

USING GROUNDCOVERS IN FRASER FIR CROPPING SYSTEMS: EFFECTS ON
GROWTH, NUTRIENT DYNAMIC AND SOIL FERTILITY

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ABSTRACT

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Groundcovers are widely used to improve the sustainability in agriculture production systems. However, the application of groundcovers in intensive short rotation tree plantations is relative new and need to be further investigated. This study aims to (1) investigate the effects of groundcovers and management practices on tree morphology, foliar macronutrients (N, P, K, Mg, and Ca) concentration and (2) on soil fertility and soil macronutrients; (3) evaluate the effects of legume groundcovers combined with low nitrogen fertilization on tree productivity, soil fertility, and nutrient. Three groundcover types including two legumes: alfalfa (*Medicago sativa*) and Dutch white clover (*Trifolium repens*) and one grass perennial rye (*Lolium perenne*) were used in combination with two management practices [banding (B) and no-banding (noB)] and bare-ground (BG) control treatment. Additional studies combining the two legumes and reduced rates of inorganic fertilizer (75%, 50%, and 25% of the recommended rate) was also conducted. Parameters measured include tree height and diameter growth, foliar macronutrients concentration, soil organic matter (SOM) content, soil bulk density, soil nutrients concentration, nitrate leaching and N mineralization rate. Results showed groundcover type selection was not critical for tree growth, and banding practice can help to avoid suppression on tree growth. Groundcover treatments result in lower foliar Ca; can help maintain foliar N levels while receive lower N fertilization; the effect of cover crops on foliar Mg, K and P was not clear. No significant increase in SOM was detected in groundcovers treatment. The lower C:N of legumes did not lead to significant greater N mineralization rates. Receiving reduced fertilization rates, groundcover can still increase soil N and tree growth, decrease soil N leaching. In conclusion, we suggest legume cover crop with high biomass production and low C:N can be introduce into short rotation tree production systems while appropriate management practices are applied.

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TABLE OF CONTENTS

LIST OF TABLES.....	vi
LIST OF FIGURES.....	viii
INTRODUCTION.....	1
Literature cited.....	5
CHAPTER 1	
LITERATURE REVIEW.....	9
Fraser fir production in Michigan.....	9
1) Fraser fir origin botanical characters.....	10
2) Fraser fir in Christmas tree production.....	11
3) Nutrients need and fertilization match	11
4) Environment concerns associated with current production system.....	11
Ground covers in agricultural production system.....	13
1) Major types of perennial ground covers.....	15
2) Benefits of perennial ground covers.....	18
Plant production/growth response to the perennial ground covers.....	28
Disadvantages of perennial ground covers.....	29
1) N deficiency.....	29
2) Water deficiency.....	30
3) Pests and diseases problems.....	31
Current research gaps.....	31
Literature cited.....	36
CHAPTER 2	
GROUND COVERS MANAGEMENT IN SHORT-ROTATION TREE CROPPING SYSTEMS: EFFECTS ON TREE MORPHOLOGY AND PLANT NUTRIENTS CHEMISTRY.....	48
Literature cited.....	74
CHAPTER 3	
EFFECTS OF GROUND COVERS MANAGEMENT ON: SOIL FERTILITY AND SOIL MACRONUTRIENTS	79
Literature cited.....	120

CHAPTER 4	
COMBINING LEGUME GROUNDCOVERS AND LOW NITROGEN FERTILIZATION IN A SHORT-ROTATION FRASER FIR (ABIES FRASERI) CROPPING SYSTEM: EFFECT ON PRODUCTIVITY, SOIL FERTILITY, AND NUTRIENT LEACHING.....	126
Literature cited.....	154
CONCLUSION.....	160
FUTURE WORK.....	162

LIST OF TABLES

Table 1. Major types of perennial cover crops.....	35
Table 2. Average monthly temperatures and total rainfall during the 2009, 2010 and 2011 growing seasons.....	65
Table 3. Cover crop biomass nutrient content as affected by different types and management practices in 2009, 2010 and 2011.....	66
Table 4. Cover crop residue C/ N ratio in 2010 and 2011.....	68
Table 5. Tree Height and Diameter growth affected by different cover crop types and management practices in 2009, 2010 and 2011.....	69
Table 6. Foliar Nutrients affected by management practices and cover crop types in 2009, 2010 and 2011.....	70
Table 7. Correlation ratios between foliar macronutrient and cover crop residue cumulative macronutrient return in 2009, 2010 and 2011.....	72
Table 8. Cover crop biomass dry weight return in 2009, 2010 and 2011.....	100
Table 9. Cover crop biomass nutrient content as affected by ground covers types combined with management practices in 2009, 2010 and 2011.....	101
Table 10. Soil Mg concentration in 0-15cm and 15-30cm affected by management practices combined with cover crop types in 2009 and 2010.....	103
Table 11. Soil K concentration in 0-15cm and 15-30cm affected by management practices combined with cover crop types in 2009 and 2010.....	104
Table 12. Soil Ca concentration in 0-15cm and 15-30cm affected by management practices combined with cover crop types in 2009 and 2010.....	105
Table 13. Soil P concentration in 0-15cm and 15-30cm affected by management practices combined with cover crop types in 2009 and 2010.....	106
Table 14. E1 soil bulk density affected by different management practices.....	107
Table 15. Correlation between soil organic matter content in 0-15cm and 15-30cm and ground	

cover biomass dry weight return.....	108
Table 16. Correlations between soil bulk density and ground cover biomass dry weight return in 2009, 2010 and 2011.....	109
Table 17. Average monthly temperatures and total rainfall during the 2009 and 2010 growing seasons.....	145
Table 18. Tree growth and root collar diameter in 2009, 2010 as affected by cropping system.....	146
Table 19. Soil nitrate concentration (ug/g) in 2009 and 2010 as affected by the different cropping systems.....	147
Table 20. E2 Soil Bulk density as affected by the cover crop types.....	148
Table 21. Cumulated drainage volume collected in 2009 and 2010.....	149

LIST OF FIGURES

Figure 1. Tree height and diameter growth as affected by management practices in 2009, 2010 and 2011.....	73
Figure 2. Cover crop residue C: N ratio in 2010 and 2011.....	110
Figure 3. Soil organic matter content in 0-15cm as affected by different cover crop types and management practices.....	112
Figure 4. Soil organic matter content in 15-30cm as affected by different cover crop types and management practices.....	115
Figure 5. Soil N Mineralization rates affected by cover crops types and management practices.....	118
Figure 6. Foliar nitrogen concentration as affected by cropping system treatments.....	150
Figure 7. Cumulated nitrate loss in 2009 and 2010 as affected by different cropping systems.....	152

INTRODUCTION

Among all the states that produce Christmas trees, Michigan ranks third and produces a large variety of 13 types (University of Illinois Extension, 2012). Of all Christmas trees species, Fraser fir has been gaining its popularity since 1994 and has become the most popular species because of its excellent needle retention, dark blue-green color and pleasant scent (Cregg and Gooch, 2008). However, Fraser fir has been indicated to have high requirements for soil properties and nutrient availability. It is native to acidic, well drained soil at high elevation zone and has a high demand for N fertilization as well as Mg and Ca (Rideout et al., 2003). The conventional way of Christmas tree production requires heavy use of inorganic N fertilizer (100-150 lbs per acre every year). This intensive use of inorganic fertilizer not only increases the production input for growers, but also causes environmental concerns such as soil acidity, soil nutrient leaching, soil erosion and degradation of soil biodiversity, eventually leading to loss of productivity for the target crop, Juo et al. (1995) reported that the decrease in pH under a cropping system was $57 \pm 7.5\%$ of another system which has received double amount of N fertilizer. Slowly reduced mineralization rates of inorganic fertilizer have been observed through the composting period (Eghball and Power, 1999; Benitez et al., 2003; Wolkowski, 2003), which demand higher application rates to meet crop N demands. Also, it has been claimed that approximately half of the applied fertilizers are lost from the systems before the cash crops can assimilate them (Drinkwater et al., 1998). This poor matching of the nutrients need of trees can negatively affect tree production and profitability.

Alternatively, the use of perennial cover crops has been demonstrated to have several potential

advantages to short-term tree production systems (Baumgartner et al., 2008; Schroth et al., 2001).

Cover crops have been demonstrated to be an efficient tool to enhance soil nutrient dynamic (Schroth et al., 2001; Fageria et al., 2009; Rombola and Tagliavini, 2006), control soil erosion (Reicosky and Forcella, 1998), improve soil properties such as soil bulk density and soil organic matter content (Reicosky et al., 1995). There are many examples that demonstrated successful use of cover crops in cropping systems, including soybean (Reddy, 2001), corn (Vaughan and Evanylo, 1998), wheat (Bakht et al., 2009), palm oil, rubber plantations, and various orchard and vineyard production systems (Baumgartner et al., 2008).

Over the last decades, since the demand for continuous forestry has increased, the practice of cover cropping has been considered for management of forestry production systems, especially for sake of improving soil quality and reducing the high cost of nitrogen fertilizer.

However, there were still many concerns about introducing cover crops into a tree production system. It has been reported that competition for soil nutrients and available water can occur between cover crops and trees (Walsh et al. 1996; Wilson et al. 2010; Wylanda et al., 1995; Malik et al., 2000). This competition has been reported to cause suppression or reduction in tree growth (Foshee et al., 1995; Mendham et al., 2004). Therefore, to avoid this negative impact of cover crops on tree yield, appropriate species selection and management practices are crucial.

In addition to tree height and diameter growth, it has been reported that cover crops also have impacts on foliar nutrient including N, P, Ca and so on. Decrease in foliar N has been found in some vineyard production systems when growing with some summer-active perennial grass covers and perennial ryegrass (Hirschfeld et al., 1992; Tan and Crabtree, 1990). The impacts of

cover crops on other foliar nutrient will highly depend on the specific element, the amount of soil original nutrients concentration and the space between cover crops and trees (Lehmann et al., 2000). Since there is only limited information about the impacts of cover crop on tree foliar nutrient, there is a need for further research.

The benefits of cover crops include enhanced soil nutrient dynamics, increased soil organic matter content, and increased soil nutrients, which has been often stated by many studies. For instance, it has been reported that the quantity of cover crop residue applied is the most important factor in increasing soil organic matter (Janzen et al., 1998; Reicosky et al., 1995); a higher amount of retained residue will increase the content of soil organic matter and soil quality more rapidly (Schomberg et al., 1994). As it is well known, the increase of soil organic matter can help to decrease soil bulk density (Veenstra, 2006). However, the contribution of cover crops to soil organic matter and nutrient also depends on C/N ratio and the components such as cellulose or lignin contents of the residue (Frankenberger and Abdelmagid 1985; Russell and Fillery 1999); these factors will have a impact on both soil microbial activity and the nutrient mineralization rates.

Therefore, the aim of this study is to investigate the impacts of cover crops on tree growth, foliar nutrient and soil properties. The specific objectives (1) evaluate the effect of three ground covers types [alfalfa (*Medicago sativa*), Dutch white clover (*Trifolium repens*) and perennial rye (*Lolium perenne*)], and management practices on tree growth and foliar macronutrient chemistry; (2) examine the effects of combining legume cover crops with low rates of N fertilization on Fraser fir productivity and nutrient status, soil fertility (nitrate) and on nutrient leaching below

the root zone; (3) evaluate the impact of ground covers and management practices on macronutrient concentration of cover crop residues and C/N ratio, and (4) evaluate the effect of each ground covers types on soil fertility and macronutrient concentration.

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CHAPTER 1

LITERATURE REVIEW

FRASER FIR PRODUCTION IN MICHIGAN

Christmas tree production is an important industry in Michigan; approximately 4 million trees were harvested per year with estimated value of more than \$100 million (Nzokou and Leefers, 2006). There are about approximately 130,000 acres of land in Christmas tree production industry in Michigan, owned by 800 Christmas tree growers (Nzokou and Leefers, 2006). Among all states that produce live Christmas trees, Michigan ranks third and produces a larger variety (13) of Christmas trees than any other state (University of Illinois Extension, 2012). Of the tree species produced for Christmas trees, Fraser fir is the most popular one because its excellent needle retention, dark blue-green color and pleasant scent.

1) Fraser fir origin botanical characters

Fraser fir is an evergreen tree species in Pine Family, which naturally grows in the Appalachian Mountains at elevations of 4000 to 6684 feet, in areas including western North Carolina, eastern Tennessee, and southwest Virginia. This region has mild summers and winters in addition to frequent precipitation. Fraser firs typically grow at an average elevation of 5000 ft with precipitation ranging from 75-100 in and summer temperatures around 59F. They normally grow to be 30 to 40 feet tall with 3/4 inch long flattened needles. Fraser firs produce cylindrical resinous cones which grow upright to be 1.5-2.5 inches long, are green to purple and have pointed, toothed bracts protruding from the cone scales.

Fraser firs prefer well-drained soils and benefit from irrigation and addition of soil organic matter.

Fraser fir requires a soil pH range between 5.2 to 5.8, and do not grow as well outside of this range. It can tolerate soil pH as high as 6.0 when the soils are very coarse texture and very well drained. During its growing season, growers must regularly test soils to ensure the pH remains within or near to the ideal range. Above a pH of 6.0, needle browning, poor health, decreasing growth rate will/can occur.

Fraser fir is classified as very shade tolerant species and is considered a climax one. The root system of Fraser fir is generally shallow because it normally occupies shallow soils in natural environments, but they are able to penetrate depths greater than 61 cm as long as soil is available (Crandall 1958).

2) Fraser fir in Christmas tree production

It was generally said that over 400 years ago, Germans first started the use of Christmas tree as part of Christmas celebration. The Christmas tree was brought to America by the Hessian mercenaries during the Revolutionary War. In 1842, Christmas trees were introduced as the a decoration for Christmas in Williamsburg, Virginia homes. By 1900, one in five American families started to have Christmas trees and by 1930, the tree had become a nearly common part of the American Christmas (Power's Tree Farm, 2007).

The Fraser fir was explored by a Scottish botanist named John Fraser in southern Appalachian Mountains of North Carolina in the late 1700s. Fraser fir represents over 90% of all the trees grown in North Carolina as Christmas trees and more than 50 million of them are grown in North Carolina on 25,000 acres for use as Christmas trees (Power's Tree Farm, 2007).

In 1994, Fraser fir was only accounted for less than 3 percent of Christmas tree acreage in Michigan (Cregg and Gooch, 2008). However, because of its outstanding form, superior needle retention, blue-green to silvery-green color, and attractive scent, it impressively became the most popular Christmas tree species within 11 years. Since the sale prices of Fraser fir are nearly double of Scots pine, tree growers have increased production of Fraser fir (Cregg and Gooch, 2008).

3) Nutrients needs and fertilization match

Fraser fir especially requires close attention to nitrogen fertility. It has been suggest that 45-70 kg/acre inorganic N fertilizers are used every year was for Fraser fir production. Some researchers from Michigan State University and experienced growers also recommended that a rate of 56 - 115 grams actual nitrogen per tree should be applied in early to mid-August (Ontario ministry of Agriculture, food and rural affairs, 2011). It is common for yellow foliage to be found close to harvest time, even when all the required nutrients conditions seem to be met (Ontario Ministry of Agriculture, food and rural affairs, 2011). After bud break, spring frost will damage the new, tender branch shoots of Fraser fir. In addition, Fraser fir requires more P and K during the production cycle (Gouin et al., 2001). However, there is no recommendation based on a solid scientific study.

4) Environmental concerns associated with current production system

The long-term and intense use of inorganic fertilizer causes many concerns among growers, researchers, and the public. The composition of inorganic fertilizer will cause a decrease in the nitrogen concentration and plant available N. It has been reported that the nitrogen

mineralization rates of 38–60% for uncomposted manures were reduced to 6–20% through the composting period (Eghball and Power, 1999; Benitez et al., 2003; Wolkowski, 2003). Because of the reduction in mineralization rate, 60% N of poultry manure were mineralized and only 10% N of compost were mineralized during the year of application (Evanylo, 1994). Thus, such low mineralization rates demand higher application rates to meet crop N demands. However, due to their quick decomposition, approximately half of the applied fertilizers are lost from the systems before the intended crops can assimilate them (Drinkwater et al., 1998).

In addition to their high cost that can negatively affect profitability, the long-term use of fertilizers can also have serious negative environmental effects, such as increasing soil acidity, soil erosion, and degradation of soil biodiversity, eventually leading to loss of productivity for the target crop (Juo et al., 1995). It has been argued that the nitrification of N fertilizers such as ammonium sulfate is likely to make soils more acid, and this soil acidity could decrease Ca_2^+ levels, and increase exchangeable Al (Little, 1997). The rapid deterioration of soils caused by heavy use of inorganic fertilizer will directly affect the productivity of a production system. It has been reported that in Malawi, most farmers in the maize-based farming systems can hardly afford optimal quantities of inorganic fertilizer (Sauer et al., 2007). Malawi alone lost US\$350 million worth of nitrogen and phosphorus through soil erosion each year, this loss equivalent to 3% of the agricultural gross domestic product of Malawi (Bojo, 1996).

Another concern is the presence of heavy metals in inorganic fertilizers, which is well established. Test results from Minnesota Department of Agriculture shows that some phosphate and micronutrient fertilizers contain high levels of arsenic, cadmium (MDA, 2007). This elevated

level of heavy metal not only cause hazard to natural environment, but also pose risks to public health (Minnesota Department of Health, 2008).

Based on all above concerns, it is important to introduce ground covers as an alternative organic fertilizer source to, firstly lower the inorganic fertilizer use, and secondly improve the sustainability of the Fraser fir production systems.

GROUND COVERS IN AGRICULTURAL PRODUCTION SYSTEM

The use of cover crops has a rich heritage. Farmers from the around the world has used cover crops to revitalize the soil and control soil erosion in their fields for centuries. For instance, bell beans were grown in vineyards during early Roman time (Firstenfeld, 2004). In northern Europe, lupins were planted to improve soil fertilities (Singh and Jauhar, 2005). Later on, to increase the quality of cover crops, hybrids were developed. For example, the hybrid between wheat (*Triticum*) and rye (*Secale*) date back to 1875.

North American farmers have long used cover crops in rotation with vegetable and field crops in orchards (Ingels et al. 1998). In California, cover crops have been used in vineyards since the early 1900s. They were frequently planted in order to reduce soil erosion, add nitrogen, and improve soil tilth and water penetration. Winter annual grains or legumes or both were planted in the fall and then mowed and disked in the early spring. However, the use of cover crop was largely abandoned during the industrial revolution (1940s to 1950s) because of the emergence of inexpensive and easy-to-apply commercial fertilizers and herbicides. During this time, conventional agriculture became to rely more on synthetic fertilizers and less on cover cropping

to enhance soil fertility. In the late 1980s and early 1990s, however, cover cropping in vineyards experienced a widespread resurgence as a result of the growing interest in sustainable agriculture. New cover crop species and cultivars, tractor implements, and irrigation methods have allowed many growers to adopt new cover cropping techniques to meet today's needs.

In 1997, there were over 770,000 acres (312,000 ha) of grapes grown in California, and substantial acreage was planted in 1998. In some tomato systems, mixtures of triticale, rye and pea were demonstrated to be the most successful and manageable cover crops (Balkcom et al., 2007). The farmers in California mainly use cover crops to reduce intercrop tillage, reduce pathogen buildup and manage soil nutrients. An informal survey of University of California Cooperative Extension (UCCE) viticulture Farm indicated that about 16 percent of the vine yard acreage in California was planted to cover crops other than resident vegetation (Ingels, 1998).

Over the last decades, the demand for continuous forestry has increased, and its position in forest management has been renewed worldwide (Löhde et al., 1999; Turckheim, 1999; Cairns, 2001; Gadow et al., 2002; Guldin, 2002; O'Hara, 2002.). In that context, the practice of using various types of vegetation covers has been considered for management of forestry production systems. For example, a nurse crop is defined as a crop of trees or shrubs that aids in the establishment of desired species in difficult site conditions has been used and is becoming part of forest practices in Britain, Scandinavia and other parts of Europe (Shepperd and Jones, 1985). A stated benefit of the nurse crop is the retardation of the growth of the target species in favor of establishment (Pommerening and Murphy, 2004). For instance, Kramer (1970) reported that silver fir grown under canopy showed a slow but long-lasting growth with a late and slow culmination. In

contrast, silver fir planted on bare land without shelter had rapid growth when young, followed by an early culmination at a lower level than under canopy, with quickly decreasing volume production thereafter. Today, the use of cover crops is regaining popularity due to increased interest in soil quality and the high cost of nitrogen fertilizer.

Perennial ground covers are frequently employed in short rotation production agriculture. Examples include palm oil and rubber plantations, and various orchards and vineyards production systems. However the use of ground covers in agroforestry and other types of short rotation tree production systems such as Christmas tree plantation and woody biomass energy crops is rather limited. In such systems, the conventional cultivation practices are based on the use of chemical inputs such as pesticides and fertilizers.

1) Major types of perennial ground covers

Cover crops are generally classified as winter or summer annuals, which germinate and die in one year or less, or perennials, which live for three or more years. Each group, comprise both leguminous and non-leguminous species. Legume cover crops are used as a source of nitrogen for the target crop (Smith et al., 1987), while grasses are mainly used to reduce NO_3 leaching and erosion (Meisinger et al., 1991). Biological N fixation by leguminous crops offers potential to reduce the need for N fertilizer (Singh et al., 2004). The major types of perennial cover crops are summarized in table 1.

Legume cover crops, in association with *Rhizobium* bacteria, can fix enough nitrogen to be used as a significant source of nitrogen for the cash crop (Smith et al., 1987). Furthermore, because their low C/N value, they decompose rapidly and contribute to soil organic matter in a short time

(Cavigelli, 1998). Among legumes, Alfalfa, Red Clover and White Clover are the most widely used ones.

Alfalfa (*Medicago sativa*) is an important perennial legume cover crop worldwide. It can be used as cover crop in a well-drained soil and soil in good conditions. It has been recognized for its superior yield and quality in seeded pastures, its superior nitrogen fixation ability and ability to scavenge mineral N (Mathers et al. 1975; Owens et al. 1994; Rasse et al. 1999). Red clover (*Trifolium pratense* L.) is a short-lived perennial considered as the most widely grown of all the true clovers. It is a dependable, low-cost, readily available workhorse that is winter hardy in much of U.S. It is used primarily as a legume green manure usually killed ahead of corn or vegetable crops planted in early summer and now is widely used in tree production systems (Marsh 1996, Eissenstate et al., 1983 and McGraw. et al., 1996). It can add a moderate amount of N, and help suppress weeds and breaks up heavy soils. White clover is the top choice for “living mulch” systems usually planted between rows of irrigated vegetables, fruit bushes or trees, They are persistent, widely adapted perennial nitrogen producers with tough stems and a dense shallow root mass that protects soil from erosion and suppresses weeds. Their low C/N ratios allow quick decomposition and a rapid release of N.

Non-legume grasses have fibrous roots that are effective in aggregating soil and reducing nitrate leaching and erosion (Meisinger et al., 1991). However, because their carbon content is high, the N is less likely to be released for use by a cash crop. The most excellent non-legumes include perennial ryegrass, perennial wheatgrass, oil radish and triticale.

Perennial Ryegrass is the world's most widely used grass. It is a quick growing, non-spreading

bunch grass with exceptional ability to germinate even in poor, rocky or wet soils (BSBI, 2010). Ryegrass has an extensive, soil-holding root systems, and can improve soil structure and water holding capacity by increasing stability of soil aggregates compared with bare fallow, it can be mixed with legumes and help the slow-growing legumes establish and overwinter in cold area (USDA NRCS Idaho State Office). Another major grass species winter rye can protect soil from erosion and reduce 30% erosion more than a bare fallow (EZ Nyakatawa - 2001). Because they are winterkilled, they can provide early-season weed control for next season (Karen A.R. 2000). Perennial wheatgrass (*Thinopyrum Intermedium*) is a high yielding, cool season, rhizomatous perennial which is used extensively for pasture, hay and soil erosion control in the Great Plains and intermountain West (Hanson 1972). Crested wheatgrass (*Agropyron cristatum. L. Gaertn.*) is a drought tolerant species because of its root system and early growth property (USDA, NRCS, Idaho State Office). It will start growth in the early spring ahead of any other native or introduced grass and becomes dormant during summer months. Oilseed radish (*Raphanus sativus*) is mustard originally developed, as the name implies, for oil production (Cavigelli et al., 1994). It establishes and grows quickly during cool weather and can be planted early in the spring to provide fast cover and a green manure crop. Oil seed radish has a thick, deep root that can help break up compacted soil layers and scavenge nitrate that has leached beyond the rooting zone of other crops (Cavigelli et al., 1994). Triticale (*Triticosecale*) is a cross between wheat (*Triticum*) and rye (*Secale*). Their requirements are similar to other fall planted small grain crops such as wheat or rye (Oelke et al., 1989).

Meadow barley (*Hordeum brachyantherum*) is a perennial grass that performs best in wetland or

riparian areas. It is also known as California barley and can tolerate clay with low calcium and low water holding capacity or serpentine (high magnesium) soils (serpentine soils are most commonly found in California not in the Pacific Northwest). Since meadow barley is a poor competitor with weeds, weed control measures should be taken before planting.

2) Benefits of perennial ground covers

Cover crops are widely used to produce organic matter, and reduce soil compaction and crusting and thus improve water infiltration and in some cases moisture retention (MacRae and Mehuys, 1985), reduce soil erosion by wind and water (Hargrove, 1991), cover crops can also be used to add or retain soil N, facilitate the availability of other nutrients (e.g. P, Ca) (Kourik and Creasy, 1986). Furthermore, cover crops suppress weeds, protect the soil and improve its chemical and physical characteristics (Webster and Wilson, 1980; Giller and Wilson, 2000). In addition to these beneficial effects, cover crops may interact with pests and diseases.

