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# Ground Covers in Fraser Fir (*Abies fraseri* [Pursh] Poir.) Production Systems: Effects on Soil Fertility, Tree Morphology and Foliar Nutrient Status

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## Summary

The effect of three ground covers [alfafa (*Medicago sativa*), Dutch white clover (*Trifolium repens*) and perennial rye (*Lolium perenne*) on soil fertility, tree morphology, and tree nutrient status in a Fraser fir-cover crop intercropping system was investigated to assess the impacts of cover crop species and management practice on the sustainability of the cropping system. Ground cover were mowed every 21 days and returned to the ground as green mulch. Parameters monitored included soil moisture, soil organic carbon and nitrogen, soil mineral nitrogen, cover crop biomass and nutrient content, and tree morphological and nutrient characteristics. Results obtained indicated that the species selection affected the amount of green manure produced and its total nitrogen and phosphorus content. Soil organic carbon and nitrogen were stable in the upper soil profile due to the relatively small quantity added with the cropping system compared to the total stock of soil C and N. Mineral nitrogen decreased over the season due to the synchrony of cover crop decomposition, mineralization and nutrient uptake by trees in the upper profile. Species selection and management practices did not affect tree relative height growth and 100-needles weight, but management practices affected relative diameter growth, indicating competition for soil moisture. Tree foliar nutrient concentrations were not significantly affected by cover species, but were much lower in some of the management practices, suggesting competition for nutrients. We conclude that careful management should be used to capitalize on cover crop benefits and avoid competition for soil nutrients and moisture.

**Key words.** cropping system – green manure – soil organic carbon – soil organic nitrogen – plantation management – soil moisture

## Introduction

Fraser fir (*Abies fraseri* [Pursh] Poir.) is a commonly grown species for Christmas tree production or short rotation silviculture for its morphological and aesthetic characteristics (Nzokou and Leefers 2007). Traditional production practices include high rates of inorganic fertilizer application throughout the growing season in addition to frequent herbicide sprayings and pesticide use (Nzokou and Leefers 2007). These practices are costly to growers and detrimental to the environment, but are necessary for farmers to maintain high soil nitrogen to ensure maximum growth and desired tree colour. However, when excess organic nitrogen exists in the soil due to imbalances of plant uptake and immobilization, the negatively charged nitrate ions become vulnerable to leaching (Thomsen 2005). Intensive fertilizer regimens disrupt production systems' innate ability to balance nutrients (Altieri 1999).

An alternative to conventional production methods is intercropping of cover crops into the growing system to function as green manures, which decreases expenses in eliminating the need for frequent inorganic fertilizer inputs (Sirrine et al. 2008). Returning cut cover crop to plots through regular mulching provides a constant flow of organic nutrient input to the soil (Pardo et al. 2009), which can alter soil carbon to nitrogen ratios and influence microbial nitrogen mobilization. Acute effects of cover crop addition include initial spikes in available nitrogen followed by decreases due to mineralization, allowing soil nitrogen to be stored until made available for plant use (Pardo et al. 2009).

While using cover crops can be advantageous to production systems, intercropping develops a complex ecosystem in which competitive interactions may occur. Where below ground competition occurs, plants compete for available soil resources, mainly water and mineral nutrients, causing a decrease in growth to the out-competed species (Casper and Jackson 1997).

Several studies on the use of ground covers in various agricultural cropping systems have been conducted. However, their use in plantation forestry and short rotation silviculture is relatively new and there is little published evidence on the effect of ground cover on such production systems. We hypothesized that when ground covers are mixed with trees both facilitative and competitive interactions occur with the response depending on the ground cover management practice. The objectives of this study are to 1) explore the effects three ground cover species and their management on Fraser fir morphology and foliar nutrient status, and 2) to determine the impact of cover crop management on soil fertility.

## Materials and Methods

### *Site description*

The experiment was conducted at the Tree Research Center in Sandhill on the campus of Michigan State University. The field coordinates are 42.65° N latitude and 84.42° W longitude. Weather conditions were relatively mild with rainfall fairly well distributed throughout the growing season. The field was surrounded by a 3-wire electric fence to reduce deer browsing. The soil is a Marietta fine sandy loam that is classified as moderately well drained with high available water capacity and medium surface runoff. Marietta soils are subject to erosion and tend to have poor tilth.

### *Plant materials and field management*

Plant materials used included Fraser fir as tree crop and three cover crops species—two legumes [Dutch white clover (*Trifolium repens*) and alfalfa (*Medicago sativa*)) and one grass (perennial rye (*Lolium perenne*)]. Fraser fir transplants were machine planted in May 2007. Dutch white clover, alfalfa (SS 100 brand) and perennial rye (VNS) seeds were purchased from Michigan State Seeds (Grand Ledge, Michigan) and hand broadcasted at the beginning of the 2007 season. The seeding rates were 28 kg $ha^{-1}$ for clover and alfalfa and 13 kg $ha^{-1}$ for rye. Cover crops were regularly mowed during the growing seasons in 2007 and 2008 to reduce competition with trees. Each plot was 0.008 ha in size and contained 35 trees (5 rows × 7 trees). Perimeter trees functioned as a buffer between plots to avoid confounding effects between treatments, and the interior fifteen trees (3 × 5) were used for data collection. Management practices included combinations of banding and no-banding treatments of each species of cover crop, and a control or bare-ground (BG) treatment where all weeds were removed by application of a 35.84 kg $ha^{-1}$ of glyphosate with a $CO_2$ powered backpack sprayer (R & D Sprayers, Baton Rouge, LA). Banding consisted of maintaining a bare 52 cm band centred around the tree row. This was achieved by applying a directed spray of glyphosate with a custom designed MANKAR sprayer (George F. Ackerman Company, Curtice, OH) at a rate of 3 L $ha^{-1}$ three times during the season. The summary of the seven treatments includes; bare-ground (BG), banded perennial rye (PR+B), non-banded perennial rye (PR+noB), banded afalfa (ALF+B), non-banded alfalfa (ALF+noB), banded white clover (WC+B), and non-banded white clover (WC+noB). All treatments were replicated 3 times in a random design.

