ***significant at P=<0.001; ns=not significant.
[y]OM=organic matter.

Table 2-3. The effect of nitrogen fertilization rate on nitrogen derived from the fertilizer (NDFF) and the C:N ration in sawdust mulch in incorporated and non-incorporated plots (n=4) on 26 Oct. 2004 and 12 Oct. 2005.

Rate of Fertilizer N (kg N·ha^{-1})	Incorporation (yes/no)	2004		2005	
		NDFF (%)	C:N	NDFF (%)	C:N
22	yes	30.7±0.7	250:1	10.5±1.1	112:1
	no	40.3±4.0	281:1	13.4±1.5	107:1
68	yes	45.4±1.6	219:1	11.6±0.8	85:1
	no	48.5±2.8	193:1	13.7±0.3	84:1
114	yes	52.6±2.8	265:1	11.9±1.4	72:1
	no	47.1±3.5	275:1	12.1±1.7	65:1
Significance[z]					
Incorporation		ns	ns	ns	ns
Nitrogen rate		***	**	ns	ns
Incorporation*Nitrogen rate		*	ns	ns	ns

[z]*Significant at P=<0.05; **significant at P=<0.01; ***significant at P=<0.001; ns=not significant.

Table 2-4: The effect of pre-plant incorporated sawdust (n=24), sawdust mulch (n=24), and N fertilizer rate (n=16), on percent nitrogen derived from the fertilizer (NDFF) in soil 26 Oct. 2004 and 12 Oct. 2005.

Rate of Fertilizer N ($kg{\cdot}ha^{-1}$)	Incorporation (yes/no)	Mulch (yes/no)	% NDFF	
			2004	2005
22	no	yes	4.6±0.9	2.2±0.41
		no	3.7±1.1	0.58±0.30
	yes	yes	2.1±0.6	1.2±0.49
		no	1.2±0.1	0.0±0.14
68	no	yes	13.5±1.7	7.5±0.72
		no	14.3±1.7	1.2±0.71
	yes	yes	4.7±1.5	3.0±0.59
		no	1.7±0.5	0.72±0.50
114	no	yes	14.2±1.7	10.5±0.84
		no	16.1±1.2	2.8±0.36
	yes	yes	8.2±1.9	3.7±0.86
		no	4.0±0.9	1.2±0.16
Significance[z]				
Incorp (I)[y]			ns	**
Mulch (M)			***	***
Nrate (N)			***	***
I x M			*	***
I x N			ns	***
M x N			***	***
I x M x N			ns	**

[z]*Significant at P=<0.05; **significant at P=<0.01; ***significant at <0.001; ns=not significant.
[y] I=Incorporation, M=Mulch, N=Nitrogen rate.

Chapter 3: The Effect of Pre-plant Incorporation with Sawdust, Sawdust Mulch, and Nitrogen Fertilizer Rate on Plant Growth and Nitrogen Uptake in A Newly Established 'Elliott' Blueberry Planting

Abstract

The effect of incorporated sawdust amendment, sawdust mulch and nitrogen (N) fertilizer rate on N uptake and plant growth in a young blueberry planting was studied in 2004 and 2005. 'Elliott' highbush blueberry plants were established on raised beds that were either constructed with the addition of a fir sawdust amendment, or left un-incorporated. Plots were then mulched with sawdust or left bare after planting. Nitrogen fertilizer, depleted ^{15}N ammonium sulfate, was applied at three rates, 22, 68, and 114 $kg \cdot ha^{-1}$ of N in the first year with non-labeled N fertilizer applied in the second year at the same rates. The total N rate was split into thirds and applied in April, May and June. Plants were destructively harvested in Dec. 2004 and Oct. 2005 to determine total plant dry weight and biomass partitioning, total N uptake, and nitrogen derived from fertilizer (NDFF). Plants in mulched plots had a greater shoot and whip growth rate than plants in un-mulched plots in both years. There was a significant interaction of incorporation by mulch for whip growth in 2004 and total dry weight and biomass partitioning in both years. Whips in un-incorporated, mulched plots had the greatest growth rate, peaking at 1.2 $cm \cdot d^{-1}$. Total plant dry weight was greatest in un-incorporated, mulched plots. Fertilizer rate had no significant effect on total plant dry weight or partitioning. Total ^{15}N uptake was greatest in plants growing in un-incorporated soil, but NDFF was greater in plants growing in incorporated soil, up to 54%. Overall, plant growth was reduced in plots that received a pre-plant incorporation of sawdust and had no surface mulch.

Introduction

Blueberries (*Vaccinium* sp.) have become a major crop with an estimated 36,230 ha planted worldwide in 2003 (Strik, 2005). Strong markets for processed and fresh fruit have resulted in good returns for growers and an increase in planted area.

In a recent survey of North American blueberry production, the planted area of highbush blueberries was expected to increase by 31% (to 29,726 ha) by 2013 (Strik and Yarborough, 2005). In Oregon, 1,538 ha of blueberries were harvested in 2005 with a farm gate value of $30.4 million (Anonymous, 2006).

Blueberries are perennial plants, with a long fruiting life. However, although fruit production may start in the second or third year after planting, they do not reach mature production until seven or eight years after planting. A recent economic study conducted by Oregon State University found that establishment costs are $20,336 per hectare and over $300,000 in cash is required to establish 8 ha of blueberries (Eleveld et al., 2005). A portion of this cost comes from the incorporation of soil amendments before planting and the use of sawdust mulch and fertilizers. Most growers in western North America use fir sawdust for incorporation and mulching.

Optimal growth for highbush blueberries is achieved in soils with a high organic matter, a pH between 4.2 and 5.5, and in soils with a high water holding capacity (Eck, 1988; Strik et al., 1993). Soil amendments are commonly used before planting in mineral soils to achieve these qualities for improved plant growth. Various studies have been completed on the effects of incorporated soil amendments in blueberry production; most have used bark (Bollen and Glennie, 1961; Odneal and Kaps, 1990) or peatmoss (Lareau, 1989). Results from these studies have been inconsistent. Lareau (1989) found that incorporating sawdust improved blueberry yield and reduced winter injury. In rabbiteye blueberry (*V. ashei* Reade), plants exhibited brighter leaf greenness and had increased linear shoot growth when incorporated sawdust amendments were added to high pH, low organic matter soils compared to un-incorporated plots (Cummings et al., 1981). Townsend (1973) and Moore (1979), however, found that pre-plant incorporation with sawdust reduced fruit yield and decreased height of young blueberry plants.

Research on the effect of surface mulch, either sawdust or other materials, has had more consistent results in blueberry. Sawdust mulch improved growth of highbush and rabbiteye blueberry cultivars (Clark, 1991; Lareau, 1989; Moore, 1979).

Spiers (1998) found that use of pine bark mulch resulted in greater plant volume and improved yield in comparison to un-mulched plants.

Retamales and Hanson (1989) found that mature blueberry plants recovered 32% of applied nitrogen fertilizer by the end of the growing season, and that leaves and young shoots accounted for 64% of this total. In field-grown mature 'Bluecrop', N fertilizer recovery was initially slow (1 to 2% recovery two weeks after the first application), but increased to 22% to 43% in September depending on in-row spacing and N rate (Bañados et al., 2006). Eaton and Patriquin (1990) found that 45-64% of fertilizer N was recovered by lowbush blueberry plants (*V. angustifolium* AIT.) within 16 months. In newly established 'Bluecrop', N rate affected plant dry weight, total N content, percent nitrogen derived from the fertilizer (NDFF), and fertilizer recovery. By October, plants fertilized with 50 $kg \cdot ha^{-1}$ of N had the largest dry weight and N accumulation and fertilizer recovery reached its maximum of 10% with 60% NDFF (Bañados et al., 2006).

No work has been reported to date on the combined effects of pre-plant incorporation with sawdust, mulch, and N fertilizer rate on blueberry plant growth, and N uptake in a newly established field.

The objectives of this study were to evaluate the effects of pre-plant incorporation with fir (*Pseudotsuga menziesii* Mirbel*)* sawdust, use of fir sawdust as a mulch, and nitrogen fertilizer rate on N uptake, partitioning, and growth of 'Elliott' blueberry plants in the first two years of establishment.

Materials and Methods

Experimental site and design

In Oct. 2003, a field of 'Elliott' northern highbush blueberry (*Vaccinium corymbosum* L.*),* Aurora, Ore., USA (lat. 45°17 ′N, long. 122°45 ′ W) on a Willamette soil (fine-silty, mixed, mesic pachic ultic argixerolls), having a 5.4 pH, 127 $mg \cdot kg^{-1}$ Bray-P, and 270 $mg \cdot kg^{-1}$ K (ammonium acetate). Nitrogen and organic matter content were 0.08% and 4-6%, respectively. Plants were established on raised beds approximately 0.30 m high with 0.75 m between plants in the row and 3.1 m between rows (4,301 plants/ha). Plants were two-year-old in 3.8 L containers and were purchased from a commercial nursery. Each treatment plot consisted of 20 plants with a 3 m un-planted buffer zone between plots.

The study encompassed 16 treatments relating to incorporation of sawdust or mulching with sawdust and nitrogen (N) fertilization rate. The experimental design was a split plot with incorporation as the main plot effect (2 levels) and combinations of surface mulching with sawdust (2 levels) and N fertilization rate (3 levels) as the sub-plot effects. There were four replications.

Incorporation. Rows received pre-plant incorporation with fir sawdust or were not incorporated before planting. Sawdust was incorporated by applying a strip of sawdust, (60% 2 mm finer C:N 790:1), 0.1 m deep and 0.4 m wide centered down the length of each incorporated row. Nitrogen fertilizer (16-16-16) was added to each incorporated row at a rate of 45 $kg{\cdot}ha^{-1}$ of N to help facilitate decomposition of sawdust, a standard commercial practice (Eleveld et al., 2005; Strik et al., 1993). The sawdust and fertilizer were incorporated into the existing soil using a rototiller. Raised beds were constructed on incorporated and non-incorporated rows using a bed shaper. Rows without added sawdust amendment received the same rate of P and K as incorporated rows.