I. The benefits of perennial cover crops on soil organic matter

Planting cover crops before or between trees or shrubs of plantation crops can improve soil physical, chemical, and biological properties and consequently lead to improved soil health and yield of principal crops. The addition of organic matter is a frequently cited benefit of using cover crops. Soil organic matter is important in improving soil fertility and productivity (Allison, 1973; Bauer and Black, 1994; Wilhelm et al., 2004). SOM stabilizes soil aggregates, makes soil easier to cultivate, increases aeration, increases soil water holding and buffering capacities; soil organic matter breakdown releases available nutrients to plants (Carter and Stewart, 1996).

The addition of organic residues is the only sure way to increase SOM levels. The effect of crop

residue on the SOM content highly depends on the amount applied to the soil, not necessarily the type of residue used. Also, determining the right organic matter level for building soil organic matter depends on the soil texture and the aggregate stability target.

The maintenance of crop residues is important because it can reduce soil erosion and increase SOM thereby improving soil quality (Janzen et al., 1998). Reicosky et al. (1995) reported a strong relationship between residue amounts and SOM in the 0-15 cm layer. The content level of SOM has a positive relationship with the amount of cover crop residues applied to the soil. An increase in the amount of cover crop residue in the soil leads to an increase in the content levels of SOM. For instance, to maintain SOM levels more than 4000 lb/A of residues must be returned to the soil every year in Iowa. Cover crops with high residue amount will increase the content of SOM and soil quality more rapidly (Schomberg et al., 1994).

To better build up soil organic matter, there should not be residue removal, because residue removal will induce losses of SOM.

Gregorich et al. (2001) concluded that residue quality plays a key role in increasing the retention of SOM in agro-ecosystems. The main biochemical factors considered to affect the formation of SOM are the C/N ratio and the components such as cellulose or lignin contents (Frankenberger and Abdelmagid 1985; Giller and Cadisch 1997; Russell and Fillery 1999), the lignin:N ratio of residues (Fox et al. 1990; Vigil and Kissel 1991; Russell and Fillery 1999), polyphenol:N ratio (Palm and Sanchez 1991; Russell and Fillery 1999) and the polyphenol plus lignin:N ratio (Constantinides and Fownes 1994; Russell and Fillery 1999).

Decomposition and N release generally occur faster for residues with lower C/N ratios and lignin

and polyphenol contents (Seneviratne, 2000). Hence, large amounts of soluble C and N compounds increase decomposition.

Since microorganisms that decompose residues need N (and other essential elements) as well as C, if there is little N in the residue, decomposition will be slow. The C/N ratio in soil is relatively constant at 12. The C/N ratio is lower in microorganisms at 8. Since microbes incorporate only about 1/3 of the C metabolized into biomass, the substrate material must have a C/N equal to 24 to satisfy the N requirement of microbes. If the C/N ratio of residue is greater than 24, available soil N is consumed by microbes and the plant-available N also the soil organic matter content will decrease.

Somda et al. (1991) used a litterbag study of legumes and non-legumes; C/N and lignin/N ratios were generally lower for legumes (8:1-27:1, and 2:1-9:1, respectively), and the decay-rate constants of both fast and slow pools were greater for legumes.

II. Increasing the nutrients use efficiency

i. Nitrogen

The contribution of N is the most commonly observed primary benefit of leguminous crops (Singh et al., 1992). Both legume and non-legume cover crops can affect N fertilizer management (Bauer and Roof, 2004). Legume cover crops fix atmospheric N and reduce N fertilizer needs. The rate of N fixed by cover crops is determined by the genetic potential of the legume species; soil factors such as pH, moisture content, and temperature also determine N fixation capacity of a legume cover crop. The main strategies of cover crops to improve the efficiency of N use are:

1. Increasing the N uptake

Ground-cover can increase the N uptake ability of trees, in Brazil, the highest mineralization rates were found under the cover crop; and the mineralization of soil N close to the cover crops can be influenced through the management of the cover crop (Schroth et al. 2001).

The main role of ground-cover crops is to create a stronger plant sink for N, by eliminating the factors that reduce crop growth and thus limit the capacity to take up N when it is available (Smil 2001; Giller et al. 2002). The other benefits of ground-cover crops usage include effective crop rotations to control disease and pests, timely sowing, good crop establishment, low weed competition, and a balanced nutrient supply (Laegreid et al., 1999; Cassman et al., 2002). Also, cover crops can affect both the recovery of N and rate of N uptake by increasing the soil water availability (Craswell and Godwin 1984). Another management practice that can effectively increase crop N demand is to grow multiple crop species that have different temporal and spatial nutrient demands (Shepherd et al., 1993) together within the one field (intercropping).

2. Manipulating N supply

Manipulating crop residue quality through choice of legume, species (Frankenberger and Abdelmagid 1985; Palm et al., 2001; Rowe et al., 2004a, b), or mixing ratios of legume to other residues with different tissue qualities can influence microbial activity and hence increase the rate of decomposition and net mineralization (Myers et al. 1994; Handayanto et al. 1997).

Also, perennial legumes have the potential of substantially increasing N inputs via N fixation, and the N mineralization potential, total biomass and N content (Ladha et al. 1993; Unkovich et al. 2000; Wang et al., 2005).

3. Capturing the excess inorganic N before it is lost

Perennial cover crops can be efficient in capturing excess inorganic N or reducing N leaching. For instance, the deep-rooted, perennial legume alfalfa (*Lucerne, Medicago sativa*) is generally considered to have an impressive ability to scavenge mineral N (Mathers et al. 1975; Owens et al. 1994; Rasse et al. 1999). Randall et al. (1997) found that nitrate leaching in the corn system to be almost 40-fold greater than in the alfalfa systems. Similar results have also been reported in Australia where the use of alfalfa and other perennial pasture species has been shown to be very effective in reducing the potential of N leaching (Dear et al. 1999; Fillery 2001; Ridley et al. 2001).

ii. P,K and other mineral nutrients

In addition to N, cover crops supply other essential nutrients to subsequent crops, when their tissues decompose, especially P, K and several other mineral nutrients. The amount of mineral nutrients contributed by cover crops is affected by environmental conditions, soil fertility, crop management practices, and the crop species (Fageria 2010). Legumes species such as Alfalfa (*Medicago sativa L.*), red clover (*Trifolium pratense L.*), sweet clover (*Melilotus officinalis L.*), and lupine (*Lupinus albus L.*) can absorb more P than most other crops (Gardner et al., 1983; Braum and Helmke, 1995).

Moreover, legumes explore subsoil nutrient pools and capture available nutrients through their extensive root systems (Gathumbi et al., 2003). With the increased ground cover, the total P runoff will be significant lower than with no cover crops (Kleinman et al., 2005; Wang et al., 2005) and incorporating cover crops can also increase P bioavailability for succeeding crops

(Cavigelli et al., 2003). The improved P uptake of succeeding cover crops is associated with several mechanisms. Cover crop residue has been indicated with the ability to convert relatively unavailable native and residual fertilizer P into forms that can be more available for crops (Fageria et al., 2009).

With the exception of P, among cover crop treatments, result also showed that promising improvement in concentrations of calcium (Ca), zinc (Zn), copper (Cu), iron (Fe), boron (B), and molybdenum (Mo) in fruit; magnesium (Mg), Zn, Cu, and Mo in plants shoots; and also Mo in roots of plants (Wang et al., 2006). Recent studies indicate that ground covers can improve the Fe-nutrition of fruit trees grown on calcareous soils by enhancing Fe-availability (Rombola and Tagliavini, 2006; Cesco et al. 2006).

III. Improving soil structure, reducing soil erosion and maintaining moisture

Cover crops can influence soil health by improving some of these organic matter-related parameters. In addition, cover crops play a dual role in improving soil structure by maintaining resource quality and providing ground cover to prevent wind and water erosion and carbon input to enhance soil quality (Reicosky and Forcella , 1998).

It is the product of these processes that aggregate, cement, and compact or unconsolidated soil material. It has been widely used to describe the quality and health of agricultural soil (Fageria, 2002). It is important for water infiltration, aeration and plant root development. Improvement of soil structure or aggregation by the action of living and decaying cover crop tissue is widely reported (Lynch and Bragg, 1985; Boyle et al., 1989; Haynes et al., 1991; Haynes and Francis, 1993). Soil with cover crop treatment had higher aggregate stability, aeration porosity and water

infiltration, and lower bulk density and penetration resistance when compared to bare soil. Improved aggregate stability with cover crops was related to increased organic carbon in the soil, while increased aeration porosity and water infiltration were strongly correlated with higher earthworm populations under cover crops (Hermawan, 1994).

Loss of topsoil by wind and water erosion caused by poor soil management is by far the single largest factor contributing to deterioration of soil's physical, chemical, and biological properties and to the further decline in productivity of most crop lands (Pierce and Lal, 1994; Fageria et al., 1997; Dabney et al., 2001). Cover crop provides vegetative cover to bared soil when there are no crops or trees present to cushion the force of falling raindrops, which otherwise would detach soil particles and make them prone to erosion. Roots from these plants will help hold soil in place on the ground. Soil will not be as easily blown away due to wind or washed away by the rain.

Applying mulch to soil can help to retain moisture, improve moisture infiltration in the soil and slow the rate of runoff, thus preventing soil erosion. Conserving soil moisture with cover crop residue has been widely reported (Smith et al., 1987; Sustainable Agriculture Network, 1998). Grass type cover crops such as rye, barley, wheat, and sorghum-sudangrass have been reported to be very effective in soil moisture conservation (Sustainable Agriculture Network, 1998). Gallaher (1977) showed that soil remained wetter and crop yields were higher when rye was left as surface mulch than when aboveground parts of the rye were removed in a conservation tillage system. Daniel et al. (1999) reported that rye had the highest biomass out of several cover crop species tested and soil had higher water contents under rye.

IV. Weed, disease and pests control

i. Weed control

Studies evaluating cover crop effects on weed management in vegetable systems often focus on weed suppression by cover crop mulch (Creamer et al. 1997; Fisk et al. 2001; Hutchinson and McGiffen 2000; Teasdale 1993; Teasdale and Abdul-Baki 1998). Weed suppression by cover crop residue increases with increasing residue quantity - natural levels of typical cover crop residues can be expected to reduce weed emergence by 75 to 90%. Generally, mature high C: N cereal grain residues persist longer and suppress weeds better than low C: N legumes (Morse, 1999). Also, high residue living cover crops suppress weeds better than dead mulch. Rye residues are among the most effective mulches and have been reported to suppress weed growth for up to 6 weeks after rye desiccation (Putnam et al., 1983). Thus perennial non-legumes normally has better performance in controlling weeds than legumes. Some cover crop species, such as hairy vetch plus oats mixtures, can grow rapidly and starve weeds of light, water and nutrients, Results of a literature survey indicate that weed population density and biomass production are markedly reduced using crop systems and intercropping strategies (Liebman and Dyck, 1993).

ii. Pests and diseases

Although the relevance of pest and disease interactions with agro-forestry measures was recognized many years ago (Epila, 1986; Huxley and Greenland, 1989.), few agro-forestry studies have included detailed investigations on such interactions.

Perennial cropping systems have great stability which allows the development of certain equilibrium between pests/diseases and their natural enemies (e.g., predators, parasitoids). This

equilibrium is an important component of biological and integrated pest control (Heitefuss, 1987). Several woody species which are commonly used in agro-forestry are hosts for plant nematodes (*Meloidogyne* spp., *Pratylenchus* spp.), including pigeonpea (*Cajanus cajan*), *Leucaena leucocephala*, *Sesbania grandiflora*, *Tephrosia vogelii* and several *Acacia* species (Page and Bridge, 1993; Duponnois et al., 1999).

It has been reported that Cover crops also influence pest management of arthropods in orchard production systems (Bugg and Waddington, 1994). It has been claimed that the incorporation of cover crops into orchard can achieve these advantages ideally: (1) not harbor important pests; (2) divert generalist pests; (3) confuse specialist pests visually and thus reduce their colonization of orchard trees; (4) alter host-plant nutrition and thereby reduce pest success; (5) reduce dust and drought stress and thereby reduce spider mite outbreaks; (6) change the microclimate and thereby reduce pest success; (7) increase natural enemy abundance or efficiency, thereby increasing biological control of arthropod pests (Bugg and Waddington, 1994). In addition, using cover crops have been reported to control many soil-borne pathogenic fungal diseases and nematodes in some other agriculture production systems (Sustainable Agriculture Network, 1998). In conclusion, adding cover crops into the crop production systems can increase the plant diversity and achieve the aim of protecting agro-forestry systems from some pests and disease outbreaks.

V. Benefit of ground covers on soil biological activity

Soil biological properties are closely related to the chemical environment in the soil and are important in controlling soil tilth such as soil chemical and physical properties (Brye et al., 2004).

Soil microbial biomass is the living component of the soil that comprises of mainly bacteria and fungi, including soil microfauna and algae (Kumar and Goh, 2000). Although it accounts for only 1 to 3% of organic C and 2 to 6% of organic N in soil (Jenkinson and Wilson, 1987), soil microorganisms have received much attention, since they play an important role in the mineralization of soil organic matter, nutrient cycling, and retention. The soil microbial biomass acts as a source-sink in nutrient cycling and as a “driving force” in nutrient availability (Coleman et al., 1983). The amount of microbial biomass is a key factor in controlling the amounts of C and N mineralization (Hassink, 1994). Soils are inhabited by a vast array of microbes responsible for the breakdown of organic matter and solubilization of nutrients. These microbes are major sources of soil enzymes and their dynamics in soils seemed to be related to management practices. Enzymes play an important role in the cycling of nutrients in nature. It has been reported that incorporation of cover crops can increase enzyme activities and accumulation in soils due to increased C turnover and nutrient availability (Said A. Hamido et al., 2009; R. Dinesh et al., 1998 and 2004).

It is well known that both crop residues and roots have several positive effects on the microbial populations in agro-forestry systems. Cover crops can benefit environmental conditions by providing moisture, temperature, availability of carbon for the proliferation of soil microorganisms. Soil with cover crops has been reported to have significantly greater microbial biomass, biomass C and total N; by this way cover crop can provide a conducive environment for microbial proliferation, enzyme synthesis and accumulation in the soil (Dinesh et al., 1998 and 2004). It has also been reported that cover crops increase soil microbiological biomass

through the decomposition of organic Carbon. Mendes et al. (1999) concluded that either cereal or legume cover crops can significantly influence soil microbial biomass, mineralizable Carbon and Nitrogen. However, legumes normally perform more effectively than non-legumes because they contain larger quantities of N and lower C/N ratio than non-legumes (Wang et al., 2007).

PLANT PRODUCTION/GROWTH RESPONSE TO THE PERENNIAL GROUND COVERS

Improvements in soil's physical, chemical, and biological environment by cover crops are known to improve production of orchard fruits and also the growth of trees. However, the effects of cover crops on tree growth and crop yield depends on the species. Kuhn et al. (2009) reported that annual cover crops with yearly mulching practice achieved higher N, soil water content and significantly higher tree production than perennial cover crops. Many other studies have reported competition in soil nutrient and water between groundcover and target crops (Walsh et al. 1996; Wilson et al. 2010; Wyland et al., 1995; Malik et al., 2000). In the mean time it has been claimed that the degree of the suppression depends on soil available water resources (Ofori and Stern 1987; Mendham et al., 2004). This competition in soil moisture has been reported to cause suppression in tree growth in a eucalyptus production system in India (Mendham et al., 2004) and a young pecan production system (Foshee et al., 1995). It has been reported that cover crops resulted in depressed tree growth at the lower rainfall site (Mendham et al., 2004). This reduction in growth of trees may be observed especially during the first year of growth because of the vigorous cover crops root systems will compete for nutrients and soil moisture with trees (Malik et al., 2000).

However if there is enough water content, cover crops can contribute to both tree growth and productivity. Perennial peanut was introduced to Hawaii almost 20 years ago for use as a living mulch for the ground, and has since been used by growers of the state as a living mulch in perennial cropping systems. Fruit tree growers who employ perennial peanut have reported improved tree growth and reduced reliance on fertilizers (Ctahr, 2009). Also, it has been reported that in Watsonville, California, apple production and the tree growth rate were improved in cover crop plots relative to the conventional plots.

DISADVANTAGES OF PERENNIAL COVER CROPS

Cover crops might have some negative effects on tree production systems, which is still not known well. Therefore, concern has been raised over the improperly chosen or incorrectly managed cover crops which may make cover crops behave like weeds by competing with tree crops (Karlen and Doran, 1991; Johnson et al., 1998).

1) N deficiency

Most types of cover crops can contribute to N credits of soil, but some may create N deficiency for the next crop if too much N is immobilized and not releases in a timely manner (Vyn et al., 1999). If the cover crop residue C to N ratio is too high, the residue will take long time to be decomposed by soil microbial, and this slow mineralization rate will cause N immobilization by microbial and a N deficiency, thus lead to a low yield in production systems. This N deficiency was showed by Karlen and Doran (1991) and even additional N fertilizer did not make up the difference. Similarly, Martinez and Guiraud (1990), Francis et al. (1998), and Wyland et al.

(1995) reported that high C/N ratio cover crops may reduce yield because the N immobilization.

2) Water deficiency

Perennial cover crops usually can develop deep roots systems and that may easily cause water-use competition between them and trees. The water deficiency problem becomes more complex when several perennial ground covers are grown in association. In the aforementioned silvopastoral experiment in Scotland (Campbell et al., 1994), the root growth of the grass (perennial ryegrass) peaked in May, and the root growth of the trees (wild cherry) peaked in June. In August, the soil was very dry, and tree and grass root growth occurred simultaneously. During this time, herbicide application increased growth and leaf N content of the trees, indicating that there was seriously competition for soil resources. This experiment indicate that inappropriate perennial crop will cause water efficiency problem and roots competition.

Rye has been used successfully as a cover crop in the U.S-northern corn and soybean belt (Dinnes et al., 2002). However, rye should not be grown to maturity as a cover crop because it can reduce the yield of subsequent trees or crops by using too much water in the spring or immobilizing large amount of N (Tollenaar et al., 1993). Thelen et al. (2004) reported that moisture stress from the inter-seeded rye was a predominate factor in soybean grain yield reduction. Similarly Kuhn BF et al. (2009) reported that vigorous tree growth and significant higher tree production were achieved in the field with annual legumes with an increase in water content, while perennial cover crops only achieve the lowest production and tree growth.

Nambiar and Nethercott (1987) also reported that in the seasonally dry climate of South Australia, annual lupines (*Lupinus angustifolius*) can be used to improve the growth of pines and substitute

for mineral fertilizer, whereas a perennial ground cover would compete with the trees for water during the dry season.

3) Pests and diseases problems

Overall, growing cover crops rarely cause pest problems. But there are still some certain cover crops that may occasionally contribute to particular pest and disease problems in localized areas, for example, by serving as an alternative host to the pest (Sustainable Agriculture Network, 1998). Moreover, some perennials may need addition disease control practices which will cost more money and time. For instance, perennial ryegrass is very susceptible to Gray Leaf Spot disease, thus fairway disease control program often necessary. The negative effects of cover crops apply to specific conditions and can be balanced against positive effects that were discussed in the preceding sections.

CURRENT RESEARCH GAPS

A large amount of research has been done to evaluate cover crops for their benefits, disadvantages and their performance within agriculture or forestry systems, while most of focus on the integration of annual cover crops into agriculture systems or orchards. Although the ground-cover practice has been used for a long time, there is limited knowledge and experience of putting them into practice or quantifying the likely outcomes in terms of the impact on timber growth and quality. More research may need to be done to investigate the effect of perennial cover crops on tree production systems.

Ground-cover crops have several benefits on enhancing soil fertility or soil health also improving

the productivity of trees. However, ground-cover crops systems are not widely used because there is an inherent conflict in agro-forestry in many areas: the expected favorable effects of cover crop root systems, intercropping, vegetative development and yield, and the root systems of the associated plants. Intercropping can induce competition for soil resources (Celette et al., 2005), vegetative development and yield can consequently be limited (Chantelot et al., 2004), and the root systems of associated plants interact in many ways. The main factors that affect the competition can be cover crops species, the plantation density of cover crops, irrigation practices and so on. Hence, more efforts should be put on improvement on genotypes of cover crops. Also, Schroth (1999) reported that an intensive exploitation by the tree roots of the soil directly beneath the ground cover is desirable, this practice will cause competition between roots of trees and cover crops, however, competition between trees and cover crops for nitrogen, in turn, may stimulate the N-fixation activity of the legumes.

Moreover, adaption of water quality models to perennial cover crops is needed to estimate environmental benefits of these practices. Through future research about the competition effects in agro-forestry systems, farmers can determine more appropriate ground-cover practices and make it more efficient for tree production systems.

The addition of organic residues is the only sure way to increase soil organic matter levels. Therefore mulching is an important management practice that will affect soil fertility to a large extent. There are only a few studies discussing the management practice effects on soil quality in the perennial cover crops-tree production systems and a lack of knowledge about how to manage these cropping systems can lead to inefficient and unsuccessful usage. Also, research is needed

on management strategies to use perennial cover crops to trap N from manure application and recycle the N at an appropriate time for the next crop. To achieve a better impact on improving soil quality, more research should be done on this topic.

The contribution of N is the most commonly observed primary benefit of cover crops (Singh et al., 1992). Both legume and non-legume cover crops can affect N fertilizer management (Bauer and Roof, 2004). Legume cover crops can fix enough nitrogen and be used as a source of nitrogen for cash crops (Smith et al., 1987) while non-legume grasses have fibrous roots that are effective in aggregating soil, so they are mainly used to reduce NO₃ leaching and erosion (Meisinger et al., 1991). However, the impacts of perennial cover crops (both legume and non-legume) on the N mineralization or N uptake has rarely been discussed or compared. Therefore more data sets about N mineralization rate and plant N uptake may be required. Furthermore, information is needed on long term cycling and balance of N and C in these systems and whether N fertilizer rates can be reduced in future due to improvement in SOM and N cycling.

Finally, the incorporation of perennial cover crops may require more inputs to establish them in the tree production systems such as seed cost, diseases or insects control and irrigation fee. It is important to evaluate the input and output (tree grow or yearly production) of perennial cover crops in tree production systems. Meanwhile, new management practices are needed to reduce the costs of implementing perennial groundcovers or living mulches. More economical knowledge of establishing perennial cover crops in tree production systems and a lower input cover crop system are important to extend perennial groundcovers to agro-forestry more widely.

CONCLUSION

In recent years the importance of perennial cover crops in tree production system is increasing due to concern for improving soil quality and reducing chemical inputs. Perennial cover crops can provide numerous benefits related to improving the SOM content, soil structure, water use efficiency, and also the reduction of soil erosion. It can also be used as a defense against pests and diseases in tree production systems. However, more studies has to be done to illustrate more detailed information about perennial cover crops effects on tree growth and time quality. Also, establishment of perennial cover crops requires critical and systematic assessment of the interactions between them and the environment, and management. With proper selection, the use and their management of perennial cover crops will be used to improve soil, water and environmental quality.

Table 1: Major types of perennial cover crops

Legumes		Non-legume	
Common name	Scientific name	Common name	Scientific name
Alfalfa	<i>Medicago sativa</i> L.	Perennial Ryegrass	<i>Lolium perenne</i>
Sunnhemp	<i>Crotalaria juncea</i> L.	Pearl Millet	<i>Pennisetum glaucum</i>
Sesbania	<i>Sesbania aculeate</i>	Meadow barley	<i>Hordeum brachyantherum</i>
Egyptian Clover	<i>Trifolium alexandrinum</i> L.	Retz Poir Oat	<i>Avena sativa</i>
Red Clover	<i>Trifolium pretense</i>	Oilseed radish	<i>Raphanus sativus</i>
Securigera varia	<i>Crown vetch</i>	Wheatgrass	<i>Thinopyrum Intermedium</i>
White Clover	<i>Trifolium repens</i> L.	Fescues	<i>Festuca spp.</i>

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CHAPTER2

GROUNDCOVERS MANAGEMENT IN SHORT-ROTATION TREE CROPPING SYSTEMS: EFFECTS ON TREE MORPHOLOGY AND PLANT NUTRIENT

ABSTRACT

Groundcovers managed as living mulches have been suggested as an approach to improve the sustainability of tree production systems for their potential in reducing nutrient loss, improving soil organic matter and fertility, reducing soil erosion, and eliminating unwanted weed populations. However, a groundcover-tree production system is a complex agroecosystem with strong potential for competition between the groundcover and trees for resources such as light, water, and soil nutrients. We investigated the effects of three groundcover types [Alfalfa (*Medicago sativa*), Dutch white clover (*Trifolium repens*) and perennial rye (*Lolium perenne*)] and two management practices, [Banding (B) and no-Banding (noB)] on tree growth and foliar macronutrient. Groundcovers were mowed every 21 days with a side discharge mower, and the cuts biomass was returned to the ground as green mulch. Parameters measured included amounts of green manure produced and their organic nutrient content, the groundcover C/N ratio, tree diameter height growth, as well as foliar macronutrients (N, P, K, Ca, and Mg) concentrations. Results indicate that groundcover type selection only affected tree height growth in 2010 while management practices significantly affected tree diameter and height growth during the three-year study period. The groundcover types choice and management practices significantly affected organic nutrient production. The increased organic nutrient content returned to the

ground did not lead to any significant effect on foliar N, Mg and P concentrations. However, observations for Ca and K suggest competition between groundcovers and trees. Our findings support the hypothesis of competition between groundcovers and trees for some macronutrients and call for the careful management of intercropped cropping systems.