### *Cover crop biomass and nutrient accumulation*

Mechanical mowing was performed every three weeks (5 cm above the ground) to control cover crop growth, minimize cover competition with crop trees, and add green manure to the soil. During each mowing, cover crop biomass returned was determined by collecting biomass from randomly selected 0.55 $m^2$ quadrants in each plot. The green biomass collected in each treatment was weighed and oven-dried at 65 °C and the dried biomass determined. Sub-samples from each treatment were used for chemical analyses.

### *Soil nitrate and ammonia*

Composite soil samples were collected from depths of 0–15 cm and 15–30 cm, within one foot of trees at two random locations within each plot using a soil auger. Samples were placed in zip-lock bags and transported to the laboratory where they were refrigerated until analysis. Subsets of soil specimens were extracted using potassium chloride. The extract obtained after filtration of the soil solution was analysed by segmented flow analysis to determine soil $NH_4^+$ and $NO_3^-$.

### *Total carbon and total nitrogen analysis*

Soil samples were oven-dried at 105 °C for 48 h and sieved to pass through a 200 μ m mesh before analysis. Total organic carbon (TOC) and total organic nitrogen (TON) were determined by dry combustion using a CHN autoanalyser (Leco, St Joseph, MI).

### *Soil moisture*

Soil moisture content was measured throughout the season using a Field Scout TDR 300 Soil Moisture Probe (Spectrum Tech Inc, Plainfield, IL). Moisture readings were taken at four randomly selected locations in each of the plots, within one foot of a tree.

### *Tissue analyses*

Foliar tissues from trees were collected in each plot for nutrient analysis. Subsets of cover crop biomass samples collected during each mowing were also processed for nutrient analysis.

Each tissue type was oven dried at 60–65 °C and ground into a fine powder. Approximately 0.3 g of material was placed into a 75 ml digestion tube and acid digested with sulfuric acid (4.5 ml) and hydrogen peroxide (1.5 ml). A digestion blank was included for verification. Samples were pre-digested for two hours and placed into a block digester (AIM600 Block Digestion System) at 340 ± 10 °C for heat digestion under a programmed temperature schedule.

Total nitrogen was determined as described by Christianson and Holt (1986). Aliquots from the digested solution were buffered and chlorinated after dialysis to form a chemical complex measured at 660 nm on a SAN++ segmented flow analyser (Skalar Inc. Atlanta, GA). The total phosphorous content determination was based on the ammonium heptamolybdate and potassium antimony (III) reaction that form under acidic environment an antimony-phospho-molybdate complex measured at 880 nm on the SAN++ segmented flow analyser.

### *Tree growth and mass of 100 needles*

Tree height and root collar diameter (RCD) were measured in early May and late August. Height and diameter growth were calculated as the difference between the final and initial measurements. Relative height growth (RHG) and relative RCD growth were calculated by dividing the height and root collar growth by the initial value for each tree. During each growth measurement, needle samples were randomly collected from trees within each plot and the average mass of one hundred needles was determined for each treatment.

### *Data analysis*

Two-way analysis of variance (ANOVA) was used to test the effects of the groundcover management system on the growth of the Fraser fir and nutrient concentrations of plants and soil. The means were separated by an LSD-test for alpha $\alpha<0.05$. Pearson's correlation coefficient was calculated to detect relationships between tree growth and nutrient status. All statistical analyses were performed using Systat 13 statistical software (Systat Software, Inc., Chicago, IL).

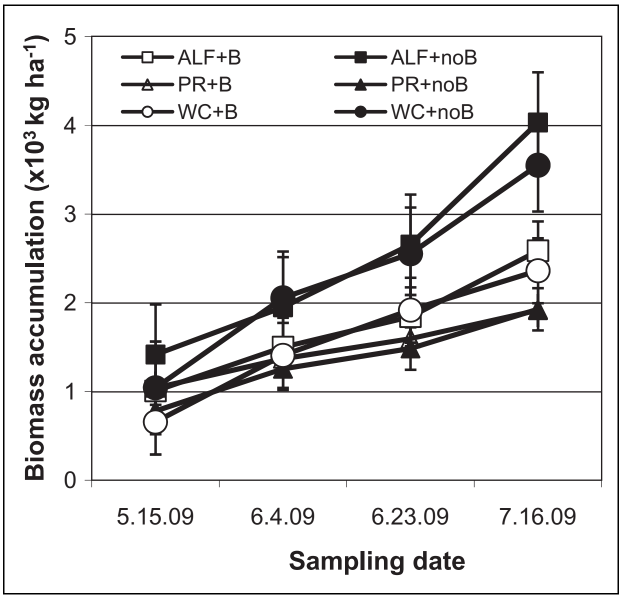


Fig. 1. Average cumulative cover crop biomass returned to respective treatment with mowing in the 2009 growing season.
Labels: ALF+B = alfalfa with banding, ALF+noB = alfalfa with no banding; PR+B = perennial rye with banding; PR+noB = perennial rye with no banding; WC+B = white clover with banding; WC+noB = white clover with no banding.