Surface mulch. In mulched treatments, sawdust was applied after planting to the top and sides of the raised beds to a depth of 5-8 cm using a sawdust spreader. Sawdust mulch was not re-applied during the course of this study.

Nitrogen fertilization rate. Plants were fertilized with 22, 68, or 114 $kg{\cdot}ha^{-1}$ of N (low, medium, or high), the equivalent of 5.11, 15.8, or 26.5 $g{\cdot}plant^{-1}$, respectively. The total N rate was split into thirds and applied on 8 Apr., 13 May, and 23 June 2004 (and on similar dates in 2005) by hand to the soil surface covering the area from the base of the plant outward to the drip-line of the bush in a circular area. All fertilizer was applied in the form of granular ammonium sulfate (21-0-0) with overhead irrigation used after application. Depleted ^{15}N fertilizer (0.01 atom % ^{15}N, Icon Isotopes, Summit, N.J.) was applied in 2004 at the rates described above. In 2005, only un-labeled fertilizer was applied. Three plants at the end of each plot receiving 22 kg·ha^{-1} of N were left un-fertilized for the purposes of comparison.

All treatment plots were fertilized with 35 kg·ha^{-1} of P and 66 kg·ha^{-1} of K each spring and were otherwise maintained according to standard commercial practice (Strik et al., 1993).

In Oct. 2003, fruit buds and any weak or low growth were removed by pruning right at planting time. Plants were pruned in Feb. 2005 using standard commercial practices with severity based on plant vigor (Strik et al., 1990). In addition, plants were pruned to prevent fruit production in 2005 by removing fruit buds. Research by Strik and Buller (2005) showed that yield of 'Elliott' in years 3 and 4 is adversely affected by early cropping in year 2. In addition, we did not want to confound the experiment by having some plants yield in 2005, due to adequate vigor, yet have others be pruned to remove fruit due to lack of vigor.

Irrigation and soil moisture. Plants were irrigated until Aug. 2004, with an overhead sprinkler system to supply ~6 cm of water per week, when rainfall was inadequate. In Aug. 2004, drip irrigation was installed and utilized so that both incorporated and non-incorporated plots received adequate water. The drip irrigation line contained 3.8 L h^{-1} emitters placed 0.15 m on either side of the base of the plant. The emitters were installed with spaghetti tubing attached, the end of which was inserted into the soil, taking into account any sawdust mulch, at a depth of about 6 cm. Inserting the tubing into the soil slightly, alleviated the problem of water run-off from the raised beds. During the 2004 season, incorporated rows received 14 h of drip irrigation per week in August (106 L·plant^{-1}) and 10.5 h of drip irrigation per week in September (80 L·plant^{-1}). Rows without incorporated sawdust received approximately 2 h of drip irrigation per week (15 L·plant^{-1}) through this same time period. In 2005, incorporated rows received ~14 h of irrigation per week (53 L·plant^{-1}) and rows without incorporated sawdust received ~2 h of irrigation per week (15 L·plant^{-1}) during the irrigation season.

Soil moisture content was monitored using TDR (time domain reflectometry, Trase System, SoilMoisture Equipment Corp., Santa Barbara, Cal.). Soil moisture was monitored at three depths, 0.15, 0.3m and 0.45 m. Wavelength guides (0.45 m) were buried 0.10 m from the base of a plant, and remained in the soil for the term of the study. Only plots receiving 68 $kg{\cdot}ha^{-1}$ of N were monitored. To measure soil moisture at 0.15 and 0.30 m, wavelength guides were inserted into the soil halfway between the base of the plant and the dripline when readings were taken.

Shoot and whip growth

Shoots and whips were measured weekly, over the course of the growing season in 2004 and 2005. In April, just as shoots were beginning to grow, one shoot on 8 individual plants was tagged in each plot (~2 shoots on un-fertilized plants). Whips were measured using the same procedure, but data collection began in late June after whips emerged, and only four whips per plot were monitored.

Summer leaf analysis

Leaf samples were collected from all treatments in late July/early August of both years for comparison to industry standard leaf sufficiency levels (Strik and Hart, 1991). Approximately 50 leaves per plot were sampled. Most recent, fully expanded leaves were gathered from all sides of the plants. Leaves were oven-dried at 60ºC until constant dry weight and mill-ground to pass a 40-mesh screen and sent for analysis to Central Analytical Laboratory (Oregon State University, Corvallis, Ore.). Ground leaf tissue was also sent to Isotope Services (Los Alamos, N.M.) for analysis of total N and atom percent ^{15}N by mass spectrometry.

Plant dry weight and nutrient uptake

In 2003, 3 nursery plants were destructively harvested, before planting, to establish a baseline dry weight and nutrient analysis. A single plant per plot was destructively harvested on 14 Dec. 2004 and 17 Oct. 2005. In 2004 towards the end of the growing season, plants that were scheduled to be destructively harvested were enclosed within a fine mesh netting to capture senescing leaves. In 2005, leaves were stripped from the plants before digging in October. After digging, all soil was removed from the root system using tap water. The total number of vegetative and flower buds, growth flushes, and whips were counted on each plant. Percent flower bud set was calculated. Plants were then divided into the following parts: whips, 1-year-old wood (grew in the current season), 2-year-old wood, 3-year-old wood, crown, large roots (greater than 2mm) and fine roots (< 2mm). Plant parts were then oven-dried at 60ºC until constant dry weight and dry weight recorded. Plant parts were randomly sub-sampled and ground to pass a 40-mesh screen. Ground samples were sent to Isotope Services (Los Alamos, N.M.) for analysis of total N concentration and atom percent ^{15}N by mass spectrometry. Atom percent values were converted to the proportion of the nitrogen derived from fertilizer (NDFF), using standard conversions (Hauck and Bremner, 1976). The ^{15}N natural abundance was assumed equal to 0.366 atom percent.

$$\%NDFF = \frac{(\text{atom }\%\ ^{15}N_{\text{natural abundance}}) - (\text{atom }\%\ ^{15}N_{\text{sample}})}{(\text{atom }\%\ ^{15}N_{\text{natural abundance}}) - (\text{atom }\%\ ^{15}N_{\text{fertilizer}})}$$

Leaf samples (senescent in 2004 and stripped in Oct. 2005) were ground and analyzed for total N and ^{15}N, as described previously, and sent to Central Analytical Laboratory (Oregon State University, Corvallis, OR) for analysis of all macro and micronutrients.

Statistical Analysis

The experimental design was a split plot with four replications. Analysis of treatment effects, using only the low, medium, and high N rate treatments in combination with incorporation and mulching was performed using the PROC MIXED procedure in SAS (SAS Institute, Inc., 1999). Treatment means were compared using LSMeans procedure with a Bonferroni adjustment. Shoot and whip growth were analyzed using the repeated statement in PROC MIXED for a split plot design. Un-fertilized treatments were generally used for observational purposes only and were not included in any analyses.

Results and Discussion

Shoot and Whip Growth

In 2004, the greatest shoot growth rate was seen approximately 2 weeks after the first fertilizer application (Figure 3-1). Mulch had a significant effect on growth early ($p<0.01$) and late ($p<0.001$) in the season, with plants in mulched plots having the greatest growth rate and total growth. Plants in un-incorporated soil with mulch and the high N rate had a peak growth rate of 0.31 $cm \cdot d^{-1}$. In comparison, plants in un-incorporated soil without mulch, receiving the medium rate of N had the lowest shoot growth rate of 0.12 $cm \cdot d^{-1}$ on the same date. There was a second, smaller peak of growth approximately 2 weeks following the second fertilizer application (Figure 3-1). Shoot growth amongst treatments followed the same trends as for the first peak. Plants in incorporated soil had little shoot growth after July 1. However, plants in non-incorporated, mulched plots that received some level of N fertilizer showed small peaks of shoot growth until the end of July; by August, all shoots had ceased to grow.

In 2005, there was an incorporation by N rate interaction ($p<0.01$) effect on shoot growth after the second fertilizer application. Over the season, there were three main peaks of growth that did not appear to be completely related to time of fertilizer application (Figure 3-2). The first increase in shoot growth rate was seen approximately 2 weeks after the first fertilization. Succeeding peaks were seen 2 and 4 weeks after the first peak event. The greatest rate of shoot growth was seen on plants in non-incorporated plots (Figure 3-2). Plants in non-incorporated soil, without mulch, receiving a low N fertilizer rate had a peak growth rate of 0.6 $cm \cdot d^{-1}$. In comparison, plants in incorporated soil, with sawdust, receiving the lowest rate of N had a shoot growth rate of 0.3 $cm \cdot d^{-1}$on the same date. In 2005, on average, shoots had two times the growth rate measured in 2004. All shoot growth ceased by early August (Figure 3-2).

The correlation between periods of maximum shoot growth rate and fertilizer applications in 2004 may have been related to the two week delay in fertilizer N being observed in leaves after application as reported by Retamales and Hanson (1989). In this study, the growth peaks in 2005 that were not correlated to fertilizer, may have been more related to the level of N reserves in the plant as the plants became older. Stored N reserves are very important for perennial growth in the spring. In a raspberry study by Rempel et al. (2004), 24%-37% of stored N was utilized for new growth. In this study, we cannot yet quantify stored N reserves in new growth.

Total shoot growth in this study, in 2004, was very similar to that reported by Haynes and Swift (1986), in young 'Bluecrop' grown on a mineral silt-loam soil, mulched with sawdust. However, growth in 2005 was almost twice that reported by Haynes and Swift (1986), perhaps because in his study plants had a fruit crop in year two. One would expect shoot growth to be reduced when in competition with a fruiting sink.