INTRODUCTION

Fraser fir [*Abies fraseri* (Pursh). Poir] is one of the most popular species for Christmas tree production in the United States because of its excellent needle retention, dark blue-green color and pleasant scent (Nzokou and Leefers 2007; Wilson et al. 2010). It is known to be demanding in terms of soil fertility, weed, disease, and insect controls for optimal growth. Current growing practices involve large-scale monocultures using intensive production techniques and heavy applications of fertilizers, herbicides, pesticides, and supplemental irrigation. Fertilization rates of 168 kg ha⁻¹ (150 lbs per acre) to 252 kg ha⁻¹ (225 lbs per acre) of actual nitrogen annually have been reportedly used in Fraser fir production (Ingels and Miller 1993).

However, the intense use of agricultural chemicals could also lead to many environmental problems such as ground water contamination (Heilman and Norby, 1998), nutrients leaching, soil erosion, loss of soil biodiversity. These environmental problems could eventually cause a decrease in growth and harm the sustainability of the production system (Juo et al., 1995).

The use of groundcovers has been proposed as a solution to improving the sustainability of several intensive production systems (Portz and Nonnecke, 2011; Lin et al., 2011; Garland et al., 2011 and O'Reilly et al., 2011). Studies have shown that groundcovers can increase SOM content, reduce soil compaction (MacRae and Mehuys, 1985), and increase the availability of soil macronutrients such as P and Ca (Kourik, 1986) in agriculture and forestry production systems. Positive effects of groundcover on crop yield and soil fertility were observed in several cropping systems including soybean (Reddy, 2001), corn (Vaughan and Evanylo, 1998), wheat (Bakht et al., 2009), viticultural systems (Baumgartner et al., 2008) and Fraser fir production systems

(Wilson et al., 2010; Lin et al., 2011).

Perennial groundcovers develop deep root systems that can easily compete with trees for water. Previous research has indicated that in mixed species cropping systems, the degree of reduction in tree growth generally depends on the competition for soil available water (Ofori and Stern 1987; Malik et al., 2000; Mendham et al., 2004). It has also been reported that groundcovers may reduce yield by causing N deficiency (Wyland et al., 1995). The competition between groundcovers and trees is particularly significant during the early growing stages (May-June), because trees are at their annual maximum nutrient need (Hart et al., 2004). Consequently, competition for nutrients is a serious concern in tree-groundcovers cropping system.

On the other hand, some cover crop species, such as legumes, have been shown to provide a substantial portion of the N required by target crops in several mixed cropping systems (Wagger, 1989a; Mendham et al., 2004; Wilson et al., 2010; Lin et al., 2011). In contrast, due to the relatively slow decomposition rate of their residues, non-legumes have been reported to be less effective in supplying N to target crops (Christensen, 1985; Wagger, 1989b). Another drawback is their strong ability to compete with target crops for soil moisture (Wagger, 1989a; Wilson et al., 2010). This project is based on the assumption that to maximize the benefits of groundcovers in Fraser fir Christmas tree production and improve the quality and profitability of the system, a careful selection of groundcover types and appropriate management practices are critical.

The objective of the study is to evaluate the effect of three groundcovers types [alfalfa (*Medicago sativa*), Dutch white clover (*Trifolium repens*) and perennial rye (*Lolium perenne*)], and management practices on tree growth and foliar macronutrients.

MATERIALS AND METHODS

Site description

The experiment was conducted at the Sandhill Farm of the Tree Research Center (TRC) at 42.65 °N and 84.42 °W, on the campus of Michigan State University between 2009 and 2011. Growing conditions measured by a local weather station indicated precipitation totals of 848 mm, 527 mm and 559 mm for 2009, 2010 and 2011, respectively. Average maximum temperatures varied from 23.1 to 28.0 °C in 2010 compared to 20.5 to 25.5 in 2009 and 20.4 to 30.2 °C in 2011 (Table 2), while average minimum varied from 11.3 to 16.7 °C in 2009, 9.7 to 18.0 °C in 2011 compared to 7.8 to 14.9 °C in 2010. The soil is a Mariette fine sandy loam, which is classified as moderately well drained with high available water capacity and medium surface runoff. The experimental field was surrounded by a 3-wire double electric fence to limit deer access to the field and to control browsing.

Experimental design and plant materials

The experiment was laid out in a randomized complete block design with three replications. The field was planted with Fraser fir transplants (plugs+2) in 2007. A total of 35 trees (5 rows x 7 trees) were included in each plot. Boundary trees were used as a buffer to avoid confounding effects between treatments, and data were collected from the interior 15 trees (3 rows x 5 trees). Groundcovers consisted of three types: two legumes (white clover and alfalfa), and one grass (perennial rye). Groundcover seeds were purchased from Michigan State Seed Company (Grand Ledge, MI) and hand-broadcasted on May 15, 2007 at seeding rates of 28 kg.ha⁻¹ for clover and

alfalfa, and 13 kg.ha^{-1} for rye.

During the three years of the study, groundcovers were mowed to 5 cm every 21 days during the growing season. The cut residues were left on the ground as green mulches. Weeds in the bare-ground treatment and banded areas were suppressed with the application of a 35.8 kg.ha^{-1} of glyphosate with a CO_2 powered backpack sprayer (R&D Sprayer, Baton Rouge, LA). Banding and no-banding were included in management practices in combination with each species. Banding treatments involved creating and maintaining a clean 70.0 cm band centered on the tree row. This was done using glyphosate applications two or three times during the season at rate of 32 oz/A with a custom designed MANKAR sprayer (George F. Ackerman Company, Curtice, OH).

The seven experimental treatments are: bare-ground (BG), banded perennial rye (PR+B), non-banded perennial rye (PR+noB), banded white clover (WC+B), non-banded white clover (WC+noB), banded alfalfa (ALF+B) and non-banded alfalfa (ALF+B).

MEASUREMENTS

Morphological measurements

Tree height and root collar diameter (RCD) were measured with a tape and a digital caliper at the beginning (early May) and end (late August) of the growing seasons for each of the three years of the study. Tree height growth and RCD expansion in each season were calculated as the difference between the initial and final measurements.

Groundcovers biomass sampling and analysis

Groundcovers biomass was determined by collecting cover crop biomass clipping from a randomly selected area (0.6 m²) in each plot. The biomass collected was weighed, oven-dried at 65°C for at least 48 h, and re-weighed for determination of the oven-dried biomass.

Nutrient concentrations of biomass samples were determined by wet chemistry techniques. Approximately 0.3 g of material was placed into a 75 mL digestion tube and digested with a mixture of sulfuric acid (4.5 mL) and hydrogen peroxide (1.5 mL). A digestion blank was included for verification. Samples were pre-digested for 2 h, and then moved into a block digester system (AIM600 Block Digestion System, Shelton, CT) where they were digested according to a preset temperature schedule as described by Wilson et al. (2010).

Aliquots of the digested solution were used to measure N and P concentrations on a SAN++ segmented flow analyzer (Skalar Inc. Atlanta, GA). Other macronutrients concentrations including K, Ca, and Mg were determined by Atomic absorption spectrophotometry on a Perkin Elmer Aanalyst 400 (Perkin Elmer, Shelton, CT).

The carbon (C), nitrogen (N) and C/N ratio of cover biomass for each cover crop types was determined by dry combustion on a Costech ECS-4010 CHNSO analyzer (Costech, Valencia, CA).

Foliage sampling and analysis

Foliage specimens were randomly collected from the current year growth from each treatment at the end of each growing season, transported to the laboratory in Ziploc bags in a cooler and refrigerated at 4 °C until further analysis. For nutrient analysis, specimens were weighed, dried and digested and analyzed for macronutrients as described above for the groundcover biomass.

Data analysis

Cover crop biomass macronutrients contents, foliar macronutrients contents and soil macronutrient concentrations were analyzed by a two-way analysis of variance to test the effect of the treatments on macronutrients dynamics in Fraser fir production system. The means were separated by a least significant difference test with $\alpha < 0.05$. Pairwise comparisons were run to compare each groundcover/banding or no-banding combination with the conventional standard. A level of significance of $\alpha < 0.05$ was used to determine statistical significance. Simple correlation analysis was run to evaluate the relationship between cover crop organic macronutrient contributions and foliar macronutrients in trees.

All data analyses were performed using Systat 13 software (Systat Software, Inc., Chicago, IL).

RESULTS

Cover crop biomass macronutrients accumulation

As expected, legume cover crops treatments consistently had significantly higher cumulated organic N content compared to the grass cover crop. The types selection had a significant effect on cumulated organic N contributions with highest value found in ALF treatments and lowest in PR treatments in 2009 ($p=0.0$), 2010 ($p=0.0$), and there were no significant effect observed in 2011 ($p=0.1$). Assessment of management practices showed significant effect in 2009 with higher cumulated organic N in no banding treatments ($p=0.0$) compared to banded treatments, however in 2010 and 2011, management practices were not significant.

Cumulated organic Mg content varied from 4.6 to 16.6 kg/ha in 2009, 4.1 to 17.0 kg/ha in 2010 and 4.5 to 13.6 kg/ha in 2011 (Table 3). The organic Mg content variation was significant in both 2009 and 2010 ($p=0.0$ in 2009 and $p=0.0$ in 2010) and not significant in 2011 ($p=0.1$). The types choice was significant with ALF treatments consistently producing the highest amounts of organic Mg, whereas PR treatments had the lowest. In both 2009 and 2010, management practices did not significantly affect the cumulated organic Mg in 2009 ($p=0.3$) and 2010 ($p=1.0$), however, the effect was significant in 2011 ($p=0.0$).

Cumulate organic K contents varied from 92.5 to 189.6 kg/ha in 2009 (Table 3), 152.6 to 395.5 kg/ha in 2010 and 93.8 to 362.9 kg/ha in 2011. The types selection significantly affected organic K content in 2009 ($p=0.0$), but was not significant in both 2010 and 2011. The effect of management practices on K content was significant only in 2010 ($p=0.0$).

Cumulated organic Ca content ranged from 28.5 to 82.0 kg/ha in 2009, 6.8 to 53.9 kg/ha and

16.0 to 72.2 kg/ha in 2011 (Table 3). The types choice affected Ca in all both 2009 and 2010 ($p=0.0$) but not in 2011 ($p=0.4$). Management practices did not statistically affect Mg in any of the three years of the study ($p=0.2$, $p=0.2$, $p=0.1$ in 2009, 2010, and 2011 respectively).

Cumulated organic P content ranged from 27.6 to 74.1 kg/ha in 2009, 29.2 to 112.2 kg/ha in 2010 and 15.0 to 87.5 kg/ha in 2011 (Table 3). Similarly to other elements, total organic P was significantly affected by the types selection in 2009 ($p=0.015$) and 2010 ($p=0.004$), but not in 2011 ($p=0.2$). Management practices significantly affect cumulated organic P only in 2009 ($p=0.0$).

Cover crop C to N ratio

C to N ratio values ranged from 9.7 to 13.6 in 2010, and from 11.2 to 21.6 in 2011 (Table 4). WC generally had the lowest C/N while PR had the highest.

Tree height and diameter growth

In 2009, tree height growth varied from 7.4cm to 10.4cm (Table 5). There was no type selection or management practices effect on height growth. In 2010, the types selection significantly affected tree height growth ($p=0.0$), with the least height growth found in PR treatments. Also, height growth were significantly affected ($p=0.0$) by management practices in 2010 (Figure 1). In 2011, the height growth significantly response as result of management practice, and non-significant effect as result of the types selection.

For tree diameter growth, in 2009, 2010 and 2011, only management practices had a significant effect with lower growth shown in all no band treatments compare to band treatments and similar to bare ground plots ($p=0.0$ in 2009, 2010 and 2011).

Tree foliar macronutrients (N, Ca, Mg, K, and P) concentration

The data on foliar macronutrient concentrations as affected by different cover crop type selection and management practices are presented in tables 5 and 6.

In 2009, foliar N concentrations varied from 14.5 to 26.6 mg/g. Management practices significantly affected foliar N with higher values found in banded plots ($p=0.0$). The groundcover type choice did not significantly affect foliar N. In both 2010 and 2011, foliar N concentrations were statistically similar among treatments $p=0.5$ and $p=0.9$.

Foliar Mg concentrations ranged from 0.7-1.2 mg/g in 2009, 0.8-1.2 mg/g in 2010, and 0.7-1.2 mg/g in 2011. Values were statistically similar between treatments in all three years of the experiment, and neither management practice or types selection affected foliar Mg (Table 6).

Correlation between cumulative groundcovers organic Mg and foliar Mg was only found in PR plots with a very strong negative ratio $r^2=-0.8$ in 2010 and a positive ratio $r^2=0.4$ in 2010 (Table 7).

Foliar Ca concentrations were not significantly different among treatments in 2009. In 2010, PR treatments had statistically lower foliar Ca concentrations ($p=0.0$). In 2011, foliar Ca concentrations were generally higher in banded plots except in WC+noB plots. The choice of groundcover types had no significant effect on foliar Ca in 2011 (Table 6).

There were no strong correlation showed in all WC treatments between cumulative cover crop organic Ca. The correlation was higher in ALF treatments compared to PR treatment during the whole study period. The correlation ratios were negative in 2009 and 2011, and positive in 2010 (Table 7).

Lower foliar K concentrations were found in all cover crop plots compared to bare ground plots in 2009 and 2010. The differences were not statistically significant in 2009 ($p=0.5$); however, in 2010, trees in cover crop treatments got significantly lower K levels compared to BG treatment ($p=0.0$). However, in 2011, higher foliar K values were observed in all ground cover treatment plots. Significantly higher K values were found in all no-band plots compared to band plots ($p=0.0$). Cumulated groundcovers K content was strongly correlated with foliar K in both 2010 and 2011. In 2010, the correlation coefficients were -0.6 for ALF, and -0.5 for PR treatments. In 2011, the coefficients were 1.0 for ALF, 0.9 for WC, and -0.7 for PR plots.

For foliar P, the type selection did not affect P concentrations. Banding treatments increased foliar P significantly in both 2009 and 2010 ($p=0.0$ in 2009 and $p=0.0$ in 2010) but not in 2011 ($p=0.2$).

Cumulated groundcovers P content was significantly correlated with foliar P in ALF plots in 2010 and 2011 ($r^2=0.8$ and 0.8). In 2011 there was a weak positive correlation with PR plots ($r^2=0.3$).

DISCUSSION

Effects of cropping systems on tree morphology

During three years, height and diameter growth followed similar trends. Type selection only affected on height growth in 2010 with significant higher growth in ALF plots compared to PR plots ($p=0.0$), while the height growth response in other groundcovers plots were statistically similar to BG plots. This result suggests the type choice is not critical for tree growth in Fraser fir production system when using a groundcover compared to the conventional bare ground management. Ctahr (2009) obtained similar results and reported improved tree growth and reduction in fertilizers needed when using living mulches with fruit trees. This result is also consistent with Wilson et al. (2010).

We found the management practice of maintaining a clean band between cover crops and trees had a significant effect on tree growth (both diameter and height growth) during the three years of the study. Significantly lower growth was obtained in plots without band, and growth in banded plots was similar to BG treatments. Many other studies have reported competition in soil nutrient and water between groundcover and target crops (Walsh et al. 1996; Wilson et al. 2010; Wyland et al., 1995; Malik et al., 2000). In our other study that evaluated the effect of cover crop system on soil nutrient, we did not observed any significant difference between all treatments. In the meantime it has been claimed that the degree of the suppression depends on soil available water resources (Ofori and Stern 1987; Mendham et al., 2004). This competition in soil moisture has been reported to cause suppression in tree growth in a eucalypt production system in India (Mendham et al., 2004) and a young pecan trees production system (Foshee et al., 1995). Also in

our previous study in 2009, significant lower soil moisture was observed in all no banded treatments (Wilson et al., 2010). Therefore, we concluded that the lower tree growth responses in all the no banded treatments might be due to competition for soil available water resources between cover crops and trees.

Effects of cropping systems on foliar macronutrient concentrations

Foliar N

Although some summer-active perennial grass covers and perennial ryegrass have been indicated to have negative impact on foliar N in some vineyards production systems (Hirschfeld et al., 1992; Tan and Crabtree, 1990), we found that no negative effects of ground covers on foliar N shown in all plots compared to control treatment, which is also agree with Lin et al (2011). This result indicated that cover crops residue cumulative N contribution can help to maintain foliar N level while all cover crops treatments only receive quarter amount of N fertilizer applied in control treatment.

In 2009, we observed a strong negative response of foliar N to cover crops cumulative N contribution in all cover crops treatments, especially in treatments that received higher residue cumulative N content. This might due to the increase in soil microorganisms' population in response to the added residue with high N content (Creamer et al., 1999). However, in 2010 and 2011 there were no clear relationships between cover crop residue cumulative N contribution and foliar N to make any conclusion.

It has been stated that cover crop residue C/N has an important effect on N mineralization rates and increasing the soil nutrient availability, thus to benefit foliar nutrient. In this study, WC had

the consistently lowest C/N ratio compared to ALF and PR (Gowariker et al., 2009). However, the statistical analysis showed no stronger better performance of WC on increasing foliar N. This result suggested that cover crop C/N has no significant effect on tree foliar N concentration.

Other foliar macronutrients

Mg is an essential element for many plant functions such as photosynthesis, nutrient uptake control and increasing iron utilization. Mg availability is affected by several different factors, among all these factors, high rates of K was reported to reduce the Mg uptake of plant roots (Mengel and Kirkby, 1987; Mary et al., 1998). However, there were only weak correlations found in 2009, 2010 and 2011 ($r^2 = -0.2, -0.3$ and 0.3). Also, trees in all treatments did not differ in foliar Mg concentration in 2009, 2010 and 2011. The lack of significant treatments effects on foliar Mg suggests that foliar Mg were not influenced by groundcover systems. This is consistent with the findings of a study on plant residues for cassava (*Manihot esculenta*) production (Hulugalle et al. 1987).

Foliar K concentrations were lower in groundcovers treatments compared to bare ground treatments in 2009 and 2010. This is consistent with other previous studies that have suggested that groundcovers are not effective in increasing foliar K due to the roots competition (Hogue et al., 2010; Neilsen et al., 2000). However in 2011, foliar K concentrations in groundcovers plots were higher than bare ground plots, contradicting the roots competition hypothesis. More studies over a longer time period are needed to determine the reasons for these contradictory trends.

Ca is held on the surface of soil clay and organic matter, therefore the availability of Ca depends on both cation exchange capacity and soil organic matter content. Foliar Ca concentration was

not affected by cover crops systems in 2009 and 2011. In 2010, the lowest foliar Ca concentration was found in PR treatments. This suggests that the lowest Ca contribution from PR biomass and the slow decomposition rate of the grass groundcover residue can cause a decrease in availability and hence foliar Ca in trees. In addition, the negative impact of PR on foliar Ca may be due to nutrient competition between the rye grass groundcovers and trees (Lehmann et al., 2000).

Foliar P concentrations were not affected by groundcover selection through the three years. In 2009, there were significantly lower foliar P found in no banded plots compared to banded plots, which might attributed to competition for nutrients uptake between trees and cover crops. In 2010 and 2011, there were only slightly differences between difference treatments. Bould and Jarrett (1962) reported that foliar P was elevated in the first few studying years. However, it has been claimed that this competition for nutrient may reduced after the cover crop is established and the nutrient start to cycle between plant and soil (Lehmann et al., 2000). Bouharmont (1978) has reported that the incorporation of cover crop has no effect on foliar P in a coffee production system. Therefore longer time will be required to observe a clear effect of cover crops on foliar P concentration.

CONCLUSION

In this study, we investigated the effect of three different cover crop types on tree height growth, diameter growth and tree foliar macronutrient in a Fraser fir production system. During the whole study period, we concluded that ground cover type selection was not critical for tree growth. In the same time, suppression in tree height and diameter growth in no banded treatments was observed, which might be due to the competition in soil moisture between cover crop and trees. This competition can be efficiently controlled and avoid the suppression in tree growth by creating a clear band in between cover crops and trees.

With reduced rates of fertilizer, foliar N in all cover crops treatments were generally similar to control treatment. This result indicated that the cover crop residue N contribution can help to maintain foliar N level. There were no clear impacts of cover crops residue N contribution or cover crop C/N on foliar N showed during the study period. More study will be need to illustrate the mechanism of how do cover crop residue affect foliar N.

We did not observed any significant effect of cover crop system on foliar Mg. For foliar Ca, we concluded that lower cumulative Ca contribution from cover crop residue will results in low foliar Ca. For foliar K and P, longer time and more specific studies will be done to observe a clearer trend.

TABLES

Table 2. Average monthly temperatures and total rainfall during the 2009, 2010 and 2011 growing seasons.

			May	Jun.	Jul.	Aug.	Sep.
2009	Average						
	Temperature	Max.	20.5	24.8	24.9	25.5	23.5
	(°C)	Min.	7.8	13.4	13.4	14.9	10.7
	Rainfall (cm)		10.9	12.6	6.1	10.5	2.4
2010	Average						
	Temperature	Max.	28.0	26.5	27.9	27.5	23.1
	(°C)	Min.	15.3	15.2	16.7	14.5	11.3
	Rainfall (cm)		12.9	10.1	6.8	3.7	7.2
2011	Average	Max.	20.4	25.4	30.2	26.8	21.1
	Temperature						
	(°C)	Min.	9.7	14.1	18.0	14.7	10.8
	Rainfall (cm)		14.6	4.0	13.0	7.8	6.7

Table 3. Cover crop biomass nutrient content as affected by different types and management practices in 2009, 2010 and 2011 (kg/ha):

2009					
	N	Mg	K	Ca	P
ALF+B	184.3 $\pm$ 1.1a	7.3 $\pm$ 0.1b	149.7 $\pm$ 6.5a	61.5 $\pm$ 0.6a	35.9 $\pm$ 0.6a
ALF+NoB	356.1 $\pm$ 0.5b	16.6 $\pm$ 0.4a	189.6 $\pm$ 5.3a	82.0 $\pm$ 1.2b	74.1 $\pm$ 1.0b
PR+B	89.5 $\pm$ 0.8c	5.0 $\pm$ 0.1b	92.5 $\pm$ 5.1a	28.5 $\pm$ 0.4c	28.7 $\pm$ 0.3a
PR+NoB	92.9 $\pm$ 0.7c	5.0 $\pm$ 0.0b	103.8 $\pm$ 2.4a	30.5 $\pm$ 0.0c	27.6 $\pm$ 0.3a
WC+B	152.0 $\pm$ 1.0d	9.3 $\pm$ 0.5b	113.0 $\pm$ 6.0a	44.6 $\pm$ 0.9c	36.9 $\pm$ 0.1a
WC+NoB	238.1 $\pm$ 1.6e	7.9 $\pm$ 0.1ab	152.7 $\pm$ 10.9a	44.6 $\pm$ 0.1a	55.3 $\pm$ 0.5c
P-value	p=0.0	p=0.0	p=0.1	p=0.0	p=0.0
2010					
ALF+B	314.7 $\pm$ 1.1a	10.4 $\pm$ 0.0ab	86.6 $\pm$ 1.3ac	34.2 $\pm$ 0.5ac	55.5 $\pm$ 0.2a
ALF+NoB	559.5 $\pm$ 3.0b	17.0 $\pm$ 0.1a	160.0 $\pm$ 2.0b	41.3 $\pm$ 0.3a	112.2 $\pm$ 1.1b
PR+B	170.2 $\pm$ 1.3c	5.5 $\pm$ 0.0c	61.8 $\pm$ 0.3a	10.4 $\pm$ 0.4d	42.1 $\pm$ 0.3a
PR+NoB	120.9 $\pm$ 1.1c	4.1 $\pm$ 0.0d	83.5 $\pm$ 5.0ac	6.8 $\pm$ 0.1d	29.2 $\pm$ 0.5a
WC+B	292.0 $\pm$ 1.6a	8.6 $\pm$ 0.2b	78.8 $\pm$ 0.2ac	25.8 $\pm$ 0.8bc	51.9 $\pm$ 2.7a
WC+NoB	477.5 $\pm$ 3.4d	15.2 $\pm$ 0.1ab	133.0 $\pm$ 1.8bc	53.9 $\pm$ 0.5e	56.4 $\pm$ 1.0a
P-value	p=0.0	p=0.0	p=0.0	p=0.0	p=0.0
2011					
ALF+B	243.0 $\pm$ 2.3ab	6.6 $\pm$ 0.1ab	109.2 $\pm$ 1.3a	23.2 $\pm$ 0.6a	27.3 $\pm$ 0.1a
ALF+NoB	575.6 $\pm$ 30.1a	13.6 $\pm$ 0.4a	362.9 $\pm$ 34.5a	72.2 $\pm$ 2.9a	87.5 $\pm$ 6.8a
PR+B	184.0 $\pm$ 1.4b	5.3 $\pm$ 0.2b	137.9 $\pm$ 2.2a	16.0 $\pm$ 0.3a	31.2 $\pm$ 0.3a
PR+NoB	161.0 $\pm$ 2.8b	5.8 $\pm$ 0.0b	93.8 $\pm$ 1.3a	36.8 $\pm$ 2.5a	27.6 $\pm$ 0.9a
WC+B	154.8 $\pm$ 1.5b	4.5 $\pm$ 0.1b	98.3 $\pm$ 3.8a	40.0 $\pm$ 3.7a	15.0 $\pm$ 0.1a
WC+NoB	296.8 $\pm$ 15.5ab	9.0 $\pm$ 0.6ab	230.5 $\pm$ 2.2a	41.8 $\pm$ 3.8a	31.9 $\pm$ 1.5a
P-value	p=0.0	p=0.0	p=0.1	p=0.2	p=0.06

Labels: ALF+B is alfalfa with band, ALF+NoB is alfalfa with no band, PR+B is perennial rye with band, PR+NoB is perennial rye with no band, WC+B is white clover with band, and WC+NoB is white clover with no band.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

Table 4. Cover crop residue C/ N ratio in 2010 and 2011

	2010 May 12	2010 June 22	2010 July 13	2010 Aug 4
ALF	11.8±0.0b	9.7±0.0b	12.1±0.0a	12.7±0.0a
PR	13.6±0.0a	12.1±0.1a	12.5±0.1a	12.3±0.0a
WC	10.2±0.0c	10.1±0.0b	11.2±0.0a	12.2±0.1a
P-value	0.0	0.0	0.3	0.7
	2011 May 31	2011 June 21	2011 July 12	2011 Aug 2
ALF	17.8±0.1ab	13.0±0.1ab	12.7±0.1a	12.9±0.0a
PR	21.6±0.1a	17.6±0.2a	16.6±0.1a	14.2±0.0b
WC	15.3±0.1b	11.2±0.0b	12.9±0.0a	12.7±0.0a
P-value	0.0	0.1	0.1	0.0

Labels: ALF is alfalfa, PR is perennial rye and WC is white clover.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

Table 5. Tree Height and Diameter growth affected by different cover crop types and management practices in 2009, 2010 and 2011.