## Results

### *Cover crop biomass accumulation*

Accumulated biomass was greatest in treatments with leguminous cover crop species, which produced more green manure than rye treatments (Fig. 1). Alfalfa treatments without bands (ALF+noB) cumulated the greatest amount of biomass (4.033 kg $ha^{-1}$), while perennial rye treatments accumulated the least (1.917–1.927 kg $ha^{-1}$). Cover crop species significantly affected biomass accumulation ($P\leq0.01$). Except for the perennial rye, treatments without banding generally produced higher cumulated amounts of biomass, but the effect of the management strategies (banding vs. no banding) were not statistically significant ($P\leq0.37$).

### *Cover crop nitrogen and phosphorous content*

As expected, the nitrogen content of the ground cover biomass returned to the ground through mowing was greater in legume treatments compared to the grass treatment (Fig. 2). The cumulated nitrogen content was greatest in WC+noB (151 kg $ha^{-1}$), followed by ALF+noB (141 kg $ha^{-1}$). Perennial rye treatments returned the least with 56 and 52 kg $ha^{-1}$ for PR+B and PR+noB respectively. Similar to biomass accumulation, cover species selection affected N accumulation ($P\leq0.01$), but management strategy did not ($P\leq0.17$). The N accumulation varied across the season ($P\leq0.03$) due to higher biomass production early in the spring.

Patterns of phosphorous content differed from N content with ALF+noB returning higher amounts of P (13.4 kg $ha^{-1}$) due to a higher P concentration. White clover treatments were intermediate and perennial rye treatments returned the least amount of P (6.1 kg $ha^{-1}$ and 6.7 kg $ha^{-1}$ for PR+noB and PR+B respectively). Phosphorus content did not vary over time ($P\leq0.104$).

### *Soil organic carbon, nitrogen and C/N ratio*

At the beginning of the growing season (May), total organic carbon (TOC) was similar among all treatments for samples from the 0–15 cm depth (Table 1). At the end of the season indicated TOC was lower ($P\leq0.05$) in WC+B than the other treatments. Otherwise, TOC did not differ among plots. Similarly, total organic nitrogen (TON) values did not vary among treatments on either sampling date, although TON tended to decrease slightly over time (Table 1).

Similar trends with few exceptions were found for samples from the deeper profile (15–30 cm) for TOC and TON. Significant differences in TOC and TON were found for WC+noB compared to other treatments, except for TON under perennial rye ($P\leq0.05$). TOC and TON values from 15–30 cm were generally lower than those obtained from samples from the upper soil profile.

Early in the season, C/N at a depth of 0–15 cm varied widely among treatments ranging from 8.6 to 10.7. Late in the season, C/N values at 0–15 cm varied less, ranging from 10.4 to 10.9 depending on the treatment. Similar trends were observed at 15–30 cm with early season C/N values ranging from 9.4 to 11.5 and late season varying from 10.4 to 11.6. Overall C/N did not vary throughout the growing season ($P\leq0.60$).

### *Soil nitrate and ammonium concentration*

Nitrate concentrations at 0–15 cm were similar in all treatments at the beginning of the growing season and tended to decrease in all treatments except BG and WC+B treatments. However, the difference between treatments was not significant in the late season sampling (Table 1). At 15–30 cm sampling depth, nitrate was lower than in the upper profile. Nitrate values for PR+B ($16.7\pm5.9$ ug $g^{-1}$) were lower than those in WC+noB treatments ($54.0\pm13.0$ ug $g^{-1}$).