Whips began growing in late June of both years. At the start of whip growth in 2004, there was a significant incorporation by mulch interaction ($p<0.05$), with plants in non-incorporated, mulched plots having the greatest growth rate -- up to 1.2 $cm \cdot d^{-1}$ (Figure 3-3). The lowest growth rate, in this same time period, was observed in incorporated plots without mulch at 0.66 $cm \cdot d^{-1}$. As the season progressed, only mulch had a significant ($p<0.0001$) effect on whip growth rate. In 2005, there was a significant ($p<0.01$) interaction of incorporation by mulch and N rate at the beginning of the season, but only mulch was significant ($p<0.0001$) during mid-season growth (Figure 3-4). Peak growth was seen at the beginning of the season when whips averaged 2.0 $cm \cdot d^{-1}$ -- a 166% increase over the growth rate in 2004.

This peak in whip growth could also have been due to a lack of fruit crop. Throop and Hanson (1997) found that blueberries have a high fertilizer N demand and absorption capacity from late bloom to mid-harvest. However, there appears to be no reported research on N partitioning, NDFF, or growth differences between one-year-shoots and whips.

Summer leaf nutrients

In 2004, leaf N concentration was significantly affected by the interaction of incorporation and mulch, and incorporation and N rate (Table 3-1). Plants in incorporated plots without mulch had a higher leaf %N than in incorporated, mulched plots (Table 3-1). The highest leaf %N was found in plants growing on un-incorporated soil. There was a similar incorporation by mulch interaction on leaf %P (Table 3-2). Leaf concentrations of Fe and K were significantly reduced with the addition of sawdust mulch (Table 3-2). However, %K increased with increased N fertilizer rate and was higher in plants grown in incorporated soil. Leaf B and Cu concentrations were oppositely affected by the interaction between incorporation and N rate (Table 3-2), as B levels increased in non-incorporated, high N fertilizer plots, while the highest concentrations of Cu were in incorporated, low N fertilizer plots. There was a significant incorporation by mulch interaction on Al and Ca concentration, with Al levels being lowest in non-incorporated, mulched plots. Manganese concentration was not significantly affected by treatment (Table 3-2).

In 2005, leaf N, Ca, and B concentrations were significantly affected only by the main effects of incorporation, mulch, and N rate (Table 3-3). Leaf %P, as in 2004, was significantly affected by the interaction between incorporation and mulch (Table 3-3), with the highest %P found in incorporated plots without mulch. Neither Fe nor Zn concentrations were significantly affected by treatment (Table 3-3).

The leaf N concentration was below standard levels for highbush blueberries in the low fertilized, incorporated plots, as well as the incorporated, mulched plots at all fertilizer levels. This was likely due to the N being immobilized as a result of fir sawdust's high C:N ratio in 2004 (Chapter 1). As the C:N ratio dropped in 2005, more N became available to the plants, and leaf N concentrations increased. Also, higher plant reserves of N could have led to increased leaf N levels.

Iron, Al and Mn concentrations within the leaves dropped significantly in 2005. This decrease was likely due to lower plant reserves in comparison to 2004 levels, rather than a lack of available nutrients. In 2004, plants began with higher than typical reserve nutrient levels due to the intensive fertilization received at the nursery prior to planting. Leaf Fe levels also could have been higher in 2004 due to the overhead irrigation that was utilized until 6 Aug. 2004. The water at the planting site contained high levels of iron oxides which could have inflated leaf Fe concentrations. Leaf Fe in 2005 was below stated sufficiency levels of 60 ppm (Cain and Eck, 1966; Strik and Hart, 1991). If the pH had been above the preferred pH for blueberries, 5.5, this would coincide with Haynes and Swift's (1986) research. However, pH in this study dropped from 2004 to 2005 in all treatments and was well within standard range for optimum blueberry growth. Leaf nutrients would thus be expected to be higher. In 2004, some plants, primarily in incorporated plots, exhibited symptoms consistent with manganese toxicity (Caruso and Ramsdell, 1995). No plants in 2005 showed deficiency symptoms. Lareau (1989) also recorded low micro-nutrient leaf concentrations, with no adverse effects on the plants.

<u>Plant Dry Weight</u>

There was no significant effect of N fertilizer rate on whole plant dry weight in 2004 or 2005. In both years, there was an incorporation by mulch interaction for dry weight (Table 3-4 and 3-5). In 2004, plants in plots with mulch had 163% greater plant dry weight than plants growing without mulch (Table 3-4). Plant dry weight in non-incorporated soil was 190% greater than in incorporated soil. There was an incorporation by N rate interaction with plants in non-incorporated, medium or high N fertilizer treatments having a greater total plant dry weight than plants in incorporated plots receiving low or medium rates of N fertilizer (Table 3- 4). There was also a mulch by N rate interaction, with plants in mulched plots receiving the medium rate of N having a greater dry weight than plants growing without mulch and with the low N rate. Plants in incorporated soil, without mulch, and receiving the medium N rate, accumulated the least dry weight, averaging 84.0 g in 2004, an increase of 469% from the average dry weight of the plants at establishment (17.9 g), or 284.3 $kg{\cdot}ha^{-1}$ gain in accumulated dry weight. In comparison, in 2004 and 2005, plants in the non-incorporated, mulched plots, receiving the medium rate of N fertilizer, had the greatest dry weight accumulation, 361.7 g (1478.7 $kg{\cdot}ha^{-1}$) and

961.7 g (2657.7 kg·ha^{-1}), respectively (Table 3-5 and 3-6). Dry weight accumulation in 2005 almost doubled that of 2004.

Nitrogen rate had no significant effect on plant biomass partitioning in 2004 or 2005 (data not shown). In 2004, on average, the greatest percentage of total plant dry weight was in large roots (28%), followed by whips (26%), two-year-old wood (16%), crown (10%), one-year-old wood and fine roots (8% each), and three-year-old wood (4%). In 2005, large roots and one-year-old wood had the greatest percentage of total dry weight (22% each), followed by whips, two-year-old wood, crown, fine roots and three-year-old wood at 18%, 14%, 10%, 8% and 7%, respectively.

Many practices, such as early cropping (Strik et al., 2003) and pruning intensity (Strik and Buller, 2005) can affect total plant dry weight and biomass partitioning in blueberry. In this study, however, plants were not cropped and pruning severity was adjusted based on plant vigor and to remove flower buds. Since fertilizer N rate had no effect on plant dry weight, the differences in plant size were likely due to changes in soil properties from the addition of sawdust amendment and mulch. Another potential factor, however, is the raised bed design. Spiers (1998) found that a fine sandy loam in a raised bed design decreased plant volume over flat ground. Perhaps in our study, combining a fir sawdust amendment to a clay loam soil in the raised bed design was less beneficial in two respects; 1) by lowering water retention in the root zone (Chapter 2) and 2) through increased irrigation requirements (Chapter 2), potentially flushing nutrients, such as N, through the soil profile faster than the plants could take them up.

It is difficult to correlate growth factors in this experiment to previous studies. Biomass studies in blueberry have primarily been in greenhouse pot studies (Eck and Stretch, 1986; Merhaut and Darnell, 1996), where growth potential was limited. Peterson et al. (1987), for example, in a pot study in rabbiteye blueberries, found that plant weight increased up to 266% over controls, but actual plant weight was not reported.

In 'Totem' strawberries, Strik, et al. (2004) found a maximum dry weight accumulation of 7.2 t·ha^{-1} the first fruiting season. In 'Kotata' blackberries, Mohadjer et al. (2001) found that mature plants accumulated 4.8-5.3 t·ha^{-1} of dry weight. Similar results were found in summer-bearing red raspberries, were plants accumulated 5.5 t·ha^{-1} (Rempel et al, 2004). In our study, plants accumulated considerably less biomass per hectare than any of these crops. However, the plants were still young, and yet the largest plants had already accumulated more than half of what was reported in blackberries (Mohadjer et al., 2001).

Nitrogen

In 2004, total plant N was significantly affected by the interactions of incorporation and mulch, and incorporation and N rate (Table 3-6). Plants growing in non-incorporated soil with mulch averaged 2,818 mg·plant^{-1} of total N in comparison to 1,065 mg·plant^{-1} of total N in plants growing in incorporated soil without mulch. Total N in plants at establishment was 164.7 mg· plant^{-1}, so total net accumulation for 2004 in non-incorporated, with mulch plots was 11.4 kg·ha^{-1} and 3.9 kg·ha^{-1} of N in incorporated, un-mulched treatments.

Nitrogen partitioning, on average, closely followed dry weight partitioning with the greatest percentage of total N in large roots (32%), followed by whips (22%), one-year-old wood (13%), two-year-old wood (12%), fine roots (11%), crown (7%), and three-year-old wood (3%).

Incorporation with sawdust significantly affected total N in whips and one-year-old wood (Table 3-7), with plants in un-incorporated plots having greater amounts of total N. There was an incorporation and mulch interaction on the total N of whips, crowns, large roots, and fine roots (Table 3-7). All parts had more total N in plants from un-incorporated with mulch plots than other treatments. The total N of two-year-old-wood and three-year-old wood was not affected by treatment (Table 3-7).

The increase in total N in plants in un-incorporated plots was probably due to the greater availability of soil N in this treatment. Incorporated sawdust immobilized available N, and there was likely more irrigation-driven leaching (Chapter 2). Comparable soil levels of N in incorporated and non-incorporated plots seen in

Chapter 2 were possibly due to labile N either already having been taken up by the plant or already passing through the soil to deeper layers.