Treatment	2009		2010		2011		3 years cumulative	
	Height (cm)	RCD (mm)	Height (cm)	RCD (mm)	Height (cm)	RCD (mm)	Height (cm)	RCD (mm)
BG	10.4±0.9a	4.3±0.5b	11.1±0.5a	10.0±2.8a	15.6±1.5b	4.8±0.7a	37.0	19.1
ALF+B	10.0±0.9a	5.0±0.5a	14.7±0.6ac	11.4±2.2a	12.8±1.3a	3.7±0.5a	37.5	20.1
ALF+NoB			10.8±0.6ac		12.0±1.5a	2.1±0.5a		
B	8.8±0.8a	2.6±0.3c	d	4.6±1.4b	c	b	31.6	9.3
PR+B	8.6±1.0a	4.9±0.5d	10.9±0.5c	10.4±2.7a	14.2±1.4b	4.2±1.1a	33.6	19.4
PR+NoB	7.4±0.9a	c	4.6±0.3b	3.6±1.5b	8.7±1.2ac	1.9±0.4b	20.6	7.1
WC+B	10.0±1.0a	4.6±0.5a			14.3±1.5b	3.4±0.5a		
WC+NoB		2.6±0.4b		9.2±2.6a		1.6±0.4a		
B	8.1±1.1a	c	5.2±0.4bc	b	7.8±1.4c	b	21.1	13.4
p-value	p=0.4	p=0.0	p=0.0	p=0.0	p=0.0	p=0.0		

Labels: ALF+B is alfalfa with band, ALF+NoB is alfalfa with no band, PR+B is perennial rye with band, PR+NoB is perennial rye with no band, WC+B is white clover with band, and WC+NoB is white clover with no band.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

Table 6. Foliar Nutrients affected by management practices and cover crop types in 2009, 2010 and 2011 (mg/g):
(Foliar Mg 2009 data is from July.9th, 2009)

Treatment	2009				
	N	Ca	Mg	K	P
ALF+B	21.2±0.2ab	2.1±0.0a	0.8±0.0a	1.7±0.1a	1.5±0.0ab
ALF+NoB	14.5±0.3b	1.6±0.1a	0.8±0.0a	2.1±0.1a	1.2±0.0b
PR+B	26.6±0.2a	2.1±0.0a	0.8±0.0a	1.7±0.1a	1.9±0.0a
PR+NoB	15.3±0.2b	1.7±0.0a	0.8±0.0a	1.5±0.1a	1.2±0.0b
WC+B	24.4±0.4ac	2.1±0.0a	0.8±0.0a	2.2±0.1a	1.6±0.0ab
WC+NoB	17.8±0.5bc	1.6±0.1a	0.9±0.0a	0.9±0.0a	1.2±0.0b
BG	18.9±0.3bc	2.4±0.0a	0.8±0.0a	2.0±0.1a	1.3±0.0b
P-value	0.0	0.4	0.4	0.5	0.0

2010					
ALF+B	15.0±0.2a	2.4±0.1ab	0.8±0.0a	4.5±0.1ab	1.2±0.0a
ALF+NoB	15.5±0.2a	3.7±0.1ab	0.8±0.0a	3.6±0.2b	1.6±0.0a
PR+B	15.7±0.1a	2.1±0.1ab	0.8±0.0a	5.1±0.0ab	1.4±0.0a
PR+NoB	14.3±0.2a	1.6±0.0b	1.2±0.0a	3.9±0.1b	1.6±0.0a
WC+B	14.9±0.1a	4.2±0.1a	0.8±0.0a	4.8±0.1ab	1.3±0.0a
WC+NoB	16.5±0.3a	4.4±0.1a	1.1±0.1a	4.1±0.1ab	1.6±0.0a
BG	16.9±0.2a	4.5±0.1a	1.0±0.0a	6.5±0.1a	1.7±0.0a
P-value	0.5	0.0	0.5	0.0	0.0

2011					
ALF+B	37.9±0.5a	5.4±0.8a	0.7±0.0a	24.2±0.4a	3.9±0.0a
ALF+NoB	39.3±0.1a	2.7±0.2a	1.0±0.0a	46.8±1.7a	4.9±0.0a
PR+B	38.4±0.5a	7.9±2.5a	0.8±0.0a	18.7±3.1a	4.4±0.0a
PR+NoB	38.2±0.9a	3.8±0.3a	1.2±0.1a	193.6±20.0a	5.8±0.0a
WC+B	44.2±0.4a	3.0±0.2a	0.9±0.0a	55.3±14.0a	4.4±0.0a
WC+NoB	43.8±0.8a	2.4±0.6a	1.2±0.1a	293.3±13.1a	5.3±0.9a
BG	40.6±1.4a	2.1±0.3a	1.1±0.1a	23.4±1.5a	4.4±0.0a
P-value	p=0.8	P=0.7	P=0.9	P=0.1	P=0.1

Labels: ALF+B is alfalfa with band, ALF+NoB is alfalfa with no band, PR+B is perennial rye with band, PR+NoB is perennial rye with no band, WC+B is white clover with band, and WC+NoB is white clover with no band.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

Table 7. Correlation ratios between foliar macronutrient and cover crop residue cumulative macronutrient return in 2009, 2010 and 2011:

	N			Mg			K		
	2009	2010	2011	2009	2010	2011	2009	2010	2011
ALF	-0.833	0.338	0.213	0.348	0.161	0.265	0.152	-0.592	0.957
PR	-0.445	0.335	0.512	-0.231	-0.814	0.369	0.229	-0.492	-0.697
WC	-0.623	0.556	0.098	-0.499	0.279	0.106	-0.604	-0.152	0.859

	Ca			P		
	2009	2010	2011	2009	2010	2011
ALF	-0.444	0.725	-0.598	-0.72	0.813	0.836
PR	-0.316	0.343	-0.553	0.501	-0.241	0.31
WC	-0.294	-0.057	-0.184	-0.863	0.038	-0.268

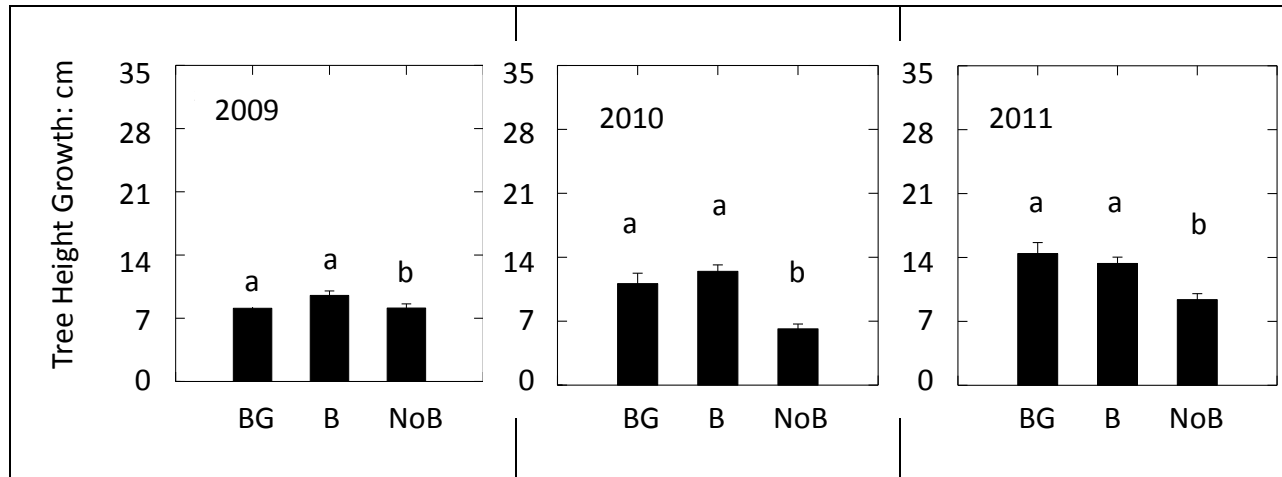
Labels: ALF is alfalfa, PR is perennial rye and WC is white clover.

Simple correlation analysis was run to show the correlation between different parameters.

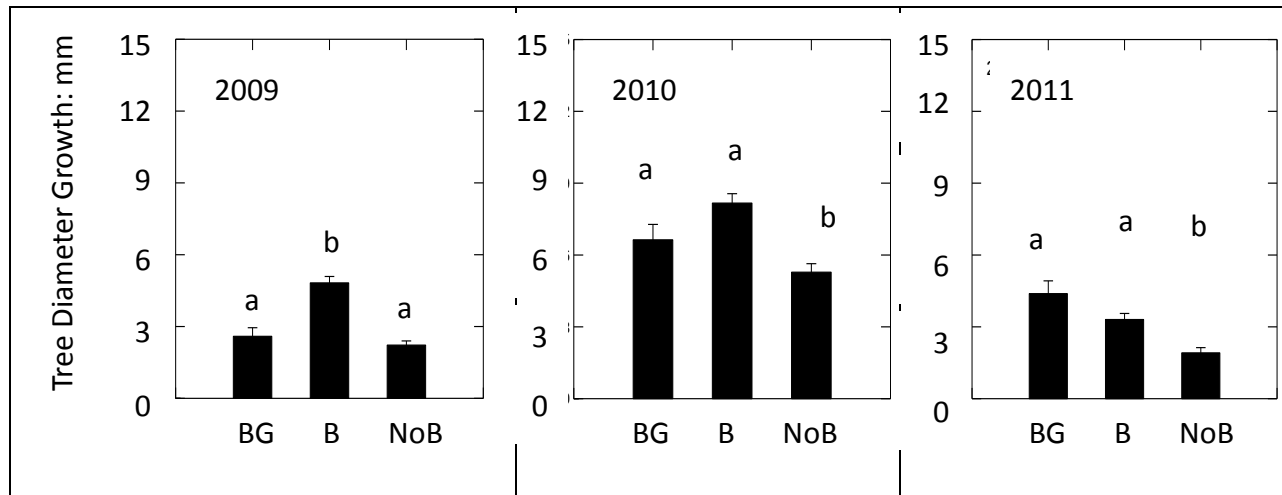
FIGURE

Figure 1. Tree height and diameter growth as affected by management practices in 2009, 2010 and 2011:

A. Height: cm



B. Diameter: mm



B is plot with band, NoB is plot with no band and BG is bare ground.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

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CHAPTER 3

EFFECTS OF GROUND COVERS MANAGEMENT ON: SOIL FERTILITY AND SOIL MACRONUTRIENTS

ABSTRACT

The ability of cover crop to improve soil structure, prevent wind and water erosion, enhance soil nutrients mineralization, and contribute carbon input to soil has been elucidated in many agricultural production systems. However, limited research has been done in evaluating the effects of incorporating cover crop in forestry production systems and most of the existing research has focused on N dynamics. Therefore, the objectives of this study were (1) to evaluate the effect of three different cover crops types [alfalfa (*Medicago sativa*), Dutch white clover (*Trifolium repens*) and perennial rye (*Lolium perenne*)] and different management practices on soil macronutrients (N, K, Ca, and Mg) in a Fraser fir (*Abies fraseri*) production system. The different management practices included banded (B) and no-banded (noB) treatments for each cover crop types and or bare-ground (BG) was used as a control treatment. Cover crop was mowed every 21 days and returned to the ground as green mulch. The parameters measured included cover crop nutrient content, soil organic matter content, soil macronutrient concentrations, soil bulk density, and N mineralization rate in soils. Soil macronutrient concentration at 0-15 and 15-30 cm depth did not differ significantly among the treatments. Results indicated that plot that received the most cover crops biomass return had higher soil organic matter and lower soil bulk density. We concluded that cover crop types and management practices should be selected carefully in order to avoid competition between trees and cover

crops.

INTRODUCTION

Cover crops are used as a tool to increase nitrogen economy (Frye et al., 1988; Sustainable Agriculture Network, 1998), reduce soil erosion (Langdale et al., 1991), improve soil physical properties (Blevins and Frye, 1993), increase nutrient retention in the production system (Staver and Brinsfield, 1998; Dinnes et al., 2002) and soil fertility (Cavigelli and Thien, 2003).

Among these different benefits, increasing soil organic matter is a key aspect of using cover crops in production systems. Normally, there is 2 to 5 percent of soil organic matter decomposes each year (Gaskell et al., 2000). The decomposition of soil organic matter supplies many important nutrients such as N, P, S, to soil which enhances the soil nutrient availability. During this decomposition period, the rate and the amount of mineralized N is very essential (Gaskell et al., 2000). A lack of synchrony between mineralized N and crop N uptake may result in N deficiency in the target crop.

Soil organic matter can also organize soil mineral particles into structural units that can improve porosity; thereby increasing soil organic matter content can lead to a decrease in soil bulk density (Veenstra, 2006). Edmeades (2003) has claimed that organically fertilized soil has higher soil organic matter levels, greater aggregate stability and lower bulk density than conventionally fertilized soil. The contribution of cover crop to soil organic matter can vary due to various factors such as climate, soil properties, and cover crop types. It has been reported that the quantity of cover crop residue applied is the most important factor in increasing soil organic matter (Janzen et al., 1998; Reicosky et al., 1995), a higher amount of residue retained will increase the content of soil organic matter and soil quality more rapidly (Schomberg et al., 1994).

Gregorich et al. (2001) reported that residue quality plays an essential role in increasing the retention of soil organic matter in agro-ecosystems. The main biological factors considered to affect the formation of soil organic matter are the C/N ratio and the components such as cellulose or lignin contents (Frankenberger and Abdelmagid 1985; Russell and Fillery 1999) which is highly dependent on the cover crop types.

A lot of research has been done to evaluate the effects of cover crops on improving soil fertility. Most studies on the use of cover crops focus on legume species and N as a primary amendment. For example, Campiglia et al. (2010) concluded that winter legume cover crops could be converted into green mulch in the spring, adding N to the soil and increasing the yield of the subsequent pepper crop. Similar results were observed in an annual cover crop-apple tree production system, where high levels of foliar N, yield, fruit quality and soil water content in the alleyways by Kuhn and Pedersen (2009).

However, other macronutrients can have a significant impact on crop yield and crop quality (Maitra et al., 2008; Andriolo et al., 2010; Kumari et al., 2008; Moody et al., 1998; Eugene et al., 2010). P and K may be as important to tree quality as N (Rathfon and Burger, 1991; Rothstein and Lisuzzo, 2006). Sleask and Briggs (2010) found that needle mass was highly correlated with foliar K concentration ($r^2=0.71$). In Christmas tree plantations, foliar Phosphorus nutrition should be addressed as an essential problem (Heiligmann and Koelling, 1997), Ma (1992) reported that P fertilizer could improve seedling growth of potted Douglas-fir and Western hemlock in various soils.

Since the use of cover crops in tree production systems is relatively new, to our knowledge there

are few published studies related to the impacts of using cover crops on soil macronutrients (K, Mg, Ca and P) in short rotation production systems.

The aim of this project was to evaluate the contribution of macronutrient by three different types cover crops to soil fertility and macronutrient concentration.

The specific objectives were to 1) evaluate the impact of ground covers types and management practices on macronutrient concentration of cover crop residues and C/N ratio, and 2) evaluate the effect of each cover crop types on soil fertility and macronutrient concentration.

MATERIALS AND METHODS

Site description

The experiment was conducted at Sandhill Farm of the Tree Research Center (TRC) at 42.65 °N and 84.42 °W on the campus of Michigan State University in 2009, 2010 and 2011. Annual total precipitation was 848 mm for 2009, 527 mm for 2010 and 559mm for 2011. In 2010, the plots were irrigated to prevent the field from getting too dry. The soil is a Mariette fine sandy loam, which is classified as moderately well drained with high available water capacity and medium surface runoff. The experimental field was surrounded by a 3-wire double electric fence to reduce deer browsing.

Experimental design and plant materials

The experiment was laid out in a randomized complete block design with three replications. The field was 39x64 m in size and planted in 2007 with Fraser fir transplants (plugs+2). There were 35 (5 rows x7 trees) trees in each plot. Boundary trees were used as a buffer to avoid confounding effects between treatments and data was collected from the interior 15 trees (3 rows x5 trees).

Cover crop consisted of three different types: two legumes [Dutch white clover (*Trifolium repens*) and alfalfa (*Medicago sativa*)] and one grass [perennial rye (*Lolium perenne*)]. The cover crop seeds were purchased from Michigan State Seed Company (Grand Ledge, MI) and hand-broadcasted on May 15, 2007 at seeding rates of 28 kg.ha⁻¹ for clover and alfalfa and 13 kg.ha⁻¹ for rye.

During 2009, 2010, and 2011, cover crops were mowed to 5 cm every 2 wk during the growing

season. The cut residues were left on the ground as green mulch. Weeds in the bare-ground treatment were removed by application of a 35.84 kg.ha^{-1} of glyphosate with a CO₂ powered backpack sprayer (R&D Sprayer, Baton Rouge, LA). Banded or no-banded were part of the different management practices used in combination with each types. Glyphosate was applied with a custom designed MANKAR sprayer (George F. Ackerman Company, Curtice, OH) to keep a 1 foot band on each side of the tree row.

The treatments analyzed were: bare-ground (BG), banded perennial rye (PR+B), no-banded perennial rye (PR+noB), banded white clover (WC+B), no-banded white clover (WC+noB), banded alfalfa (ALF+B) and no-banded alfalfa (ALF+B).

MEASUREMENT

Cover crop biomass, nutrients analysis and C: N ratio

Cover crop biomass was determined by collecting cover crop biomass clippings from a randomly selected area (0.55 m^2) in each plot. The biomass collected in each treatment was then weighed, oven-dried at 65°C , the dried biomass was determined.

The dried biomass was analyzed by a Costech ECS-4010 CHNSO analyzer for C: N ratio.

Three sub-samples of cover crop biomass from each treatment were analyzed. Approximately 0.3 g of material was placed into a 75 mL digestion tube and digested with a mixture of sulfuric acid (4.5 mL) and hydrogen peroxide (1.5 mL). A digestion blank was included for verification. Samples were pre-digested for 2 h and placed into a block digester system (AIM600 Block Digestion System, Shelton, CT) at $340 \pm 10^\circ\text{C}$ for heat digestion according to manufacturer's introduction.

Aliquots of the digested solution were measured at 660 nm on a SAN++ segmented flow analyzer (Skalar Inc. Atlanta, GA) to determine P concentration. K, Ca, Mg concentrations were determined by Atomic absorption spectrophotometry.

Soil organic matter content

Two soil samples were randomly taken from each plot at 2 different soil depths (0-15cm and 15-30cm) using a soil auger in mid May and late August of each growing season. The soil samples were placed in zip lock bags and transported on ice to the laboratory where they were refrigerated (4°C) until analysis. Then the samples were analyzed follow the procedure involves

reduction of potassium dichromate ($K_2Cr_2O_7$) by OC compounds and subsequent determination of the unreduced dichromate by oxidation-reduction titration with ferrous ammonium sulfate (Walkley, 1947).

Soil N mineralization study

On June 24, 2010, 3 cylinders were inserted into each plot randomly between tree rows, with two nylon bags placed flat on the bottom of each cylinder. One of the nylon bags contained 3g of sodium-saturated cation (C-249) and the other contained 3g of chloride-saturated anion (ASB-1P) resin. One cylinder was randomly selected and removed on July 14, Aug. 4 and Aug. 24 in 2010. On June 2 2011, 4 cylinders were inserted into each plot similar to the method used in 2010. The cylinders were removed on June 23rd, July 14th, Aug. 3rd and Aug. 24th.

Then the resin bags and soil from inside the cylinders were extracted with 2M KCl to remove NH_4^+ and NO_3^- . The extraction was analyzed to determine the inorganic N content (NH_4^+ and NO_3^-). The net mineralization rate was determined by the equation: $(NH_4^+ + NO_3^-)_{t+1} - (NH_4^+ + NO_3^-)_t$.

Soil nutrient analysis

Composite samples were taken from 0-15 and 15-30 cm at two random locations in each plot using a soil auger in 5.29 and 8.25 in 2009 and 5.10 and 8.25 in 2010. The soil samples were placed in zip lock bags and transported on ice to the laboratory where they were refrigerated (4°C) until analysis. Ammonium acetate (1M, pH 7) was used to extract exchangeable cations. K, Ca, Mg were determined using an atomic absorption spectrophotometer (AIM600 Block Digestion System, Shelton, CT). Soil was extracted using a Bray-1 solution. Soil P was determined by a

SAN⁺⁺ segmented flow analyzer (Skalar Inc. Atlanta, GA).

Soil bulk density

Soil Bulk density is defined as the ratio of dry soil mass to bulk soil volume. The soil bulk density test was done twice a year, in early May and late August, during 2009, 2010, and 2011. Two locations, one foot between two trees in the interior, were randomly selected in each plot.

Data analysis

Cover crop biomass macronutrient content, foliar macronutrient content and soil macronutrient concentration were analyzed by two-way analysis of variance to test the effect of the treatments on macronutrient dynamics in the Fraser fir production system. The means were separated by a least significant difference test with $\alpha < 0.05$. Pairwise comparison was run to compare each groundcover/banding or no-banding combination with the conventional standard. A level of significance of $\alpha < 0.05$ was used to determine statistical significance. Simple correlation analysis was run to investigate the correlation between different parameters.

All data analyses were performed using Systat 13 software (Systat Software, Inc., Chicago, IL).

RESULTS

Cover crop biomass dry weight

The cover crop biomass dry weights ranged from 1.9 to 4.0 tons/hc in 2009, 2.0 to 7.3 tons/hc in 2010 and 1.7-5.5 tons/hc in 2011 (Table 8). In 2009 and 2011, there were no significant effects of the different management practices on the cover crop biomass dry weights. In 2009 and 2010 ALF consistently had the highest biomass dry weight return and PR had the lowest. This trend was significant in 2010 ($p=0.0$). In 2011, highest biomass return was seen in ALF plots, WC had the lowest biomass dry weight return.

Cover crop biomass macronutrients content

Mg: Cover crop biomass Mg varied from 4.6 to 16.6 kg/ha in 2009, 4.1 to 17.0 kg/ha in 2010 and 4.5 to 13.6 kg/ha in 2011. There were significant differences in the cover crop biomass Mg content in both 2009 and 2010 ($p=0.0$ in 2009 and $p=0.0$ in 2010) between different treatments. ALF cover crop treatments consistently had the highest biomass Mg content whereas PR treatments had the lowest. In both 2009 and 2010, the management practices did not affect cover crop biomass Mg significantly ($p=0.3$ in 2009 and $p=1.0$ in 2010). However, in 2011, significantly higher cover crop biomass organic Mg was found in all no-banded plots compared to banded plots.

K: Cover crop biomass K content varied from 92.5 to 189.6 kg/ha in 2009, 152.6 to 395.5 kg/ha in 2010 and 93.8 to 362.9 kg/ha in 2011. During the experiment period, ground covers type selection only affected cover crop biomass K content in 2009 with significantly higher in ALF treatments compared to PR treatments ($p=0.0$). The different management practices only affected

cover crop biomass K contents 2010 ($p=0.0$), with significantly higher biomass K content found in all no banding treatments.

Ca: Cover crop biomass Ca content ranged from 28.5 to 82.0 kg/ha in 2009, 6.8 to 53.9 kg/ha and 16.0 to 72.2 kg/ha in 2011. There were generally higher biomass Ca content found in ALF treatments and lower content found in PR treatments during the three years of this study. Cover crop biomass Ca content was not consistently affected by the different management practices ($p=0.2$ in 2009, $p=0.2$ in 2010 and $p=0.1$ in 2011).

P: Total P content in cover crop biomass ranged from 27.6 to 74.1 kg/ha in 2009, 29.2 to 112.3 kg/ha in 2010, and 15.0 to 87.5 kg/ha in 2011. Similar to the other elements, total P content in cover crop biomass was significantly affected by types selection with consistently high biomass P content were found in ALF plots and low content found in PR plots in 2009 ($p=0.0$) and 2010 ($p=0.0$), but not in 2011 ($p=0.2$). Management practices only affected total P content in cover crop biomass in 2009, with statistically higher values found in no banded treatments than banded treatments ($p=0.0$).

