# Evaluation of fall-seeded cereal cover crops and tillage management in organic dry bean production.

**BY**

**RACHEL EVANS**

**A Thesis submitted to the Faculty of Graduate Studies of**
**The University of Manitoba**
**in partial fulfilment of the requirements for the degree of**

**MASTER OF SCIENCE**

**Department of Plant Science**
**University of Manitoba**
**Winnipeg, Manitoba**

## ACKNOWLEDGEMENTS

To my supervisor, Dr. Martin Entz, and committee members, Dr. Yvonne Lawley, Dr. Paul Bullock and Dr. Belay Ayele, thank you for your patience and guidance throughout this process. Martin, thank you for always challenging me to think bigger. Yvonne, thank you for your candid help as I started the writing process.

To Keith Bamford and Joanne Thiessen-Martens, thank you for providing a thoughtful, encouraging environment to be a student.

To all my peers, but especially Sarah Braman, Kristen Podolsky, Caroline Halde, Iris Vaisman, Kristine Waddell, you are a group of exceptional, inspiring women and I am so lucky to have met you.

To my friends and family, thank you for continuously asking me "How's your thesis going?" I am so thankful you care to ask. Love you Mom and Dad. Without you, I would not be where I am.

To Kyle, who came into my life during the writing stage and never stopped picking me up when I was discouraged. I am so glad I have you in my corner.

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## ABSTRACT

Evans, Rachel L. M.Sc., Evaluation of fall-seeded cereal cover crops and tillage management in organic dry bean production. The University of Manitoba, October 2015. Major Professor: Martin H. Entz.

Weed control is the primary challenge in organic dry edible bean (*Phaseolus vulgaris* L.) production, however no previous Canadian studies have considered cereal cover crops for organic pulse production. The objectives of this study were to characterize the effects of fall rye (*Secale cereal* L.), barley (*Hordeum vulgare* L.) and oat (*Avena sativa* L.) cover crops and tillage management on weeds and the soil microclimate in organic dry beans. Above ground weed biomass was significantly lower in fall rye (3778 kg $ha^{-1}$) and NT treatments (4867 kg $ha^{-1}$). Fall rye significantly lowered spring soil nitrate-N by 72% and 74% in 2011 and 2012, respectively. Cover crops did not affect soil moisture or soil growing degree day ($GDD_{soil}$) accumulation in early spring. Further research is needed on fall-seeded fall rye termination in organic conditions to reduce its competitiveness with the main crop.

# 1.0 INTRODUCTION

**1.1.**

Cover crops are crops grown for the ecological services and benefits they provide to farming systems (Sarrantonio and Gallandt 2003). Low input and organic farming systems rely on integrated management practices like cover crops to control weeds (Gallandt et al. 1999). Cereal cover crops, with their fibrous root systems, are effective at scavenging for nitrogen (N) after a cash crop (Wayland et al. 1996, Feyereisen et al. 2006). They also protect soil from erosion and suppress weeds (Barnes and Putnam 1983, Blackshaw 2008). Fall rye is a popular cover crop choice because it is a winter annual and fits easily into a rotation, it is a high biomass producer and is proven to be allelopathic (Liebl et al. 1992).

There has been substantial research on fall rye during the 1990s and 2000s linked to concern over agricultural water contamination and soil erosion. Conventional corn (*Zea mayes* L.) - soybean (*Glycine max* L.) producers in the Midwestern US have had success with fall rye as an alternative to tillage after corn and before soybeans (De Bruin et al. 2005). Rye scavenges and recycles N after using corn and maintains soil cover over winter. In spring, rye is terminated with herbicides and soybeans are seeded into the rye residue. Flood (2008) tested this system in conventional dry bean production in Manitoba. In organic systems, rye cover crops terminated without tillage (mowing or blade roller) did effectively control weeds in dry beans (Bernstein et al. 2014). Thus, regardless of the system, studies highlight the ability of fall-seeded fall rye to suppress weeds in the following main crop.

In Canada, few studies have been conducted on fall rye cover crops, none in organic production. In Ontario, research showed the potential of fall rye in conventional soybean production (Wagner-Riddle et al. 1994). In Southern Alberta, Blackshaw (2008) found fall rye was successful at controlling weeds and increasing yields in dry bean systems without in crop herbicides. Flood (2008) studied the use of fall rye in conventional dry bean systems in Manitoba and found that rye incorporated early (low biomass) or late (high biomass) provided significant weed control. Dry bean yields were sometimes higher (1285 kg $ha^{-1}$ vs. 1061 kg $ha^{-1}$ ), comparable or lower (1428 kg $ha^{-1}$ vs. 2659 kg $ha^{-1}$ ) than dry beans grown without rye cover crops.

Organic systems are sometimes criticized for their heavy reliance on tillage for weed control. Frequent tillage is linked to soil degradation. A key component to reduced tillage systems is crop residue which helps to reduce weed pressure and conserve moisture. Cover crops can provide these services while also extending soil cover into parts of the season vulnerable to soil loss (Sarrantonio and Gallandt 2003). Fall-seeded cover crops are a popular choice because they are seeded late in the year and continue growing early in spring. How best to terminate winter annual cover crops without tillage is still an important research question.

A challenge with fall-seeded cover crops in Canada is our relatively short growing season, compared to similar grain producing regions in the United States. As such, the combined focus of research has been timing and method of fall rye termination, cash crop seeding date and the effect on cash crop emergence, development and yield. A possible alternative to fall rye is a fall-seeded spring annual cereal, which would not have to be terminated since it will winter kill. Research in Alberta showed that fall-seeded oat and barley proved effective in weed control (Blackshaw 2008).

Since dry beans are a product for human consumption there are obvious marketing opportunities if farmers are able to produce them organically since it reduces risk of pesticide residues on the seeds. The present study builds on previous research to investigate the opportunity of using fall seeded fall rye, barley and oat cover crops to control weeds in organic (no input) dry beans, and if the cover crop residue can be managed with and without tillage. Thus, a winter annual cereal (green mulch) was compared to two spring annual cereals (brown mulch) to determine the effect on the agronomics of organic dry beans. The main objectives of this study were:

1. To compare fall-seeded winter cereal cover crops to fall-seeded spring annual cover crops and their management on weeds and bean agronomy (Chapter 3).

2. To evaluate the effect of cover crop and management on early season soil microclimate conditions (Chapter 4).

### 1.2 Literature Cited


Barnes, J.P. and A.R. Putnam. 1983. Rye residues contribute weed suppression in no-tillage cropping systems. J. Chemical Ecol. 9(8):1045-1057.

Bernstein, E.R., D.E. Stoltenberg, J.L. Posner, and J.L. Hedtcke. 2014. Weed community dynamics and suppression in tilled and no-tillage transitional organic winter rye-soybean systems. Weed Sci. 62: 125-137.

Blackshaw, R.E. 2008. Agronomic benefits of cereal cover crops in dry bean production systems in western Canada. Crop Protection. 27:208-214.

DeBruin, J.L., P.M. Porter and N.R.Jordan. 2005. Use of a rye cover crop following corn in rotation with soybean in the Upper Midwest. Agron. J. 97:587-598.

Feyereisen, G. W., B.N. Wilson, G.R. Sands, J.S. Strock and P.M. Porter. 2006. Potential for a rye cover crop to reduce nitrate loss in southwestern Minnesota. Agronomy Journal 98: 1416-1426.

Flood, H. 2008. Fall rye cover crops increase sustainability of dry bean production. M.Sc. Thesis. University of Manitoba. Winnipeg, Manitoba.

Gallandt, E. R., M. Liebman, and D.R. Huggins. 1999. Improving soil quality: implications for weed management. J. Crop Prod. 2.1: 95

Liebl, R., F.W. Simmons, L.M. Wax and E.W. Stoller. 1992. Effect of rye (*Secale cereale*) mulch on weed control and soil moisture in soybean (*Glycine max*). Weed Tech. 6:838-846.

Sarrantonio, M. and E. Gallandt. 2003. The role of cover crops in North American cropping systems. J. Crop Prod. 8:53-74.

Wagner-Riddle, C., T.J. Gillespie and C.J. Swanton. 1994. Rye cover crop management impact on soil water content, soil temperature and soybean growth. Can. J. Plant Sc. 74:485-495.

Wayland, L.J., L.E. Jackson, and W.E. Chaney. 1996. Winter cover crop in vegetable cropping system: Impact on nitrate leaching soil water, and crop yield. Agric. Ecosyst. Environ. 59:1–17

# 2.0 LITERATURE REVIEW

## 2.1 Dry bean production in Canada

Dry edible beans (*Phaeseolus vulgaris* L.), also called common beans or field beans, are an important food crop around the world. An excellent source of protein, dry beans are high in dietary fibre, high in essential vitamins and have a low glycemic index, making them an important dietary staple (AAFC 2013). Pulses are also promoted to improve the sustainability of cropping systems by reducing fertilizer use and consequently reducing the on-farm carbon footprint (Pulse Canada 2010).

Canada is a key player in global dry bean markets. In 2011, the Canadian pulse export was a $2.7 billion industry. Canada accounts for 35% of the global trade, and is in the top five for dry bean exporters (Pulse Canada 2010). Domestic production of pulses is concentrated in Saskatchewan, Manitoba, Ontario, Quebec and Alberta (Pulse Canada 2010). Each region specializes in particular types of pulses depending on the growing conditions. Manitoba's pulse acres are concentrated in dry beans. In 2012, dry beans were seeded on 54, 956 ha in Manitoba. Navy beans (22,368 ha) are the leading bean type used by producers, followed by pinto (20,131 ha), black (5867 ha), kidney and cranberry (4387 ha). However, the number of pulse acres is reducing as farmers switch to better priced and easier to grow crops like soybeans that are generally produced for animal feed (MPGA 2012).

## 2.2 Dry bean agronomy

Within the genus *Phaseolus*, there are a wide variety of growth habits, ranging from determinate bush types to indeterminate vine types. Singh (1982) suggested the following bean classification system: Type I = determinate upright bush, Type II = indeterminate upright bush, Type III = indeterminate, prostrate, non-climbing or semi-climbing and Type IV = indeterminate, strong climbers. Each type is classified based on the growth habit (determinate vs. indeterminate), stem strength (weak vs. strong), climbing ability (non-climber vs. strong climber) and flowering pattern (basal vs. along entire or partial stem length). Determinate growth means that beans will stop growing vegetatively once flowering has begun, as compared to indeterminate growth where vegetative growth and flowering continue so long as environmental conditions permit.

In field production, determinate bush types are more suitable for solid seeded production and indeterminate vine types are more suitable for row cropping (MAFRD 2006).The bean seed has two cotyledons that are exposed above the soil after germination. This causes dry beans to be susceptible to excess moisture, salinity and late spring frosts that could damage the cotyledons. The first two leaves to grow are the single or unifoliate leaves. All subsequent leaves are three-clustered leaflets called the trifoliate leaves (MAFRD 2006). Dry beans are a warm season crop, with ideal soil temperature for germination of at least 12º C and growing temperatures being approximately 24º C. Greater than 30º C can cause flower blasting and less than 10º C will inhibit growth and development (MAFRD 2006). Dry beans can reach maturity in 90 -120 days depending on the variety (Miklas and Singh 2007, MAFRD 2006).

Although a leguminous crop, dry beans are considered poor nitrogen (N) fixers due to comparatively low fixation capacity (Graham and Ranalli 1997). Therefore, the majority of producers treat dry beans as any other grain crop and fertilize accordingly (Buttery et al. 1987, McAndrew et al. 2000). The rhizobium inoculant for dry beans is Rhizobium *phaseoli.* Interestingly, studies have shown that as soil N increases the fixation by nodules often decreases (Edje et al. 1975, Westermann et al. 1981) which is contrary to the standard practice of fertilizing dry beans.

Current nitrogen fertilization rates for dry beans are 45 to 100 kg $ha^{-1}$ according to the Manitoba Soil Fertility Guide (2007). Bean yields are likely to benefit from fertilizer applications when soil nitrate is low in spring, spring temperatures are below average, target yields are high or root rot is a concern (MAFRD 2006). Dry beans are only somewhat responsive to phosphorus ($P_2 O_5$) based on Manitoba studies (McAndrew 1999). Potassium fertilization is only recommended for soils with less than 112 kg $ha^{-1}$ of $K_2O$ in the upper 15 cm of soil (MAFRD 2006).

Historically, dry beans have been seeded in wide rows (75-90 cm). However, as more grain producers are incorporating dry beans into rotations without specialized equipment, seeding occurs in narrow- row or solid seed arrangements (Shirtliffe and Johnston 2002). The difference in seeding arrangement results in different management practices, from weed management to harvesting. Row- cropped beans will suffer from increased inter-competition for light, nutrients and water. Weed management in row- cropped systems is done with inter- row cultivations and/or herbicides. Options are generally limited to herbicides with solid seeded beans, since in crop cultivation is not possible (MAFRD 2006).

Perhaps because of the increase in solid seeded beans across Canada, the presence of herbicide residues on post- harvest beans has been an issue for Canadian dry bean exports. In 2008, an Ontario shipment of dry beans was rejected due to high levels of residual herbicides (Gillard 2011). Beans are also very sensitive to herbicide residues in soil (MAFRD 2006). Other options for weed control in dry beans are needed.

### 2.3 Organic agriculture management

Organic agriculture is "a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, agronomic, biological and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system." (FAO 1999). In other words, organic agriculture considers the farm to be a living organism that ideally acts as a closed looped system (Kristiansen and Merfield 2006, Woodward and Vogtmann 2004). This is in contrast to the 'reductionist' approach that characterizes conventional agriculture and treats weeds and pests in isolation from the system (Kristiansen and Merfield 2006). Organic crop agronomy must manage crop pests and nutrient budgets by understanding that all components of the system act together. Liebman and Gallandt (1997) coined the expression "[using] many little hammers" to describe the type of management needed in organic production. For example, weed control is not solely about removing a weed, but about using a preventative approach (Nazarko et al. 2003).

The essential component of the organic system is its crop rotation. Crop rotation will affect all other components of the organic system, i.e. soil biology, soil moisture, nutrient status, weed communities, and disease. Crop rotation is the first management decision made by a producer, dictated by climate and available markets, and is followed by all other cultural management decisions. Cultural practices are strategies to “achieve specific tasks or general whole-farm outcomes” (von Fragstein und Niemsdorff and Kristiansen 2006) such as, seeding timing and arrangement, timing of tillage operations, and weed control practices. Cultural practices decide mechanical practices, such as tillage and mowing.

Soil fertility and weed management are two areas where conventional agriculture has simplified, but where organic producers need to diversify management practices. Soil fertility is limited to animal manures, composts and green manures so management decisions should be structured to ensure nutrient availability at the correct time or for the crop with high nutrient requirements. A green manure is a cover crop grown explicitly for adding soil nutrients (Cherr et al. 2006).