Uptake of fertilizer nitrogen

In Aug. 2004, there was a significant incorporation by mulch and N rate interaction for leaf nitrogen derived from the fertilizer (NDFF; Table 3-2). The greatest leaf NDFF was found in plants growing in incorporated soil, without mulch, receiving the high rate of N fertilizer (Table 3-2). By leaf senescence in Dec. 2004, %N was 1.0 and NDFF was at 60% (Table 3-8), indicating luxury consumption of N. In Dec. 2004, incorporation and N rate significantly affected uptake of fertilizer N on a whole plant basis (Table 3-9). Plants in non-incorporated plots took up, on average, 703 $mg \cdot plant^{-1}$ of fertilizer N, compared to 441 $mg \cdot plant^{-1}$ of fertilizer N in incorporated plots. Increasing rates of applied N increased nitrogen derived from the fertilizer (NDFF), from 497 $mg \cdot plant^{-1}$ to 858 $mg \cdot plant^{-1}$. Fertilizer use recovery in this study varied from 2.7 to 13% in non-incorporated plots to 1.7 to 8.6% in incorporated plots. These results are fairly consistent with previous research in young blueberries (Bañados et al., 2006), which recovered 10%-17% of the applied N fertilizer. The greatest percent fertilizer recovery in this study was observed in plants that received the lowest N fertilizer application rate. The low fertilizer N uptake could be attributed to plant size and N need. Young plants appear to need only small quantities of fertilizer N.

Percent total plant NDFF was significantly affected by the interaction of incorporation and mulch (Table 3-10). Plants in incorporated plots without mulch had a greater percentage of NDFF than plants in un-incorporated, mulched plots. The percent of NDFF in one-year-old wood, crowns, large roots, fine roots and whips, was significantly affected by the interaction of incorporation and mulch

Use of a pre-plant incorporation with sawdust coupled with no mulch in this study reduced shoot and whip growth and decreased total plant dry weight, even though plant NDFF was greater in incorporated treatments. Care should be taken when incorporating sawdust amendments before planting, as these amendments may adversely affect young blueberry growth.

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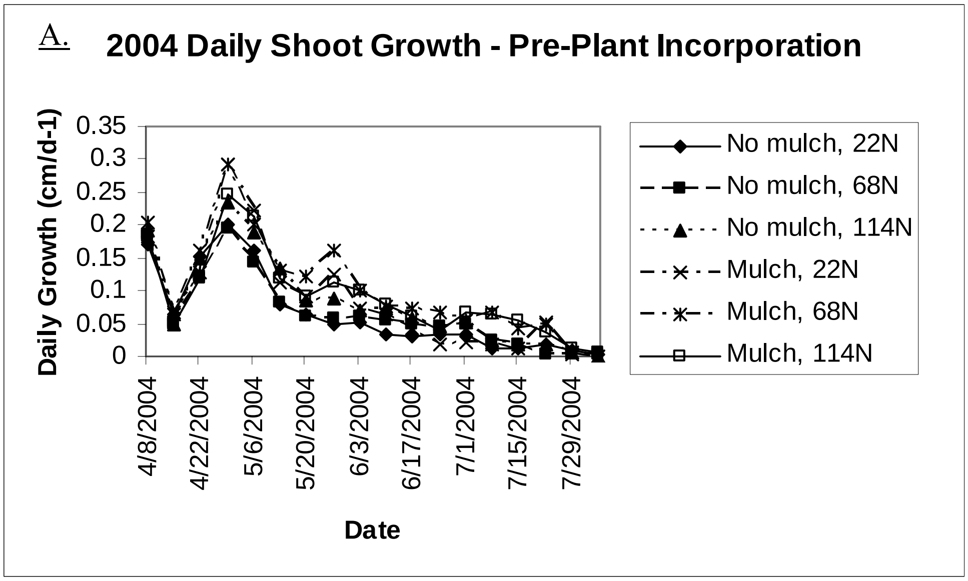


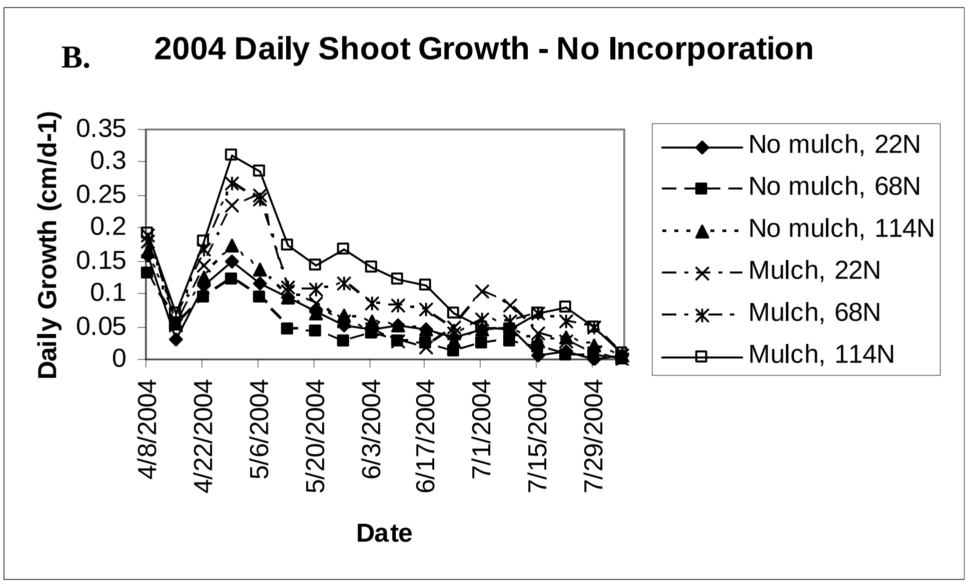
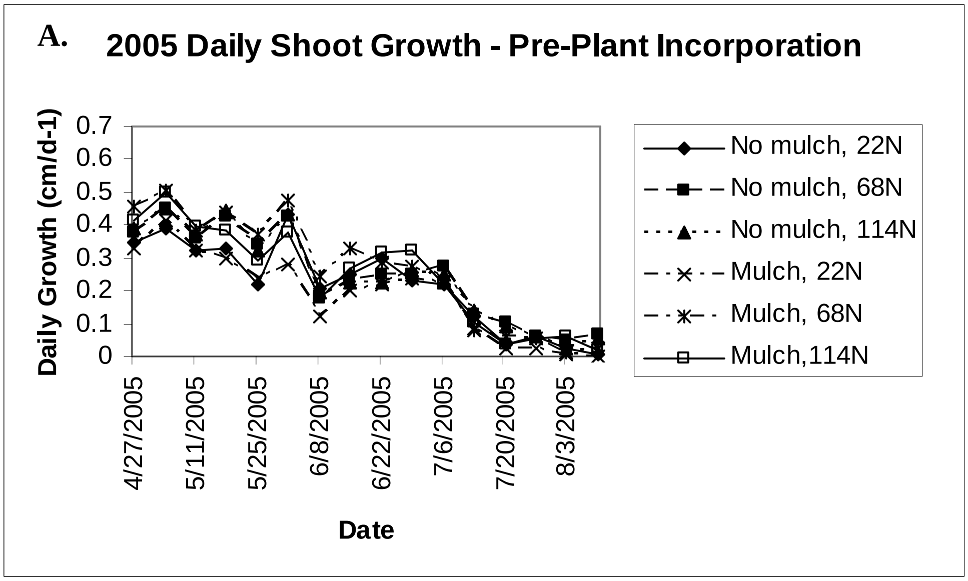


Figure 3-1. The effect of sawdust mulch and N fertilizer rate on daily shoot growth ($cm \cdot d^{-1}$) in 2004 in A) incorporated with pre-plant sawdust amendments and B) no incorporation. Data points represent collection dates.



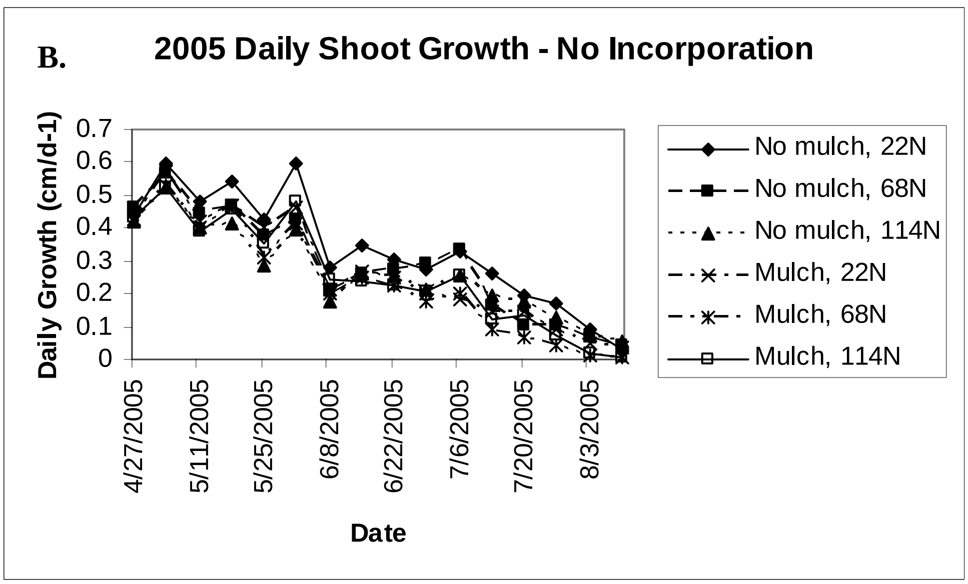
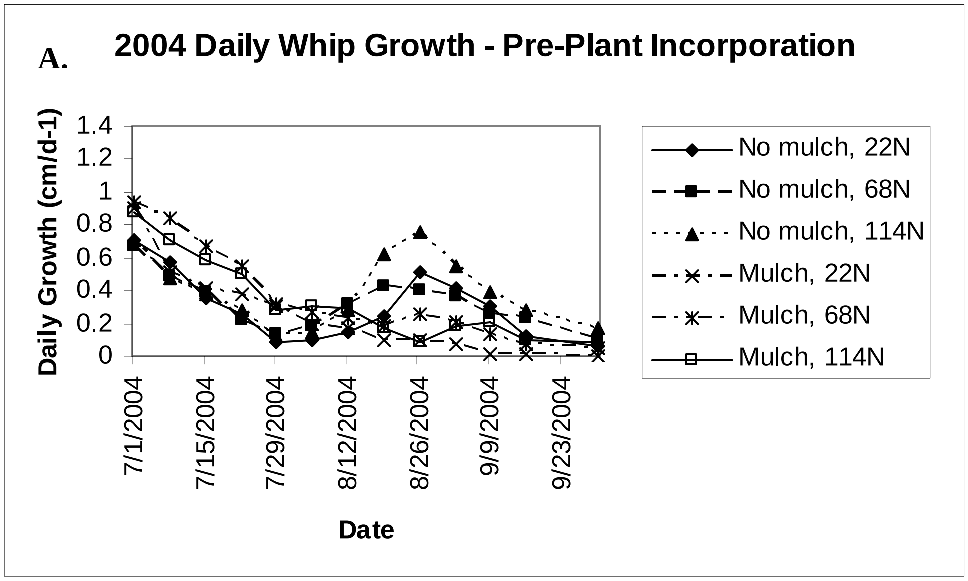