Cover crop C to N ratio

In 2010, cover crops C to N ratio ranged from 9.7 to 13.6 (Figure 2); WC generally had the lowest values, while PR had the highest, especially in May and June, PR had a significantly higher C to N ratio than WC and ALF.

Cover crop residue C to N ratio in 2011 followed a similar trend in 2010, ranging from 11.2 to 21.6, with the highest values found in PR plots and the lowest found in WC plots. In May, June and Aug, this difference was statistically significant between PR and WC treatments.

Soil organic matter content as affected by ground cover types and management practices

Soil organic matter content was generally higher in 0-15cm depth than in 15-30cm. It consistently increased from 2009 to 2011 (Figure 3). Higher SOM content was found in all cover crop plots compared to bare ground plots. There were no significant effects between either cover crop type selection or management practices on SOM content (Figure 3). However, the SOM content in no-banded plots were always higher than banded plots and bare ground plots during the three year in both 0-15cm and 15-30cm depth (Figure 3 and 4).

Soil N mineralization rates

Soil N mineralization rates varied through the growing seasons between 2010 and 2011 (Figure 5). However, there was no significant difference among the different types and management practices. In 2010, among all cover crop treatments, the mineralization rates were consistently highest in WC plots and lowest in PR plots. This trend was observed on Jun.24 to Aug.3, 2011. However, N immobilization occurred between Aug.3 to Aug.24, 2011. The highest immobilization rates were found in WC plots and lowest in ALF plots.

Among the different treatments, no banded plots had the highest N mineralization rates compared to the banded and bare ground plots from July 14 to Aug. 4, Aug. 4 to Aug. 24 in 2010 and Jun.24 to Aug.3 in 2011. From Aug.3 to Aug.24 in 2011, higher immobilization rates were observed in all no banded plots.

Soil Macronutrients concentration

Soil Mg: Soil Mg concentration varied from 0.1 to 0.2 mg/g in 2009 and 2010 (Table 3). During the study period, we did not find any significant effects of management practices on soil Mg

concentration. Species selection had a significantly greater effect on upper depth soil Mg concentration in 2010 August with significantly greater values found in ALF treatments compared to WC treatments ($p=0.0$).

Soil K: Soil K concentration varied from 0.1 to 0.4 mg/g in 2009 and 0.0 to 0.5 mg/g in 2010. Soil K concentration was generally higher in cover crop plots compared to bare ground plots (except 15-30cm depth in May 2009 and 0-15cm depth in May 2010), but were not significantly different. This indicates that neither ground covers type selection nor different management practices affected soil K concentration.

Soil Ca: Soil Ca concentrations were generally lower in 2009 in a range from 0.4 to 1.2 mg/g and varied from 0.2 to 1.5 mg/g in 2010 (Table 5). Similar to soil K, there was no significant effect of ground covers type selection and management practices on soil Ca concentration.

Soil available P: Similar to soil Ca and K, there were no significant effects of cover cropping system on soil available P values. Soil available P was consistently higher in 0-15cm compared to 15-30cm depth (Table 13). In 2009, soil available P values were ranged from 22.1 to 57.2 mg/g in 0-15cm depth and 8.3 to 42.0 mg/g in 15-30cm depth. In 2010 May, soil available P values were similar to the values in 2009 in 0-15cm depth, however, there was a decrease in soil available P found in 15-30cm depth and this decrease was observed in 2010 August in both soil depths.

Soil bulk density

In 2009 and 2010, there was no significant effect of the ground covers type selection or the different management practices on soil bulk density (Table 14). However, consistently low soil

bulk density values were found in all no banded plots. In 2011, the soil bulk density was significantly lower in no banded plots compared to banded plots and bare ground (Table 14).

DISCUSSION

Cover crop biomass macronutrients return

In this study, three different types of cover crops were used: two legumes [Dutch white clover (*Trifolium repens*) and alfalfa (*Medicago sativa*)] and one grass [perennial rye (*Lolium perenne*)].

During 2009 and 2010, we found that cover crop biomass Mg and Ca content were always significantly greatest in ALF treatments and lowest in PR treatments. The results indicate that types selection had a significant effect on cover crop biomass Mg and Ca contents. This trend is likely due to the process of plants taking up Mg and Ca mainly by mass flow, which is affected by soil moisture. In a previous study with Fraser firs growing with various cover crop species, serious competition was observed soil water between perennial rye and trees (Wilson et al., 2010). This could also be due to the genetic difference between legumes and grasses. In a study predicting the nutrient return from 6 different cover crop species, it was reported that legumes can store over twice as much Ca than rye (Hoyt 1989). Also, significantly lower biomass production in PR treatments was observed in 2009 and 2010, which could be another reason for lowest biomass Mg and Ca return during these two years.

Similar to cover crop biomass Mg and Ca, cover crop biomass K return was significantly affected by cover crop types in 2009 with greatest biomass K return in WC treatments and lowest values in PR plots. This might due to the stronger ability of legumes to accumulate K than grasses (Hoyt 1989). In 2010, management practices significantly affected cover crop biomass K return with no banded treatments producing more biomass K than the banded treatments; this was highly related to the greater residue biomass production in all no banded plots.

In 2009 and 2010, ground covers type selection significant affected biomass P returns with greater biomass P found in ALF treatments and least in PR treatments. These significantly greater P contributions of legumes than those of the perennial rye system were observed in our previous study (Wilson et al., 2010), which indicated legumes might has a stronger ability to cumulate P in residues.

Effects of cover crops on soil organic matter and soil bulk density

Soil organic matter (SOM) is commonly used to represent the organic constituents in the soil, including undecayed plant and animal tissues, their partial decomposition products, and the soil biomass (<http://karnet.up.wroc.pl/~weber/def2.htm>). SOM is important in improving soil fertility and productivity (Allison, 1973; Bauer and Black, 1994; Wilhelm et al., 2004) and is an important indicator of ecosystem sustainability (Huang et al., 2011).

Cover crops' ability to increase soil organic matter is one of the greatest advantages to using cover crops. In this study, we found that soil organic matter content in both 0-15cm and 15-30cm depth were highly related to the cover crop biomass returned (Table 16). This agreed with the results of Reicosky et al. (1995) which discussed the use of cover crops to maintain environmental quality in agricultural production systems. This study also showed a strong positive relationship between residue biomass and SOM in the 0-15 cm layer (Reicosky et al, 1995). It has been stated that the effect of cover crops on increasing soil organic matter content also depends on the mineralization rate of the crop residues (Prunt, 2005). In 2011, immobilization occurred in all cover crop treatments (Figure 5), which might explain the lack of effects of cover crops residues shown on the soil organic matter in 15-30cm depth.

Through these three years, significant in greater soil organic matter content was not observed in cover crops treatments compared to the bare ground treatments through three years. However, non-significant higher values found in all cover crops plots than bare ground plots suggested that the contribution of cover crops residues do have positive effect on soil organic ecosystems.

According to previous studies, it takes long time and requires a large input of plant material to observe an obvious change in soil organic matter content (Nadporozhskaya et al., 2006; Sollins et al. 1984; Snapp et al., 2011; Johnston et al., 2009). It has also been reported that it is very difficult to increase soil organic matter content by 1%. But even this small increase can improve soil fertility significantly (Gaskell et al., 2000). Therefore, we suggest that a long-term study will be needed to indicate significant treatment effects of cover crops on soil organic matter content.

Soil bulk density (BD) is defined as the ratio of dry soil mass to bulk soil volume and is used to measure soil compaction. The incorporation of cover crop residue can help to build SOM, and it is well documented that the increase of SOM can help to decrease soil bulk density (Hagan et al., 2011; Edmeades, 2003; McGourty and Reganold, 2005; USDA, 2008). The lower BD value stated an improvement in BD, and this decrease can reduce the soil water runoff and the nutrient leaching in the soil (Hagan et al., 2011). In this study, there were no significant differences in soil bulk density between different treatments in 2009 and 2010. However, we observed strong correlations between BD and biomass dry weight return in this study period; since we observed a positive effect of biomass dry weight return on increasing SOM content, this might explain why the lower soil bulk density found in all no banded plots which received higher residue return.

Also, the BD values became significant lower in all no banded treatments in 2011 growing

season compared to banded treatments (Table 14). This result suggests that greater amount of residue maintenance result in higher soil organic matter content, thus help to soil bulk density.

Effects of cover crops residue C/N ratio on soil N mineralization rates

C/N is the ratio which indicates the relative mass of C to the mass of N (USDA, 2011). This is important because it has a significant impact on cover crop residue decomposition and nutrient cycling (primarily N) (Gowariker et al., 2009). It was found that when the cover crop residue C/N ratio is higher than 20:1, the N immobilization will occur, leading to a N deficit; when the C/N ratio is lower than 20:1, it is indicated that the N need of soil microorganisms will adequate and excess N will be released to the soil, thus becoming available to target crops (Gowariker et al., 2009; McGourty et al., 2005). In our study, the C/N of all cover crop biomass was lower than 20:1 but varied over time. To our expectation, of the three cover crop types, WC consistently had the lowest C/N and PR had the highest. In 2010 and 2011, there were no significant differences found between the different treatments. In 2010, we observed higher N mineralization rates in all treatments that received residue with lower C/N. This finding agrees with the findings of Fornara et al (2011) studying about the relative effects of using 6 different cover crops on net and on gross rates of soil N mineralization in grassland. However, from Aug. 3 to Aug. 24, there was great N immobilization observed in all cover crops treatment plots, especially in WC treatments which received residue return with lowest C/N. When cover crop residues are incorporated into the soil, soil microorganisms will increases in response to the added food source; therefore as the soil microorganism populations increase, the N in the cover crop residue may be immobilized and used as part of the physical structure of the microbes (Creamer et al., 1999). This

immobilization of N observed could also be due to soil autotrophic nitrifiers which have been documented to compete for NH_4^+ with plants and other soil microorganisms (Kaye and Hart, 1997). We suggested that more researches needed to understand the interaction of soil microorganisms to better understand the trends observed.

Effects of cover crops on soil macronutrients

Non-leguminous grasses have fibrous roots which are effective in aggregating soil and reducing nitrate leaching and soil erosion (Meisinger et al., 1991). While legumes it is well established that have the ability to contribute to soil N because of their N-fixing, they do not provide other nutrients except N from outer sources; therefore cover crops are lacking effects on increasing soil macronutrients (Lehmann et al., 2000). Fourie et al. (2007) did not detect any significant tendencies in soil exchangeable K, Ca, Mg and P. In our study, we did not find any significant effect of cover crops on soil total P in 2009 and 2010 either.

Barber and Navarro (1994) reported that only soil K was increase by *Dolichos lablab* from 14 different cover crops. In this study, we found greater but not significant soil K in ground covers plots in comparison to in bare ground plots in 2009 and 2010. This might due to the effect of K translocation caused by cover crop roots from the subsoil (Lal et al., 1993) which was also suggested by many other researchers (Eckert, 1991; Smyth et al., 1991).

For soil exchangeable Mg and Ca, although there were a few differences between treatments, no significant effects of cover crop on soil exchangeable Mg and Ca were observed. This result agreed to the research of using 8 different cover crops in a vineyard, which also shown that there were no significant effect of cover crops treatments on soil Mg and Ca (Fourie et al., 2007).

CONCLUSION

Cover crop residue macronutrient cumulative content was evaluated in 2009, 2010 and 2011.

Ground covers type selection significantly affected cumulative Mg, Ca content in 2009 and 2010, P in 2010 and K in 2009 with lowest value found in PR plots and greatest in legumes treatments.

This might contribute to the different abilities of storage nutrient between legumes and grass.

The management practices only significantly affected cover crop cumulative K content in 2010 and P content in 2009 by increasing the residue dry weight. During this study period, we found SOM in 0-15cm and 15-30cm were highly correlated to the amount of cover crop residue added to the ground. This correlation became weak when N immobilization happened in the end of 2011 growing season. However, the increase in SOM was not significant in all cover crop treatments compared to bare ground treatment. To observe a significant increase, a long term study must be conducted. In addition, it was showed that cover crops can help to decrease BD through adding SOM, and this effect highly depends on cover crops residue amount too.

In 2010 and 2011 growing season, cover crop residue C/N was evaluated. The values varied through time to time. To our expectation non-legume had the consistently highest C to N ratios compared to the other two legumes. Residue with lower C/N decomposed faster, however the differences between different cover crops were not significant.

For the effects of cover crops on soil macronutrient, there was no clear trend showed and no significant differences between treatments in soil macronutrient (Mg, Ca, K, P) in 2009 and 2010. Relatively higher soil extractable K observed in all cover crops plots which might be due to the K translocation caused by cover crop roots.

TABLES

Table 8. Cover crop biomass dry weight return in 2009, 2010 and 2011 (tons/hc):

	2009	2010	2011
ALF+B	2.6±0.1a	4.4±0.1ab	3.0±0.0a
ALF+NoB	4.0±0.1a	7.3±0.2a	5.5±0.1a
PR+B	1.9±0.1a	2.7±0.1b	3.0±0.0a
PR+NoB	1.9±0.2a	2.0±0.2b	3.0±0.4a
WC+B	2.4±0.1a	3.5±0.2b	1.7±0.0a
WC+NoB	3.5±0.1a	5.5±0.1ab	3.7±0.4a
p-value	0.2	0.0	0.4

Labels: ALF+B is alfalfa with band, ALF+NoB is alfalfa with no band, PR+B is perennial rye with band, PR+NoB is perennial rye with no band, WC+B is white clover with band, and WC+NoB is white clover with no band.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

Table 9. Cover crop biomass nutrient content as affected by ground covers types combined with management practices in 2009, 2010 and 2011 (kg/ha):

2009				
	Mg	K	Ca	P
ALF+B	7.3±0.1b	149.7±6.5a	61.5±0.6a	35.9±0.6a
ALF+NoB	16.6±0.36a	189.6±5.3a	82.0±1.2b	74.1±1.0b
PR+B	5.0±0.06b	92.5±5.1a	28.5±0.4c	28.7±0.3a
PR+NoB	4.6±0.0b	103.8±2.4a	30.5±0.0c	27.6±0.3a
WC+B	9.3±0.5b	113.0±6.0a	44.6±0.9c	36.9±0.1a
WC+NoB	7.9±0.1ab	152.7±10.9a	44.6±0.1a	55.3±0.5c
P-value	p=0.0	p=0.1	p=0.0	p=0.0
2010				
ALF+B	10.4±0.0ab	86.6±1.3ac	34.2±0.5ac	55.5±0.2a
ALF+NoB	17.0±0.1a	160.0±2.0b	41.3±0.3a	112.2±1.1b
PR+B	5.5±0.0c	61.8±0.3a	10.4±0.4d	42.1±0.3a
PR+NoB	4.1±0.0d	83.5±5.0ac	6.8±0.1d	29.2±0.5a
WC+B	8.6±0.2b	78.8±0.2ac	25.8±0.8bc	51.9±2.7a
WC+NoB	15.18±0.09ab	133.03±1.80bc	53.94±0.45e	56.37±0.96a
P-value	p=0.0	p=0.0	p=0.0	p=0.0
2011				
ALF+B	6.6±0.1ab	109.2±1.3a	23.2±0.6a	27.3±0.1a
ALF+NoB	13.6±0.4a	362.9±34.5a	72.2±2.9a	87.5±6.8a
PR+B	5.3±0.2b	137.9±2.2a	16.0±0.3a	31.2±0.3a
PR+NoB	5.8±0.0b	93.8±1.3a	36.8±2.5a	27.6±0.9a
WC+B	4.5±0.1b	98.3±3.8a	40.0±3.7a	15.0±0.1a
WC+NoB	9.0±0.6ab	230.5±2.2a	41.8±3.8a	31.9±1.5a
P-value	p=0.0	p=0.1	p=0.2	p=0.1

Labels: ALF+B is alfalfa with band, ALF+NoB is alfalfa with no band, PR+B is perennial rye with band, PR+NoB is perennial rye with no band, WC+B is white clover with band, and WC+NoB is white clover with no band.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

Table 10. Soil Mg concentration in 0-15cm and 15-30cm affected by management practices combined with cover crop types in 2009 and 2010 (mg/g):

	2009.May.29		2009.Aug.25	
	0-15cm	15-30cm	0-15cm	15-30cm
ALF+B	0.1 ±0.0a	0.1 ±0.0a	0.1 ±0.0a	0.1 ±0.0a
ALF+NoB	0.1 ±0.0a	0.1 ±0.0a	0.1 ±0.0a	0.2 ±0.0a
PR+B	0.1 ±0.0a	0.1 ±0.0a	0.1 ±0.0a	0.2 ±0.0a
PR+NoB	0.1 ±0.0a	0.1 ±0.0a	0.1 ±0.0a	0.1 ±0.0a
WC+B	0.1 ±0.0a	0.1 ±0.0a	0.1 ±0.0a	0.1 ±0.0a
WC+NoB	0.2 ±0.0a	0.1 ±0.0a	0.1 ±0.0a	0.1 ±0.0a
BG	0.1 ±0.0a	0.1 ±0.0a	0.1 ±0.0a	0.1 ±0.0a
P-value	1.0	1.0	0.7	0.4

	2010.May.10		2010.Aug.25	
	0-15cm	15-30cm	0-15cm	15-30cm
ALF+B	0.1 ±0.0a	0.1 ±0.0a	0.1 ±0.0ab	0.1 ±0.0a
ALF+NoB	0.1 ±0.0a	0.1 ±0.0a	0.2 ±0.0a	0.2 ±0.0a
PR+B	0.1 ±0.0a	0.1 ±0.0a	0.1 ±0.0ab	0.1 ±0.0a
PR+NoB	0.1 ±0.0a	0.1 ±0.0a	0.2 ±0.0ab	0.2 ±0.0a
WC+B	0.1 ±0.0a	0.1 ±0.0a	0.1 ±0.0b	0.1 ±0.0a
WC+NoB	0.1 ±0.0a	0.1 ±0.0a	0.1 ±0.0b	0.1 ±0.0a
BG	0.1 ±0.0a	0.1 ±0.0a	0.1 ±0.0ab	0.1 ±0.0a
P-value	1.0	1.0	0.0	0.2

Labels: ALF+B is alfalfa with band, ALF+NoB is alfalfa with no band, PR+B is perennial rye with band, PR+NoB is perennial rye with no band, WC+B is white clover with band, and WC+NoB is white clover with no band.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

Table 11. Soil K concentration in 0-15cm and 15-30cm affected by management practices combined with cover crop types in 2009 and 2010 (mg/g):

	2009.May.29		2009.Aug.25	
	0-15cm	15-30cm	0-15cm	15-30cm
ALF+B	0.4±0.0a	0.1±0.0a	0.2±0.0a	0.2±0.0a
ALF+NoB	0.2±0.0a	0.1±0.0a	0.2±0.0a	0.1±0.0a
PR+B	0.3±0.0a	0.2±0.0a	0.2±0.0a	0.2±0.0a
PR+NoB	0.2±0.0a	0.1±0.0a	0.2±0.0a	0.1±0.0a
WC+B	0.2±0.0a	0.1±0.0a	0.2±0.0a	0.2±0.0a
WC+NoB	0.2±0.0a	0.2±0.0a	0.3±0.0a	0.2±0.0a
BG	0.2±0.0a	0.1±0.0a	0.2±0.0a	0.1±0.0a
P-value	0.3	0.6	0.2	0.4

	2010.May.10		2010.Aug.25	
	0-15cm	15-30cm	0-15cm	15-30cm
ALF+B	0.3±0.0a	0.3±0.0a	0.2±0.0a	0.1±0.0a
ALF+NoB	0.5±0.0a	0.2±0.0a	0.2±0.0a	0.1±0.0a
PR+B	0.2±0.0a	0.4±0.0a	0.2±0.0a	0.2±0.0a
PR+NoB	0.4±0.0a	0.3±0.0a	0.4±0.0a	0.0±0.0a
WC+B	0.4±0.0a	0.5±0.1a	0.5±0.1a	0.1±0.0a
WC+NoB	0.4±0.0a	0.4±0.0a	0.2±0.0a	0.1±0.0a
BG	0.4±0.1a	0.0±0.0a	0.1±0.0a	0.0±0.0a
P-value	1.0	0.4	1.0	0.1

Labels: ALF+B is alfalfa with band, ALF+NoB is alfalfa with no band, PR+B is perennial rye with band, PR+NoB is perennial rye with no band, WC+B is white clover with band, and WC+NoB is white clover with no band.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

Table 12. Soil Ca concentration in 0-15cm and 15-30cm affected by management practices combined with cover crop types in 2009 and 2010 (mg/g):

	2009.May.29		2009.Aug.25	
	0-15cm	15-30cm	0-15cm	15-30cm
ALF+B	0.4±0.0a	0.6±0.0a	0.8±0.1a	1.0±0.0a
ALF+NoB	0.6±0.0a	0.8±0.0a	0.6±0.0a	1.1±0.0a
PR+B	0.6±0.0a	0.5±0.0a	0.7±0.1a	1.1±0.1a
PR+NoB	0.4±0.0a	0.7±0.0a	0.7±0.0a	1.0±0.0a
WC+B	0.6±0.0a	0.7±0.0a	0.7±0.1a	1.2±0.1a
WC+NoB	0.4±0.0a	0.7±0.0a	0.6±0.0a	1.1±0.0a
BG	0.5±0.0a	0.7±0.0a	0.9±0.0a	1.1±0.0a
P-value	0.5	0.8	1.0	0.4

	2010.May.10		2010.Aug.25	
	0-15cm	15-30cm	0-15cm	15-30cm
ALF+B	0.5±0.0a	0.9±0.1a	0.6±0.0a	1.0±0.1a
ALF+NoB	0.9±0.0a	0.9±0.1a	0.7±0.0a	1.0±0.0a
PR+B	0.9±0.0a	0.8±0.0a	0.5±0.0a	0.9±0.0a
PR+NoB	0.8±0.0a	0.8±0.0a	0.6±0.0a	1.4±0.1a
WC+B	0.2±0.0a	0.7±0.1a	0.4±0.0a	0.7±0.0a
WC+NoB	0.6±0.1a	0.9±0.0a	0.4±0.0a	0.8±0.0a
BG	1.5±0.2a	0.8±0.0a	0.5±0.0a	0.9±0.1a
P-value	0.3	1.0	0.3	0.5

Labels: ALF+B is alfalfa with band, ALF+NoB is alfalfa with no band, PR+B is perennial rye with band, PR+NoB is perennial rye with no band, WC+B is white clover with band, and WC+NoB is white clover with no band.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

Table 13. Soil P concentration in 0-15cm and 15-30cm affected by management practices combined with cover crop types in 2009 and 2010 (mg/g):

	2009.May.29		2009.Aug.25	
	0-15cm	15-30cm	0-15cm	15-30cm
ALF+B	25.9±1.05a	15.8±1.3a	35.1±1.6a	17.9±1.0a
ALF+NoB	29.3±0.69a	20.3±0.5a	33.3±1.6a	14.1±0.4a
PR+B	52.7±1.43a	29.1±0.8a	57.2±0.9a	28.7±2.3a
PR+NoB	23.1±2.95a	8.3±1.4a	22.1±1.9a	9.9±0.9a
WC+B	31.0±1.52a	16.4±0.7a	27.8±0.7a	10.8±0.4a
WC+NoB	32.0±2.37a	26.6±2.1a	38.2±1.9a	42.0±3.0a
BG	31.3±2.30a	26.8±2.1a	39.9±3.2a	26.6±3.0a
P-value	P=0.5	P=0.5	P=0.3	P=0.3

	2010.May.10		2010.Aug.25	
	0-15cm	15-30cm	0-15cm	15-30cm
ALF+B	38.5±2.4a	12.5±1.4a	14.8±0.5a	2.1±0.2a
ALF+NoB	28.7±1.2a	8.4±0.3a	7.3±0.2a	5.1±0.6a
PR+B	52.1±0.5a	18.8±0.4a	17.3±1.0a	11.5±0.6a
PR+NoB	15.4±1.4a	4.3±0.5a	4.7±0.7a	3.6±0.7a
WC+B	26.0±0.9a	6.4±0.6a	15.7±0.6a	6.0±0.1a
WC+NoB	30.0±2.9a	18.5±1.5a	6.8±0.8a	8.5±1.1a
BG	47.1±1.7a	8.3±0.7a	13.9±1.4a	7.9±1.0a
P-value	0.1	0.2	0.3	0.6

Labels: ALF+B is alfalfa with band, ALF+NoB is alfalfa with no band, PR+B is perennial rye with band, PR+NoB is perennial rye with no band, WC+B is white clover with band, and WC+NoB is white clover with no band.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

Table 14. E1 soil bulk density affected by different management practices: g/cm³

	2009	2010	2011
Band	1.2 ±0.0a	1.3 ±0.0a	1.2 ±0.0a
No band	1.1 ±0.0a	1.2 ±0.0a	1.0 ±0.0b
Bare ground	1.3 ±0.0a	1.3 ±0.0a	1.3 ±0.0a
	P=0.2	P=0.2	P=0.0

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

Table 15. Correlation between soil organic matter content in 0-15cm and 15-30cm and ground cover biomass dry weight return:

		0-15cm	15-30cm
ALF	2009	0.841	0.786
	2010	0.828	0.561
	2011	0.546	0.270
PR	2009	0.439	0.623
	2010	0.753	0.778
	2011	0.774	0.092
WC	2009	0.626	0.706
	2010	0.807	0.805
	2011	-0.088	0.020

Labels: ALF is alfalfa, PR is perennial rye and WC is white clover.