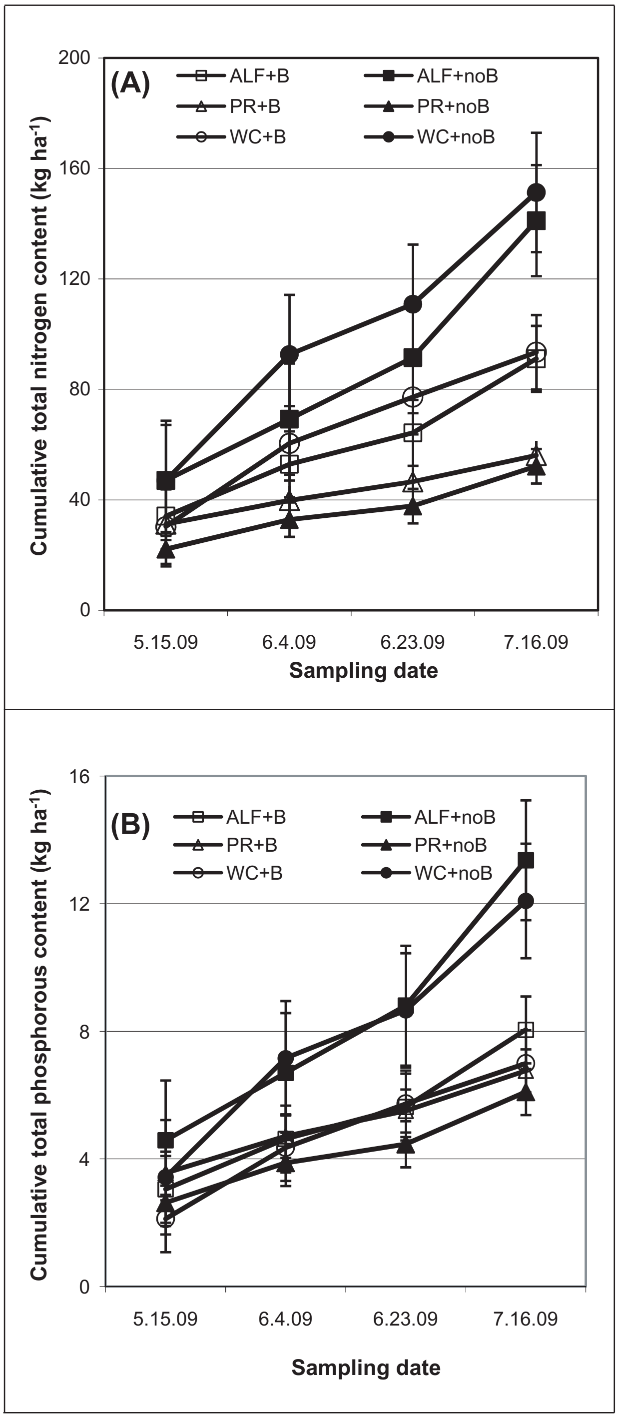


Fig. 2. Cumulative (A) nitrogen and (B) phosphorous returned in green manure during the 2009 growing season.
Labels: ALF+B = alfalfa with banding, ALF+noB = alfalfa with no banding; PR+B = perennial rye with banding; PR+noB = perennial rye with no banding; WC+B = white clover with banding; WC+noB = white clover with no banding.

Ammonia concentrations also varied in the 0–15 cm profile for the early season sampling with higher values for PR+noB (233.8±56.4 ug $g^{-1}$) compared to BG treatments (41.2±17.6 ug $g^{-1}$). However, in the late season sampling, there was no difference between treatments. At the 15–30 cm profile, ammonia did not vary across the season.

*Soil moisture*

With few exceptions, soil moisture content was similar in BG and banded treatments for all three ground cover species (Fig. 3). PR+B consistently had lower moisture content compared to BG, and WC+B, and WC+noB tended to have higher soil moisture content. For measurements conducted in July (low rainfall), ALF+noB and PR+noB had significantly lower soil moisture content. As expected, management practice (banding or no banding) had significant effects on soil moisture ($P \leq 0.00$), but the ground cover species also affected ($P \leq 0.04$) soil moisture content.

*Foliar weight and tree growth*

Needle masses in all treatments increased from May to August (Fig. 4) but did not vary among treatments. Both ground cover crop species ($P \leq 0.36$) and management practices ($P \leq 0.44$) did not affect the needle biomass. There was no treatment effect on RHG ($P \leq 0.43$), RRCD growth ($P \leq 0.00$) was significantly affected (Fig. 5). RRCD was generally lower in treatments without bands compared to banded treatments that generally displayed RRCD values similar to BG treatments.

*Foliar nutrient concentrations*

Foliar N concentrations were similar in all treatments in June and July, but treatments varied in ALF+noB, WC+B, and PR+B for August samples (Fig. 6). At the end of the season, banded treatments generally had higher foliar N concentrations compared to BG, and non-banded treatments had lower N concentrations. As a consequence, the management practice had a statistically significant effect on the foliar N concentrations ($P \leq 0.00$). Surprisingly, the ground cover species did not significantly affect foliar N concentrations ($P \leq 0.76$).

Foliar P concentrations displayed trends very similar to foliar N concentrations. Concentrations were statistically similar in both June and July, but differences were observed at the end of the growing season when banded treatments had higher P concentrations compared to non-banded treatments. The management strategies had a significant effect on P concentrations ($P \leq 0.00$) while the ground cover species had no significant effect ($P \leq 0.93$).

## Discussion

Cover crop species affected the total dry weight of green manure returned to the system with the two legumes (alfalfa and white clover) returning significantly more biomass than the grass species (perennial rye). This observation is in agreement with previous studies conducted on biomass quantification (CLINE and SILVERNAIL 2001). Genetic differences and the ability to fix atmospheric N dictate why the two legumes were able to grow larger.

Biomass production was directly related to the quantity of organic nitrogen and phosphorus returned to the system and helped improve the total nutrient budget. As

Table 1. Total soil carbon, nitrogen, nitrates and ammonia concentrations in early (May 29) and late (August 25) growing season as related to the ground cover species and management practice.