Figure 3-2. The effect of sawdust mulch and N fertilizer rate on daily shoot growth ($cm \cdot d^{-1}$) in 2005 in A) incorporated with pre-plant sawdust amendments and B) no incorporation. Data points represent collection dates.



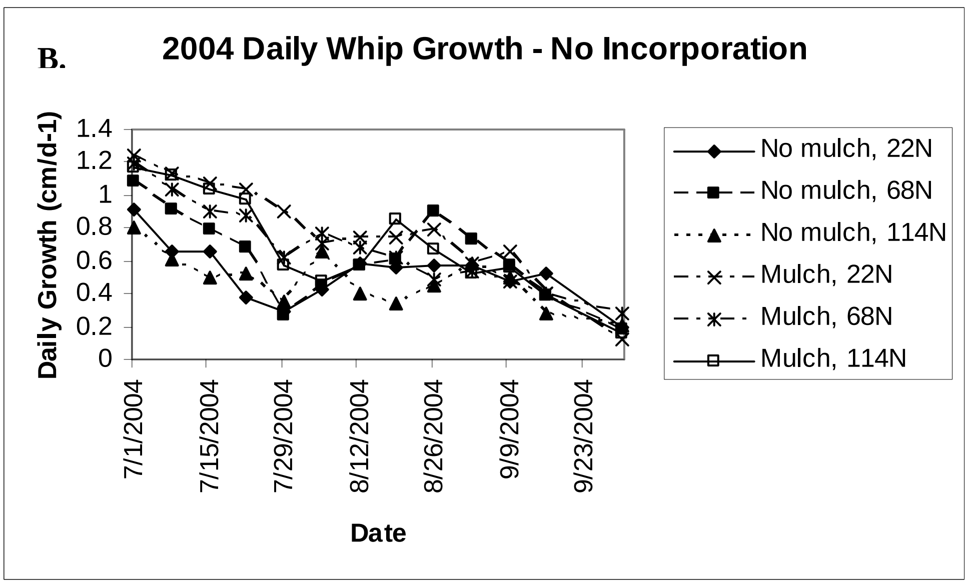


Figure 3-3. The effect of sawdust mulch and N fertilizer rate on daily whip growth ($cm{\cdot}d^{-1}$) in 2004 in A) incorporated with pre-plant sawdust amendments and B) no incorporation. Data points represent collection dates.

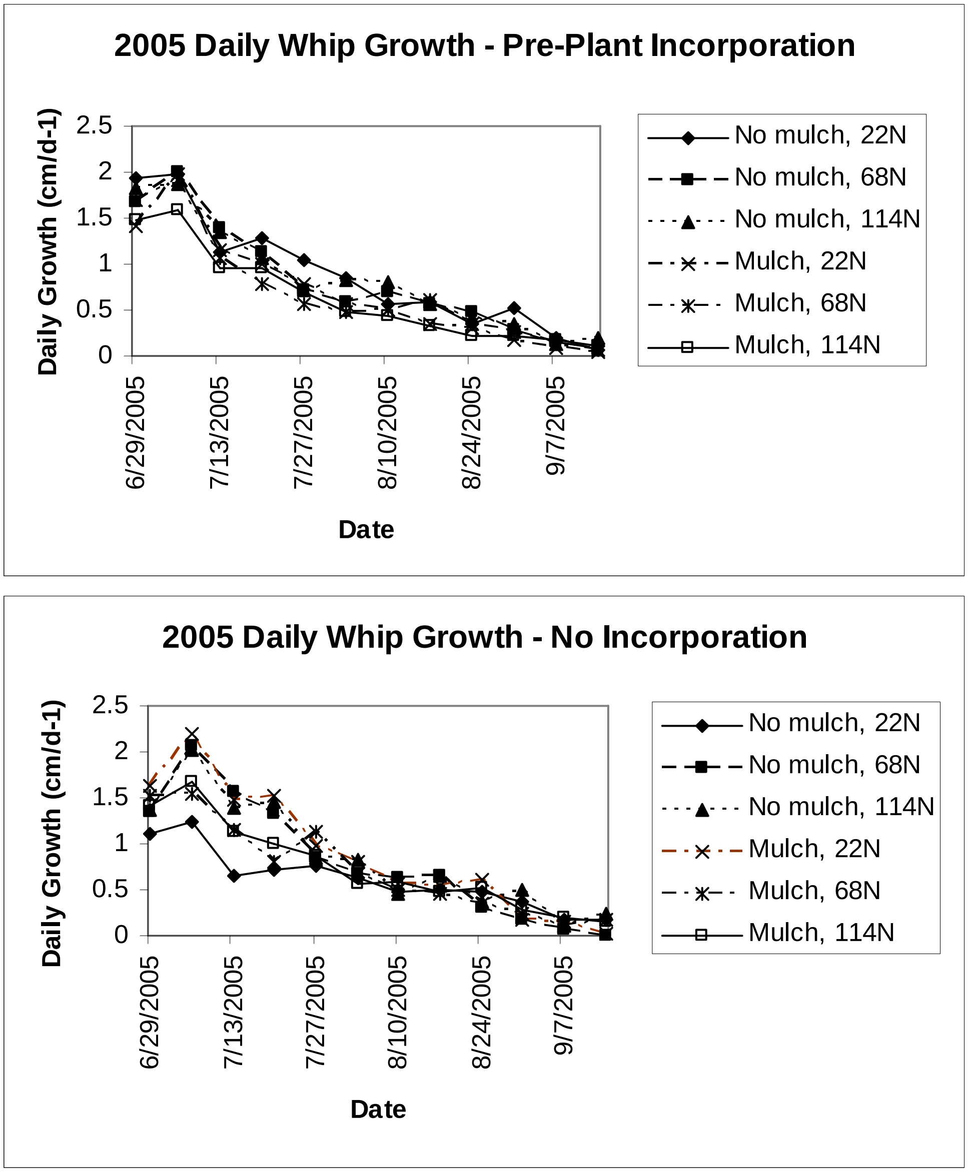


Figure 3-4. The effect of sawdust mulch and N fertilizer rate on daily whip growth ($cm{\cdot}d^{-1}$) in 2004 in A) incorporated with pre-plant sawdust amendments and B) no incorporation. Data points represent collection dates.

Table 3-1. Effect of N fertilization rate (n=16), pre-plant incorporation with sawdust (n=24) and surface sawdust mulch (n=24) on N concentration in leaves and percentage of total N from the fertilizer, 18 August, 2004.

Rate of N fertilization (kg·ha^{-1})	Incorporation (yes/no)	Surface mulch (yes/no)	N concentration (%)	Percent of N in leaves from fertilizer (%)
22	yes	yes	1.3	63.2
68			1.4	64.7
114			1.5	68.0
22	yes	no	1.5	56.8
68			1.7	63.1
114			1.9	73.8
22	no	yes	1.8	50.3
68			1.8	32.9
114			1.9	60.4
22	no	no	1.7	52.5
68			1.8	54.7
114			1.8	57.5
Significance[z]:				
N rate			**	*
Incorporation (I)[y]			***	ns
Mulch (M)			**	ns
N rate * I			ns	ns
N rate * M			ns	ns
I * M			***	ns
I* M * N rate			ns	*

[z]*Significant at P=<0.05; **significant at P=<0.01; ***significant at P=<0.001; ns=not significant.

[y]I=Incorporation, M= Mulch.

Table 3-2. The effect of pre-plant incorporated sawdust (n=24), sawdust mulch (n=24), and N fertilizer rate (n=16) on leaf nutrient content, Aug. 2004.