Simple correlation analysis was run to show the correlation between different parameters.

Table 16. Correlations between soil bulk density and ground cover biomass dry weight return in 2009, 2010 and 2011:

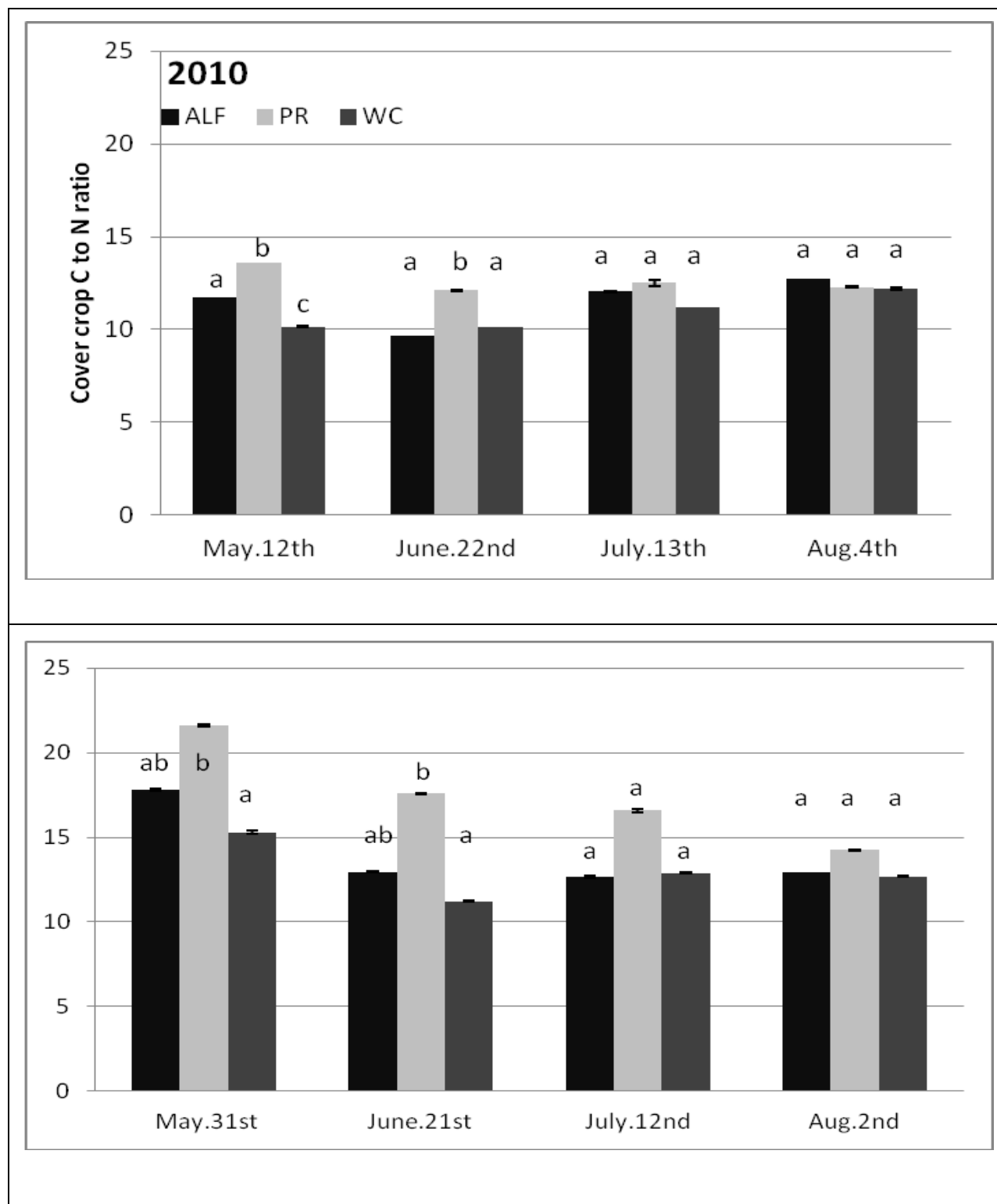
	ALF	PR	WC
2009	-0.5	-0.2	-0.7
2010	-0.9	-0.6	-0.6
2011	-0.8	-0.7	-0.5

Labels: ALF is alfalfa, PR is perennial rye and WC is white clover.

Simple correlation analysis was run to show the correlation between different parameters.

FIGURES

Figure 2. Cover crop residue C: N ratio in 2010 and 2011:



Labels: ALF is alfalfa, PR is perennial rye and WC is white clover.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

Figure 3. Soil organic matter content in 0-15cm as affected by different cover crop types and management practices (%):

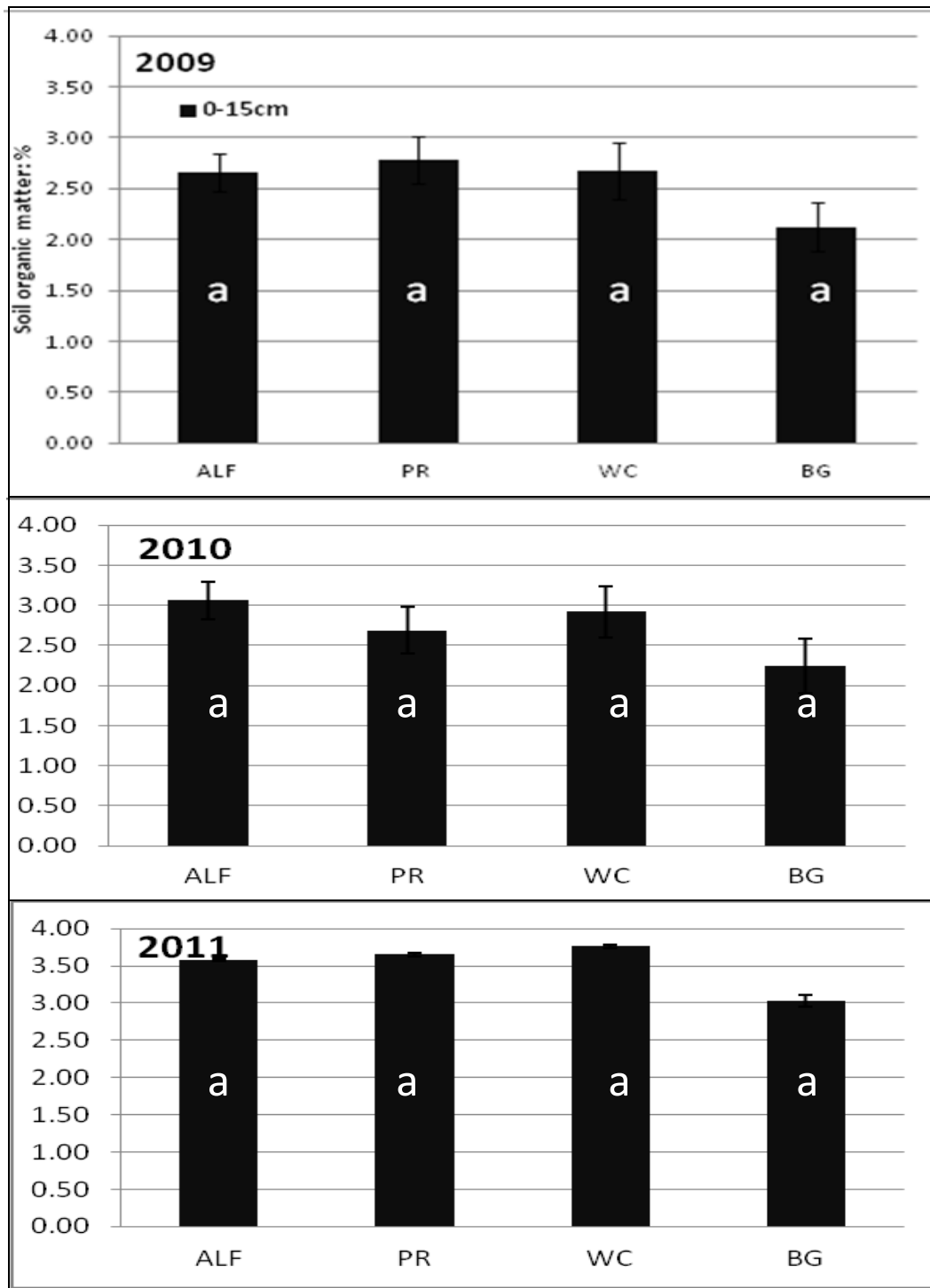
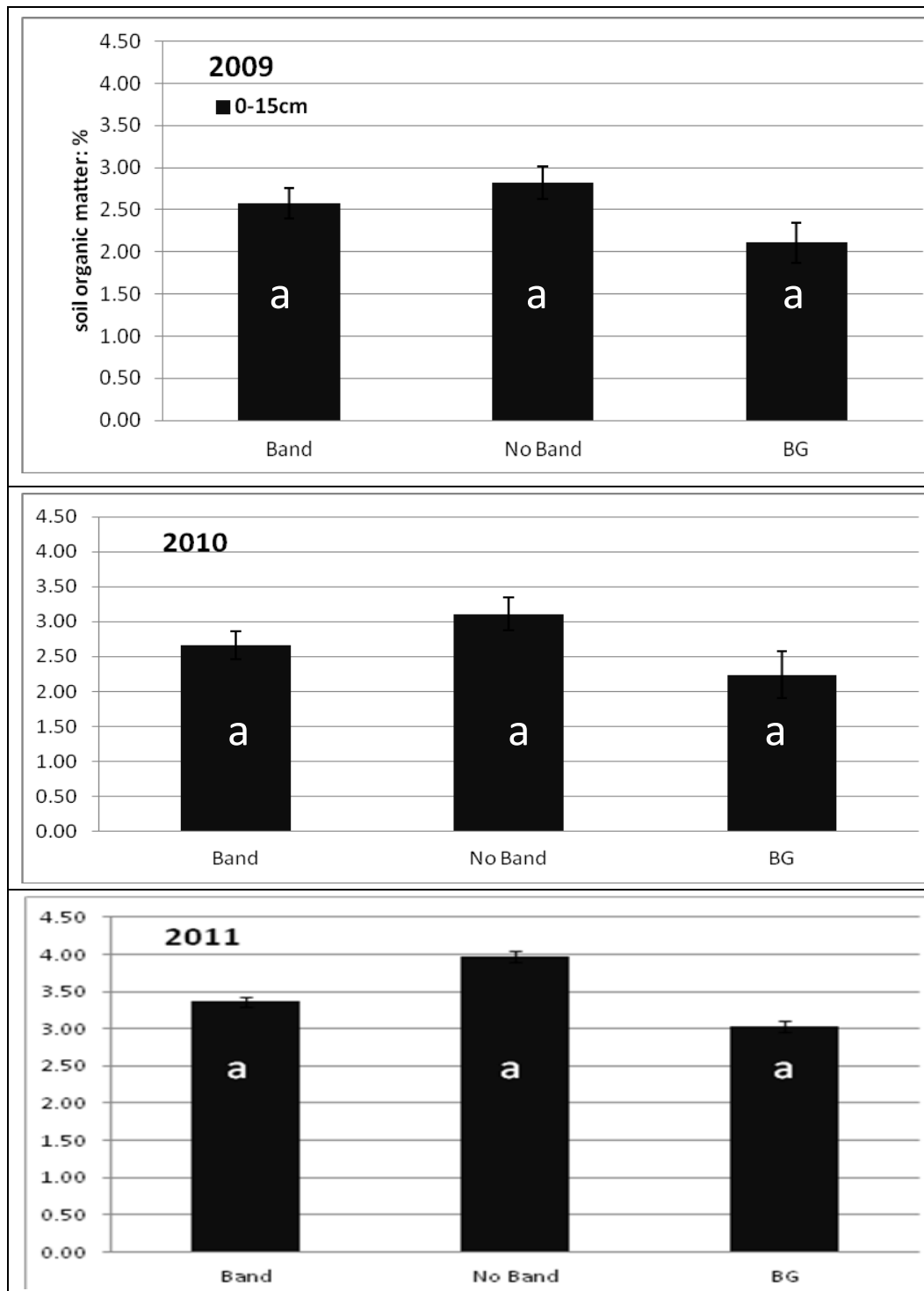


Figure 3. Soil organic matter content in 0-15cm as affected by different cover crop types and management practices (%):



Labels: ALF is alfalfa, PR is perennial rye, WC is white clover.

Band is plot with band, No Band is plot with no band and BG is bare ground.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

Figure 4. Soil organic matter content in 15-30cm as affected by different cover crop types and management practices (%):

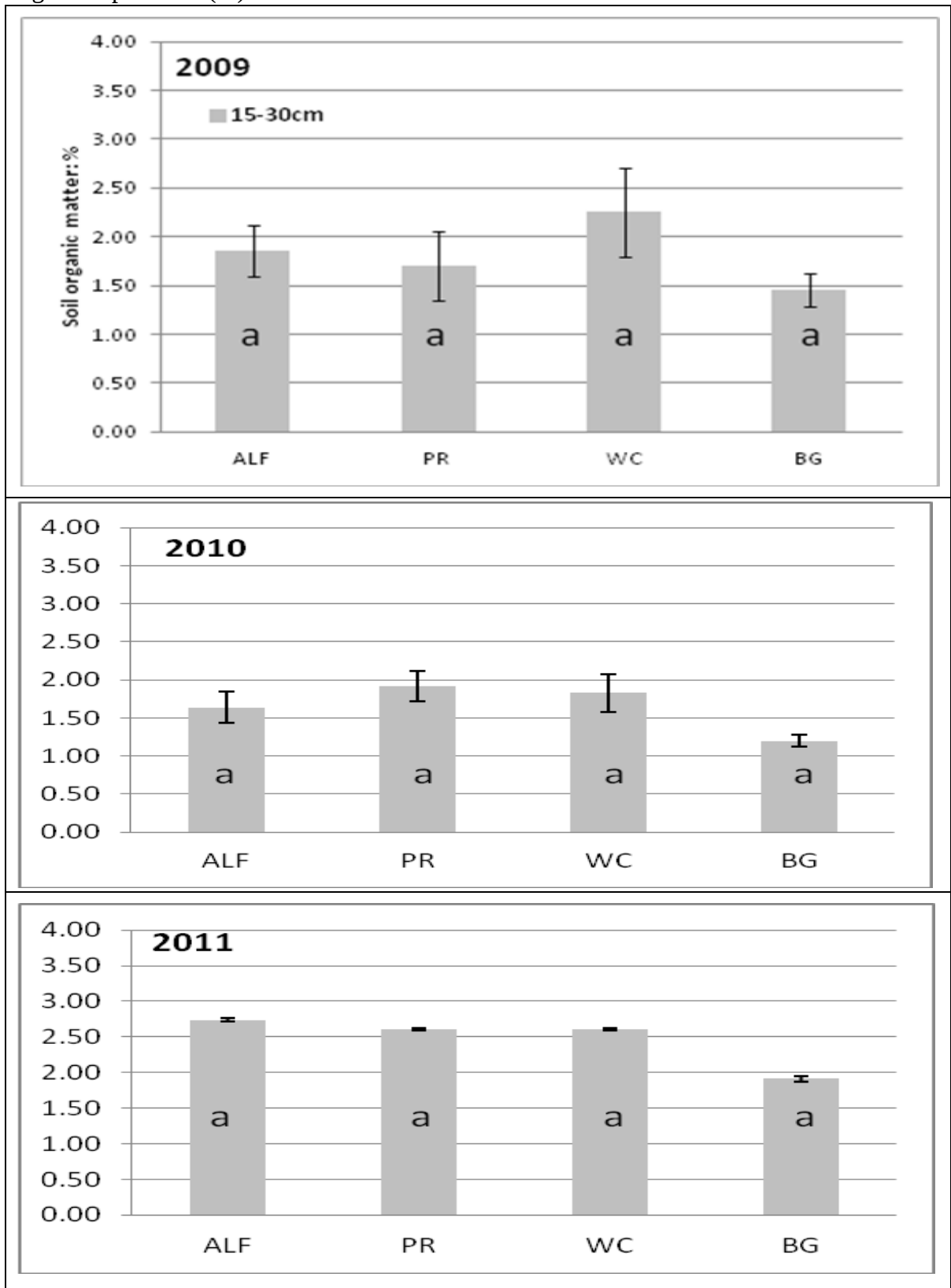
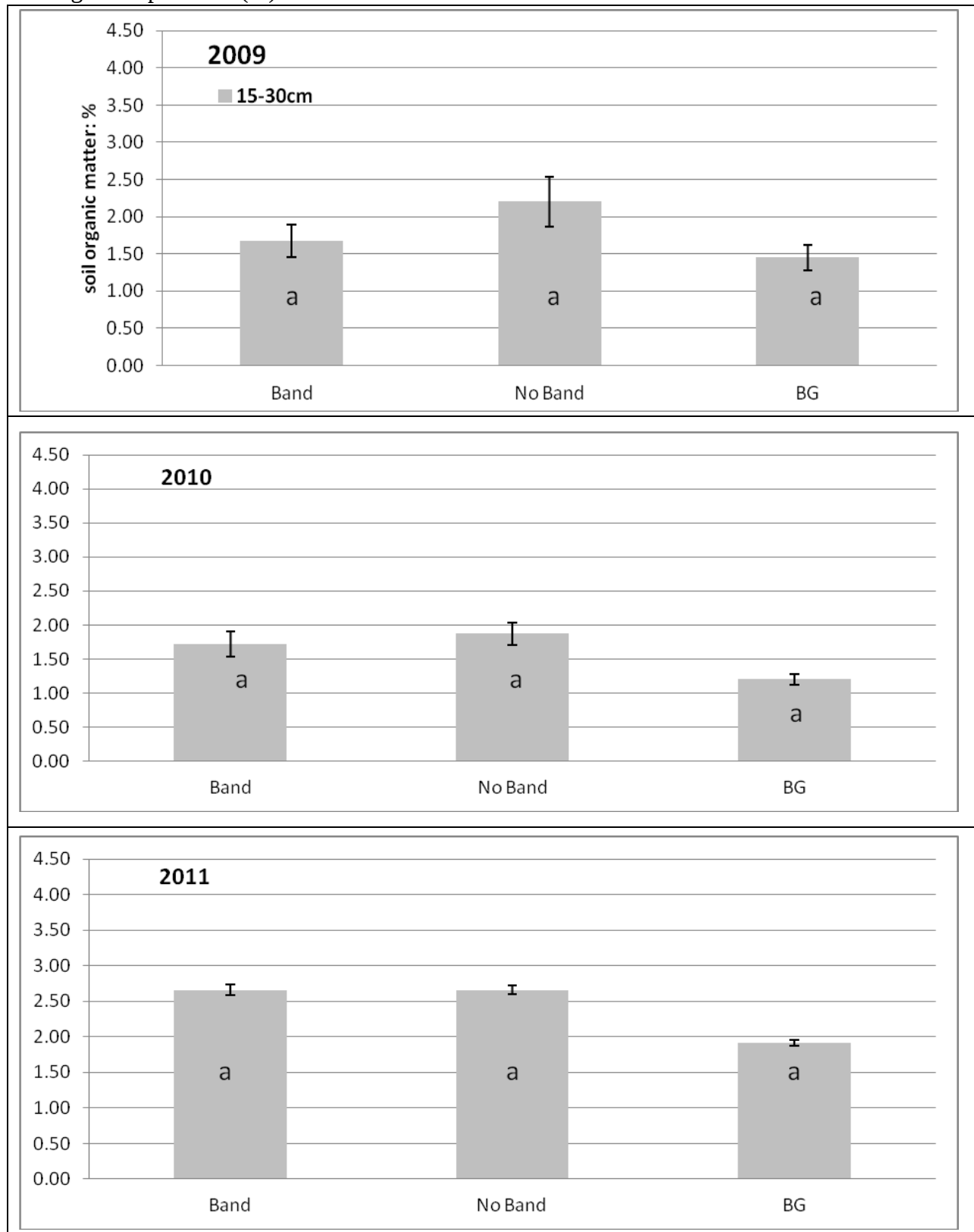


Figure 4. Soil organic matter content in 15-30cm as affected by different cover crop types and management practices (%):



Labels: ALF is alfalfa, PR is perennial rye, WC is white clover, Band is plot with band, No Band is plot with no band and BG is bare ground.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

Figure 5. Soil N Mineralization rates affected by cover crops types and management practices: (ppm/day)

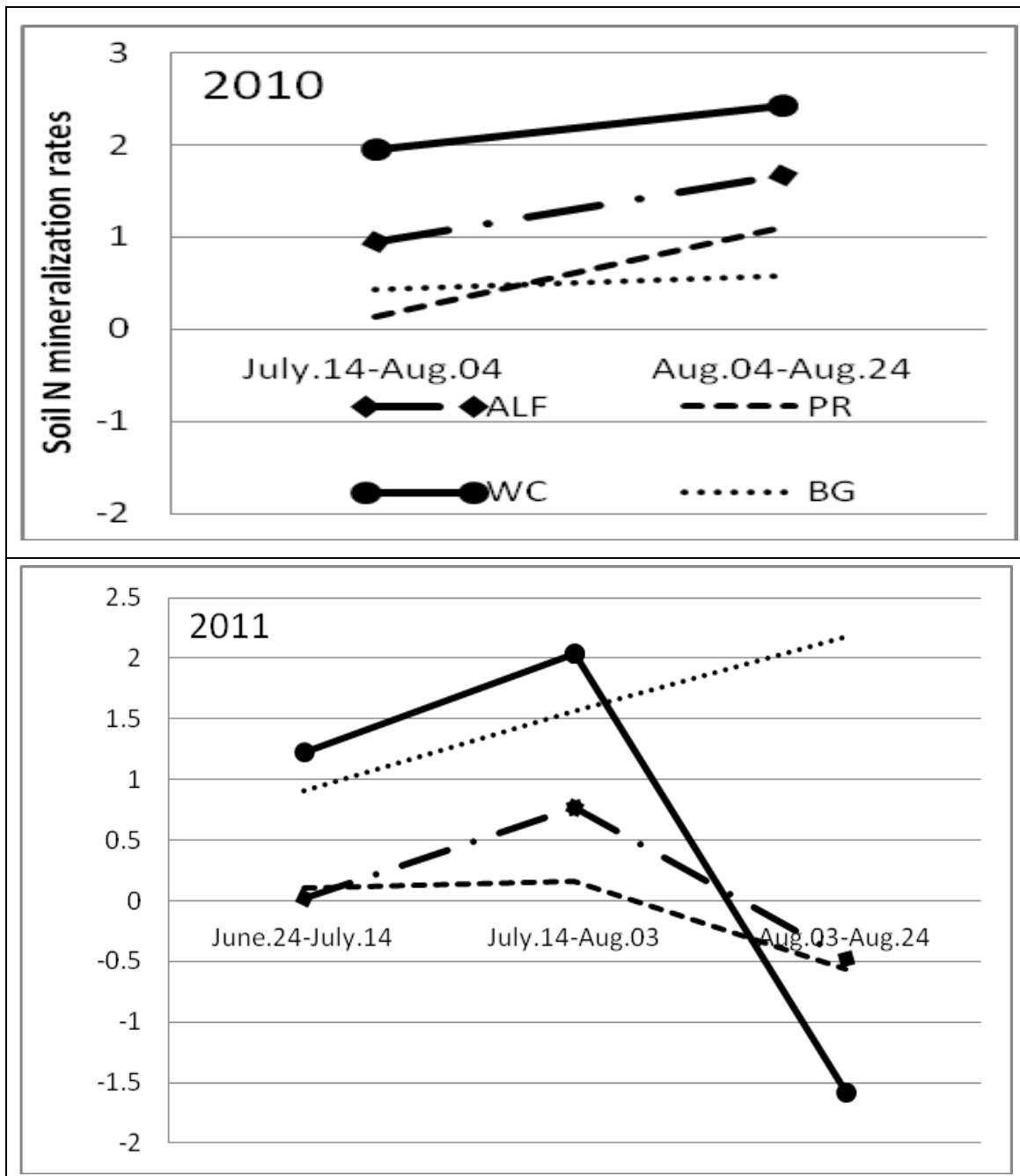
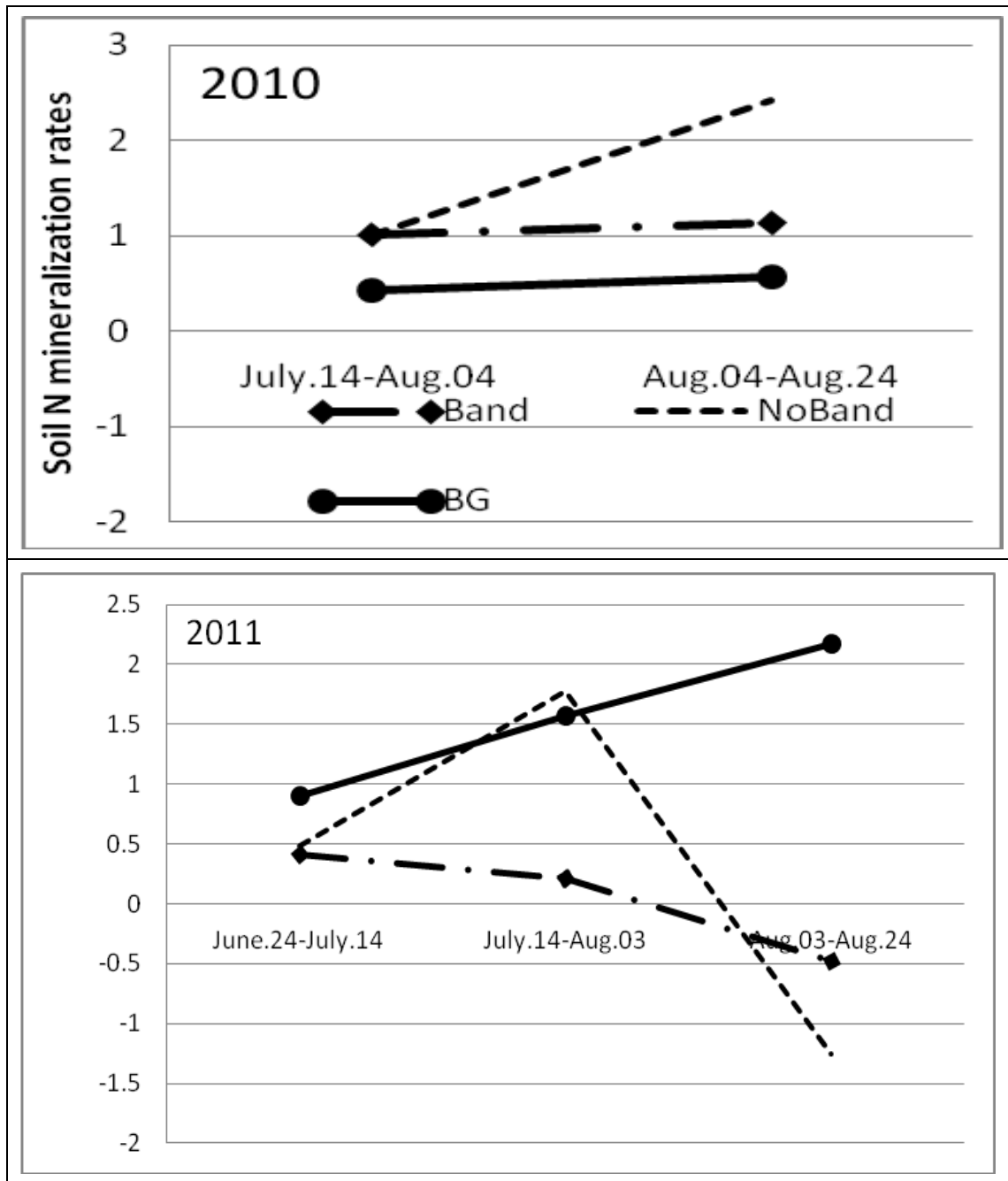


Figure 5. Soil N Mineralization rates affected by cover crops types and management practices: (ppm/day)



Labels: ALF is alfalfa, PR is perennial rye, WC is white clover, Band is plot with band, No Band is plot with no band and BG is bare ground.