Cover crop mulches affect weed population dynamics, while growing cover crops may suppress weed growth (Gallandt et al., 1999). Cover crops alter the “predictable patterns of soil disturbance, crop competition, cultivation and herbicide use...” (Liebman and Dyck, 1993). Such that, by “inserting cover crops into selected niches within organic cropping systems, the number and diversity of these stresses may be expanded” (Sarrantonio and Gallandt, 2003). Cover crop characteristics needed for weed control include quick establishment, smothering ability as well as the physical (e.g. light, moisture) and chemical (e.g. allelopathy) effect of residues.  Therefore, not all cover crops are created equal, as cover crops vary in these characteristics. Additionally, cover crop management will also affect how cover crops influence weed populations. Cover crops are of great interest to organic farmers and researchers, but information for Canada is limited.

### 2.3.1 Conservation tillage in organic agriculture

Conservation tillage is a reduced or no-till system that decreases the amount of soil disturbance from agriculture. The Food and Agriculture Organization (2013) defines conservation agriculture as having three components: a diverse crop rotation, zero or reduced tillage and continuous soil cover. In varying degrees, this includes no-till, strip-till, ridge till and mulch till (FAO 2013). Conservation agriculture reduces soil erosion, increases water holding capacity, increases soil organic matter, and positively affects soil microbial communities (Hussain et al. 1999, Lal 1993).

In conventional agriculture, the increase in no-till farming has been promoted by its soil water conservation benefits in addition to erosion control, and its adoption by producers has been facilitated by the increase in herbicide resistant crops (Roberts et al. 2006). However, organic production often relies on tillage for seed bed preparation, weed control, the incorporation of soil amendments (Morse and Creamer 2006). To control weeds while simultaneously reducing tillage, organic producers can increase the complexity of their crop rotations by using cover crops. This has led to extensive research on methods of terminating or managing cover crop residues without tillage. A survey of 1,702 farmers across the United States found that 84% of respondents had used cover crops. The study also found that farmers were most likely to terminate their cover crops with herbicides (59 %), followed by tillage (10 %) and mowing (4 %) (SARE 2015).

Novel mechanical approaches for managing cover crops without tillage have been garnering attention, especially the blade roller. Research in the Canadian prairies has shown this implement can successfully kill green manure crops like pea, fababean and oat (Vaisman et al. 2011, Shirtliffe and Johnston 2012) and provide season long weed control (Halde et al. 2014). Other studies have shown mowing to be an effective method of no-till cover crop termination (Blackshaw et al. 2010, De Bruin et al. 2005). However, neither implement is without its limitations, namely, reduced N mineralization with the blade roller (Vaisman et al. 2011) and moisture use and regrowth with mowing (Wagner-Riddle et al. 1994).

Flame weeding is a no- till, thermal weed control practice common for organic row crops that uses propane or natural gas fuel. Inter- row flamers can be mounted on the back of a tractor or in a hand held fashion (Diver 2002). The goal with flaming is not to char weeds, but to scorch them to a point of wilting. Extreme heat (90 - 100º C) causes water in plant tissues to expand and cell walls to rupture. A field test on flaming efficacy is when a thumb imprints into a leaf. Plants will remain green immediately after flaming but will brown in a few days after. Weeds should be targeted when at the 1-2 leaf stage (Diver 2002, COG 2001). Some weeds can be evasive to flaming if they are clonal or having a growing point below soil (COG 2001). Hot and dry conditions are the most suitable for flaming and will have the best weed control.

## 2.4 Cover crops

A cover crop is a "crop grown primarily to cover the soil in order to protect it from soil erosion and nutrient losses between periods of regular crop production" (Pitchers and McKee 1938) and to improve soil fertility and provide other ecological services (Sarrantonio and Gallandt 2003). The choice of cover crop will depend on the producer's crop rotation and goals, as each cover crop type will have its own benefits and challenges.

The benefits of cover crops include conserving or using soil moisture, enhancing water infiltration, cycling mobile soil nutrients like nitrate, weed control, and sustaining mycorrhizal fungi (Sarrantonio and Gallandt 2003). Soil cover plays an integral role in reducing evaporation from soil. The role of cover crops in the soil water cycle depends on many factors like climate and precipitation, cover crop species and how cover crops are managed (Unger and Vigil 1998).

Growing cover crops can reduce soil moisture in spring and early summer (Liebl et al. 1992, Munawar et al. 1990) and cover crop water use can be regulated by management. For example, winter cover crop mulches such as fall rye use less water if terminated early (e.g. Two weeks before main crop planting) (Wagner-Riddle et al. 1994). Water use by cover crops makes them more suitable for humid and sub-humid climates, which are not limited by soil moisture, than in semi-arid regions (Dabney et al. 2001). However, Blackshaw (2008) has described effective cover crop systems for dryland southern Alberta, which uses fall-seeded rye, barley and oat cover crops in conventional dry bean production. Depleting soil moisture in dry conditions can negatively impact the yield of the following main crop. Liebl et al. (1992) measured soil moisture in soybean after a fall rye cover crop. Late terminated fall rye (at seeding) had lower soil moisture in the following growing season under dry conditions. Growing season soil moisture was higher under the fall rye mulch during wet periods. Under extremely wet conditions, a cover crop may use up excess moisture.

Cover crops also increase the availability of soil nitrogen for the main crop. Cereals are beneficial as nitrogen scavengers, cycling leached nitrogen back to surface soil. Wyland et al. (1996) found that there was a 65 – 70% reduction in nitrate leaching when winter rye and phacelia (*Phacelia tanacetifolia)* cover crops are used in a broccoli (*Brassica oleracea*) crop, compared to fallow treatments. Leguminous green manure cover crops can act as a source of nitrogen when soil incorporated. However the use of green manures as an effective N source is often constrained by the difficulty in predicting the timing of release of nitrogen from residues (Sarrantonio and Gallandt, 2003).

For many producers, it is not seen as economically feasible to grow a cover crop, even if there are understood ecological or economic benefits. Singer et al. (2007) performed a survey of 1600 farms in the Mid-West United States found that only 18% of producers had ever grown a cover crop. In the last 5 years, only 11 % of producers had grown a cover crop. The survey also showed that there was a correlation between on farm crop diversity and cover crop usage. When producers were asked questions on cover crop benefits, 96% of respondents said cover crops control erosion and 74 % said cover crops increase soil organic matter (Singer et al. 2007). It becomes a trade-off between short term economic gains and long term ecological services. Limitations include seed costs, termination method and yield penalty on the main crop (DeBruin et al. 2005).

Another barrier to adoption of cover crops is how to incorporate them into a farming system. Sarrantonio and Gallandt (2003) summarized the variety of ways cover crops fit into an annual crop rotation. The type of system will depend primarily on climate, cover crop systems in the mid-Atlantic United States will differ from those in the northern Great Plains due to the difference in growing season length, heat units and precipitation. Secondly, it will depend on the producer's crop rotation. A successful cover crop will fit into rotational gaps (Sarrantonio and Gallandt 2003). Within the wide range of farming systems, adaptations are required to have successful integration of cover crops. Adaptations include cover crop species, management type and timing.

### 2.4.1 Cover crops in Manitoba

Cover crop research in Manitoba has centered on themes such as green manures, nutrient cycling and reduced tillage. Green manures are cover crops grown during one full growing season, that are terminated at flowering and residues are either incorporated or left on the soil surface. This system is primarily a function of limitations like a short growing season and average annual precipitation. Figure 1 illustrates five management options for incorporating cover crops into annual crop production.

Characteristics of an ideal green manure crop include high biomass production for weed suppression, limited effect on nutrients and moisture for the main crop, added nitrogen to the soil and no significant effect on main crop seeding. Halde et al. (2014) studied 10 different green manure combinations, which were terminated at flowering using the blade roller. The following spring wheat (*Triticum aestivum* L.) was planted.

The authors found that of all species combinations used in the study, any mix that included hairy vetch (*Vicia villosa* Roth) appeared to be the most promising. Hairy vetch mixes had significantly higher biomass and soil nitrogen, both in the fall of the green manure and the subsequent spring, resulting in higher yields that were comparable to conventional wheat yields for the region.

In addition to green manure species, termination method and frequency of tillage have also proved to be important determinants of main crop yield. Vaisman et al. (2011) studied the effect of reducing tillage during the green manure phase of a green manure-wheat rotation using the blade roller and found that best scenario was to terminate the green manure with the blade roller, followed by spring tillage prior to the main crop. Replacing tillage with rolling reduced soil nitrogen in fall after the green manure. However, overall wheat yields and protein were still higher than those of commercial organic wheat (Entz et al. 2001, Vaisman et al. 2014). Similarly, Podolsky (2013) found that although tillage provided the most soil nitrate-N at seeding of the main crop, reduced tillage implements such as the blade roller + tillage and wide blade cultivator treatments, resulted in sufficient soil nitrate at main crop seeding, 127 kg ha and 98 kg ha, respectively.  To further this, Podolsky (2013) concluded that too much lag between green manure termination and main crop seeding means that there is time for the green manure to decompose and weeds to establish. Thus, other cultural management practices like delayed planting of the green manure or fall-seeded main crops could minimize this window. Other, more novel, management practices include the use of incorporating livestock to graze down the green manure, providing a source of income during an otherwise profit-free period (Cicek et al. 2014).

Another option is using fall-seeded cover crops, however limited work has been done on this in Manitoba. Flood (2008) found that fall-seeded fall rye cover crops had the potential to improve the sustainability of conventional dry bean production systems. In the absence of in-crop herbicides, fall rye reduced weed biomass compared to the no cover control by 52% to 92%. Dry bean yields were comparable to conventional practices in 1 of 4 site-years, no different in 2 of 4 site-years and lower in 1 of 4 site-years. Results from this study indicated that water usage by fall rye, combined with adverse environmental conditions were responsible for the reduced dry bean yields.

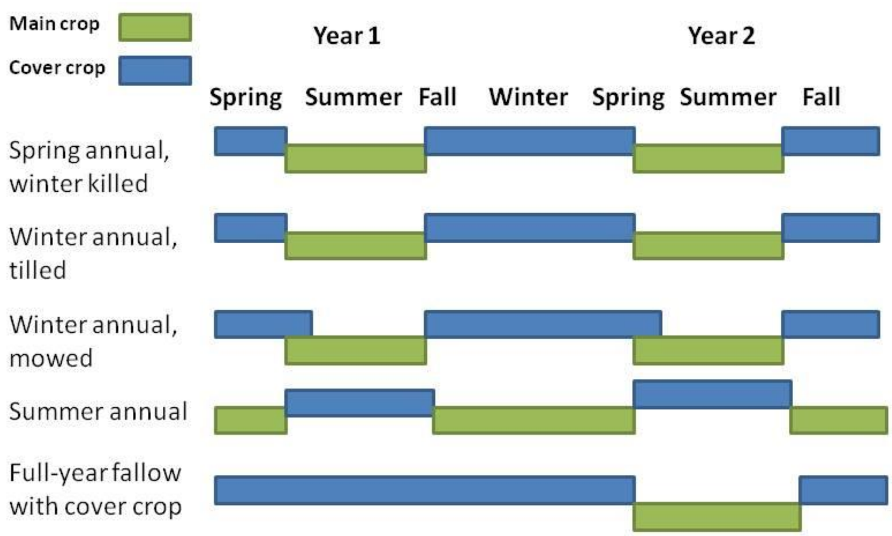



**Figure 1.** Five management options for the inclusion of cover crops in annual cropping systems (Adapted from Sarrantonio and Gallandt 2003)

## 2.5 The mechanisms of weed control by cover crops

Cover crops control weeds directly and indirectly. Directly, the growing cover crop or the cover crop mulch may compete with weeds for moisture, light, and nutrients

(Kruidhof et al. 2009). Indirectly, a cover crop may impact weed communities through soil chemical interactions (Weston 1996, Inderjit and Keating 1999, Bhowmik and Inderjit 2003) from the crop itself or its management, for example tillage or no-till management of cover crop residues.

### 2.5.1 Physical effect of cover crops on weeds

#### 2.5.1.1. Light interception

Cover crops interfere with weed germination and growth by intercepting incoming solar radiation. A living cover crop may compete with weeds for light, while killed cover crop mulches intercept light from reaching the soil surface. In fact, the competitive ability of cover crops is largely attributed to light interception (Teasdale 1993). Specifically, the advantage of cover crop mulches is early season light interception, which has been shown to be more important for reducing weed germination than over the whole growing season (Kruidhoff et al. 2009).

Light requirement for seed germination is dependent on plant species, soil temperature and soil moisture. In a survey of 271 species, Grime et al. (1981) found that dependency on light for germination was sometimes related to seed size, with seeds weighing less than 0.1 mg being light-requiring while seeds with a larger mass were less light dependent. More often, the response of a seed to light depends on the combination of environmental factors, with light being more essential if other conditions for germination were not being met (Baskin and Baskin 1988). Gallagher and Cardina

(1988) found that light dependency could be overcome for pigweed (*Amaranthus* spp.) if other environmental factors were non-limiting. Teasdale (1993) found that velvetleaf (*Abutilon theophrasti* L.) and common lambsquarters (*Chenopodium album* L.) germination was significantly reduced by hairy vetch mulches in controlled greenhouse conditions due to reduced light under the mulch.

Mulch quantity is an important factor determining the quantity of light available to germinating weeds. Teasdale (1993) found that to reduce the establishment of common lambsquarters by 50%, a hairy vetch residue rate of 1 Mg $ha^{-1}$ was needed. To achieve similar results for green foxtail (*Setaria viridis* L.) or velvetleaf, a residue rate greater than 10 times this amount was needed. The authors attributed the response of common lambsquarters to mulch residue rate to greater light requirement for germination and small seed size. However, mulch quantity is a major limitation in cover crop systems in Manitoba. In order achieve sufficient hairy vetch biomass for weed control in field trials (6 to 7.6 Mg $ha^{-1}$), a full growing season was required (Halde et al. 2014).

Mulch architecture can play an important role in the efficacy of mulch weed control. Light can be reduced in quantity and quality by other vegetation. The detection of light by plants is through the phytochrome system, which mediates photoregulated growth in plants and seeds. Wavelengths in the red part of the spectrum (~667 nm) are absorbed by plant leaves first, so canopy shade is higher in far-red light (~730nm). Therefore, a light source that is high in red spectrum wavelengths would signify the absence of vegetation and so would indicate a potentially competition-free space, a mechanism coined "gap-detection" by Grimes et al. (1981). Teasdale and Mohler (2000) observed that the random distribution of mulch seems to provide sites for emergence, therefore the more diverse the spaces are in a mulch, the more opportunities there are for weeds to emerge. Weed seed size plays an important role in the sensitivity of weeds to the presence of mulches. Teasdale and Mohler (2000) determined that this was an inverse relationship, weeds that were able to grow up and through residue in the absence of light, were attributed to their large seed size and thus, large seed reserves. Velvetleaf was the least sensitive to mulches in this study, followed by green foxtail and common lambsquarters.