| Treatment | May 29, 2009 | | | | | August 25, 2009 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | TOC (mg g$^{-1}$) | TON (mg g$^{-1}$) | C/N | $NO_3^-$ (µ g g$^{-1}$) | NH4$^+$ (µ g g$^{-1}$) | TOC (mg g$^{-1}$) | TON (mg g$^{-1}$) | C/N | $NO_3^-$ (µ g g$^{-1}$) | NH4$^+$ (µg g$^{-1}$) |
| | | | | | Sampling depth 0–15 cm | | | | | |
| BG | 17.5 ± 2.1 a | 2.1 ± 0.3 a | 8.6 | 45.7 ± 8.0 a | 41.2 ± 17.6 a | 17.8 ± 2.6 a | 1.7 ± 0.3 a | 10.5 | 51.6 ± 20.7 a | 70.7 ± 22.5 a |
| ALF+B | 17.8 ± 1.6 a | 1.8 ± 0.2 a | 10.2 | 40.9 ± 29.9 a | 206.4 ± 14.9 ab | 17.5 ± 0.7 a | 1.6 ± 0.1 a | 10.8 | 39.6 ± 12.4 a | 70.6 ± 29.8 a |
| ALF+noB | 18.1 ± 1.3 a | 1.8 ± 0.2 a | 10.0 | 45.9 ± 10.6 a | 75.1 ± 35.0 ab | 19.6 ± 2.5 a | 1.8 ± 0.2 a | 10.5 | 37.7 ± 13.1 a | 50.5 ± 10.8 a |
| PR+B | 19.6 ± 2.7 a | 1.8 ± 0.3 a | 10.7 | 34.0 ± 12.2 a | 148.2 ± 48.5 a b | 18.6 ± 2.8 a | 1.8 ± 0.3 a | 10.6 | 32.6 ± 5.0 a | 95.6 ± 10.5 a |
| PR+noB | 16.6 ± 3.2 a | 1.8 ± 0.4 a | 9.5 | 19.2 ± 1.9 a | 233.8 ± 56.4 b | 17.9 ± 3.7 a | 1.6 ± 0.3 a | 10.9 | 13.0 ± 9.4 a | 48.8 ± 4.9 a |
| WC+B | 16.4 ± 1.7 a | 1.6 ± 0.2 a | 10.2 | 33.6 ± 6.4 a | 126.6 ± 61.2 ab | 15.1 ± 1.6 b | 1.5 ± 0.2 a | 10.4 | 56.8 ± 5.6 a | 40.3 ± 4.0 a |
| WC+noB | 19.3 ± 5.3 a | 2.2 ± 0.4 a | 8.8 | 64.5 ± 45.4 a | 57.0 ± 24.8 ab | 21.9 ± 1.6 a | 1.5 ± 0.2 a | 10.6 | 40.1 ± 17.6 a | 84.3 ± 26.5 a |
| | | | | | Sampling depth 15–30 cm | | | | | |
| BG | 12.5 ± 2.4 a | 1.2 ± 0.2 a | 10.1 | 26.5 ± 3.3 a | 25.0 ± 12.7 a | 14.4 ± 1.6 ab | 1.3 ± 0.1 a | 10.7 | 33.7 ± 10.7 ab | 22.2 ± 3.1 a |
| ALF+B | 12.6 ± 1.1 a | 1.1 ± 0.1 a | 11.4 | 43.1 ± 12.8 a | 12.4 ± 2.8 a | 13.1 ± 1.3 ab | 1.2 ± 0.1 a | 10.6 | 31.4 ± 3.4 ab | 19.7 ± 0.3 a |
| ALF+noB | 14.3 ± 1.2 a | 1.4 ± 0.1 a | 10.5 | 16.3 ± 1.8 a | 7.3 ± 0.3 a | 14.7 ± 1.8 ab | 1.3 ± 0.1 a | 11.6 | 20.9 ± 2.7 ab | 20.9 ± 3.3 a |
| PR+B | 15.0 ± 1.0 a | 1.4 ± 0.1 a | 11.0 | 32.8 ± 9.0 a | 12.7 ± 3.4 a | 15.9 ± 2.0 ab | 1.5 ± 0.2 ab | 10.8 | 16.7 ± 5.9 a | 34.8 ± 5.4 a |
| PR+noB | 10.5 ± 3.3 a | 1.0 ± 0.3 a | 10.0 | 40.8 ± 10.9 a | 14.5 ± 6.8 a | 13.7 ± 2.1 ab | 1.2 ± 0.2 a | 11.2 | 20.1 ± 5.2 ab | 45.6 ± 18.5 a |
| WC+B | 12.3 ± 2.6 a | 1.1 ± 0.2 a | 11.5 | 37.0 ± 8.9 a | 20.0 ± 13.1 a | 12.7 ± 1.4 a | 1.2 ± 0.1 a | 10.9 | 38.2 ± 4.8 ab | 19.4 ± 5.4 a |
| WC+noB | 12.7 ± 0.9 a | 1.4 ± 0.2 a | 9.4 | 13.6 ± 2.4 a | 66.9 ± 63.3 a | 16.5 ± 1.2 b | 1.6 ± 0.1 b | 10.4 | 54.0 ± 13.0 b | 27.9 ± 8.6 a |

Values followed by the same letters mean no statistical difference using the Tukey's Honestly-Significant-Difference Test.
TOC, TON and C/N measurement in May and August were analysed using the repeated measures mixed model. The model was not significant for TOC (P=0.65), TON (P=0.57) and C/N (P=0.60)
Treatments: BG = bare-ground, ALF+B = Alfalfa with banding, ALF+noB = Alfalfa with no banding, PR+B = Perennial rye with banding, PR+noB = Perennial rye with no banding, WC+B = White clover with banding, WC+noB = White clover with no banding.