Negative values states immobilization happened.

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CHAPTER 4

COMBINING LEGUME GROUND COVERS AND LOW NITROGEN FERTILIZATION ON IN SHORT ROTATION FRASER FIR (*ABIES FRASERI*) CROPPING SYSTEM: EFFECT ON PRODUCTIVITY, SOIL FERTILITY AND NUTRIENT LEACHING

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ABSTRACT

High rates of inorganic fertilizers are used in conventional intensive production systems such as *Abies fraseri* (Fraser fir) cropping systems for Christmas trees. Ground covers can be used as green mulches, help reduce the use of farm chemicals and provide several environmental benefits. We investigated the performance of a low input cropping system by combining two legume cover crops [Dutch white clover (*Trifolium repens*) and alfalfa (*Medicago sativa*)] in combination with low rates of inorganic fertilizers as a step towards a more sustainable production system. The randomized block design comprised one cover crop and one of three applications of reduced rate inorganic fertilizer (75%, 50% and 25% of the recommended rate). A conventional system using herbicides for weed control and the 100% rate of inorganic fertilizer was used as control. Parameters measured included tree morphology, foliar nitrogen concentration, soil mineral nitrogen, and nitrate-N leaching below the rootzone. A significant positive growth response (height and diameter) was obtained in all alfalfa based cropping systems. This was accompanied by foliar nutrient concentrations similar to conventional plots and a reduction in nitrate-N leaching. However, in white clover based cropping systems the growth response was reduced (both height and diameter), suggesting competition for soil

resources. In addition, the total nitrate-N leaching was higher in this system, suggesting an imbalance between mineral nitrogen availability and use in white clover based cropping systems. We conclude that if the potential competition between cover crops and trees can be properly managed, legume cover crops can be effectively used to make intensive production tree based systems more sustainable. Further studies related to mineralization and macronutrient flows are needed before any definite recommendation can be made about the use of these systems in large-scale production systems.

INTRODUCTION

In conventional agricultural and forestry production systems, inorganic fertilizers are widely used. However, approximately half of the applied fertilizers are lost from the systems before the cash crops can assimilate them (Drinkwater et al., 1998). In addition to their high cost that can negatively affect profitability, the long-term use of fertilizers can also have serious negative environmental effects, such as increasing soil acidity, soil erosion, and degradation of soil biodiversity, eventually leading to loss of productivity for the target crop (Juo et al., 1995).

Conversely, using ground covers can bring several potential advantages to the sustainability of intensive forestry and agricultural production systems. Ground covers can contribute organic matter to soil and reduce soil compaction and crusting, thus improving water infiltration and in some cases moisture retention (MacRae and Mehuys, 1985). They also have the ability to reduce soil erosion by wind and water (Hargrove, 1991), add or retain soil N, facilitate the availability of other nutrients like phosphorous and calcium (Kourik, 1986), suppress weeds, and improve chemical and physical characteristics of soil (Giller and Wilson, 2000).

Examples of successful use of cover crops in cropping systems include soybean (Reddy, 2001), corn (Vaughan and Evanylo, 1998), wheat (Bakht et al., 2009), *palm* oil, rubber plantations, and various orchard and vineyard production systems (Baumgartner et al., 2008). For example, the incorporation of cover crops has proven to significantly reduce nitrate leaching in rubber tree plantations (Schroth et al., 2001) and in cereal grass based systems where they are reported to be

more efficient in the uptake of residual soil N (Meisinger et al., 1991; Shipley et al., 1992). Brinsfield and Staver (1991) reported that perennial ryegrass exhibited the best response with regard to the absorption of unused soil N due to its quick-growing and fibrous root system.

However, intercropping systems are known to be complex ecosystems in which both facilitation and competitive interactions may occur. In tree-cover crop systems with relatively wide spacing, the competition for resources is mainly belowground (Hanninen, 1998). The aboveground abiotic factors, e.g. light, temperature and humidity, are usually of minor importance (Casper and Jackson, 1997; Köchy and Wilson, 1997). In belowground competition, plants reduce the available soil resources, mainly water and mineral nutrients, and decrease the growth and success of their neighbors (Casper and Jackson, 1997). In general, it has been suggested that root competition is more important than shoot competition and has a greater impact on plant performance (Wilson, 1988; Gerry and Wilson, 1995; Weiner et al., 1997).

Due to these potentially negative consequences, growers and farm managers tend to be very concerned about introducing cover crops when they have an existing functional inorganic fertilization program. Consequently, the use of ground covers in agro-forestry and other types of short rotation tree production systems such as Christmas tree plantation and woody biomass plantations is relatively limited.

A logical intermediary step is to determine reduced fertilization levels combined with cover crops that can be acceptable as a first step, low risk option for growers, but still provide the same

ecological and environmental benefits that ground covers bring to the sustainability of cropping systems. This study explored the effects of combining legume cover crops with low rates of inorganic fertilizers. The overall aim of this project was to develop low input sustainable farming systems for Fraser fir production that will meet the nutritional requirements of trees and improve soil fertility while reducing nutrient losses to leaching.

The specific objectives of were to 1) examine the effects of combining legume cover crops with low rates of N fertilization on Fraser fir productivity and nutrient status, 2) evaluate the impact on soil fertility (nitrate⁻N), and 3) determine the impact of these cropping systems on nutrient leaching below the root zone.

MATERIAL AND METHODS

Site description

The experiment was conducted in 2009 and 2010 at Sandhill Farm of the Tree Research Center (TRC) (42°65'N, 84°42'E) on the campus of Michigan State University, in East Lansing, Michigan. The average summer and winter temperatures are 15.5 °C and -6.6 °C, respectively. Annual average precipitation is 853 mm, with rainfall distributed fairly evenly throughout the year. The soil at Sandhill is a Mariette fine sandy loam soil, which is classified as moderately well drained with high available water capacity and medium surface runoff. The experimental field was surrounded by a 3-wire double electric fence to prevent deer damage.

Experimental design and plant materials

The field was 39×64 m in size, and the experiment was established as a randomized complete block design with three replications. Each experimental plot was 7.2×10.8m and contained 35 trees established at 1.8 x 1.8 m spacing. The field was established in 2007 using Fraser fir transplants (plugs+2) obtained from a local commercial nursery (Peterson's Riverview Nursery, Allegan, MI). Transplants were machine planted on May 8, 2007. Plants in border rows were used as a buffer and not included in measurements, therefore restricting data collection to the area of the remaining 15 interior trees in each plot.

Two legume cover crops: Dutch white clover (*Trifolium repens*) and alfalfa (*Medicago sativa*) were seeded between pre-planted rows of Fraser fir trees. The cover crop seeds were purchased

from Michigan State Seeds Company (Grand Ledge, Michigan) and hand broadcasted on May 15, 2007 at seeding rates of 28 kg ha^{-1} for both types.

A total of seven treatments were applied, including a bare ground conventional control with 100% of the recommended rate of inorganic nitrogen (BG100), 3 alfalfa treatments combining alfalfa ground covers in combination with each of 25%, 50% and 75% of the recommended rate of inorganic nitrogen (ALF25, ALF50, and ALF75), and three white clover treatments combining this ground cover and each of 25%, 50% or 75% of the recommended rate of inorganic fertilizer (WC25, WC50, and WC75). The fertilizer used was a granular formulation of ammonium sulfate (21% nitrogen) applied manually around trees in each plot at the beginning of the growing season. The rates of fertilizer applied were 135 kg nitrogen/ha for bare ground plots, and 33.75, 67.5, and 101.25 kg/ha for alfalfa and white clover plots fertilizer at 25, 50, and 75% respectively.

BG100 plots were sprayed with glyphosate (Roundup Pro) at rate of 32 oz/gal twice during each growing season for complete control of emerging weed populations. A clear 2-feet band (1-foot on each side) was maintained with the same herbicide application along tree rows in cover crop plot in order to reduce competition between ground covers and trees.

Cover crops were mowed every two weeks during the growing seasons 2009 and 2010, using a mower equipped with side discharge and the cut residues were returned as mulch to the ground.

MEASUREMENTS

Soil nitrate

Soil samples from two profiles, 0-15 cm and 15-30 cm, were taken at two random locations within each plot using a soil auger in mid May and late August of each growing season for analysis of mineral nitrogen content. The soil samples were placed in zip lock bags and stored in an ice-loaded cooler (4 °C) and transported to the laboratory where they were refrigerated until analysis. Samples were mixed thoroughly and a subset of approximately 5g of the soil extracted with potassium chloride. The extracts were then filtered before analysis on a SAN⁺⁺ segmented flow analyzer (Skalar Inc., Atlanta, GA).

Leachate collection and analysis

Suction lysimeters (model 1900L48-B02M2: Soil Moisture Measurement Corp. Santa Barbara, CA) were installed to reach 3 feet depth in the center of each plot to collect leachate below the root zone for determination of nutrient leaching. The drainage was collected once a week, its volume recorded and the sample transported under cold storage to the laboratory for further analysis. Aliquots from all plots were analyzed on the SAN⁺⁺ segmented flow analyzer (Skalar Inc., Atlanta, GA) to determine their nitrate concentration and the total mineral nitrogen lost for the week.

Tissue analyses

In late August in both 2009 and 2010, needles were randomly collected from each plot for nutrient analysis. The needles were oven-dried at 65 °C for at least two days and ground into a fine powder. Approximately 0.3 g of material was placed into a 75 ml digestion tube and digested with a mixture of 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 °C ± 10 °C for heat digestion under a programmed temperature schedule.

Total nitrogen was determined as described by Wilson et al. (2010). 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 analyzer (Skalar Inc. Atlanta, GA).

Morphological measurements

Tree height and root collar diameter (RCD) were measured with a tape and a digital caliper at the beginning (early May) and end (late August) of each growing season. Tree height growth and RCD expansion were calculated as the difference between the initial and final measurements.

Data analysis

Morphological data, foliar nitrogen and soil nitrate concentrations were analyzed by two-way analysis of variance (ANOVA) to test the effect of the treatments on growth, foliar nitrogen and

soil fertility. The means were separated by an LSD-test with $\alpha < 0.05$. Pairwise comparison was run to compare each ground cover/fertilizer rate combination to the conventional standard. The leaching data was analyzed using the mixed model for repeated measures procedures. All data analyses were performed using Systat 13 software (Systat Software, Inc., Chicago, IL). A level of significance of $\alpha < 0.05$ was used to determine statistical significance.

RESULTS

Average temperatures and rainfall

Rainfall patterns were similar in both years of the study. The total rainfall during the growing season was 424.7 mm (2009) and 407.1 mm (2010). Monthly rainfall totals varied from 24.1 mm to 126.2 mm in 2009 and 37.4 to 128.9 mm in 2010 (Tabel 17). Average maximum and minimum temperatures were slightly higher in 2010 compared to 2009 (Tabel 17). Average maximum temperatures varied from 23.08 to 28.02 °C in 2010 compared to 20.5 to 25.5 °C in 2009, while average minimum varied from 11.26 to 16.74 °C in 2009 compared to 7.8 to 14.9 °C in 2010.

Tree growth

Tree morphological response was significantly higher in 2010 compared to 2009 with greater height and RCD growth in all treatments (Table 18). The height growth response to alfalfa and fertilizer cropping system treatments was generally higher compared to BG100 control treatments (except ALF75 in 2009) for both 2009 and 2010. However, statistical analyses indicated that differences in height were not statistically significant ($p=0.2$ and $p=0.8$ in 2009 and 2010, respectively). Conversely, the height growth response in white clover treatments was statistically significant in both years ($p=0.0$ and $p=0.0$ in 2009 and 2010) with white clover treatments generally having less height growth compared to BG100 control treatments.

Diameter growth response was similar to height for alfalfa treatments, with RCD growth values statistically similar to BG100 control treatments in both 2009 and 2010 ($p=0.1$ and $p=0.2$

respectively). White clover treatments had similar RCD growth responses to BG100 control in 2009 ($p=0.5$), but in 2009, RCD growth response was significantly lower in white clover treatments compared to BG100 control plots ($p < 0.0$).

Tree foliar nitrogen concentrations

There was no difference in Fraser fir foliar nitrogen concentrations between ALF treatments and BG100 in both years ($p=0.6$ in 2009 and $p=0.7$ in 2010). A similar trend was observed for trees in white clover treatments in 2010. However, measurements of trees' foliar nutrient concentrations in 2009 were statistically ($p=0.0$) different due to trees in WC50 plots having lower foliar N than other treatments in the same group (Figure 6). In 2009, foliar N concentrations of trees specimens in BG100 plots were generally higher than WC treatments (Figure 6).

Soil nitrate concentration and bulk density

Soil nitrate concentrations at the upper soil profile (0-15cm) were generally higher in cover crop treatments (except ALF25 treatment in 2010) compared to BG100 control plots in both years. BG100 plots had 45 $\mu\text{g/g}$ (2009) and 38.6 $\mu\text{g/g}$ in 2010. Alfalfa nitrate concentrations varied from 50.39 $\mu\text{g/g}$ to 57.5 $\mu\text{g/g}$ in 2009 and from 33.5 $\mu\text{g/g}$ to 46.7 $\mu\text{g/g}$ in 2010. Nitrate levels in white clover plots were much higher than alfalfa plots, varying from 82.2 to 103.2 $\mu\text{g/g}$ in 2009 and 38.6 $\mu\text{g/g}$ to 91.5 $\mu\text{g/g}$ in 2010. However, due to the very high variability in the data, the differences were not statistically significant (Table 19). In the deeper profile (15-30 cm) soil

nitrate concentrations were much lower than those determined in the upper profile and varied from 8.1 µg/g to 12.2 µg/g in 2009 and 4.3 µg/g to 6.34 µg/g in 2010 for alfalfa, and 8.1 µg/g to 10.8 µg/g in 2009 and 4.3 µg/g to 5.7 µg/g in 2010 for white clover. There was no statistical difference between BG100 control and alfalfa or white clover treatments.

Soil bulk density values (Table 20) remained statistically similar between BG100 plots and cover crop treatments at the end of the 2009 and 2010 seasons ($p=0.4$ for 2009 and $p=0.7$ for 2010), suggesting no short-term effect of the cover crop types on soil bulk density.

Drainage volumes and nitrogen content

Cumulative leachate volumes were statistically similar in 2009 ($p=0.6$) and 2010 ($p=0.9$), indicating that cropping system treatments or cover crop types did not affect the water drainage through the soil profiles. Volumes collected ranged from 5471 ml to 8039 ml in 2009 and 4262 ml to 7296 ml in 2010 (Table 20). As the growing season progressed, the cumulative nitrate nitrogen leached (Figure 7) was consistently higher for BG100 control compared to all alfalfa treatments in both years. However, in white clover treatments, the cumulated nitrogen leached in WC25 treatment was the highest in 2009, while the WC75 treatment had the highest leaching nitrogen content curve in 2010.

DISCUSSION

Effect of cropping system on tree growth and productivity

In this study, the growth response to alfalfa based cropping systems was similar to the conventional system (BG100) using the full rate of inorganic fertilizer. This is a very positive outcome because even the combination of using the lowest amount of the recommended rate of inorganic fertilizer (ALF25) produced acceptable growth. This result can be attributed to the fact that the regular mulching of alfalfa cover crop biomass led to decomposition and produced enough organic nitrogen to help meet the nutritional needs of trees. This assumption is supported by Wilson et al. (2010) who reported that mowing alfalfa ground covers once every three weeks returned an average of 2.5 tons/ha of green manure to the ground, corresponding to 85 kg/ha of accumulated organic nitrogen. Similar results have been reported in cultivated grapes (Costello, 2010) and several other fruit based agricultural cropping systems (Radovich et al., 2009). The finding is also in line with Kuhn and Pedersen (2009) who reported that a cover crop based system with regular mulching produced vigorous tree growth and significantly higher tree productivity. Excellent growth and morphological characteristics have also reported in cover crop based systems for red birch (*Betula pubescens* Ehrh. f. *rubra* Ulniven f. *nova*) by Hanninen (1998) and “Smoother Golden Delicious” apples trees by Shribbs and Skroch (1986). In addition to nitrogen nutrition, increased productivity in ground cover based systems due to stimulation of microbial activities favoring populations of non-parasitic nematodes over plant parasitic species has also been reported (Sanchez et al. 2003). However, improved nutrition does not always

translate to improved yields. For example, Schroth et al. (2000) reported that the vegetative growth of palms, as measured by trunk diameter and leaf length, was not affected by increased site productivity.

In the white clover based cropping systems of the current study, height and diameter growth responses were significantly lower than the conventional treatment. Such growth inhibition is likely due to increased competition for resources needed for height and diameter expansion. The fact that foliar nitrogen concentrations were similar in the conventional control system and both cover crop types cropping systems suggests that the reduced morphological development observed in white clover plots was caused by limiting factors other than nitrogen. Previous work has shown that the competition for soil moisture can lead to depressed growth (Wilson et al., 2010). Tree diameter growth has been reported to be very sensitive to competition with cover crops (Welker and Glenn, 1989; Meyer et al., 1992). Low diameter growth responses in trees as observed in white clover based systems in this study have been associated with competition for moisture caused by ground cover that can induce excessive absorption of soil moisture (Pedersen et al., 2009).

Effect on soil density and nitrate-N fertility

Soil mineral nitrate-N concentrations were generally higher in 2009 compared to 2010 (Tabel 19). The reasons for lower levels of soil nitrate-N (NO_3^- -N) in 2010 are unknown, but warmer spring and summer temperatures may have caused intensive decomposition and mineralization of the

green manure from the cover crops during the growing season, leading to improved uptake and/or leaching resulting in lower soil NO_3^- -N levels towards the end of the growing season when samples were taken.

In both years of the study, although the cover crop based cropping system had higher soil NO_3^- -N concentrations, there was no significant effect of cropping systems on soil mineral NO_3^- -N at the two profiles sampled in the study. This is an indication that the green manure decomposition and mineralization produced enough mineral NO_3^- -N to more than compensate for the lower rate of inorganic fertilization applied. This finding is consistent with Sanchez et al. (2003) who found increased soil mineral nitrogen levels when combining ground covers with full rate nitrogen fertilization. Several soil and plant factors are known to determine green manure decomposition. Soil factors include texture, acidity, microbial activity and soil fertility (Fageria, 2007; Thonissen et al., 2000). Main plant factors are the C/N and lignin/N, (lignin+polyphenol)/N ratios (Fageria, 2007; Gil and Fick, 2001). The lack of difference in soil mineral nitrogen in our study indicate either similarities for these factors between the various treatments for each system tested or nutrient flow patterns out of the soil profile resulting in similar residual soil nitrogen concentrations. Both alfalfa and white clover have very low C/N ratios that will make them mineralize rather quickly once returned to the ground as green manure (Fageria et al., 2007). In addition, increases in nitrogen pools in the soil can increase the nitrogen mineralization, leading to large pools of highly mobile forms of nitrogen in the soil (Schroth et al., 2001). Since the total amount of green manure produced in each types of cover crop was

similar for all combination treatments, it can be suggested that the fast decomposition of this material enhanced the nitrogen mineralization, leading to enhanced uptake and leaching below the root zone. Furthermore, the manuring process used in this study that promotes continuous decomposition and mineralization throughout the season and can lead to synchrony between mineral nitrogen release and nitrogen uptake by trees leading to low residual soil mineral nitrogen.

Effect of cropping system on nitrogen leaching

In this study there was surprisingly no difference in drainage volumes collected between cover crop treatments and the bare ground conventional treatment. It was expected that total volumes collected would be significantly different because of enhanced moisture uptake in cover crop plots or increased evaporation in bare ground treatments. The lack of difference indicates either an excellent distribution of rainfall in the area during both years of the study or a mutual cancellation of these opposing effects leading to similar water drainage below the root zone in all treatments. This is consistent with previous work that found no apparent effect on drainage volume in cover crops treatments (Kirchmann and Bergström, 2001; Macdonald et al., 2005; Meisinger et al., 1991; Davies et al., 1996). Nitrate leaching was reduced in alfalfa plots compared to bare ground control, and increasing the nitrogen application rates in combination with the alfalfa ground cover did not increase the nitrogen leaching losses at any stage of the experiment. The result obtained was opposite in white clover plots where the ground cover combined with 75 or 50% of the rate of conventional fertilization resulted in increased nitrate

leaching.

In complex intercropped systems, the amount of N scavenged depends on several factors including weather, soil water, soil type, cover crop types, and cover crop growth (Sattell et al., 1999). Therefore, the different nitrate leaching response can be attributed to the cover crop types' characteristics. Alfalfa has the ability to develop deep root systems quickly and is well known for its ability to scavenge mineral N (Mathers et al., 1975; Owens et al., 1994; Rasse et al., 1999), hence the low nitrate loss observed in alfalfa treatments.

The opposite trend observed in white clover could be due to a number of factors, including a poor cover crop root system in white clover compared to alfalfa, reduced tree nitrate uptake making more nitrate available in the system, or a better mineralization rate leading to excessive soil nitrate production and increased leaching below the root zone.

CONCLUSION

The productivity of these systems, measured as height and diameter growth, was similar in alfalfa based cropping systems compared to the conventional production system as result of optimal growing conditions when combining regular mulching with low inorganic fertilizer applications. The positive growth result obtained in alfalfa cropping systems was supported by excellent foliar nitrogen concentrations, similar soil mineral nitrogen, and reduced nitrate leaching content. The picture was slightly different in white clover based cropping systems where reduced height and diameter growth was sometimes observed due to competition for non-nitrogen soil resources. Slightly higher nitrate leaching was also observed in some white clover cropping systems, suggesting an imbalance between mineral nitrogen availability and uptake. Based on the results obtained in this study, we conclude that if the competition between cover crops and trees can be controlled, the use of cover crop can be combined with very low rates of inorganic fertilizers to achieve several benefits, such as enhanced tree growth and sufficient foliar nitrogen, while reducing the adverse impacts to groundwater systems. Further studies related to the mineralization rate of the various types under these conditions, other macronutrients, and competition for other soil resources are needed before any conclusion can be made about the use of these cropping systems under operational conditions.

TABLES

Table 17. Average monthly temperatures and total rainfall during the 2009 and 2010 growing seasons.

			May	Jun.	Jul.	Aug.	Sep.
2009	Average	Max.	20.5	24.8	24.9	25.5	23.5
	Temperature (°C)	Min.	7.8	13.4	13.4	14.9	10.7
	Rainfall(cm)		10.9	12.6	6.1	10.5	2.4
2010	Average	Max.	28.0	26.5	27.9	27.5	23.1
	Temperature (°C)	Min.	15.3	15.2	16.7	14.5	11.3
	Rainfall(cm)		12.9	10.1	6.8	3.7	7.2

Table 18. Tree growth and root collar diameter in 2009, 2010 as affected by cropping system.