#### 2.5.1.2. Soil temperature

Brady and Weil (1996) state soil temperature is caused by three factors: the net amount of heat energy the soil absorbs, the energy required to cause a change in soil temperature  and the energy required for evaporation. Of the solar radiation emitted, about only 10% is absorbed by the soil, the remaining is reflected and used to evaporate water from leaf and soil surfaces. The amount of incoming radiation that is transferred through soil will depend on many variables. Soil moisture will affect how much radiation is absorbed. Wet soil will reflect roughly 10% of incoming radiation, while dry soil will reflect 20%. The albedo of the soil surface is also an important factor (Brady and Weil 1996). Black soils, for example, are a more absorptive surface than vegetative surfaces (Milthorpe and Moorby 1974).

Soil temperature has two periodic fluctuations, diurnal and seasonal. In both cases, the largest flux in temperature occurs at the soil surface. Teasdale and Mohler (1993) found that mulches reduce daily maximum temperatures, but had little effect on daily minimum temperatures. Soil temperature changes may affect the germination of certain weed seeds. For example, lamb's quarters which germinates in spring and summer is able to germinate at high (25/15, 30/ 15 and 30/20º C) and low temperatures (15/ 6º C,) but strictly spring annual common ragweed (*Ambrosia artemisiifolia*) requires exposure to low temperatures in order to germinate (Baskin and Baskin 1987).

Fluctuating soil temperatures are an important factor for breaking dormancy amongst many weed species. Germination can be increased by the frequency and the magnitude of diurnal fluctuations (Fenner and Thompson 2005). In the comprehensive analysis by Thompson and Grime (1983), 116 weed species were germinated in fluctuating and constant soil temperatures in light and dark. Many of the weeds that germinated in darkness are prominent agricultural weeds, such as quackgrass (*Agropyrons repens* L.) and Lady's thumb (*Polygonum persicaria* L.) A total of 46 species required the combination of light and fluctuating temperatures and 39 species responded in dark. Studies have shown that the physical presence of cover crop mulches is an important property of weed control (Teasdale and Mohler 1993, Teasdale and Mohler 2000).

Mulches affect soil microclimate by absorbing and reflecting solar radiation, while also reducing evaporative losses (Oke 1990). Management of cover crops can affect how much mulch biomass is accumulated. Greater biomass will often result in decreased soil temperature. Wilkins and Bellinder (1996) found that lower soil temperature was related to the amount of rye biomass at the time of mowing, finding that soil temperature decreased by 3º C and 6º C in early killed and late killed rye, respectively. Thus, timing of management was also a significant variable. As well, soil temperature was lower under mulch compared to bare soil.

Mulches can also affect soil temperature by increasing soil moisture. Water has a higher specific heat than that of soil, meaning that water requires more energy per unit to warm than does soil. This means that soils that are wet in spring will require a longer time to warm than drier soils (Brady and Weil 2009). Bullied and Van Acker (2003) studied the implications of this by looking at the effect of tillage system on weed and canola emergence periodicity. In a survey of 2 million ha in Southern Manitoba, the authors found that soils from conventional tillage systems warmed more quickly than soils in conservation tillage fields. Canola was found to have earlier emergence over weeds in conservation vs. conventional fields, indicating that canola may have the competitive advantage in conservation systems.

### 2.5.2 Chemical effect of cover crops on weeds

#### 2.5.2.1 Allelopathy

Rice (1984) defined allelopathy as the effect of one plant (including microorganisms) on another plant through the release of chemical compounds into the environment. Most often, allelochemicals are secondary metabolites formed from primary metabolism pathways in plants. This effect can be inhibitory or stimulatory. Allelochemicals can be present in roots, shoots or leaf blades, and are exuded from living plants or leached from decomposing residues (Barnes and Putnam 1986).

Allelopathic characteristics have been identified in several crop species used as cover crops. Early work on barley "smother crops" demonstrated that living plants and aqueous solutions of live barley roots inhibited germination of chickweed (*Stellaria media* L.) and Shepard's purse (*Capsella bursa-pastoris* L.) but not wheat (Overland 1966). Later, Liu and Lovett (1990) confirmed the phytotoxicity of barley allelochemicals. Putnam et al. (1983) showed that winter barley cover crop residues reduced weed densities by 90 % of the no cover crop control. Research has shown oat shoot extracts have inhibitory effects on the germination of lettuce seeds (*Lactuca sativa* L.) that was attributed to the presence of L-trypotphan in the solutions (Kato-Nugushi et al. 1994). Under field conditions, residues of fall-seeded oats that were frost-killed reduced weed biomass the following spring by 42 % of the no cover control (Putnam et al. 1983). There has also been extensive research on fall rye allelopathy. Rye residues left on the soil surface reduced the germination of common ragweed (*Ambrosia artemesifolia* L.), redroot pigweed (*Amaranthus retroflexus* L.) and common purslane (*Portulaca oleracea* L.) by 43, 95 and 100%, respectively (Putnam et al. 1983). Barnes et al. (1986) reported that a living rye cover crop reduced weed biomass by 90 % of the no cover controls and by 69 % when terminated after 40 days. Therefore, there exists important opportunities for exploiting the allelopathic properties of these cereal cover crops.

In Canada, allelopathy has been attributed for the weed control provided by fall rye cover crops in no-till dry bean production. Flood and Entz (2009) found that fall rye extracts significantly reduced the germination of redroot pigweed (*Amaranthus retroflexus)* and green foxtail (*Setaria virdis)* but not in dry beans. Other studies have found that fall rye has weed control benefits for bean production systems (Shrestha et al.

2002, Bernstein et al. 2012). Blackshaw (2008) found that fall rye cover crops had 36 to 58% lower weed biomass compared to the no-cover control in zero herbicide treatments, resulting in dry bean yields that were 26 to 48 % higher than in the absence of the rye cover crop.

The management of crop residues may influence the strength of allelopathic effects. Soil incorporated crop residues result in faster decomposition and therefore faster release of allelochemicals (Dow et al. 1995). However, Kruidhof et al. (2009), who studied the effects of pre-treatment and placement of winter rye and winter oilseed rape residues on weed seedling emergence, concluded that incorporated residues had a negative effect on early emerging seedlings and a stimulatory effect on late emerging seedlings. Their explanation was allelochemicals can be emitted at low concentrations which can be stimulatory to weed germination, a phenomena described earlier by Lovett et al. (1989). Between cover crop species, treatment of the residues was the most important factor for oilseed rape and placement of the residues was most important for winter rye.  The treatment of residues affected the rate of breakdown, and the subsequent release of allelochemicals (Kruidhof et al 2009).

#### 2.5.2.2 Nitrogen

Researchers have long known that increases of nitrogen, either in the form of nitrate ($NO_3$), ammonium nitrate ($NH_4(NO_3)$) or potassium nitrate ($KNO_3$ ) can promote the germination of weed seeds when light or soil temperature conditions are not conducive to germination (Morinaga 1926, Toole et al. 1956, Fawcett and Slife 1978). In early work on the effect of nitrogen on weeds, a survey of 53 weed species by Steinbauer and Grisby (1957) found that 50% had increased germination in nitrate solutions. Early field studies were interested in the effect of rates and timing of inorganic nitrogen fertilizer applications on weed seed germination (Fawcett and Slife 1978). It is this early work that has led to integrated weed management approaches that focus on exploiting patterns of N availability to reduce the germination of weeds (Liebman and Davis 2000).

In organic systems, cover crops/ green manures are an important component of weed control and nutrient cycling. Therefore, understanding the relationship between how a cover crop influences weeds and soil N offers an opportunity to improve weed control and yields. Factors such as biomass production, cover crop species (C/ N ratio) and management are important variables in nitrogen immobilization and mineralization. Low biomass mulch situations can be stimulatory to weeds as the mulch is quickly decomposed releasing soil nitrate (Gallagher and Cardina 1998, Blum et al. 1997). For example, Teasdale and Pillai (2005) demonstrated that hairy vetch solutions with 15 ppm of ammonium can increase the germination of pigweed species by 115%. Conversely, the temporary immobilization of soil nitrate-N due to high carbon (C/N >30:1) decomposing residues may inhibit germination (Liebman and Mohler 2001).

The management of cover crop residues will also have an effect on N release from cover crop mulches. Generally, soil incorporation and tillage practices that increase the surface area of mulch material (i.e. decrease the particle size) will be metabolized by microbes more quickly than material that is left intact on the soil surface. This more rapid metabolization causes increases in N explained by more rapid mineralization (Malpassi et al. 2000). Wyland et al. (1996) found that winter cover crop plots managed with minimum tillage had spikes in the inorganic nitrate, net mineralizable nitrate and microbial biomass nitrate that decreased within 6 weeks after the initial incorporation.

### 2.6 No-till vs. tillage management of the cover crop

Cover crops are most often seeded in fall, to compete with winter annual weeds after the main crop (E.g. corn, soybean, winter wheat) is harvested and to inhibit seedling emergence in spring. Residue placement is critical for competing with spring growth of weeds, as is attaining sufficient biomass for season long weed control (Teasdale 1996). In the US Midwest and Mid-Atlantic, fall-seeded cover crops are able to produce significant biomass without limiting the availability of these resources for the subsequent main crop due to a warmer, wetter climate and longer growing season. In the semi-arid Prairie regions of the US and Canada, using fall-seeded cover crops in organic no-till (NT) systems is limited by a short growing season, that results in a trade-off between producing sufficient biomass for weed control, seeding conditions for the main crop and excessive moisture use by the cover crop (Carr et al.2012).

Fall-seeded cover crops may be winter annuals (E.g. Fall rye) or spring annuals (E.g. Barley, oats). Spring annuals have the advantage of senescing over the winter. Winter annual cover crops must be terminated as close to the seeding date of the subsequent crop to minimize competition. Podolsky (2013) found that a lag between the termination of pea-barley green manures and main crop seeding resulted in reduced weed control due to mulch decomposition. This was found to be especially important in reduced tillage systems, which rely on cover crop biomass to provide weed control.

Winter annual cover crops can provide extremely effective control, but termination is required the following spring, either through tillage, herbicides or more novel no-till methods. In Alberta, Blackshaw (2008) found that fall rye cover crops had better weed control and higher yields in zero-herbicide NT dry bean production than spring annual barley and oat cover crops seeded in fall.

Cover crop residue management, with or without tillage, is an important factor of weed control. The type of management can have a significant effect on the weed population and density. In Alberta, NT fall rye cover crops had reduced weed densities compared to no-cover control plots (Blackshaw 2008). In Ontario, Swanton et al. (1999) found that the response of weed densities to tillage in fall rye-corn systems was inconsistent; sometimes being higher, lower or the same as NT depending on environmental conditions and relative timing of weed management practices. Tillage can also have a stimulatory response in weeds. Teasdale et al. (1991) found that weed species and population dynamics were affected by tillage in fall rye-corn and hairy vetch-corn systems. In NT production, weeds increased after year 1, however in tillage systems weeds increased after year 2. This was explained by the act of burying seeds in tillage systems, and leaving the seeds on the soil surface under no- till management.

As previously discussed, cover crop residues affect the soil microclimate through various mechanisms (E.g. light, temperature, nitrogen) which can reduce or stimulate weed germination. In one study, the combination of cover crops and no-till management decreased weed density but weed biomass was unchanged, indicating that "sufficient weeds became established to develop a biomass equivalent to the treatment without cover crop" (Teasdale et al. 1991). Teasdale and Mohler (2000) determined that weed emergence rate decreases exponentially with increasing mulch rates up to 1.6 $kg^{-1}ha^{-1}$ . In other studies, increased weed emergence has been observed when mulches provided more favorable conditions for germination, such as when mulches are conserving moisture during droughty periods (Blum et al. 1997, Mohler and Teasdale 1993). A model designed by Teasdale et al. (1991) determines that in order to reduce weed biomass by 75%, there needs to be sufficient biomass to cover 97% of soil.

## 2.7 Fall rye cover crops

### 2.7.1 Fall rye benefits as a cover crop

Fall rye is generally considered to be the most effective winter cover crop for controlling erosion in the colder growing regions of North America. Characteristics that make it suitable are the ability to grow quickly at temperatures as low as 4$^{o}$ C, deep fibrous roots and late seeding option (Sarrantonio and Gallandt 2003). Incorporation of fall rye adds large amounts of carbon to soil, leading to increases in SOM (Canadian Organic Growers 2001). The extensive root systems of fall rye also make it a good catch crop for scavenging nitrate from soil (Feyereisen et al. 2006). Fall rye cover crops are a popular choice as a winter annual cover crop. In addition to organic systems, fall rye is used in conventional corn-soybean systems in the US Midwest and Mid-Atlantic. Corn and soybeans are the predominant crops in these regions, growing 97.3 million acres of corn and 77.1 million acres of soybeans in 2013 (USDA 2013). Due to high amounts of nitrogen fertilizer, herbicides and tillage, cover crops are being promoted as a way to reduce nitrate leaching (Malpassi et al. 2000) and weed pressure in no-till systems (DeBruin et al. 2005).

There has also been increasing no-till research where fall rye is used for weed control (Bernstein et al. 2014, Carr et al. 2012, Flood 2008). It is allelopathic and produces a weed suppressing mulch (Liebl et al. 1992, COG 2001). Table 1 summarizes the use of fall rye in CT and NT systems and the effect on weeds and main crop yield. Fall-seeded and spring terminated fall rye cover crops decreased weed biomass by 63% compared to a no cover crop control in Michigan (Barnes and Putnam 1983). In Alberta, dry beans had lower weed biomass following fall rye than the control, and without herbicides, yields were higher in fall rye treatments than no cover crop (Blackshaw 2008). In Ontario, dry beans and soybeans had lower weed pressure with NT fall rye cover crops than without, and NT rye cover crops increased yields in soybeans (Shrestha et al. 2002). DeBruin et al. (2005) found that rye cover crop performance was dependant on weed pressure, where, under low weed pressure, NT fall rye performed as well as the 2 x herbicide treatment. However, under high weed pressure NT fall rye did not have good weed control. Table 1 summarizes some relevant research on fall rye cover crops, indicating the termination method used and the effect on weeds and main crop yield.

### 2.7.2 Growing fall rye cover crops

#### 2.7.2.1 Establishment and production

Fall rye (*Secale cereale* L.) is a winter annual grain with baking, malting and livestock feed end uses (MAFRD 2012). Rye grows well on sandy loam to clay textured soils. Ideal seeding dates in Manitoba range from August 25 to September 25. Seeding should be timed to allow rye growth to the 5 to 6 leave stage (10 – 15 cm) before freeze up (COG 2001). Ideal seeding depth is 2.5 cm (MAFRD 2012). Rye is extremely cold hardy, frost and weed resistant. It also does well in droughty conditions. However, fall rye cannot tolerate salinity or excess moisture (McLelland 1999). In a typical growing season, fall rye can reach 1.5 m in height, such that, it can produce 4.5 - 10 t/ ha of straw (COG 2001). Fall rye can be harvested in late July or early August.