Rate of N fertilizer ($kg \cdot ha^{-1}$)	Incorp. (yes/no)	Mulch (yes/no)	Macronutrients (%)					Micronutrients (ppm)					
			N	P	K	Ca	Mg	Fe	B	Cu	Mn	Zn	Al
22	yes	yes	1.3	0.08	0.48	0.91	0.28	155	25	8.8	272	12.0	109
	yes	no	1.5	0.09	0.70	0.89	0.29	172	30	6.8	313	11.8	147
	no	yes	1.8	0.10	0.43	0.95	0.24	147	28	8.8	278	11.3	87
	no	no	1.7	0.10	0.61	0.76	0.20	178	23	8.5	279	12.0	101
68	yes	yes	1.4	0.09	0.57	0.85	0.26	158	25	6.5	362	9.8	118
	yes	no	1.7	0.11	0.74	0.94	0.29	188	37	8.0	379	11.5	182
	no	yes	1.8	0.11	0.51	0.81	0.20	137	24	6.8	294	9.3	76
	no	no	1.8	0.10	0.63	0.77	0.21	165	24	7.5	277	10.8	92
114	yes	yes	1.5	0.10	0.62	0.82	0.24	150	26	8.8	309	10.3	122
	yes	no	1.9	0.12	0.76	0.94	0.30	180	39	7.3	430	10.0	218
	no	yes	1.9	0.11	0.53	0.80	0.20	152	23	6.5	294	8.8	79
	no	no	1.8	0.10	0.65	0.72	0.19	175	26	5.3	285	9.0	101
Significance[z]													
N Rate (N)[y]			**	ns	***	ns	***	ns	*	ns	ns	ns	***
Incorp. (I)			***	ns	***	ns	ns	ns	***	ns	ns	ns	***
Mulch (M)			***	***	**	ns	ns	***	ns	ns	ns	***	ns
I x M			***	***	ns	**	**	ns	***	ns	ns	ns	***
I x N			ns	**	ns	ns	ns	ns	*	*	ns	ns	*
M x N			ns	ns	ns	ns	*	ns	**	ns	ns	ns	ns
I x M x N			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[z]*Significant at p<0.05; **significant at p<0.01; ***significant at p<0.001; ns=not significant.

[y]I=Incorporation, M= Mulch, N= Nitrogen rate.

Table 3-3. The effect of pre-plant incorporated sawdust (n=24), sawdust mulch (n=24), and N fertilizer rate (n=16), on leaf nutrient content, Jul. 2005.

Rate of N fertilizer (kg·ha^{-1})	Incorp. (yes/no)	Mulch (yes/no)	Macronutrients (%)					Micronutrients (ppm)					
			N	P	K	Ca	Mg	Fe	B	Cu	Mn	Zn	Al
22	yes	yes	1.5	0.14	0.50	0.56	0.17	44	16	3.5	86	10.3	46
	yes	no	1.6	0.15	0.54	0.57	0.17	44	15	3.3	86	10.5	48
	no	yes	1.6	0.13	0.50	0.55	0.17	40	13	2.5	72	10.0	43
	no	no	1.7	0.14	0.51	0.51	0.17	40	11	2.8	80	11.3	46
68	yes	yes	1.8	0.14	0.51	0.56	0.17	48	15	3.0	90	10.5	49
	yes	no	1.7	0.14	0.53	0.56	0.18	42	14	3.0	84	11.8	50
	no	yes	1.7	0.13	0.51	0.51	0.17	39	11	3.0	88	10.3	45
	no	no	1.8	0.14	0.53	0.48	0.17	43	11	4.3	92	12.0	48
114	yes	yes	1.6	0.14	0.54	0.57	0.18	43	15	2.8	91	10.0	52
	yes	no	1.8	0.15	0.54	0.53	0.18	45	14	3.0	94	11.3	52
	no	yes	1.7	0.13	0.51	0.51	0.17	41	11	2.8	87	9.5	45
	no	no	1.9	0.15	0.57	0.47	0.16	44	11	3.5	95	10.8	49
Significance[z]													
N Rate (N)[y]			**	**	ns	*	ns	ns	**	ns	ns	ns	**
Incorp (I)			***	***	***	**	ns	ns	***	*	ns	ns	ns
Mulch (M)			***	*	***	**	ns	ns	**	ns	***	ns	*
I x M			ns	**	ns	ns	ns	ns	ns	*	ns	ns	ns
I x N			ns	ns	ns	ns	*	ns	ns	**	*	ns	ns
M x N			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
I x M x N			ns	ns	**	ns	ns	ns	ns	ns	ns	ns	ns

[z]*Significant at $p<0.05$; **significant at $p<0.01$; ***significant at $p<0.001$; ns=not significant.
[y]I=Incorporation, M= Mulch, N= Nitrogen rate.

Table 3-4. The effect of pre-plant incorporation with sawdust (n=24), sawdust mulch (n=24), and nitrogen rate (n=16) on dry weight per plant part in Dec. 2004 (mean ± SE).

Rate of Fertilizer N ($kg \cdot ha^{-1}$)	Mulch (yes/no)	Incorporation (yes/no)	1-year wood (g)	2-year wood (g)	3-year wood (g)	Crown (g)	Roots (g)	Total plant (g)
22	No	Yes	32.8±3.3	21.0±2.5	13.8±2.0	14.2±1.8	49.5±8.4	124.3±14.4
	No	No	48.2±5.4	19.2±5.1	--	15.4±3.9	52.1±7.4	134.9±14.3
	Yes	Yes	48.4±17.5	20.2±3.6	15.4±0.6	12.8±2.9	53.8±8.8	142.8±29.6
	Yes	No	113.6±10.8	19.7±6.2	11.1±2.0	23.2±3.2	74.3±8.3	239.4±22.9
68	No	Yes	27.4±4.4	14.9±2.0	5.5±1.0	8.1±1.6	30.8±5.1	84.0±11.8
	No	No	60.6±6.0	19.7±2.3	7.7±0.9	10.9±1.6	53.0±3.9	151.9±10.1
	Yes	Yes	46.3±16.2	16.9±3.2	10.1±2.9	12.8±4.4	52.9±4.5	139.0±25.8
	Yes	No	173.7±25.1	22.5±3.6	29.4±7.4	29.0±5.8	107.1±15.4	361.8±40.1
114	No	Yes	45.5±5.0	20.9±2.8	6.5±0.0	13.3±2.9	38.4±4.6	119.7±9.4
	No	No	62.7±13.0	22.1±3.4	19.5±4.9	11.1±3.8	56.0±4.4	161.6±23.2
	Yes	Yes	50.0±14.4	21.3±0.7	12.7±3.0	15.5±1.4	54.7±12.3	147.8±31.3
	Yes	No	117.5±11.4	20.4±3.9	13.1±1.3	23.5±3.3	75.2±10.6	246.4±26.4
Significance[z]								
Incorporation (I)[y]			***	ns	ns	ns	*	***
Mulch (M)			***	ns	ns	***	***	***
Nitrogen rate (N)			ns	ns	ns	ns	ns	ns
I x M			***	ns	ns	**	ns	**
I x N			*	ns	ns	ns	ns	*
M x N			ns	ns	ns	ns	ns	*
I x M x N			ns	ns	*	ns	ns	ns

[z]*Significant at $p<0.05$; **significant at $p<0.01$; ***significant at $p<0.001$; ns=not significant.
[y]I=Incorporation, M= Mulch, N= Nitrogen rate.

Table 3-5. The effect of pre-plant incorporation with sawdust (n=24), sawdust mulch (n=24), and nitrogen rate (n=16) on dry weight per plant part in Oct. 2005 (mean ± SE)

Rate of Fertilizer N ($kg \cdot ha^{-1}$)	Mulch (yes/no)	Incorporation (yes/no)	1-year wood (g)	2-year wood (g)	3-year wood (g)	Crown (g)	Roots (g)	Total plant (g)
22	No	Yes	281.4±39.8	77.7±22.9	48.9±6.0	75.3±21.2	191.1±30.5	674.3±92.6
	No	No	263.4±21.7	90.1±26.1	53.1±3.2	54.4±11.5	214.4±18.3	675.5±51.6
	Yes	Yes	204.1±36.4	78.8±18.4	39.9±15.1	73.2±7.0	154.0±35.6	550.0±92.3
	Yes	No	335.0±24.2	184.1±16.9	50.0±14.1	95.8±18.3	221.4±17.2	886.3±50.4
68	No	Yes	263.6±41.8	83.2±27.4	53.3±5.6	46.5±6.6	203.2±20.3	649.7±78.7
	No	No	232.0±52.9	98.1±29.0	46.9±7.2	57.1±24.5	181.3±12.7	603.6±114.0
	Yes	Yes	245.0±72.0	86.6±41.2	62.9±17.2	65.5±29.6	184.1±54.8	628.5±206.6
	Yes	No	385.5±45.4	165.8±30.4	79.1±13.8	97.5±22.0	233.9±10.4	961.7±77.6
114	No	Yes	281.5±22.7	56.6±13.4	67.2±18.5	53.8±8.0	209.8±13.1	669.3±49.3
	No	No	228.0±33.4	78.2±20.7	37.0±4.5	54.5±28.7	175.5±19.9	573.3±85.4
	Yes	Yes	265.7±32.0	62.7±16.6	44.0±8.9	61.0±9.2	178.8±25.4	612.1±79.4
	Yes	No	324.6±48.4	134.1±30.0	73.8±19.2	82.2±18.7	212.3±32.6	827.0±117.4
Significance[z]								
Incorporation (I)[y]			ns	**	ns	ns	ns	*
Mulch (M)			ns	*	ns	**	ns	ns
Nitrogen rate (N)			ns	ns	ns	ns	ns	ns
I x M			**	*	*	ns	ns	**
I x N			ns	ns	ns	ns	ns	ns
M x N			ns	ns	ns	ns	ns	ns
I x M x N			ns	ns	ns	ns	ns	ns

[z]*Significant at $p<0.05$; **significant at $p<0.01$; ***significant at $p<0.001$; ns=not significant.
[y]I=Incorporation, M= Mulch, N= Nitrogen rate.

Table 3-6. Effect of N fertilization rate (n=16), pre-plant incorporation with sawdust (n=24), and surface sawdust mulch (n=24) on total plant nitrogen content, Dec. 2004 (mean ± SE).