		2009		2010		2 years cumulative	
	Treatmen	Height	RCD (mm)	Height	RCD (mm)	Height	RCD
	t	(cm)		(cm)		(cm)	(mm)
ALF	BG100	11.7 ±0.9a	3.9 ±0.4a	18.4 ±1.5a	14.0 ±0.8a	30.1	18.0
	ALF25	12.8 ±1.2a	4.8 ±0.3a	20.9 ±1.8a	15.8 ±0.7a	33.6	20.7
	ALF50	14.1 ±1.1a	5.2 ±0.4a	19.2 ±1.7a	13.3 ±0.8a	33.3	18.5
	ALF75	11.1 ±1.1a	3.9 ±0.4a	19.8 ±1.6a	14.2 ±0.9a	30.9	18.2
	p-value	p=0.2	p=0.1	p=0.8	p=0.2		
WC	BG100	11.7 ±0.9a	3.9 ±0.4a	18.4 ±1.5b	14.0 ±0.8a	30.1	18.0
	WC25	7.3 ±0.8b	4.2 ±0.4a	11.9 ±1.2a	7.0 ±0.9b	19.2	11.6
	WC50	10.6 ±1.1ac	4.8 ±0.5a	13.8 ±1.7ab	11.8 ±0.9a	24.4	16.6
	WC75	8.0 ±0.6bc	4.6 ±0.3a	13.8 ±1.0ab	12.2 ±1.0a	21.8	18.9
	p-value	p=0.0	p=0.5	p=0.0	p=0.0		

Labels: RCD is root collar diameter. BG100 is bare ground with 100%N, ALF25 is alfalfa with 25%N, ALF50 is alfalfa with 50%N, ALF75 is alfalfa with 75%N, WC25 is white clover with 25%N, WC50 is white clover with 50%N, and WC75 is white clover.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

Table 19. Soil nitrate concentration (ug/g) in 2009 and 2010 as affected by the different cropping systems.

Treatment		0-15cm		15-30cm	
		2009	2010	2009	2010
ALF	BG100	45.0 ±3.1a	8.2 ±0.3a	38.6 ±1.0a	4.3 ±0.1a
	ALF25	57.5 ±1.5a	10.4 ±0.1a	33.5 ±0.4a	6.3 ±0.1a
	ALF50	71.9 ±0.7a	12.3 ±0.9a	44.9 ±0.8a	5.9 ±0.2a
	ALF75	50.4 ±3.1a	9.1 ±0.5a	46.7 ±1.6a	5.5 ±0.1a
	p-value	p=0.5	p=0.8	p=0.4	p=0.1
WC	BG100	45.0 ±3.1a	8.2 ±0.3a	38.6 ±1.0a	4.3 ±0.1a
	WC25	126.0 ±8.3a	9.4 ±0.4a	48.3 ±0.9a	4.8 ±0.0a
	WC50	103.2 ±3.9a	10.8 ±0.4a	91.5 ±8.4a	5.7 ±0.1a
	WC75	82.2 ±1.6a	10.8 ±0.5a	73.1 ±3.2a	5.2 ±0.1a
	p-value	p=0.2	p=0.8	p=0.4	p=0.2

Labels: BG100 is bare ground with 100%N, ALF25 is alfalfa with 25%N, ALF50 is alfalfa with 50%N, ALF75 is alfalfa with 75%N, WC25 is white clover with 25%N, WC50 is white clover with 50%N, and WC75 is white clover.

The soil samples were collected on August 25 in 2009, and August 24 in 2010.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Values followed by the same letters mean there was no significant difference between treatments.

Table 20. E2 Soil Bulk density as affected by the cover crop types.

	Soil Bulk density (g/cm ³)	
	2009	2010
BG	1.3 ±0.1a	1.1 ±0.1a
ALF	1.1 ±0.1a	1.2 ±0.0a
WC	1.3 ±0.1a	1.1 ±0.1a

Labels: BG is bare ground, ALF is alfalfa, WC is white clover. Each value represents the average of 3 replicates. Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test.

There was no cover crop types effect on soil bulk density in both years (p=0.4 for 2009 and p=0.7 for 2010). Values followed by the same letters mean there was no significant difference between treatments

Table 21. Cumulated drainage volume collected in 2009 and 2010.

	Volume (ml)	
	2009	2010
BG100	6934 ±1052 a	6484 ±1017 a
ALF25	5471 ±802 a	4262 ±582 a
ALF50	7621 ±609 a	6458 ±1431a
ALF75	6448 ±1372 a	7296 ±2230 a
WC25	6449 ±826 a	5435 ±1205 a
WC50	8039 ±909 a	6453 ±2318 a
WC75	7063 ±1113 a	5648 ±935 a

Labels: BG100 is bare ground with 100%N, ALF25 is alfalfa with 25%N, ALF50 is alfalfa with 50%N, ALF75 is alfalfa with 75%N, WC25 is white clover with 25%N, WC50 is white clover with 50%N, and WC75 is white clover.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. There was no treatment effect on cumulative leachate volume in 2009(p=0.6) and 2010(p=0.9). Values followed by the same letters mean there was no significant difference between treatments.

FIGURES

Figure 6. Foliar nitrogen concentration as affected by cropping system treatments.

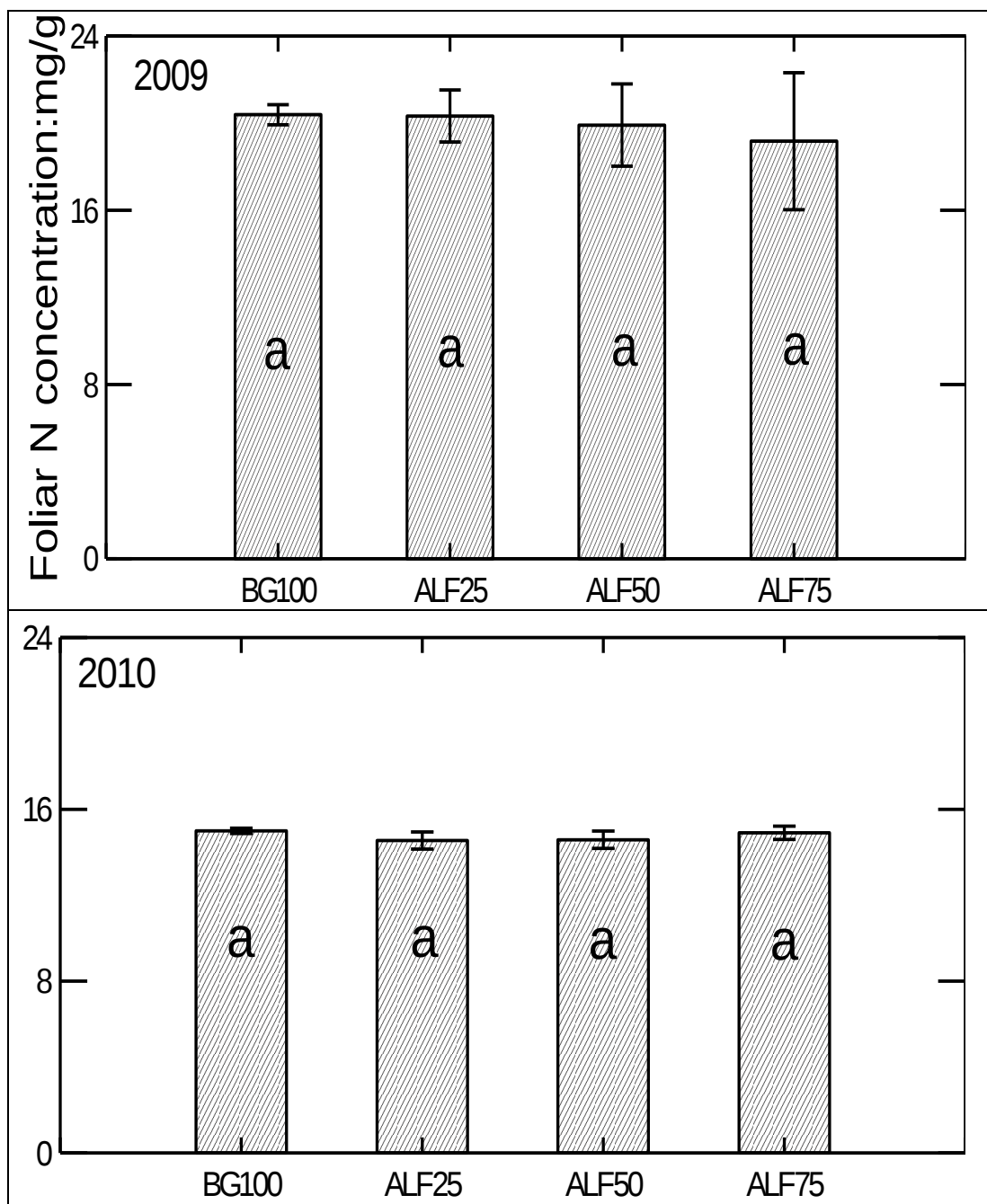
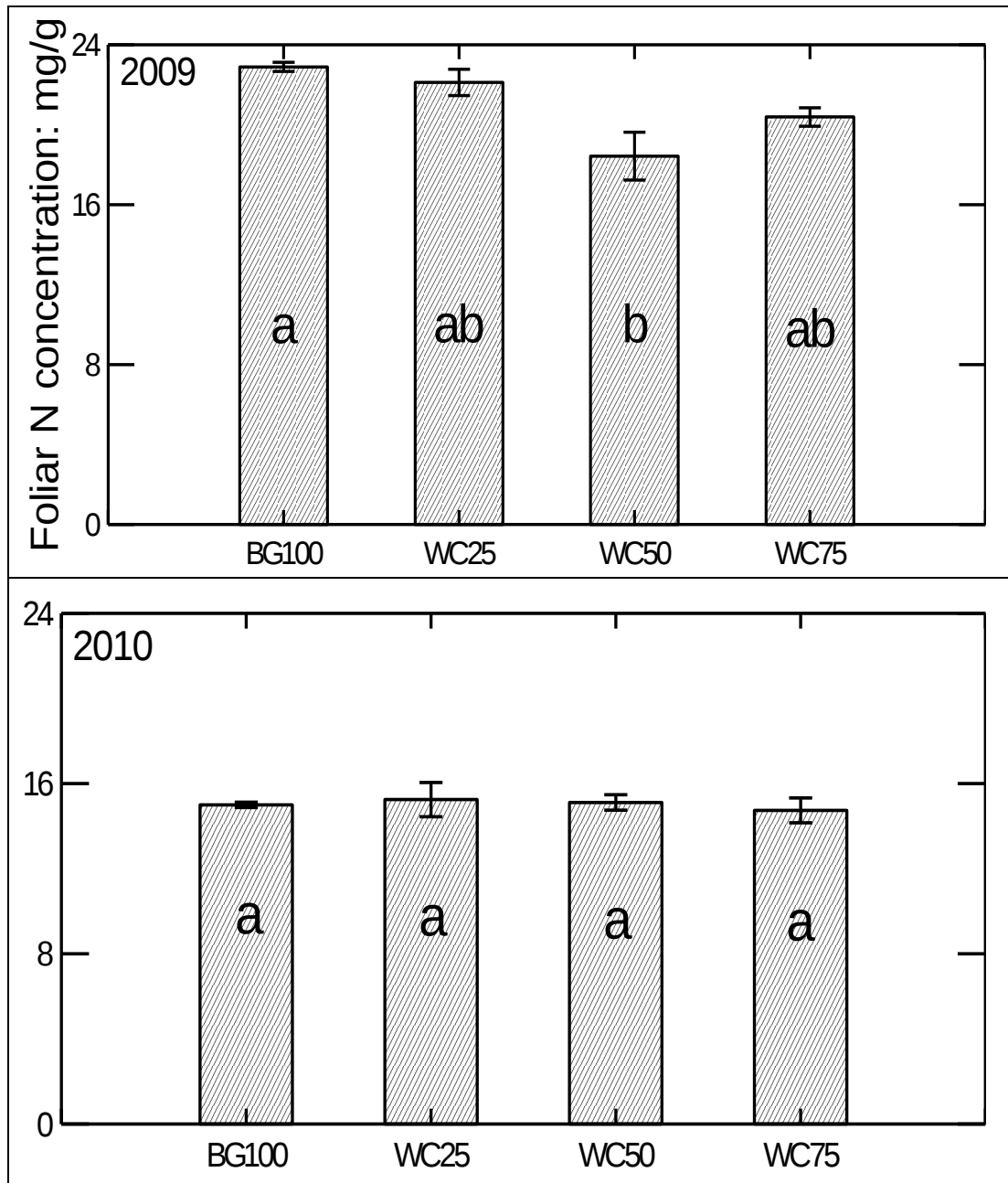


Figure 6. Foliar nitrogen concentration as affected by cropping system treatments.



Labels: BG100 is bare ground with 100%N, ALF25 is alfalfa with 25%N, ALF50 is alfalfa with 50%N, ALF75 is alfalfa with 75%N, WC25 is white clover with 25%N, WC50 is white clover with 50%N, and WC75 is white clover.

Data was analyzed by analysis of variance, and pairwise comparison using the Turkey's Honestly-Significant-Difference Test. Except for white clover treatments in 2009, there was generally no treatment effect on foliar N concentration except in 2009, WC had significantly lower foliar N than BG ($p=0.016$). Values followed by the same letters mean there was no significant difference between treatments.

Figure 7. Cumulated nitrate loss in 2009 and 2010 as affected by different cropping systems

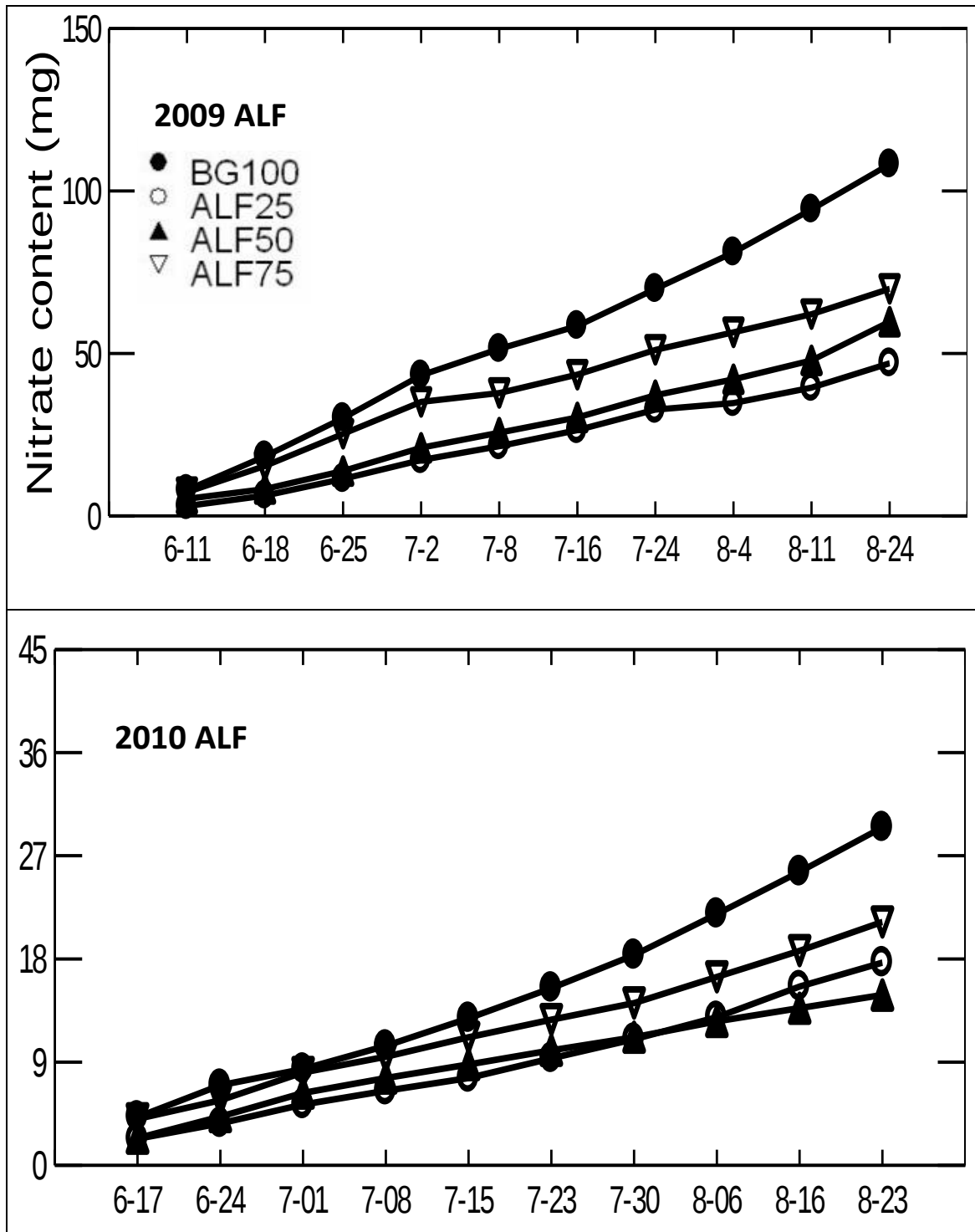
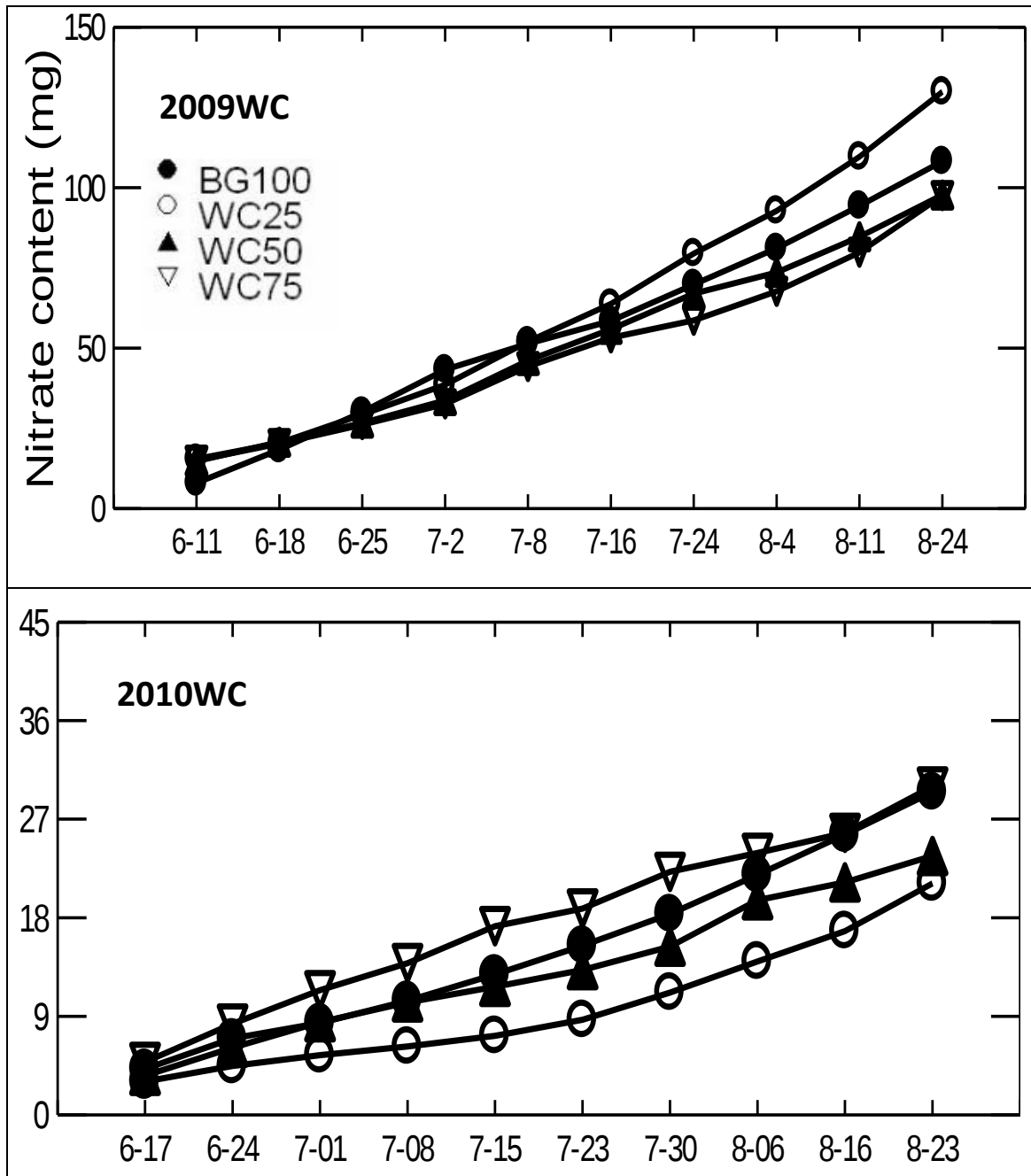


Figure 7. Cumulated nitrate loss in 2009 and 2010 as affected by different cropping systems



Labels: BG100 is bare ground with 100%N, ALF25 is alfalfa with 25%N, ALF50 is alfalfa with 50%N, ALF75 is alfalfa with 75%N, WC25 is white clover with 25%N, WC50 is white clover with 50%N, and WC75 is white clover.

Data was analyzed by analysis of variance with repeated measures procedure. There was a significant treatment effect for alfalfa treatments in 2009 ($p=0.1$) and 2010 ($p=0.9$) and white clover in 2009 ($p=0.7$) and 2010 ($p=0.8$).

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CONCLUSION

In this three years study, we investigated the effects of three cover crops and management practices on tree growth, foliar nutrient and soil properties in a Fraser fir production system.

In chapter 2, we investigated the effects of three groundcover types [Alfalfa (*Medicago sativa*), Dutch white clover (*Trifolium repens*) and perennial rye (*Lolium perenne*)] and two management practices, [Banding (B) and no-Banding (noB)] on tree growth and foliar macronutrient. We concluded that types selection was not critical for tree growth. In the same time, suppression in tree height and diameter growth in no banded treatments was observed which might due to the competition in soil moisture between cover crop and trees. We suggested that this competition can be efficiently controlled and avoid the suppression in tree growth by creating a clear band in between cover crops and trees.

This foliar N analysis result indicated that the cover crop residue N contribution can help to maintain foliar N level. There was no significant effect of cover crop system on foliar Mg. For foliar Ca, we concluded that lower cumulative Ca contribution from cover crop residue resulted in low foliar Ca. For foliar K and P, longer time and more specific research will be done to observe a clearer trend.

In chapter 3, we investigated the performance of a low input cropping system by combining two legume cover crops [Dutch white clover (*Trifolium repens*) and alfalfa (*Medicago sativa*)] in combination with low rates of inorganic fertilizers as a step towards a more sustainable production system.

Based on the results obtained in this study, we conclude that if the competition between cover

crops and trees can be controlled, the use of cover crop can be combined with very low rates of inorganic fertilizers to achieve several benefits, such as enhanced tree growth and sufficient foliar nitrogen, while reducing the adverse impacts to groundwater systems.

In chapter 4, we investigated the effects of different types and management practice on cover crops residue cumulative nutrient return and C to N ratio. Also we evaluated the contribution of cover crops on soil organic matter, soil N mineralization rates, soil bulk density and soil macronutrient.

We found the types selection only resulted in different cumulative Mg and Ca in cover crops residues. Soil organic matter in cover crops treatments were similar to bare ground treatments. The degree of the improvement in both SOM and soil bulk density highly depends on the amount of residue being returned to the ground. To our expectation, management practice did not lead to difference in cover crop residue C to N ratios, and legumes have the consistently lower values compared to non-legumes. The lower C to N ratio did increase the soil N mineralization rate, but not significantly.

Therefore we concluded that the use of cover crop can help reduce soil N leaching and reduce the N fertilizer use. Although there were some competitions in soil nutrient observed, while proper management practice was applied, most of the negative effects of cover crops on tree production systems can be avoided or reduced. For Michigan Fraser fir growers, we will recommend that legume cover crop with higher biomass production and lower C/N ratio can be introduced into their production systems.

FUTURE WORK

The current stage of ground cover study mainly focuses on evaluating and investigating the impacts of ground cover-Fraser fir system on the productivity of Fraser fir and soil fertility. Therefore, much work has been done to measure tree growth, analyze tree foliar and soil nutrients concentration and evaluate the change in soil fertility. As the conclusion of this 3 years study, we suggest that legume cover crop with high biomass production and low C to N ratio can be introduced into short rotation tree production systems while appropriate management practices are applied. However, more efforts remain to be done in the future to illustrate the nutrient dynamic in this ground cover- Fraser fir system.

In this study, we did not see any apparent effects of ground cover nutrient contribution on tree productivity. As it has been mentioned many times, soil available water is very essential to tree productivity. Also, soil temperature will affect evaporation, which can also affect soil moisture. Nevertheless, we did not track soil moisture or soil temperature in 2010 and 2011, which to some extent makes us unable to fully interpret the competition relationship between different types of ground cover and trees and the result caused by this relationship. Therefore, I consider soil moisture and temperature as necessary parts in future study.

In addition, microbial activity is a very important part in this agro-forestry biological system. It directly affects the decomposition rate of the ground cover residues and also the nutrient release. More importantly it will compete with trees in soil nutrients and available water as well. Thus, a more comprehensive understanding on soil microbial diversity and biomass can provide us a better view of this agro-forestry biological system and help us to make a more effective selection

of ground cover types.

This study has indicated that ground cover can be used in Fraser fir production system as a practical way to lower the input of inorganic fertilizer, improve soil fertility and also maintain tree productivity. However, in order to introduce ground cover to plant trees, an economic model must be established to show the cost of using and managing ground cover in tree production system and also the profits it can bring compared to the conventional way.

Finally, since the production cycle of Christmas tree production system is normally 8-10 years. A longer time of research shall be carried to illustrate the impact of ground covers on tree productivity, soil nutrients and soil fertility.