#### 2.7.2.2 Termination of rye cover crops

Fall rye can be managed with tillage, herbicides or mowing. The timing and method determines the level of competition between rye regrowth and residue with the subsequent crop. Ideally, termination should occur as closely to cash crop seeding as possible (Canadian Organic Growers 2001). An advantage of termination with tillage is that it can occur immediately prior to seeding. However, tillage will also incorporate residues and not result in a mulch for weed suppression.

Mowing is an important technique for organic and reduced input systems (DeBruin et al. 2005; Wilkins and Bellinder 1996). A challenge with using mow kill systems is timing of the mowing relative to crop phenology. The goal is to terminate so there is little to no regrowth of fall rye. Wilkins and Bellinder (1996) found that when they compared mowing at rye first node, boot, 100% head and watery kernel, the most effective kill was after flowering. Delaying rye termination until this time means that energy reserves are being directed to kernal filling, rather than vegetative growth, which means there are limited root reserves to redirect into vegetative growth once again (Mirsky et al. 2009). In addition, if mowing occurs at later dates, this can lower soil temperatures and remove excessive amounts of moisture, which could be negative in short growing season situations (Wilkins and Bellinder 1996). There is a risk of any regrowth, no matter how few, to mature and shatter, leaving seeds on the soil surface (Wilkins and Bellinder 1996). However, mowing will not control weeds that can survive mowing, such as those with rhizomes or low seed heads (Ross and Lembi 1985).

Regrowth is also influenced by the uniformity of the distribution of the mowed residue. Thus, sickle bar or flail mower are considered more suitable for mow kill management than rotary mowers which were observed to distribute residue more heavily on one side (i.e., windrowing) (Wilkins and Bellinder 1996).

**Table 1.** Summary of relevant research on fall rye cover crops managed using conventional tillage (CT) and no-till (NT) methods, and the effect on weeds and main crop yield.

| Authors | Location | Main crop | Termination method | Weed control | Main crop yield |
|---|---|---|---|---|---|
| Barnes and Putnam (1983) | Michigan, USA | Peas (*Pisum sativum* L. cv. Sparkle) | NT (Herbicides) | Reduced by 94% of no cover control | No effect of rye on pea yield |
| Bernstein et al. (2014) | Wisconsin, USA | Soybean (*Glycine max*) | Tillage and No-till (Mowing, blade roller) | NT fall rye termination controlled weeds 75% of control | Soybean yield was reduced by 24% in NT treatments |
| Blackshaw (2008) | Alberta | Dry bean (Phaseolus vulgaris L.) | NT (Herbicides) | Lower weed density with fall rye than no cover crop | Dry beans (no in-crop herbicide) after fall rye resulted in 20 - 90 % higher yields than without fall rye |
| De Bruin et al.(2005) | Minnesota, USA | Soybean (*Glycine max*) | Mowing (1 x), Mowing (2 x), Herbicide (1 x), Herbicide (2 x ), Mowing + Herbicide (1x) | Mowing (1 x) as good as herbicide (2 x) in low weed pressure. Mowing (1 x or 2 x) not as good as mowing + Herbicide in high weed pressure | No difference |
| Flood (2008) | Manitoba | Dry bean (*Phaseolus vulgaris* L.) | CT vs. NT (Herbicides) | Rye decreased weed biomass 3 out of 4 years | Rye increased yield 1 year out of 4, yielded the same as no cover 2 years out of 4, decreased yield 1 year out of 4 |
| Liebl et al. (1992) | Illinois, USA | Soybean (*Glycine max*) | NT (Herbicides) | Reduced by 90% of corn stubble | Late-killed rye had reduced yields compared to early-killed rye. Early-killed rye was comparable to conventional. |
| Shrestha et al. (2002) | Ontario | Dry bean (*Phaseolus vulgaris* L.) Soybean (*Glycine max*) | CT vs. NT (Herbicides) | Higher weed pressure in CT than NT | Soybean yields highest in cover crop treatments |
| Swanton et al. (1999) | Ontario | Corn (*Zea mays* L.) | CT vs. NT (Herbicides) | Reduced 1 year out of 3 | No difference between CT and NT |
| Wagner-Riddle et al. (1994) | Ontario | Soybean (*Glycine max*) | NT (Herbicides) | n/a | No difference |

### 2.7.3 Challenges of fall rye cover crops

Although fall rye can be an excellent cover crop, it is not a one size fits all solution to weed management challenges in no-till or organic systems. Constrained by a short growing season and relatively low rainfall (300 to 500 mm annually), termination timing is the primary challenge to incorporating fall rye into crop rotations in the Northern Great Plains (Carr et al. 2012). Without chemical termination as an option, organic producers are very limited in mechanical termination options. As previously discussed, the literature has shown that NT termination methods like the blade roller or mowing are more successful when termination coincides with fall rye anthesis. However, if a producer waits until time there may be potentially negative effects on the subsequent crop.

Timing of termination is the most significant factor in decreased yields of the subsequent main crop. Soybean yields were lower after rye cover crops were terminated at soybean seeding compared to yields after rye cover crops that were terminated two weeks prior to seeding. Yields were explained by soybean stand reductions after late killed rye (Liebl et al. 1992). When rye is terminated early using herbicides and incorporated with tillage, yields were similar or higher than the conventional system, when soybeans are planted in corn stubble without tillage (Liebl et al. 1992). In Minnesota, DeBruin et al. (2005) compared combinations of mowing and herbicide applications for spring termination of a fall-seeded fall rye cover crop prior to planting soybeans. The authors found that when rye was terminated early (early to mid-May), "regrowth was similar to that of uncut rye but decreased dramatically when mowed at anthesis in early June." Decreased soybean yields in these treatments was attributed to increased competition from rye regrowth. However, if rye treatments were managed with a secondary weed control, using either mowing or herbicide, soybean yields after a fall rye cover crop were often comparable to yields in a two-pass herbicide, no cover crop treatment (DeBruin et al. 2005).

Timing and method of fall rye termination will influence seeding conditions for the main crop. The consequences of delayed seeding are typically seen as delayed development, emergence and sometimes decreased yields. In Alberta, Blackshaw (2008) found that fall-seeded rye cover crops terminated 1 -2 days prior to main crop planting caused delayed dry bean emergence by 3 - 4 days compared to the no-cover control, increasing the time to maturity in 2 years of 3years. In Minnesota, a late planting date caused by delayed rye management caused a 30% reduction in soybean establishment in 1 out of 4 site-years. In addition to timing, rye terminated with mowing caused reduced soybean establishment compared to rye terminated with herbicides but this did not translate into a yield penalty (DeBruin et al. 2005). Similarly, Liebl et al. (1992) found that stand reductions resulted in reduced soybean yields in late-killed rye (at soybean planting) compared to early-killed rye (2 weeks prior to soybean planting). In the above mentioned studies, authors cited cooler soil temperatures (Blackshaw 2008), competition for resources (DeBruin et al. 2005), large amounts of residue and allelopathy (Liebl et al. 1992) as causes for the negative effects on main crop growth and development. Thus, the same characteristics that make rye such a strong competitor with weeds also makes it challenging to incorporate as a cover crop in reduced tillage or herbicide-free crop rotations.

**2.7.4 Literature Cited**

Agriculture and Agri-Food Canada. 2005. Crop profile for dry bean in Canada. Pest Management Centre-Pesticide Risk Reduction Program. Ottawa, Ontario.

Araujo, A.P. and M.G. Teixeira. 2008. Relationship of grain yield and accumualtion of biomass, nitrogen and phosphorus in common bean cultivars. R. Bras. Ci. Solo. 32:1977-1986.

Barnes, J.P. and A.R. Putnam. 1983. Rye residues contribute weed suppression in no-tillage cropping systems. J. Chemical Ecol. 9(8):1045-1057.

Bernstein, E.R., D.E. Stoltenberg, J.L. Posner, and J.L. Hedtcke. 2014. Weed community dynamics and suppression in tilled and no-tillage transitional organic winter rye-soybean systems. Weed Sci. 62: 125-137.

Bernstein, E.R., J.L. Posner, D.E. Stoltenberg, and J.L. Hedtcke. 2011. Organically managed no-tillage rye-soybean systems: Agronomic, economic and environmental assessment. Agron. J. 103:1169–1179

Blackshaw, R.E. 2008. Agronomic benefits of cereal cover crops in dry bean production systems in western Canada. Crop Protection. 27:208-214.

Blackshaw, R.E. and L.J. Molnar. 2008. Integration of conservation tillage and herbicides for sustainable dry bean production. Weed Technology. 22(1):168-176.

Blackshaw, R.E., L.J. Molnar, G.W. Clayton, K.N. Harker and T. Entz. 2007. Dry bean production in zero and conventional tillage. Agron. J. 99:122-126.

Blevins, R.L., D. Cook, S.H. Phillips and R.E. Phillips. 1971. Influence of no-tillage on soil moisture. Agron. J. 63:593-596.

Bottenberg, H., J.Masiunas, C. Eastman and D.Eastburn. 1997. The impact of rye cover crops on weeds, insects and diseases in snap bean cropping systems. Journal of Sustainable Agriculture. 9:131-155.

Brady, N.C. and R.R. Weil. 2002. The nature and property of soils. 13th ed. New Jersey: Pearson Education.

Burgess, J. 1985. An introduction to plant cell development. Cambridge University Press. Cambridge, United Kingdom.

Carr, P.M., R.L. Anderson, Y.E. Lawley, P.R. Miller and S.F. Zwinger. 2012. Organic zero-till in the northern US Great Plains Region: Opportunities and obstacles. Renewable Agriculture and Food Systems Renewable Agric. Food Syst. 27 (1 ): 12-20.

Carson, P. L. 1980. Recommended potassium test. p. 12-13. In W. C. Dahnke, (ed.). Recommended chemical soil test procedures for the North Central Region. North Central Region Publication 221 (revised). N.D. Agric. Exp. Stn., Fargo, N.D
Dabney, S.M., J.A. Delgado amd D.W. Reeves. 2001. Using winter cover crops to improve soil and water quality. Commun. Soil sci. plant anal. 37(7&8):1221-1250.

DeBruin, J.L., P.M.Porter and N.R.Jordan. 2005. Use of a rye cover crop following corn in rotation with soybean in the Upper Midwest. Agron. J. 97:587-598.

Diver, S. 2002. Flame weeding for vegetable crops. Approproate Technology Transfer for Rural Areas (ATTRA). [Online] Available:http://www.agrisk.umn.edu/uploads/ARL02969.pdf [2014 Dec 12].

Doran, J.W. and M.S. Smith. 1991. Role of cover crops in nitrogen cycling In: Cover crops for clean water. Soil Water Cons. Soc. P. 85-107.

Drinkwater, L.E., R.R. Janke and L. Rossoni-Longnecker. 2000. Effects of tillage intensity on nitrogen dynamics in legume-based grain systems. Plant and Soil. 227:99-113.

Duiker, S.W. 2014. Penn State Extension. Crop and Soil Management Section 10: Cover crops.[Online] Available: http://extension.psu.edu/agronomy-guide/cm/sec10

Entz, M. H., R. Guilford and R. Gulden. 2001. Crop yield and soil nutrient status on 14 organic farms in the eastern portion of the northern Great Plains. Can. J. Plant Sci. 81(2):351-354.

Ferraz, L.C.L., A.C. Filho, L.C.B. Nasser and J. Azevedo. 1999. Effects of soil moisture, organic matter and grass mulching on the carpogenic germination of sclerotia and infection of bean by Sclerotinia sclerotiorum. Plant Pathology. 48:77-82.

Flood, H. 2008. Fall rye cover crops increase sustainability of dry bean production. M.Sc. Thesis. University of Manitoba. Winnipeg, Manitoba.

Flood, H. E. and M.H. Entz. 2009. Effects of wheat, triticale and rye plant extracts on germination of navy bean (*Phaselous vulgaris*) and selected weed species. Can. J. Plant Sci. 89:999-1002.

Francis, C.A., M. Prager and G. Tejada. 1982. Effects of relative planting dates in bean (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.) intercropping patterns. Field Crops Research 5: 45-54.

Gardiner, T. R., and L.E. Craker. 1981. Bean growth and light interception in a bean-maize intercrop. Field Crops Research. 4: 313-320.

Graham, P. H. and P. Ranalli. 1997. Common bean (*Phaseolus vulgaris* L.).Field

Crops Research. 53(1): 131-146.

Grime, J. P., G. Mason, A. Curtis, J. Rodman and S.R. Band, S. R. 1981. A comparative study of germination characteristics in a local flora. The Journal of Ecology, 1017-1059.
Halde, C., R.H. Gulden and M.H. Entz. 2014. Selecting cover crop mulches for organic rotational no-till systems in Manitoba, Canada. Agron. J. 106(4): 1193-1204.

Huffman, S. A., and K. A. Barbarick. 1981. Soil nitrate analysis by cadmium reduction 1. Communications in Soil Science & Plant Analysis 12.1: 79

Kantar, M., and P. Porter. 2014. Relationship between planting date, growing degree days and the winter rye (L.) variety "Rymin" in Minnesota. Crop Management. 13(1):

Kelner, D. J., J.K. Vessey and M.H. Entz. 1997. The nitrogen dynamics of 1-, 2-and 3-year stands of alfalfa in a cropping system. Agriculture, Ecosystems & Environment. 64(1):1-10.

Kruidhof, H. M., L. Bastiaans and M.J. Kropff. 2008. Ecological weed management by cover cropping: effects on weed growth in autumn and weed establishment in spring. Weed Research. 48(6): 492-502.

Kruidhoff, H.M., L. Bastiaans and M.J. Kropff. 2009. Cover crop residue management for optimizing weed control. Plant Soil. 318:169-184.

Lebaron, M. J. (1974). A description: Developmental stages of the common bean plant. University of Idaho, College of Agriculture, Cooperative Extension Service, Current Information Series, P. 228.

Liebl, R., F.W. Simmons, L.M. Wax and E.W. Stoller. 1992. Effect of rye (*Secale cereale*) mulch on weed control and soil moisture in soybean (*Glycine max*). Weed Tech. 6:838-846.

Lund, R.E. 1975. Tables for an approximate test for outliers in linear models. Technometrics. 17 (4): 473-476.

Malhi, S. S., R. Lemke, Z.H. Wang and B.S. Chhabra. 2006. Tillage, nitrogen and crop residue effects on crop yield, nutrient uptake, soil quality, and greenhouse gas emissions. Soil and Tillage Research. 90(1):171-183.

Manitoba Agriculture, Food and Rural Development. 2011. Field beans - Production. [Online] Available http://www.gov.mb.ca/agriculture/crops/production/field-beans.html [2011 May].

Meisinger J.J., W. L. Hargrove, R. L. Mikkelsen, J. R. Williams, and V. W. Benson. 1991. Effects of cover crops on groundwater quality. Soil Water Cons. 57-84.

Mirsky, S.B., W.S. Curran, D.A. Mortensen, M.R. Ryan, and D.L. Shumway. 2009. Control of cereal rye with a roller/crimper as influenced by cover crop phenology. Agron. J. 101 (6): 1589 -1596.