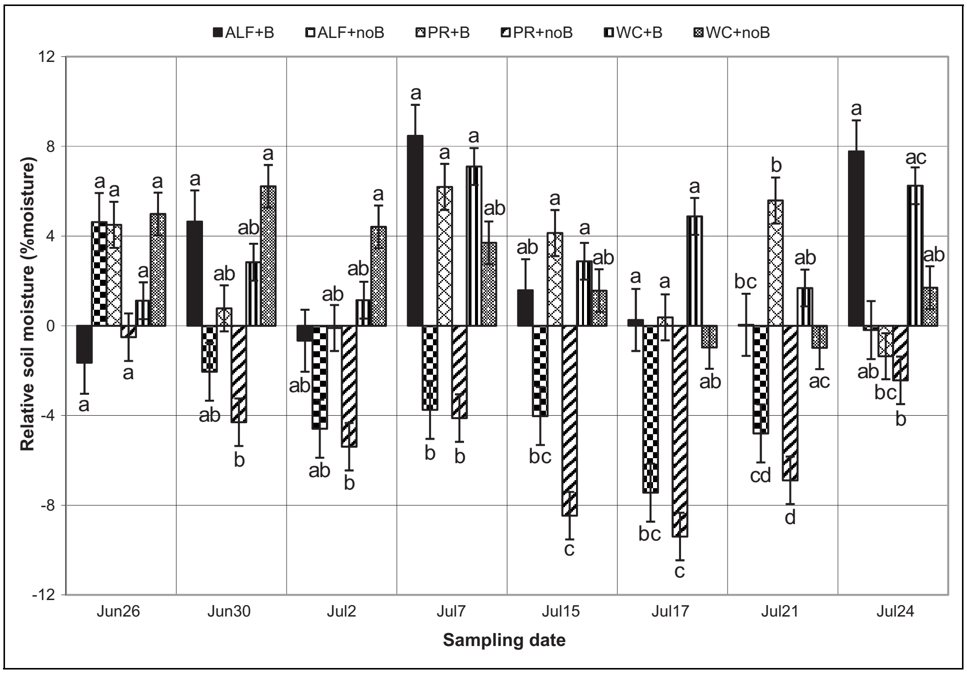


Fig. 3. Volumetric soil moisture content June to July of cover crop treatments relative to bare-ground control. Bars represent the difference in soil moisture content between bare-ground control treatments and respective cover crop treatments. Mean separation by Tukey's Honestly-Significant-Difference Test at each sampling date; treatments followed by the same letter (a–d) are statistically similar.
Labels: ALF+B = alfalfa with banding, ALF+noB = alfalfa with no banding; PR+B = perennial rye with banding; PR+noB = perennial rye with no banding; WC+B = white clover with banding; WC+noB = white clover with no banding.

expected, species selection was critical in relation to total organic N contribution to the site. It has long been demonstrated that significant amounts of N can be added by the inclusion of N fixing legumes to production systems (Rennie and Kemp 1983). This was evident in this project with some of the legume treatments contributing

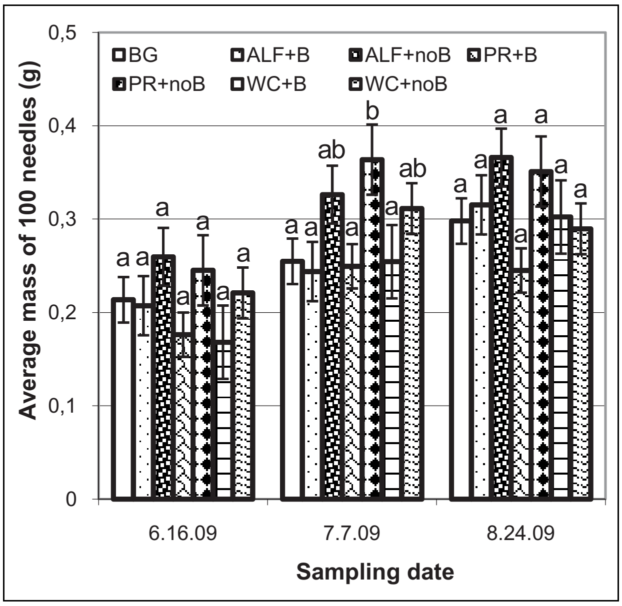


Fig. 4. Tree dried needle masses by cover crop treatment throughout the growing season. Mean separation by Tukey's Honestly-Significant-Difference Test at each sampling date; treatments followed by the same letter (a–b) are statistically similar for that date.
Labels: ALF+B = alfalfa with banding, ALF+noB = alfalfa with no banding; PR+B = perennial rye with banding; PR+noB = perennial rye with no banding; WC+B = white clover with banding; WC+noB = white clover with no banding.

three times as much organic N as the grass species. The green manure returned added to the soil organic pool that can become available to the plant through mineralization (PARDO et al. 2009) thus increasing the overall fertility of the site.

The P contributions of legumes were also significantly higher than those of the perennial rye system. Cover crops have been reported to improve the P budget in the soil (CAVIGELLI and THIEN 2003). Residues of cover crops may recycle normally unavailable phosphorous into forms more available to the target crop. The residue decomposing process improves the P availability by releasing $CO_2$, which forms $H_2CO_3$ in the soil solution, resulting in the dissolution of primary P containing minerals (SHARPLEY and SMITH 1989). It is also possible that organic compounds released during decomposition processes may increase P availability by blocking P-adsorption sites (EASTERWOOD and SARTAIN 1990).

*Effect of cover crops on soil fertility*

The short-term effect of the cover crop species and management practices on SOC, SON, and soil nitrogen ions was not very well defined. The addition of organic residues is the only way to increase soil organic matter levels (FAGERIA 2007). The effect of crop residue on soil organic matter content is highly related to the amount and only weakly to the type of residue applied (FAGERIA 2007). The addition of green manure to the sites was expected to have a significant positive influence on soil physical, chemical and biological properties. In this study with few exceptions, early and late season TOC and TON were generally stable in the upper soil horizon. This was not surprising because it has been reported that when total stocks of C and N in the soil are of sufficient size, the differences in C or N input from treatments compared to controls are small (GRIFFIN and PORTER 2004). For example, COLLINS et al. (1992) compared continuous wheat and wheat-pea rotations in place for 25 years, and found