Rate of fertilizer N ($kg \cdot ha^{-1}$)	Mulch (yes/no)	Incorporation (yes/no)	Plant Nitrogen (mg)
22	No	Yes	970.0±148.0
	No	No	1490.8±131.6
	Yes	Yes	1027.9±288.3
	Yes	No	2291.1±134.7
68	No	Yes	946.6±137.4
	No	No	1641.0±116.0
	Yes	Yes	996.0±296.1
	Yes	No	3678.6±442.0
114	No	Yes	1278.6±101.8
	No	No	1728.1±225.1
	Yes	Yes	1146.5±199.2
	Yes	No	2484.5±252.8
Significance[z]			
Incorporation (I)[y]			***
Mulch (M)			***
Nitrogen rate (N)			ns
I x M			***
I x N			*
M x N			ns
I x M x N			ns

[z]*Significant at p<0.05; **significant at p<0.01; ***significant at p<0.001; ns=not significant.
[y]I=Incorporation, M= Mulch, N= Nitrogen rate.

Table 3-7. The effect of pre-plant incorporation with sawdust (n=24), sawdust mulch (n=24), and nitrogen rate (n=16) on average total N per plant part in Dec. 2004.

Rate of Fertilizer N ($kg{\cdot}ha^{-1}$)	Mulch (yes/no)	Incorporation (yes/no)	Whips (mg)	1-year wood (mg)	2-year wood (mg)	3-year wood (mg)	Crown (mg)	Large Roots (mg)	Fine Roots (mg)
22	No	Yes	122	158	146	70	81	294	135
	No	No	270	272	166	--	121	549	181
	Yes	Yes	222	126	126	89	74	350	86
	Yes	No	687	239	153	72	202	679	277
68	No	Yes	175	116	138	42	71	329	95
	No	No	427	173	173	50	87	554	177
	Yes	Yes	209	116	119	56	75	313	107
	Yes	No	1123	411	197	210	245	1147	347
114	No	Yes	319	162	198	50	108	385	94
	No	No	351	256	193	122	93	574	200
	Yes	Yes	238	150	148	70	102	370	103
	Yes	No	856	212	196	91	181	705	266
Significance[z]									
Incorporation (I)[y]			***	**	ns	ns	*	***	*
Mulch (M)			***	ns	ns	ns	**	**	*
Nitrogen rate (N)			*	ns	ns	ns	ns	ns	ns
I x M			***	ns	ns	ns	**	**	*
I x N			*	ns	ns	ns	ns	ns	ns
M x N			ns	ns	ns	ns	ns	ns	ns
I x M x N			ns	ns	ns	ns	ns	ns	ns

[z]*Significant at $p<0.05$; **significant at $p<0.01$; ***significant at $p<0.001$; ns=not significant.
[y]I=Incorporation, M= Mulch, N= Nitrogen rate.

Table 3-8. The effect of pre-plant incorporated sawdust, sawdust mulch, and N fertilizer rate on percent nitrogen and nitrogen derived from the fertilizer (NDFF) in senescent leaves, Dec 2004 (n=4, mean ± SE).

Rate of Fertilizer N (kg·ha^{-1})	Incorporation (yes/no)	Mulch (yes/no)	2004	
			N (%)	NDFF (%)
22	no	yes	0.81±0.09	28.5±3.4
		no	0.82±0.03	38.3±3.5
	yes	yes	0.46±0.09	57.4±7.8
		no	0.53±0.03	51.2±3.3
68	no	yes	0.86±0.06	28.5±8.3
		no	0.82±0.03	49.4±3.9
	yes	yes	0.32±0.09	55.6±2.0
		no	1.15±0.12	48.3±2.6
114	no	yes	0.91±0.08	42.1±7.3
		no	0.95±0.02	51.5±2.5
	yes	yes	0.66±0.08	67.0±3.7
		no	0.98±0.06	60.4±1.4
Significance[z]				
Incorp (I)[y]			**	**
Mulch (M)			***	ns
Nrate (N)			***	**
I x M			***	***
I x N			ns	ns
M x N			**	ns
I x M x N			***	ns

[z]*Significant at P=<0.05; **significant at P=<0.01; ***significant at <0.001; ns=not significant.
[y] I=Incorporation, M=Mulch, N=Nitrogen rate.

Table 3-9. Effect of nitrogen fertilization rate and pre-plant incorporation with sawdust and surface sawdust mulch (averaged over mulch) on total plant nitrogen derived from fertilizer (NDFF), Dec. 2004 (n = 8; mean ± SE).

Rate of N fertilizer ($kg \cdot ha^{-1}$)	Incorporation (yes/no)	Plant NDFF (mg)
22	yes	410.0±32.1
68		510.9±87.6
114		747.4±67.2
22	no	584.3±49.0
68		900.1±146.0
114		969.9±87.8
Significance[z]:		
Nitrogen rate		**
Incorporation		**
Mulch		ns

[z]*Significant at $p<0.05$; **significant at $p<0.01$; ns=not significant.

Table 3-10. Effect of N fertilization rate (n=16), pre-plant incorporation with sawdust (n=24) and surface sawdust mulch (n=24), on total plant nitrogen derived from fertilizer (NDFF), Dec. 2004 (mean ± SE).

Rate of fertilizer N ($kg \cdot ha^{-1}$)	Mulch (yes/no)	Incorporation (yes/no)	Plant NDFF (%)
22	No	Yes	42.8±5.5
	No	No	39.9±3.3
	Yes	Yes	45.6±5.6
	Yes	No	25.2±2.8
68	No	Yes	54.6±2.7
	No	No	52.1±3.5
	Yes	Yes	49.5±2.3
	Yes	No	24.0±7.2
114	No	Yes	65.3±1.5
	No	No	53.6±2.1
	Yes	Yes	58.5±6.1
	Yes	No	41.8±6.8
Significance[z]			
Incorporation (I)[y]			**
Mulch (M)			***
Nitrogen rate (N)			**
I x M			**
I x N			ns
M x N			ns
I x M x N			ns

[z]*Significant at p<0.05; **significant at p<0.01; ***significant at p<0.001; ns=not significant.
[y]I=Incorporation, M= Mulch, N= Nitrogen rate.

Chapter 4: Conclusions

This research evaluated two elements on the effects of pre-plant fir incorporated sawdust amendments, fir sawdust mulch, and nitrogen fertilizer rate in a newly established ‘Elliott’ blueberry planting - soil properties and plant growth. The soil property research determined effects on soil nutrients, soil pH and organic matter, soil moisture and soil temperature. The plant based study determined the effects on plant growth, nitrogen fertilizer uptake and partitioning.

Soil Properties. There was a wider range in soil temperature in plots incorporated with sawdust and mulched, from -2 ºC in winter to 41 ºC in summer at 0.15 m, than other plots, particularly un-mulched treatments. Sawdust mulch did not appear to mitigate summer or winter soil temperatures. Incorporated plots required 5-6 times more irrigation water than non-incorporated plots during the growing season. Soil pH was reduced with higher rates of application of fertilizer N, but incorporating sawdust amendment or mulch minimized the reduction in pH. Phosphorus levels were higher in mulched plots, where pH was generally higher. Pre-plant incorporation with sawdust and use of a mulch increased organic matter by ~50% the first year. The C:N ratio of the sawdust mulch declined during this study, especially in plots fertilized with high rates of N. Sawdust mulch had from 30% to 52% of nitrogen derived from the fertilizer (NDFF) in Oct. 2004. Soil in plots that were incorporated, had no mulch, and received high fertilizer N had the greatest NDFF in 2004 and 2005 with the NDFF in these plots dropping to about half by Oct. 2005.

Plant growth. Plants in mulched plots had a greater shoot and whip growth rate than plants in un-mulched plots in both years. There was a significant interaction of incorporation by mulch for whip growth in 2004 and total dry weight and biomass partitioning in both years. Whips in un-incorporated, mulched plots had the greatest growth rate, peaking at 1.2 $cm \cdot d^{-1}$. Total plant dry weight was greatest in un-incorporated, mulched plots. Fertilizer rate had no significant effect on total plant dry weight or partitioning. Total ^{15}N uptake was greatest in plants growing in un-incorporated soil, but NDFF was greater in plants growing in incorporated soil, up to

54%. Overall, plant growth was reduced in plots that received a pre-plant incorporation of sawdust amendment and had no surface mulch.

This research indicates that higher rates of N fertilizer do not increase plant growth, but higher rates of fertilizer will help lower soil pH and facilitate breakdown of high C:N ratio sawdust. Mulching with sawdust is beneficial to blueberry plant growth and in increasing soil organic matter. Pre-plant incorporation of sawdust amendments appear to be detrimental to blueberry growth. Soil type and properties should be considered closely before adding incorporating sawdust.

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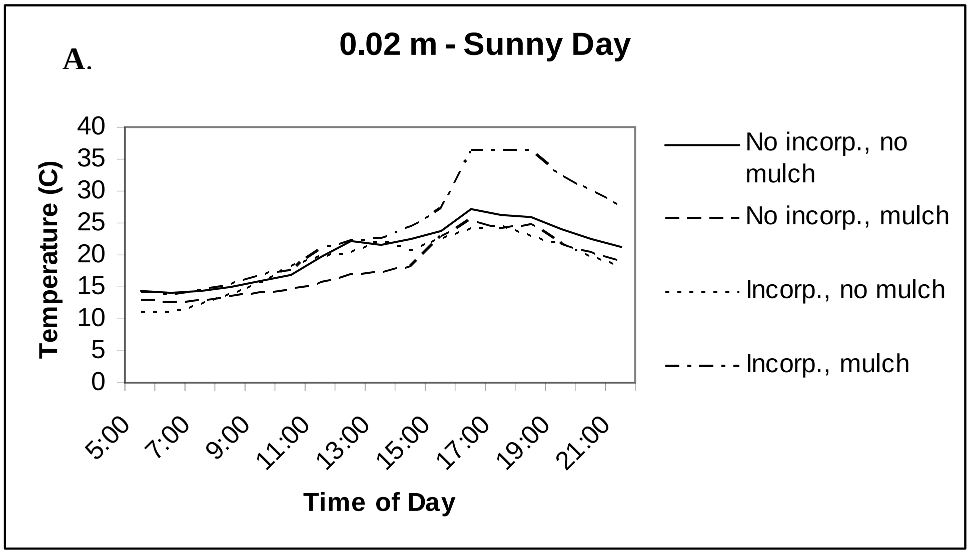
APPENDIX