Mwaja, V.N., J.B.Masiunas and L.A. Weston. 1995. Effects of fertility on biomass, phytotoxicity and allelochemical content of cereal rye. J. Chemical Ecol. 21(1):81-95.

Olsen, S.R. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular, March 1954. Washington, DC. 939:1-19

Ontario Ministry of Agriculture, Food and Rural Affairs. 2009. Dry Edible Beans: Planting and Crop Development. [Online] Available: http://www.omafra.gov.on.ca/english/crops/pub811/5planting.html [2014 Oct 25]

Podolsky, K. 2013. Reduced tillage implements for management of an organic green manure: effects on nitrogen, weeds and wheat yield. M.Sc. Thesis. University of Manitoba. Winnipeg, Manitoba.

Posner, J. L., J.O. Baldock and J.L. Hedtcke. 2008. Organic and conventional production systems in the Wisconsin integrated cropping systems trials: I. Productivity 1990–2002. Agron. J. 100(2): 253-260.

Putnam, A. R., M.G. Nair, J.P. Barnes, R.R. Baker and P.E. Dunn. 1990. Allelopathy: a viable weed control strategy. In New directions in biological control, alternatives for suppressing agricultural pests and diseases. Proceedings of a UCLA colloquium held at Frisco, Colorado, January 20-27, 1989. (pp. 317-322). Wiley-Liss Inc.

Reicosky, D.C.,W.D. Kemper, G.W. Langdale, C.L. Douglas, Jr., and P.E. Rasmussen. 1995. Soil organic matter changes resulting from tillage and biomass production. J. Soil and Water Cons. 50 (3):253-261.

Ruffo, M.L., D.G. Bullock and G.A. Bollero. 2004. Soybean yield as affected by biomass and nitrogen uptake of cereal rye in winter cover crop rotations. Agron.J. 96 (3): 800-805.

Sarrantonio, M. and E. Gallandt. 2003. The role of cover crops in North American cropping systems. J. Crop Prod. 8:53-74.

Sarrantonio, M., and T. W. Scott. 1988. Tillage effects on availability of nitrogen to corn following a winter green manure crop. Soil Science Society of America Journal 52.6: 1661-1668.

SAS Institute Inc. 2001. Version 9.2. SAS Institute, Cary, NC.

Saskatchewan Agriculture. 2015 [Online] Available: http://www.agriculture.gov.sk.ca/Varieties-Grain-Crops-2015

Saskatchewan Pulse Growers. 2000. Pulse Production Manual. Saskatchewan Pulse

Growers. Saskatoon, SK.
Shrestha, A., S.Z. Knezevic, R.C. Roy, B.R. Ball-Coelho and C.J. Swanton. 2002. Effect of tillage, cover crop and crop rotation on the composition of weed flora in a sandy soil. Weed Research. 42:76-87.

Singer, J.W., S.M. Nusser and C.J. Alf. 2007. Are cover crops being used in the US corn belt? J. Soil and Water Cons. 62:353-358.

SARE 2015. 2014-2015 Annual report cover crop survey. Sustainable Agriculture Research and Education.[Online] Available: http://www.ctic.org/media/pdf/20142015CoverCropReport_Draft6.pdf
Swanton, C.J., A. Shrestha, R.C. Roy, B.R. Ball-Coehlo and S.Z. Knezevic. 1999. Effect of tillage systems, N, and cover crop on the composition of weed flora. Weed Sci. 47:454-461.

Teasdale, J. R., and C.L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agron. J. 85(3): 673-680.

Teasdale, J.R. 1993. Interaction of light, soil moisture and temperature with weed suppression by hairy vetch residue. Weed Sci. 41:46-51.

Teasdale, J.R. and C.L. Mohler. 2000. The quantitive relationship between weed emergence and the physical properties of mulches. Weed Sci. 48:385-392.

Teasdale, J.R., C.E. Beste and W.E. Potts. 1991. Response of weeds to tillage and cover crop residues. Weed Sci. 39:195-199.

Uchino, H., K. Iwama, Y. Jitsuyama, T. Yudate and S. Nakamura. 2009. Yield losses of soybean and maize by competition with interseeded cover crops and weeds in organic-based cropping systems. Field crops research. 113(3): 342-351.

Vaisman, I., M.H. Entz, D.N. Flaten and R.H. Gulden. 2011. Blade roller–green manure interactions on nitrogen dynamics, weeds, and organic wheat. Agron. J. 103(3): 879-889.

Varco, J. J., W.W. Frye, M.S. Smith and C.T. MacKown. 1993. Tillage effects on legume decomposition and transformation of legume and fertilizer nitrogen-15. Soil Sci. Soc. Amer. J. 57(3): 750-756.

Wagner-Riddle, C., T.J. Gillespie and C.J. Swanton. 1994. Rye cover crop management impact on soil water content, soil temperature and soybean growth. Can. J. Plant Sc. 74:485-495.

Weston, L. A.1996. Utilization of allelopathy for weed management in agroecosystems. Agron. J. 88(6):860-866.

Wilkins, E.D. and R.R. Bellinder. 1996. Mow-kill regulation of winter cereals for spring no-till crop production. Weed Tech. 10:247-252.

Wilson, J. B. 1988. Shoot competition and root competition. Journal of Applied Ecology, 279-296.

Yield Manitoba 2013 [Online] Available:
http://www.mmpp.com/mmpp.nsf/mmpp_publications.html
Zyla, L. E., R. L. Kushwaha, and A. Vandenberg. 2002. Development of a new crop lifter for direct cut harvesting dry bean. Canadian Biosystems Engineering 44: 2-9.

## 3.0 AGRONOMIC EFFECTS OF FALL SEEDED CEREAL COVER CROPS ON ORGANIC DRY BEANS AND WEEDS

### 3.1 Abstract

Fall-seeded cover crops can be a valuable tool in integrated farming systems. There has been substantial research on fall rye cover crops for controlling weeds in soybeans but few studies have examined its use for other pulse crops in Canada. The objective of this study was to characterize the effects of fall rye (*Secale cereal* L.), barley (*Hordeum vulgare* L.) and oat (*Avena sativa* L.) cover crops on weed control in organic *Phaseolus* beans. Both tillage (T) and no-till (NT) management of the cover crop residue were tested. This study was conducted at the Ian N. Morrison research farm in Carman, Manitoba and repeated twice. Cover crops were seeded in fall of each year (2010 and 2011). The annual cover crop species (barley and oat) winter killed, and were either tilled or left untilled. Fall rye was not tilled until immediately prior to dry bean seeding. To facilitate no-till, fall rye termination beans were seeded into growing rye and rye was mowed once it reached full anthesis. This occurred 18 days after planting (DAP) in 2011 and 11 DAP in 2012. Spring soil nitrate-N levels were similar for barley, oat and no cover crop treatments, but fall rye treatments were significantly lower in both years. Weed biomass at bean harvest was significantly lower in fall rye cover crops under NT management compared with all other treatments. Bean above ground biomass at maturity was affected by year but not cover crop or tillage management. Under high indigenous soil nitrate-N in 2012, weed and crop biomass were 59 % and 49 % higher than under lower indigenous soil N in the 2011 experiment. The highest bean seed yields were in the

barley, oat and no cover crop treatments; yields were significantly lower in fall rye treatments. Oat and barley planted in fall were not different in all parameters as treatments with no cover crop suggesting that fall cover could be combined with no yield penalty for beans. No-till treatments provided superior weed control to till treatments. No-till yields were as high as tillage treatment yields 1 year out of 2. Research results indicate that NT fall rye can provide season long weed control, however further research is needed on its management to reduce its competitiveness with the cash crop.

### 3.2 Introduction

There has been growing interest by organic producers in reducing the reliance on tillage for weed control. Frequent tillage is linked to soil degradation through the loss of organic matter, which can lead to decreased water holding capacity, soil structure and stresses soil microbial populations (Reikosky et al. 1995). Common organic pulse production practices include row-cropping and frequent inter-row tillage operations (rotary hoeing, tine weeding, inter-row cultivation) (Bernstein et al. 2011, Posner et al. 2008). Incorporating fall rye cover crops into conventional pulse production has been shown to reduce tillage, scavenge and recycle soil N and compete with weeds (DeBruin et al. 2005, Blackshaw 2008, Wagner-Riddle et al. 1994, Flood 2008). Therefore, there is interest in modelling an organic pulse production system after fall rye - soybean (*Glycine max*) systems that are common in the Midwestern United States.

A challenge with fall-seeded cover crops in Canada is our relatively short growing season and low annual precipitation (~350 - 550 mm), compared to regions that have had success with fall rye - soybean in the United States (e.g., Illinois, Wisconsin, Ohio). More commonly, organic producers in Canada have shifted towards taking an entire growing season to produce a green manure crop (Entz et al. 2001). Researchers have shown that taking a full growing season can produce enough biomass to provide season long weed control in the subsequent year (Vaisman et al. 2011, Halde et al. 2014). Although these systems show great potential for weed control and nutrient cycling, it does involve incurring a season without the sales of grain. Therefore, research into fall-seeded cover crops is warranted.

The most significant limitation to incorporating fall-seeded cover crops into Western Canadian organic farms is termination methodology of the cover crop. Research on organic NT and fall-seeded cover crops is limited. The present study is the first study on organic NT fall rye cover crops in Canada. In Wisconsin, Bernstein et al. (2014) found NT termination methods (blade roller vs. mowing) in organic soybeans provided effective weed control and were determined to be a successful alterative to tillage. A possible alternative to fall rye is a fall-seeded spring annual cereal, which would not have to be terminated since it will winter kill. Fall-seeded oat and barley proved effective in weed control in Alberta (Blackshaw 2008).

The overall goal of this study was to characterize the effect of fall-seeded cover crops on weeds in organic dry beans. Specific objectives were a) to compare the effect of a winter annual cereal cover crop to spring annual cereal cover crops on weeds and beans, and b) to compare the effect of spring cover crop residue management (till or no-till) on weeds and the main crop, dry edible beans.

## 3.3 Materials and methods

### 3.3.1 Site description

This study was conducted in Carman, Manitoba at the University of Manitoba's Ian N. Morrison Research Station between 2010 and 2012. The experiment was repeated once (2010/2011) under low indigenous soil N conditions and once (2011/2012) under high indigenous soil N conditions. In 2011, the experiment area was previously barley green feed and in 2012, the site was barley green feed after three years of alfalfa. Both sites were previously managed without chemicals; the location used in 2011 has been managed organically since 2002 and the location used in 2012 was managed without chemicals for four years prior to the present study. Soil series of both locations were Denman Series, which are characterized as an Orthic Black Chernozem with a sandy clay loam surface texture. Spring soil tests indicate that there were differences in background nitrogen and potassium, but not phosphorus (Table 2). An investigation into differences in macronutrients is described in section 2.4.1.

**Table 2.** Soil series, previous crop, sampling date, soil nutrient status at dry bean seeding for two years at the Ian N. Morrison research farm in Carman, MB.

| Year | Soil Series | Previous Crop Rotation | Sampling Date | Nitrate-N | Olsen-P | $K_2O_5$ |
|---|---|---|---|---|---|---|
| | | | | ----------------kg $ha^{-1}$ | --------------- | |
| 2011 | Denham Series | Organic research trial (2009) - Barley green feed (2010) | June 10 | 20 | 35 | 350 |
| 2012 | Denham Series | Alfalfa (2008 - 2010) - Barley green feed (2011) | June 1 | 53 | 39 | 942 |

### 3.3.2 Weather

The 2011 and 2012 growing seasons experienced markedly different precipitation patterns in Carman. The fall of 2010 was very wet, with 72 % of total growing season precipitation falling between August and October. These wet conditions affected cover crop establishment requiring the reseeding of fall rye. This was followed by a wet April and May, and then a drier June, July and August. The fall of 2011 had warm and drier growing conditions for cover crops, which were seeded on August 31. The spring of 2012 experienced only slightly higher (7%) than the long term average precipitation for May and June. Although the conditions were wetter in the spring of 2011, 2012 had higher total growing season precipitation (Table 3). There was little variation in the mean monthly temperatures across all years, and as compared to the 30 year average (Table 3).

**Table 3.** Total monthly precipitation and mean monthly temperature during the 2010, 2011 and 2012 growing seasons at Carman, Manitoba (Manitoba Agriculture, Food and Rural Development). Growing season (April 15 – September 15) and monthly long term averages.

| Year | Apr. | May | Jun. | Jul. | Aug. | Sept. | Oct. | Growing Season† |
|---|---|---|---|---|---|---|---|---|
| Precipitation (mm) | | | | | | | | |
| 2010 | 35.3 | 159.2 | 73.2 | 48 | 138.4 | 106.5 | 56.7 | 418.8 |
| 2011 | 43.6 | 72.0 | 59.2 | 37.6 | 12.2 | 64.5 | 7.8 | 181.0 |
| 2012 | 18.5 | 63.2 | 86.2 | 27.8 | 47.2 | 2.9 | 84.5 | 224.4 |
| LTA‡ | 30.9 | 59.8 | 75.5 | 73.5 | 66.8 | 59.5 | 43.8 | 275.6 |
| Temperature ($^{0}$C) | | | | | | | | |
| 2010 | 8.7 | 11.6 | 16.4 | 19.6 | 18.7 | 11.8 | 8.3 | 16.6 |
| 2011 | 4.4 | 10.4 | 16.7 | 20.3 | 19.3 | 14.0 | 8.7 | 16.7 |
| 2012 | 6.5 | 12.2 | 17.7 | 21.9 | 19.0 | 12.5 | 4.2 | 17.7 |
| LTA‡ | 4.4 | 12.4 | 17.2 | 19.7 | 18.1 | 12.2 | 5.7 | 16.9 |

† Growing season is April 15 to September 15.
‡ Monthly long term averages (1971-2001) for Graysville, MB (Environment Canada), 14 km west of Carman.

### 3.3.3 Experimental design

The experimental design was a randomized complete block in a split plot arrangement. Each block was replicated four times. The dimensions of the experimental units were: Main plots measured 4 m x 8 m and subplots measured 2 m x 8 m. The main plot treatment was cover crop species: Fall rye, barley, oat or a no cover crop control. Immediately prior to seeding dry beans, the subplot tillage treatment (tillage or no-till) was applied. Barley, oat and control no-till subplots were treated with flaming prior to bean emergence, while fall rye no-till subplots were mowed. Table 4 summarizes field operations and the timing of treatment application in 2011 and 2012.