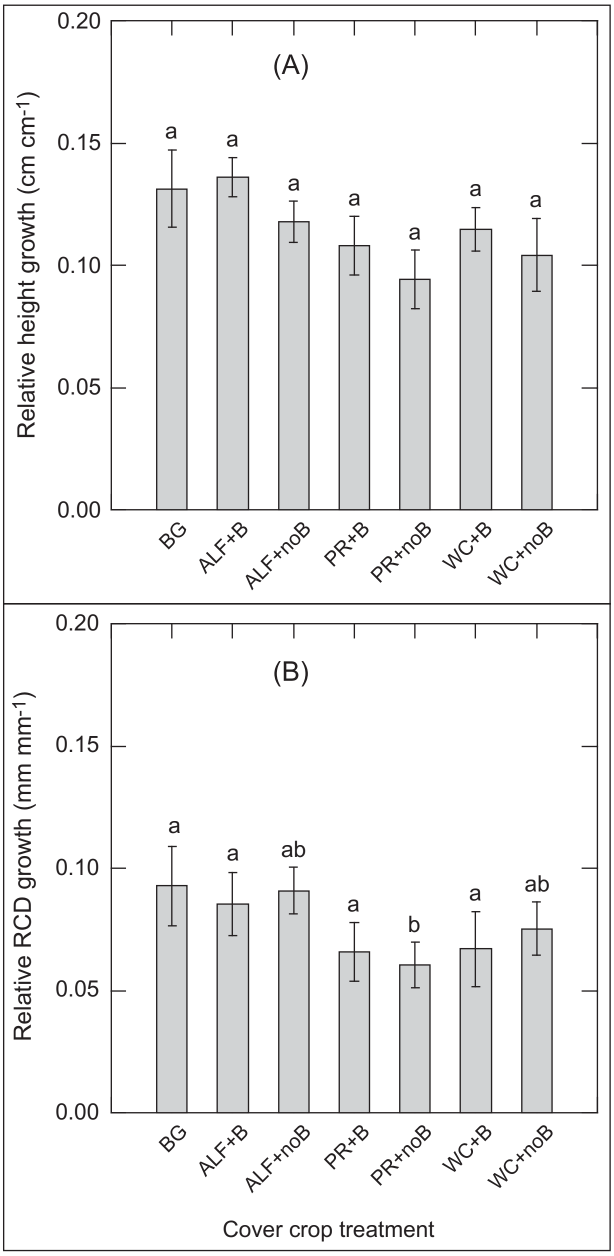


Fig. 5. Relative Fraser fir height growth (A) and relative root collar diameter growth (B). Tukey's Honestly-Significant-Difference Test was used to measure variance within treatments at each sampling date; treatments with the same letter are statistically insignificant.
Labels: ALF+B = alfalfa with banding, ALF+noB = alfalfa with no banding; PR+B = perennial rye with banding; PR+noB = perennial rye with no banding; WC+B = white clover with banding; WC+noB = white clover with no banding.