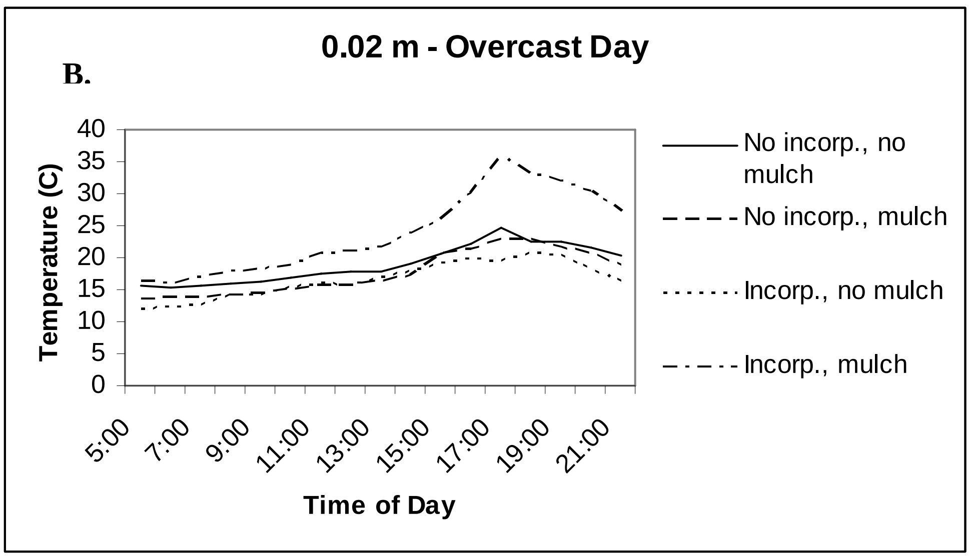


Figure A-1. The effect of pre-plant incorporated sawdust and sawdust mulch on soil temperature (C°) at 0.02 m on A) sunny day (June 12, 2005), and B) overcast day (June 17, 2005).

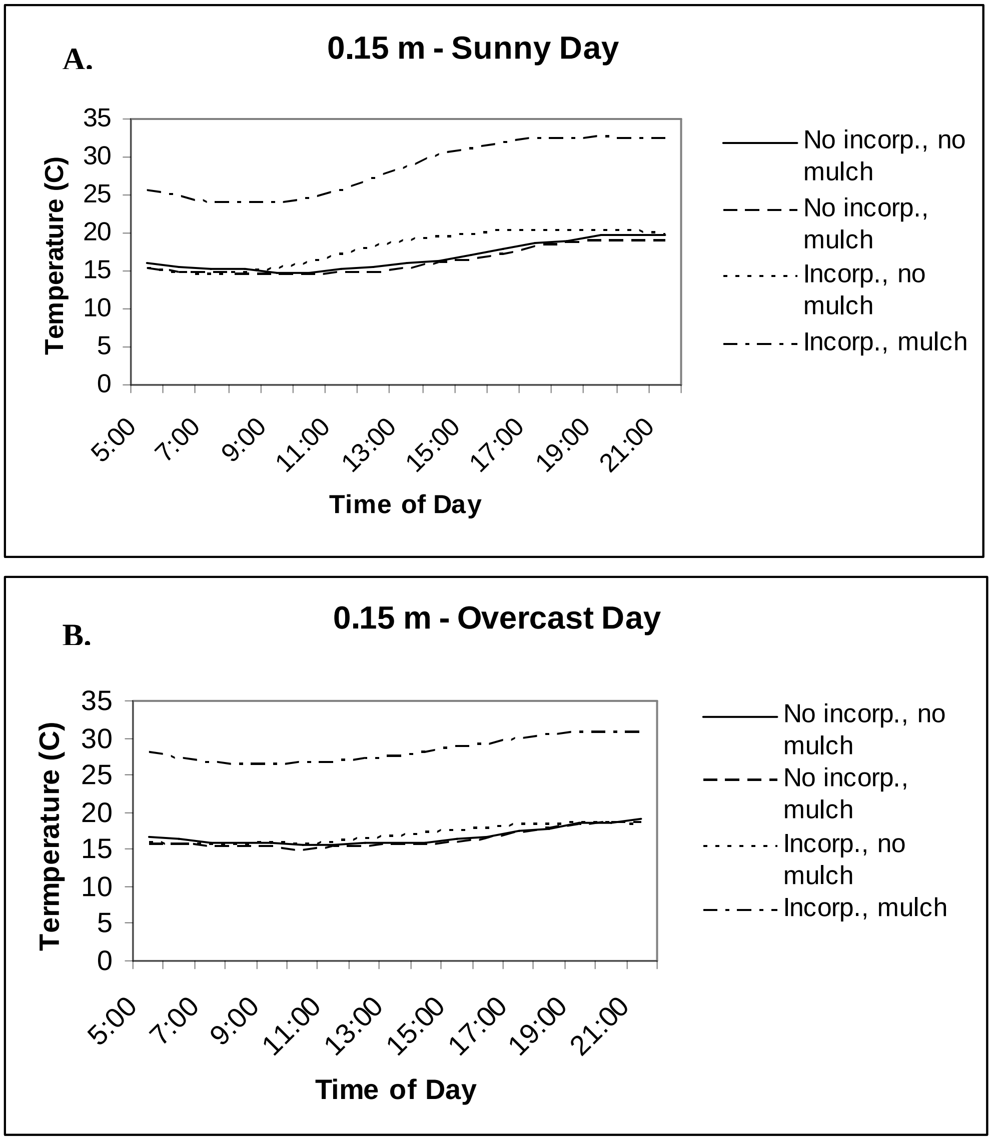


Figure A-2. The effect of pre-plant incorporated sawdust and sawdust mulch on soil temperature (C°) at 0.15 m on A) sunny day (June 12, 2005), and B) overcast day (June 17, 2005).

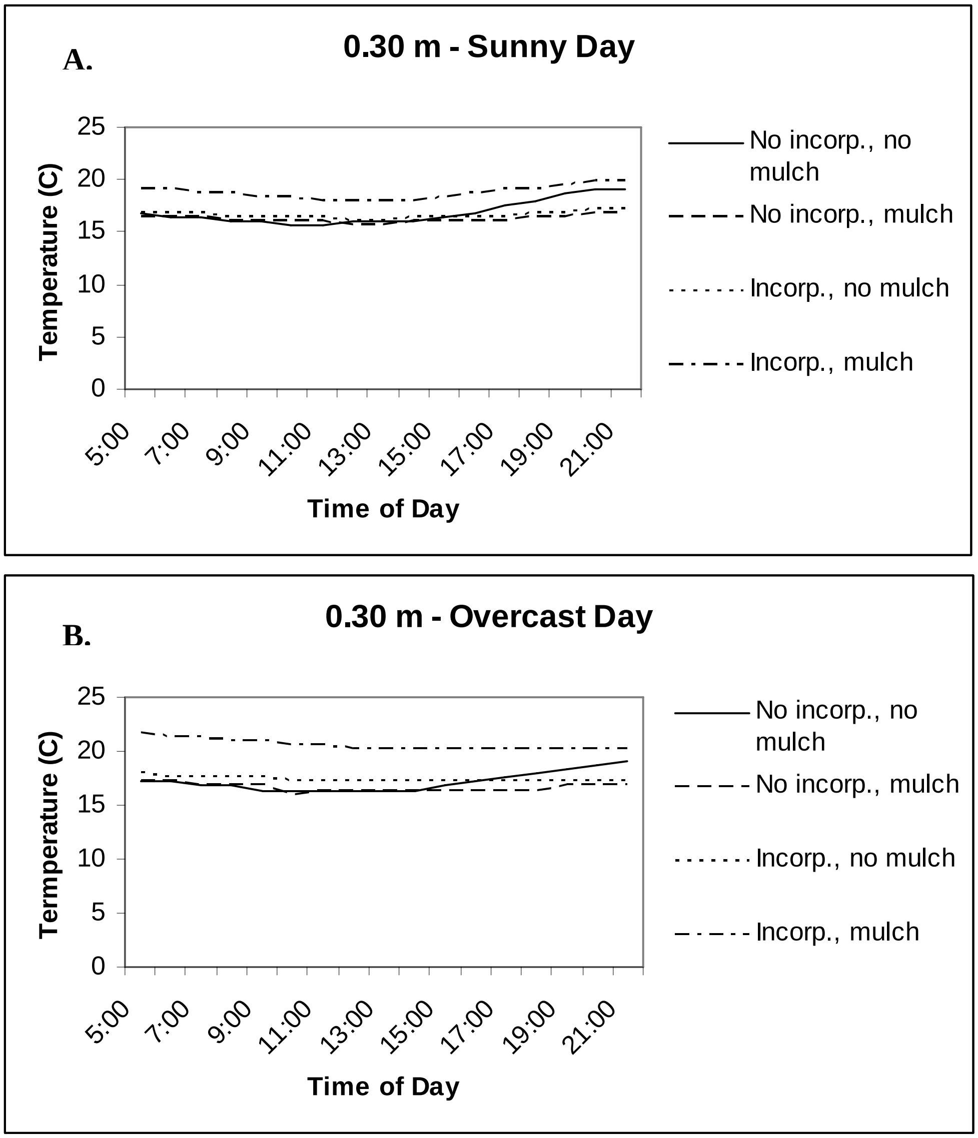


Figure A-3. The effect of pre-plant incorporated sawdust and sawdust mulch on soil temperature (C°) at 0.30 m on A) sunny day (June 12, 2005), and B) overcast day (June 17, 2005).