**Table 4.** Summarized field operations and timing in 2011 and 2012. Fall rye with tillage (Fall rye + T), fall rye without tillage (Fall rye + NT), barley with tillage (Barley + T), barley without tillage (Barley + NT), oat with tillage (Oat + T), oat without tillage (Oat + NT), control with tillage (Control + T) and control without tillage (Control + NT).

| | Field Operation | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2011 | | | | 2012 | | | |
| Treatment | Dry bean seeding | Tillage | Flaming | Mowing | Dry bean seeding | Tillage | Flaming | Mowing |
| Control + T | June 6 | June 6 | n/a† | n/a | June 1 | June 1 | n/a | n/a |
| Fall rye + T | June 6 | June 6 | n/a | n/a | June 1 | June 1 | n/a | n/a |
| Barley + T | June 6 | June 6 | n/a | n/a | June 1 | June 1 | n/a | n/a |
| Oat + T | June 6 | June 6 | n/a | n/a | June 1 | June 1 | n/a | n/a |
| Control + NT | June 6 | n/a | June 10 | n/a | June 1 | n/a | June 6 | n/a |
| Fall rye + NT | June 6 | n/a | n/a | June 24 | June 1 | n/a | n/a | June 12 |
| Barley + NT | June 6 | n/a | June 10 | n/a | June 1 | n/a | June 6 | n/a |
| Oat + NT | June 6 | n/a | June 10 | n/a | June 1 | n/a | June 6 | n/a |

† n/a: *not applicable.* Field operation was not performed for that given treatment.

***Establishing cover crops***. The establishment of the experiment began with cover crop seeding in the fall of 2010 and 2011. Tillage with a cultivator was done prior to seeding all cover crop treatments. Fall rye, oats and barley were seeded to 3.5 to 4 cm depth at 100 kg $ha^{-1}$, 85 kg $ha^{-1}$ and 100 kg $ha^{-1}$, respectively. Due to wet conditions in the fall of 2010, fall rye had to be reseeded on September 20$^{th}$, 2010. Cover crop cultivar, seeding date and seeding rate are summarized in Table 5.

**Table 5.** Cover crop cultivar, seeding date and seeding rate at each site year location.

| Year | Crop | Cultivar | Seeding Date | Seeding Rate |
|---|---|---|---|---|
| | | | | kg $ha^{-1}$ |
| 2010 | Fall Rye | Hazlet | September 20 | ~ 100 |
| | Oats | Leggett | August 30 | ~ 85 |
| | Barley | AC Metcalfe | August 30 | ~ 100 |
| 2011 | Fall Rye | Hazlet | August 31 | ~ 100 |
| | Oats | Leggett | August 31 | ~ 85 |
| | Barley | AC Metcalfe | August 31 | ~ 100 |

***Dry bean seeding***. Dry bean seeding occurred on June 6 in 2011 and June 1 in 2012. Prior to seeding, main plots were randomly assigned tillage and NT treatments. Tillage was achieved using a rotovator operating at a soil depth of 7 to 8 cm. Navy beans (cv. Envoy) were inoculated at recommended rates using Nodulator © Becker Underwood, a GMO free peat based inoculant. Beans were seeded to a 2.5 cm depth in 15 cm row spacing using an offset disc opener zero-till drill. No-till treatments were seeded directly into any residue present. The seeding rate in all cases was 130 kg $ha^{-1}$, based on recommended seeding rates for solid seeded dry beans (Manitoba Agriculture, Food and Rural Development 2011).

***Flame weeding***. Controlling weeds with heat, or flame weeding, can be an alternative to mechanical weed control. Flaming is a common practice in high value organic vegetable production, where it can replace inter-row cultivations (Diver 2002). In this study, flaming was applied to barley, oat and control no-till plots during the time period between dry bean seeding and emergence. Flaming was conducted using a propane fuelled "Tiger Torch". In this experiment, cover crop was considered the primary method of weed control, while the secondary method of weed control was either tillage (in the tillage treatments) or flaming (in the NT treatments).

The flaming procedure began at one end of the subplot, the torch was moved across the width of the plot with sweeping motions. Time was kept to ensure time spent working end to end was approximately 12 minutes for each experimental unit. The purpose of flaming is not to burn but to wilt plant material. Heat causes plant cells to rupture, and weeds to die back to the apical meristem (Diver 2002). In 2011, a fuel shortage went unnoticed in block 2, 3 and 4, so subplots were hand weeded on June 24, 2011. This was done using a sickle blade, without uprooting weeds to ensure minimal soil disturbance. The clipped weed biomass was left in the plots on the soil surface.

***No-till fall rye termination***. Fall rye is used in reduced tillage systems because it often provides exceptional weed control (DeBruin et al. 2005). However, since it is a winter annual, it requires termination in spring to avoid competition with the cash crop. Termination without tillage in an organic system can be accomplished with mowing or using the blade roller. Previous research indicates the most effective time to terminate fall rye using a NT mechanical method is at 90 % anthesis (Wilkins and Bellinder 1996). This timing coincides with the plant shifting energy from vegetative growth to reproductive development. At this point, the plant has exhausted root reserves and is susceptible to damage. Mowing was chosen for this study because it allowed for dry bean seeding to occur at the appropriate time. A blade roller, due to its design, would have meant waiting until after rye was terminated to seed beans, and would have resulted in an unacceptable delay of bean seeding.

Fall rye in NT treatments was mowed with a flail mower adjusted above the height of growing dry beans. Mowing was done in one pass of the tractor. In 2011, mowing occurred 18 days after planting (DAP) and 11 DAP in 2012. Residue from mowed rye was left on the plot, or put back on if blown off during mowing. Edges that were not mowed were clipped with garden shears to prevent an edge effect.

### 3.3.4 Data collection

***Fall and spring cover crop biomass***. Cover crop biomass was measured in late fall in the year of establishment. Fall rye biomass was sampled again prior to dry bean seeding and fall rye regrowth was measured at bean harvest. Plots were sampled using a ¼ meter quadrat randomly placed twice per subplot from opposite ends of the plot. Edges were avoided when sampling. Biomass was sorted (rye plants from weeds) and plant material was placed in the oven to dry at 60º C for at least 72 hours. Oven dried samples were then weighed.

***Gravimetric soil moisture content***. Gravimetric soil moisture content was measured using a composite sample of two subsamples per main plot taken from three soil depths: 0 – 15 cm, 15 - 30 cm and 30 - 60 cm. Each cover crop was sampled separately for both till and no-till subplot. The reason for this is that sampling occurred 4 DAP and 3 DAP in 2011 and 2012, respectively. Although each depth was processed separately, during analysis soil depths were combined to provide a total soil moisture content (0 - 60 cm). In 2012, four sample bags ripped and soil was lost from the samples after being dried. Damaged samples were recorded and removed from analysis.

Wet samples were weighed immediately and transferred to an oven set at 60º C to dry for at least 72 hours. Oven dried soil samples were reweighed and gravimetric soil moisture was calculated using the following formula:

$$\text{Gravimetric soil moisture (g } H_2O/\text{ g soil)} = \frac{\text{Soil wet weight (g)} - \text{soil dry weight (g)}}{\text{Soil dry weight (g)}}$$

[Eq.1]

***Spring soil nutrient status.*** Treatments from the experiment were sampled for soil nitrate-N, phosphorus (Olsen-P) and potassium ($K_2O$) in spring at the time of dry bean seeding. A composite sample from the upper 15 cm of the soil profile was sampled using a soil probe (3 cm diameter) at two depths, 0 – 5 cm and 5 – 15 cm. Soil was sampled using a "W" pattern positioned lengthwise through the plot. In 2011, a composite sample of five cores per experimental unit was collected. In 2012, to ensure a more representative sample size, this was increased to 8 composites per experimental unit. Samples were stored at 4º C until shipped to Agvise laboratories (Northwood, ND). Analysis for soil nitrate-N used the cadmium reduction method (Huffman and Barbarick 1981), Olsen bicarbonate-P method for phosphorus ($P_2O_5$) (Olsen 1954) and the ammonium acetate exchangeable K test for potassium ($K_2O$) (Carson 1980). To convert parts per million (ppm) to kilograms per hectare, a soil bulk density of 1000 $kg/m^{-3}$ was assumed.

***Dry bean population***. In 2011, dry bean plant population density was measured using a ¼ meter quadrat at three randomly selected locations per subplot. Since dry beans were seeded in 15 cm rows, this area encompasses two bean rows 25 cm in length. The quadrat was placed 1 meter from the ends of the plot, with approximately 2 meters separating subsequent placements. Placement was away from plot edges. In 2012, dry bean population was sampled twice per subplot using one meter of row measured with a ruler.

The ruler was placed away from the edges of the plot. Populations were averaged per subplot.

***Dry bean development and height***. Dry bean development was measured using an adaptation of the dry bean development scale (Lebaron 1974), where one is equal to the V1 stage or first trifoliate leaf is unfolded. At the time of sampling, bean plants in most treatments have already unfolded the unifoliate leaves. Decimals (0.1 – 0.9) are used to indicate the proportion of openness in the unfolded leaf. For example, 0.1 would mean 10% of the first trifoliate leaf is unfolded and 1.1 would mean the first trifoliate has fully extended and 10% of the second trifoliate leaf has opened. Dry bean plant height was measured from the base of the bean stem exposed from the soil surface to the first internode. Heights were measured from one meter of bean row twice per subplot.

***Soil splash ratings***. In 2011, after a heavy rain, it was observed that there was a difference in the amount of soil splashed onto the undersides of bean leaves. Therefore, a *posteriori* hypothesis was formulated; fall rye NT residues reduce soil splash on the lower leaves of the cash crop. To quantify this observation, a rating was given to 10 consecutive plants in one meter of row based on a visual rating of percent leaf covered in soil. On a scale from 1 to 10, 1 represented 10% soil coverage and 10 represented 100% soil coverage.

***Accumulated weed and bean biomass***. Accumulated above ground weed and dry bean biomass was measured at dry bean harvest maturity using a ¼ meter quadrat randomly sampled twice per subplot from opposite ends of the plot. Plot edges were avoided and plants were removed within an inch of the soil surface when sampling. Biomass was sorted (bean plants from weeds) and then separate weed and bean biomass was placed in the oven to dry at 60ºC for at least 72 hours. Oven dried samples were then weighed.

***Dry bean yield***. Dry beans were not harvested with a combine at the end of the season due to plot weediness. Yield was measured using a 1 $m^2$quadrat taken twice from the centre of each subplot. Dry bean yield samples were air dried on drying beds for at least 7 days and threshed by hand using an upright belt thresher. Grain samples were then weighed.

### 3.3.5 Statistical analysis

Analysis of variance (ANOVA) was used for analyzing the treatment effects from the randomized complete block split-plot design. Data was tested with the PROC Mixed procedure from Statistical Analysis Software (SAS Institute Inc. 2001). Fixed effects included the variables block, cover crop, tillage and year. The effect of year was combined for analysis. Differences across treatments and within treatments (LSD test) were considered significant at a P value of <0.05. Assumptions of ANOVA were verified using PROC Univariate to test for normality of the residuals. A Shapiro-Wilkes test value greater than 0.05 was considered to indicate the population was normally distributed. Normal distribution of the residuals was verified visually using the plot of studentized residuals and using critical values provided by Lund's test (Lund 1975).

## 3.4 Results and discussion

### 3.4.1 Cover crop biomass in the establishment year

Fall-seeded cover crops offer an opportunity to maintain soil cover during a window where a typical cropping system would leave soil uncovered. Cover crops are seeded after the harvest of the main crop, protecting soil from wind and water erosion and competing with germinating weeds. Biomass production of fall-seeded cover crops is an important determining factor for erosion protection and fall weed control, since control is proportional to biomass production (Teasdale and Mohler 2000). In this study, cover crop biomass was measured in late fall (October 19, 2010 and October 31, 2011) to quantify differences in biomass production between barley, oat and fall rye in the establishment year.

The effect of cover crop species on fall biomass production was dependant on year (Table 12). All three cover crop treatments were statistically similar within year, but biomass production was higher in 2012 than in 2011. For example, fall rye biomass was 404 kg $ha^{-1}$ in 2011 and 1457 kg $ha^{-1}$ in 2012. In addition, cover crop biomass in 2011 was not statistically different from the control. That is, weed growth in the control treatment matched cover crop growth in the seeded treatments. Differences in biomass production in each year was related to differences in fall growing conditions. In the fall of 2011 conditions were cold and wet. Fall rye treatments were drowned out and had to be reseeded. In contrast, conditions in the fall of 2012 were warm and dry (Table 3).

No studies could be found that reported values for fall biomass production by cereal cover crops. Instead, most studies report biomass values at seeding. In Alberta, Blackshaw and Molnar (2008) found that fall-seeded fall rye biomass production ranged from 2000 kg $ha^{-1}$ to 6500 kg $ha^{-1}$ at dry bean seeding the subsequent year. Fall-seeded spring oat and barley biomass at dry bean seeding ranged from 400 kg $ha^{-1}$ to 1148 kg $ha^{-1}$ (Blackshaw 2008). In Ontario, fall rye biomass ranged from 1750 kg $ha^{-1}$ to 4500 kg $ha^{-1}$ at soybean seeding (Wagner-Riddle et al. 1994). Variability in biomass at seeding depended on weather (Blackshaw and Molnar 2008, Blackshaw 2008) and termination dates (Wagner-Riddle 1994).

Fall growth and canopy closure are important determinants of fall weed control. Biomass production has been shown to be positively correlated with light interception. Previous studies indicate that early season light competition is relatively more important for weed suppression than interception later in the season (Kruidhoff et al. 2008). Allelopathy is another important mechanisms of weed control by the early cover crop growth. Spring planted fall rye reduced early season biomass of lambsquarter (*Chenopodium album* L.) by 98%, large crabgrass (*Digitaria sanguinalis* L.) by 42% and common ragweed (*Ambrosia artemisifolia* L.) by 90% after 42 days of growth (Barnes and Putnam 1983). In another experiment, Barnes and Putnam (1983) showed that weed suppression increased with the age of the rye plants.

The findings of the present study indicate that the spring cereal cover crops selected did not differ from winter annual cereal cover crops in their ability to produce biomass in the establishment year (Fall 2011 and Fall 2012). Isolating the effect of cover crop on fall weed control was not possible since weeds were not measured at this time. However, other studies have shown that fall-seeded cover crops, and cover crops acting on germinating weeds in spring have a significantly reduced weed biomass (Blackshaw et al. 2007, Wagner-Riddle et al. 1994). In order to maximize on potential weed control benefits provided by fall-seeded cover crops management practices that increase fall biomass could be beneficial. Wagner-Riddle et al (1994) found that early planted fall rye had increased cover crop biomass but reduced weed biomass compared to late planted fall rye.

### 3.4.2 Effect of cover crop and tillage on soil macronutrients at dry bean seeding

One question in the present study was: how do fall-seeded cereal cover crops affect soil nutrient status for the subsequent crop? Cereal cover crops are very effective N scavengers due to fibrous root systems (Meisinger et al. 1991). Organic producers have restricted fertility options so adding another cereal crop to their rotation places additional stress on limited soil nitrogen resources. To investigate soil macronutrient uptake, fall-seeded cereal cover crop treatments were compared to the no cover crop control for soil nitrogen, soil phosphorus and soil potassium in the upper 15 cm of soil at dry bean seeding. It was hypothesized that spring annual cereals seeded in fall could provide the advantage of reduced nutrient uptake compared to a winter annual fall-seeded cover crop, based on the assumption that winter annual cover crops would continue to utilize soil nutrients during spring growth. Phosphorus (Olsen bicarbonate extractable - P), potassium ($K_2 O_5$) and nitrate ($NO_3$) were sampled immediately prior to dry bean seeding.