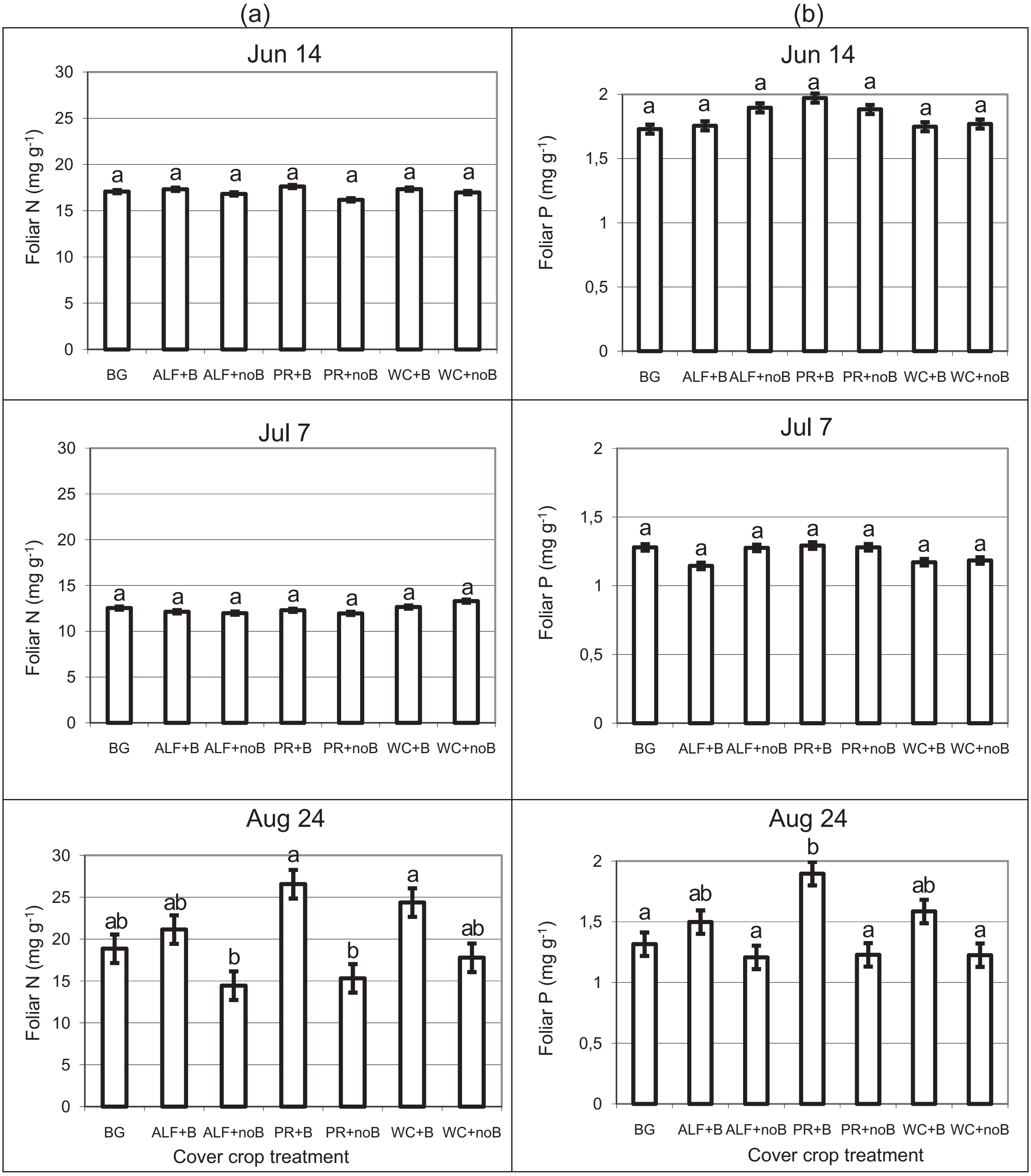


Fig. 6. Changes in foliar nitrogen (A) and phosphorous (B) as affected by cover crop species and management. Tukey's Honestly-Significant-Difference Test was used to measure variance within treatments at each sampling date; treatments with the same letter are statistically insignificant.
Labels: ALF+B = alfalfa with banding, ALF+noB = alfalfa with no banding; PR+B = perennial rye with banding; PR+noB = perennial rye with no banding; WC+B = white clover with banding; WC+noB = white clover with no banding.

no significant effect on SOC and SON. While we did not observe substantial changes in C/N ratios, previous studies have observed increases in C/N ratios aboveground and root biomass especially adds to soil nitrogen and carbon banks over time (Puget and Drinkwater 2001). A possible explanation of the short-term stability in organic parameters is the C/N ratio of the green manure used. The C/N ratio of the residue plays an important role in the immobilization of soil N because the plant tissue is a primary sink for C and N (Fageria 2007).

Legume residues in our study contained considerable amounts of N and certainly a relatively low C/N ratio leading to faster decomposition, mineralization and release of N, compared to perennial rye treatments. C/N values were generally much higher in the upper horizon, indicative of superior fertility compared to deeper horizons. High C/N values allow slow mobilization of nitrogen (Snapp and Borden 2005) as microbial populations grow, allowing organically fertilized treatments to release nitrogen at steady rates as opposed to spontaneous rates observed in traditionally fertilized treatments (Poudel et al. 2002). Our higher C/N values could be explained by a healthy soil microbial population, which led to rapid decomposition and turnover of nutrients.

Treatments incorporating cover crop all showed decreases in mineral N ($NH_4^+$-N and $NO_3^-$-N) over the growing season in the upper soil profile while BG treatments showed increases for both ions. This can be due to a combination of factors including synchrony between cover crop decomposition, mineralization and uptake by trees, or increased leaching below the tested upper soils profile. Decreases in mineral N have been previously linked to greater demand for this nutrient by higher plants and microbes that grow vigorously during the season, as well as leaching, runoff and erosion (Singh et al. 1989; Srivastava 1992). This can be especially true for cover crops with highly degradable residues such as legumes where the mineralization rate of plant-derived C and N can be as high as 80 % (Griffin and Porter 2004).

### *Effect of cover crop management on tree morphology and foliar nutrient concentration*

In our study, the cover crop management practice and species selection had no significant impact on height growth and needle dry weight, suggesting the tree-cover crop production system was appropriate for promoting growth and supplying nutrients to the tree. Such results have been reported in several studies focused on other agriculture crops. For example, Ctahr (2009) reported improved tree growth and reduced reliance on fertilizers when using living mulches with fruit trees. Similarly in other studies, annual mulching achieved higher soil N and water content, resulting in vigorous tree growth (Costello 2010). However, there are also several reports on competition for nutrients and moisture leading to depressed growth (Walsh et al. 1996). Competition was evidenced in our diameter growth response variable especially in treatments without bands where slow growth was associated with low moisture content in cover crop treatments. While cover crops have the potential to compete with primary crops for water, groundcover can absorb water in the soil, reducing the vulnerability of nitrate to leaching (Pedersen et al. 2009) and can reduce soil temperatures proportional to height of cover (Walsh et al. 1996) to prevent drying of soils. When incorporating cover crops in production systems, careful management practices should be utilized to capitalize on the benefits of intercropping without risking reduced growth as observed in treatments lacking bands. Even so, adding clear bands between trees and cover crops reduced competition.

During the peak of the growing season (July), decreases in tree foliar N and P were observed probably due to shifts in the nutrient allocation towards developing secondary xylem and phloem tissue. However, it is also possible that nutrient uptake by plants was lower in this month due to reduced rainfall in July (60.7 mm) as previously reported by Pardo et al. (2009) in semiarid conditions. The choice of cover crop species had no influence on the tree foliar nutrient concentration. Nevertheless, because the management practice significantly affected this parameter, it is likely that competition for nutrients was occurring between the cover crop and trees. Our results also suggest that intercropping cover crop species with the addition of bands can help alleviate competition for nutrients, resulting in foliar nutrient concentrations equal or superior to those of traditional production practices.

### *Conclusion*

This study investigated the effect of the choice of ground cover species and management practice on green manure production and nutrient content, soil characteristics, tree morphology and foliar nutrient concentration. Species selection significantly affected the amount of green manure produced and its total N and P content. Soil organic carbon and nitrogen were stable in the upper soil profile and unchanged in the deeper soil profile. We hypothesized that the insignificant variation in soil organic nutrients is due to the relative small size of the quantities added compared to the total stock of C and N in the soil. Soil nitrate and ammonia were highly variable with no clear separation related to either the cover crop species or the management practice. This was attributed to either the synchrony between the cover crop decomposition, mineralization, and nutrient uptake by trees in the upper profile, or to the leaching of excess nutrients below the sampling profile. The treatment effects on morphological parameters and foliar nutrient concentration suggest some level of competition for soil moisture and nutrients. Further studies are needed to evaluate treatment effects on other macronutrients. Our conclusion is that careful management is necessary to capitalize on the benefits of cover crop and avoid competition for soil nutrients and moisture.

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