Results showed that the winter annual cover crop did not have statistically different soil available P and K status than spring annual cover crops (Table 6). Soil test results indicate that P was not significantly different between cover crop, management or years.

Potassium was similarly unaffected by cover crop and management treatments, but was significantly lower in 2011 (210 kg $ha^{-1}$) than in 2012 (565 kg $ha^{-1}$) (Table 6). Previous research has shown barley, oat and rye have similar N, P and K uptake based on an annual growing season (Malhi et al. 2006, Ruffo et al. 2004).

Results were very different for nitrogen. Fall rye reduced soil nitrate-N by 72 % and 74% compared to all other treatments in 2011 and 2012. It was expected that fall rye would reduce soil nitrate-N at seeding compared to the spring annual cover crops based on the difference of life cycle. Soil analysis partially confirmed the hypotheses. Oat and barley cover crops had similar soil nitrate-N to the control at seeding, which was greater than nitrate-N under fall rye in both years. However, the magnitude of the effect of cover crop was greater in 2012 than in 2011 for nitrate-N (Table 7). In 2011, oat (22 kg $ha^{-1}$), barley (26 kg $ha^{-1}$) and the control (26 kg $ha^{-1}$) were higher than fall rye (7 kg $ha^{-1}$). In 2012, oat (63 kg $ha^{-1}$), barley (65 kg $ha^{-1}$) and the control (65 kg $ha^{-1}$) were higher than fall rye (17 kg $ha^{-1}$). The difference is attributed to differences in indigenous soil since trial locations/ previous crop rotation were not the same from year 1 to year 2 (Table 2).

The difference in soil nitrate-N is likely related to the difference in cover crop life cycle. Cover crops were seeded on the same day, with the exception of fall rye in 2010 which had to be reseeded. In fall 2010, cereal cover crops had 363 GDD before temperatures dropped consistently dropped below freezing. In fall 2011, cereal cover crops had 422 GDD (MAFRD Ag-Weather Program) and had reached the 5-leaf stage before freeze up. The difference of GDDs is also indicative of the year to year differences in this study, where 2012 remained warmer for a longer period of time post seeding. Oat and barley cover crops never reached maturity, as they senesced over winter, so their nitrate-N removal will correspond with the stage they reached before freezing. On the other hand, fall rye had continued nutrient removal in spring.

The significance of year on soil macronutrients is likely attributed to the management history of each location. In 2011, the experiment was located on a different section of the Carman Research Station than in 2012 (Table 2). The location in 2012 was on land that had been in alfalfa hay two years prior. In comparison, the section used in 2011 had been in a rotation of organic annual grains. Alfalfa is commonly added to crop rotations to increase soil nitrogen. In Manitoba, 1-, 2- and 3-year-old alfalfa stands were found to increase soil nitrate-N by an average of 84, 148 and 137 kg N $ha^{-1}$, respectively (Kelner et al. 1997).

Tillage prior to seeding increased soil nitrate-N (39 kg $ha^{-1}$) compared to NT (33 kg $ha^{-1}$) in both years (Table 7). No-till management of cover crop residues will typically have reduced N contributions compared to soil incorporated cover crop residues (Vaisman et al. 2011). Vaisman et al. (2011) also showed that soil incorporated cover crop residues had increased nitrate-N availability for the subsequent crop. The authors tributed this effect to the mineralization of residues (Varco et al. 1993), the mineralization of indigenous soil organic matter with tillage (Drinkwater et al. 2000), and the immobilization nitrate-N in no-till treatments (Sarantonio and Scott 1988).

It is a noteworthy fact that there was no interaction between cover crop and management, which indicates that rye lowered N in both till and no-till treatments. Incorporation of cereal cover crop residues can immobilize nitrate-N concentrations in soil depending on the C/N ratio of the biomass (Doran and Smith 1991). When tillage treatments were applied in spring, oat and barley cover crop residue had nearly completely decomposed. In contrast, there was substantial fall rye biomass at seeding although residues were still green when incorporated. Immobilization may not have occurred immediately in fall rye treatments since the C/N ratio of fall rye at the boot stage is approximately 40:1 (Duiker 2014). A C/N ratio less than 20:1 will cause mineralization, while higher will cause immobilization (Brady and Weil 2002). Therefore, it is possible that immobilization was not captured by the one-time sampling date (4 DAP). The ability to predict the timing of nitrate-N mineralization/ immobilization from incorporated cover crops and green manures remains difficult (Sarrantonio and Gallandt 2003).

Regardless, the absolute difference between tillage and NT is approximately 6 kg nitrate-N $ha^{-1}$, a very small difference. More importantly, fall-seeded spring annual cover crops were not different than the control in their nitrate-N removal. This may be an advantage of spring annual cereals used as fall-seeded cover crops if weed control can also be achieved. It is also important to recognize that soil nitrate-N was collected from the upper 15 cm and therefore represents only the nitrogen that would be removed by early bean growth.

**Table 6.** Soil available phosphorus (Olsen-P) and potassium ($K_2O_5$) (kg $ha^{-1}$) at seeding in response to cover crop, management and year.

| Treatment | Olsen-P | $K_2O_5$ |
|---|---|---|
| | ------------------kg $ha^{-1}$ | ------------------ |
| Cover crop | | |
| Control | 42 **a**† | 389 **a** |
| Barley | 37 **a** | 390 **a** |
| Oats | 35 **a** | 384 **a** |
| Rye | 33 **a** | 387 **a** |
| | | |
| Management | | |
| Till | 37 **a** | 392 **a** |
| No till | 37 **a** | 383 **a** |
| | | |
| Year | | |
| 2011 | 39 **a** | 210 **b** |
| 2012 | 35 **a** | 565 **a** |
| | | |
| Source of variation | | |
| Cover crop | ns | ns |
| Management | ns | ns |
| Year | ns | <0.0001 |

† Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test.

‡ Values are presented in kg $ha^{-1}$ assuming a soil bulk density of 1000 kg $m^{-3}$ using a conversion factor of 1.5 from parts per million (ppm).

**Table 7.** The effect of cover crop and year (2011 and 2012) on soil nitrate in 0 – 15 cm. Mean and differences are indicated by different letters within year, cover crop and management.

| Treatment | Cover crop | Soil nitrate |
|---|---|---|
| Year | | ---------------kg ha$^{-1}$-------------- |
| 2011 | Control | 26 **b**[†] |
| | Barley | 26 **b** |
| | Oats | 22 **b** |
| | Rye | 7 **c** |
| 2012 | Control | 65 **a** |
| | Barley | 65 **a** |
| | Oats | 63 **a** |
| | Rye | 17 **b** |
| Management | | |
| Till | | 39 **a** |
| No till | | 33 **b** |
| Source of variation | | |
| Cover crop | | ns |
| Management | | 0.0121 |
| Year | | ns |
| Cover crop x management | | ns |
| Cover crop x year | | <0.0001 |
| Management x year | | ns |
| Cover crop x management x year | | ns |

[†] Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test.

### 3.4.3 Soil moisture at seeding

Some studies have found that moisture use by cover crops can reduce yields of subsequent cash crops in semi-arid areas of the Northern Great Plains (Carr et al. 2012, Dabney et al. 2001). A fall-seeded cover crop will also transpire soil moisture compared to soil evaporation on a field left unseeded. However, in times of excess spring moisture, depleting moisture in fall could also be an advantage in terms of field accessibility in spring. This study considered the effects of cover crops on soil moisture at the time of dry bean seeding using gravimetric soil moisture measurements.

Results of the present study showed that gravimetric soil moisture content was unaffected by cover crop type in both 2011 and 2012, even though the years differed markedly in growing season precipitation (Table 8). In 2011, soil saturation appeared to mask any treatment effects. For example, from April to May 2011 precipitation was 127% of the long term average (Table 3). Other cover crop studies at the Ian N. Morrison research station have also found that cover crops will not affect soil moisture under excess moisture (Flood 2008, Podolsky 2013).

In 2012, there was a significant effect of tillage on gravimetric soil moisture at seeding that resulted in NT treatments (0.27 g/g) having slightly higher soil moisture than tillage treatments (0.26 g/g). Tillage provides aeration that speeds drying of surface soils (Brady and Weil 2002). The lack of soil water differences between cover crops in 2012 could not be attributed to the masking effect of excess water as fall 2011 and spring in 2012 had normal levels of precipitation (Table 3). Other possible explanations included, cover crop residues can reduce soil evaporation and retain soil moisture (Teasdale and Mohler 1993). In addition to the observation that spring annual cover crops decomposed more slowly in 2012, there was also residue from the previous barley silage crop that could have resulted in no statistical difference between spring annual, winter annual and no cover crop treatments (Figure 2). Soil moisture is higher than expected given the growing season, and it is unclear why.

Soil moisture under spring annual cover crops was not different than the winter annual fall rye. In 2011, the residue of spring annual cover crops had decomposed rapidly, and there was a dense population of Shepherd's Purse (*Capsella bursa-pastoris* L.) in the spring annual cover crop and control plots (Figure 2). Therefore, a possible explanation for the similarity in spring soil moisture across cover crop treatments is because of water use by weeds present in barley and oat cover crop treatments was comparable to water use by fall rye cover crops. So in one instance the cover crop used water, while in the other instance the weeds used water.

**Table 8**. Soil moisture at bean seeding (0-60 cm) in response to cover crop species, tillage management and year.

| Treatment | 2011 | 2012 |
|---|---|---|
| | -----------------------------------$H_2O$ g/ soil g--------------------------------- | |
| Cover crop | | |
| Control | 0.2 | 0.27 |
| Barley | 0.2 | 0.27 |
| Oats | 0.19 | 0.3 |
| Rye | 0.2 | 0.23 |
| Management | | |
| Till | 0.2 | 0.26 **b** |
| No till | 0.2 | 0.27 **a** |
| Source of variation | | |
| Cover crop | ns | ns |
| Management | ns | 0.0218 |
| Year | ns | ns |

[†] Means within a column followed by a different letters are significantly different at $P<0.05$ according to Fischer's protected LSD test.

### 3.4.4. Crop establishment and productivity

#### 3.4.4.1. Dry bean plant population

Plant population is the first step in ensuring optimal crop yields. There are numerous factors that can affect emergence including environmental conditions, surface residue, tillage and planting depth. The recommended seeding rate for solid seeded dry edible beans in 15 cm rows is 40 – 42 plants/$m^2$ (Manitoba Agriculture, Food and Rural Development 2011). In this study, dry bean plant population was significantly affected by year. Average plant population was 35 plants/$m^2$ in 2011 and 30 plants/ $m^2$ in 2012 (Table 9). This result is contrary to what was expected, since in 2011, spring conditions were cold compared to warmer conditions in 2012 (Table 3). Seeding rates did not change year to year, therefore its uncertain as to why this occurred.

There was no effect of cover crop or tillage on dry bean plant population (Table 9). In the systems studied here, large variation in the quantity of surface residue present at dry bean seeding was encountered. While fall rye cover crops were increasing in biomass, oat and barley cover crops were subject to decomposition processes in spring. Very little of the residues from barley and oat cover crops remained at seeding. In contrast, fall rye was flowering when beans were seeded. This posed a challenge for seeding. Tillage operations were somewhat hindered by the substantial fall rye residue. The result was rye plants that were uprooted and stems that were intact, rather than chopped, and incorporated to varying degrees. In the fall rye + NT treatment, rye was still rooted and standing at the time of seeding so it was sometimes possible to place the dry bean seed

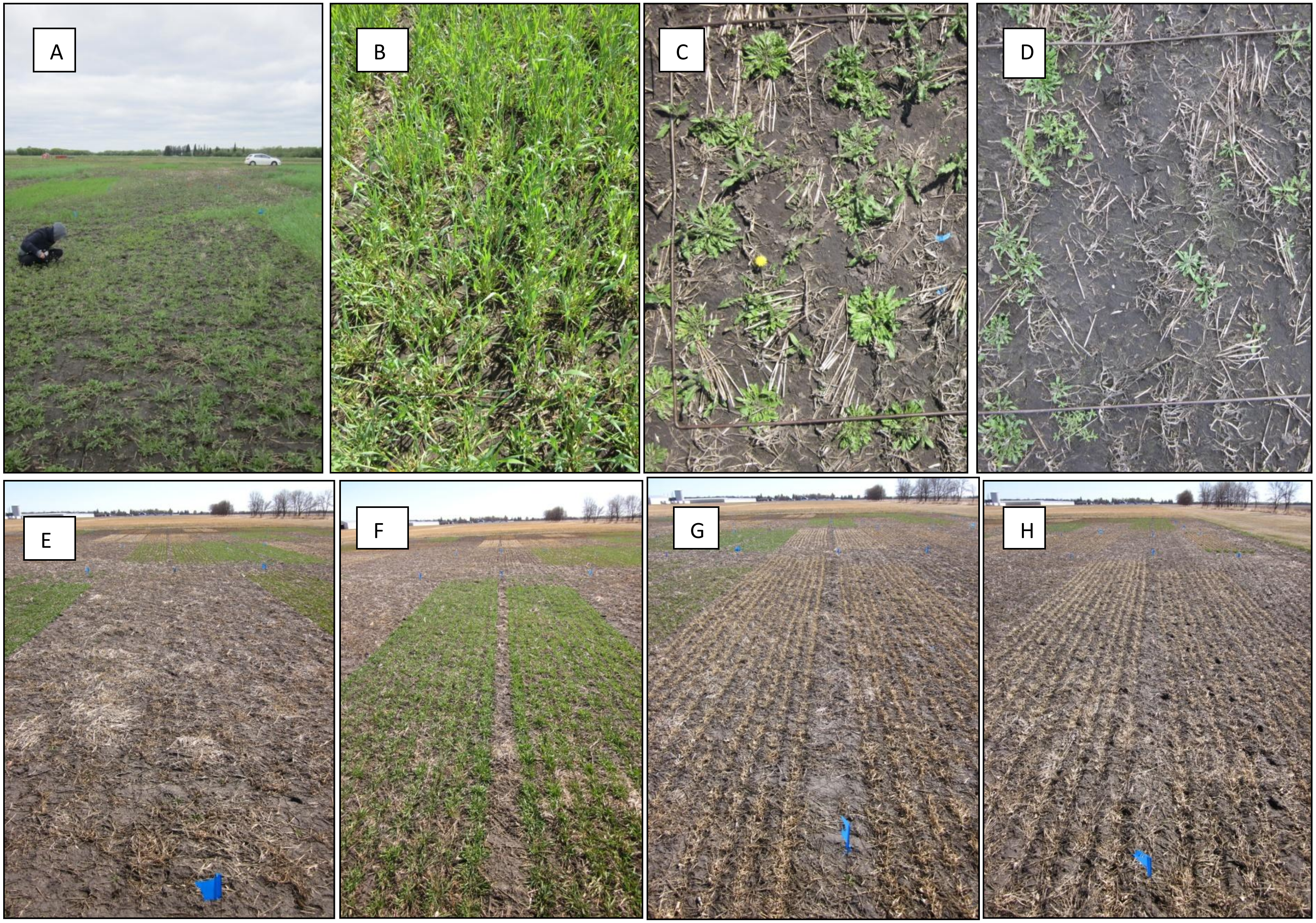



**Figure 2**. Early spring surface residue in control, fall rye, oat and barley cover crop treatments in 2011 (a, b, c, d, respectively) and 2012 (e, f, g, h, respectively).

row in the inter-row space between fall rye rows. Interestingly, bean plant population was unaffected by these differences.

Previous studies have found that cover crop residues in NT systems will cause delayed emergence in dry beans, but in these cases maturity was never affected (Blackshaw et al. 2007, Blackshaw and Molnar 2008). This is in contrast to Wagner-Riddle et al. (1994) who found that soybean emergence was lower (20 plants $m^{2}$) under high mulch (3.5 - 4.8 Mg $ha^{-1}$) treatments than in low mulch (2.2 - 3.4 Mg $ha^{-1}$) treatments (30 plants $m^{2}$). Conversely, it has been observed that large seeded plants, such as beans, are better able to grow up and around mulches due to large seed energy reserves (Teasdale 1993). This is a positive outcome from this study, which shows that there is potential for dry beans in fall rye + NT systems.

#### 3.4.4.2. Development

A limitation to using fall seeded rye cover crops in Manitoba is the relatively short growing season and slow accumulation of GDD in spring. This results in limited growth before fall freeze up, but also limited growth in spring. Mowing for the termination of fall rye is most effective at 90% anthesis (Wilkins and Bellinder 1996), which in Manitoba is approximately early June. Research in Minnesota has shown that a minimum of 309 GDD had to be accumulated in fall to avoid delaying rye anthesis the subsequent spring (Kantar and Porter 2014). In this study, rather than delay seeding of dry beans until after the fall rye + NT treatments have been terminated, seeding occurred at dry bean optimal timing. Thus, fall rye and dry beans acted as an intercrop until fall rye was mowed. On the other hand, plots were tilled prior to bean seeding in the fall rye plus tillage treatments.

Development ratings were not an *a priori* hypothesis, instead they are an attempt to quantify field observations. During the gap between dry bean seeding and fall rye mowing it was observed that dry beans may have been out competed by the nearly mature fall rye in NT treatments, which was noticeably expressed as slower development relative to the control. Therefore, dry bean development was measured at 18 DAP and 20 DAP in 2011 and 2012, respectively.

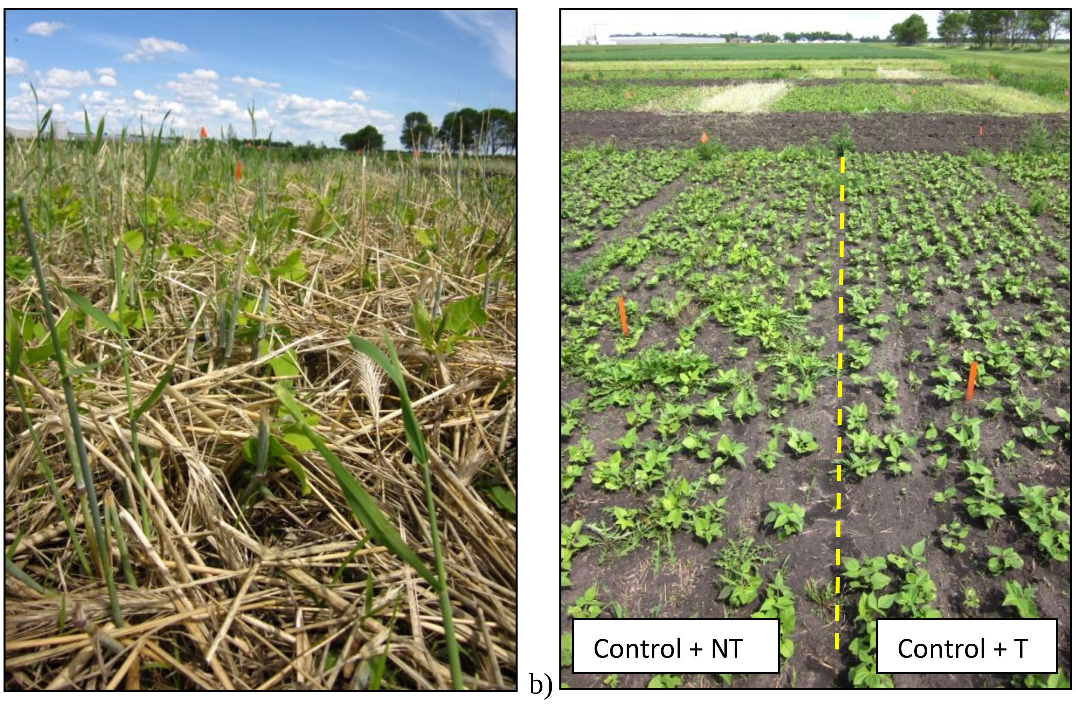
The development of dry beans was significantly delayed in fall rye cover crops compared to all other treatments. When sampled, dry beans in fall rye treatments had a rating of 0.9, which corresponds to 90% unfolding of the first true leaf. In comparison, the control treatments had a development rating of 1.4, which means that the first true leaf had fully unfolded and the second leaf was still in the bud stage (Table 9). Dry beans under barley and oat cover crops were not statistically different than the control.

Intercropping can be a very productive farming practice, but requires careful planning and management considerations to lessen the competitive effects of either crop. Most often, which ever crop is seeded first has the competitive advantage (Francis et al. 1982, Uchino et al. 2009). Due to the requirements for successful fall rye termination in the fall rye + NT system, fall rye was approximately one meter tall at the time of bean seeding. In addition to timing, dry beans were also tightly spaced between rye. Productive maize-bean intercropping systems are row cropped for adequate light penetration (Gardiner and Craker 1981) and root dispersal (Wilson 1988). However, the fall rye + NT system was not designed as an intercrop and it is uncertain what effects would be present if it was.

Interestingly, it was not only dry bean development under fall rye that was affected by NT management. All treatments under NT management were significantly delayed compared to tillage management as evidenced by a non-significant cover crop x management interaction. Mulched treatments will often have delayed emergence, pod fill and maturity (Wagner-Riddle et al. 1994). In fall rye + tillage, this response is explained by the effect of heavy residue cover (Figure 3). However in the barley + NT, oat + NT and control + NT delayed bean development is possibly attributed to the weed biomass (unmeasured data) present after these treatments were flame weeded.

There was also an effect of year on dry bean development. According to Manitoba's Ag-Weather Program, 217 GDD had accumulated from dry bean seeding to the time of sampling in 2011, compared to 252 GDD in 2012. The influence of warmer conditions in 2012 was twofold. First, dry beans had a mean development rating of 1.6 in 2012 compared to 1.1 in 2011. Second, the warmer conditions also meant that fall rye matured more quickly in 2012, and so could be terminated earlier (11 DAP in 2012 compared to 18 DAP in 2011). This means that beans remained in the fall rye understory for a week longer in 2011 than in 2012. So if we compared fall rye + NT systems, beans in 2012 had better growing conditions and less competition than beans in 2011. This important seasonal difference reinforces why development ratings were analyzed separately by year, since it is difficult to compare years when GDD are different.

Terminating fall rye without tillage still has its challenges, namely competition with the main crop. Dry bean development was delayed under NT treatments. This can partially be explained by the availability of light under the fall rye canopy, as dry beans were significantly etiolated. However, there are advantages to reducing tillage since NT treatments had significantly lower weed biomass at the end of season. Fall rye can reduce weed germination at the 5 leaf stage (Flood 2008) so in future research, managing the competitiveness of fall rye by terminating earlier could be a possible way of incorporating its strong weed suppressive qualities into dry bean systems. Other possibilities may include earlier maturing varieties of rye. For example,  Mirsky et al. (2009) found that fall rye cv. Aroostook matured earlier than cv. Wheeler, the latter was the variety used in this study.




a) b)

**Figure 3**. Growing conditions for dry beans under a) high biomass (fall rye + NT treatments) and b) low biomass (control + NT and control + T). Photos were taken on June 12, 2012.

**Table 9.** Dry bean population (plants $m^{-2}$) and development rating in response to cover crop, management and year. Sampling occurred 18 DAP in 2011 and 20 DAP in 2012.

| Treatment | Plant population | Development rating |
|---|---|---|
| Cover crop | | |
| Control | 31 **a** | 1.4 **a**† |
| Barley | 33 **a** | 1.5 **a** |
| Oats | 34 **a** | 1.4 **a** |
| Rye | 32 **a** | 0.9 **b** |
| Management | | |
| Till | 33 **a** | 1.4 **a** |
| No till | 31 **a** | 1.2 **b** |
| Year | | |
| 2011 | 35 **a**† | 1.1 **b** |
| 2012 | 30 **b** | 1.6 **a** |
| Source of variation | | |
| Cover crop | ns | <0.0001 |
| Management | ns | 0.0047 |
| Year | 0.0029 | 0.0015 |
| Cover crop x management | ns | ns |
| Cover crop x year | ns | ns |
| Management x year | ns | ns |
| Cover crop x management x year | ns | ns |

† Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test.

### 3.4.4.3. Internode length

It was observed in the field that dry bean seedlings in fall rye + NT treatments were etiolated to the first internode. Etiolation is the process where a plant is grown in absence of light (Burgess 1985). It is a shade avoidance mechanism in plants; an etiolated seedling will have a long, thin stem, long internodes, fewer leaves that are often yellowing from reduced photosynthesis. As previously discussed, dry beans acted as an intercrop until fall rye was terminated. As an attempt to quantify the impact of practices used to terminate fall rye, the length to the first internode of dry beans was measured in all treatments.

In both years, significant cover crop x tillage management interactions showed that the magnitude of the internode etiolation due to fall rye (compared with other cover crops) was much greater in the no-till vs. the tilled system (Table 10). That is to say, the effect of tillage system on the internode length depended on the cover crop yield. Internode length was greater under fall rye + NT than any other treatment combination, resulting in a mean internode length of 7.9 cm in 2011 and 6.0 cm in 2012 (Table 10). In 2011, the internode length of the control, oat and barley cover crops were statistically similar within a management regime (T or NT), and were less than in fall rye cover crops. In 2012, oat and barley cover crops were not statistically different from each other or when managed with or without tillage. There was no effect of sampling date on bean internode length in 2011 or 2012.

In this study, cereal cover crops were grown to compete with weeds. An apparent disadvantage of fall rye cover crops is the physical effect it has on growing conditions for dry beans, particularly when it is managed without tillage. Internode length has demonstrated that in rye cover crops, dry beans are struggling for light resources compared to beans grown in CNT+T treatments, which most closely represents conventional practices. Living mulches can provide weed control benefits compared to dead mulches through interspecific competition for light, moisture and nutrients (Weston 1996). However, a successful living mulch is one that can control weeds while also not interfering with the cash crop (Putnam et al. 1990). As such, it appears that NT management of cover crop residues may increase the competitive effect of cover crop on dry beans.

An interesting advantage of an elongated stem is that it may ease the straight cut harvesting of dry beans. Straight cutting of dry beans is becoming more common as grain farmers are tending to solid seed in the way they would with small grains. A plant with a taller stem to the first pods could also mean fewer harvest losses. A typical cutting height for direct cut dry beans is 40 mm from the soil surface (Zyla et al. 2002). Therefore, beans in the control treatments may have increased pod loss compared to rye cover crop treatments. Perhaps due to the popularity of straight cutting dry beans, dry bean cultivars are now also classified based on the percentage of pods that clear the cutter bar at swathing. Dry bean cv. Envoy (used in the present study) has a 73% pod clearance according to Saskatchewan Agriculture, *Varieties of Grain Crops* (2015). A caveat of this is whether comparable bean yields are achieved in plants that are shaded as seedlings. In comparable studies, mowed fall rye cover crops caused a yield reduction in soybeans (De Bruin et al. 2005, Wagner-Riddle et al. 1994) but when incorporated other studies have found that bean yields were not affected by cereal cover crops and tillage treatments (Shrestha et al. 2002).

**Table 10**. Dry bean height to the first internode in response to cover crop, management and sampling date‡ for 2011 and 2012.

| Management | Cover crop | Dry bean height (cm) | |
|---|---|---|---|
| | | 2011 | 2012 |
| Till | Control | 3.8 **c**† | 3.9 **d**† |
| | Barley | 4.0 **c** | 3.8 **d** |
| | Oats | 3.8 **c** | 4.1 **cd** |
| | Rye | 4.9 **b** | 4.6 **b** |
| No till | Control | 4.6 **b** | 4.5 **bc** |
| | Barley | 4.5 **b** | 4.1 **cd** |
| | Oats | 4.6 **b** | 3.9 **d** |
| | Rye | 7.9 **a** | 6.0 **a** |
| Date | | | |
| 1 | | 4.6 **a** | 4.4 **a** |
| 2 | | 4.6 **a** | 4.3 **a** |
| Source of variation | | | |
| Cover crop | | ns | ns |
| Management | | ns | ns |
| Date | | ns | ns |
| Cover crop x management | | 0.0006 | <0.0001 |
| Cover crop x date | | ns | ns |
| Management x date | | ns | ns |

† Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test.
‡Sampling date 1 was 18 DAP and sampling date 2 was 30 DAP in 2011. Sampling date 1 was 20 DAP and sampling date 2 was 34 DAP in 2012.

### 3.4.4.5 Soil splash on bean leaves

Diseases and weeds pose the greatest production problems for dry bean growers. White mold (*Sclerotinia scleroterium*) is the most common disease in Manitoba with 60-80% of the acres affected, depending on the year (Agriculture and Agri-Food Canada 2005). White molds can persist in soils for years. Bacterial blights *(Xanthomonas campestris* pv. phaseoli (Smith)) are typically seed-borne, but can survive in plant residues. These diseases are spread plant to plant by rain, hail, wind or irrigation (Graham and Ranalli 1997).

An interesting visual observation during this experiment was that beans growing in fall rye treatments had little to no soil that splashed onto the underside of bean leaves during a rain event (Figure 4). To quantify this observation, a 1 to 10 rating system (1 being lowest to 10 being highest) was used to describe the proportion of soil coverage on the underside of bean leaves. In both years, significant cover crop x management x year interactions showed that fall rye reduced soil splash (compared to all other cover crops) more under NT than in tillage systems, but the magnitude of this effect was dependant on year (Table 11). In both years, beans growing in fall rye + NT treatments had virtually no soil splash on the underside of leaves. The magnitude of the effect of till vs. no-till on soil splash in fall rye treatments was greater in 2012 than in 2011.

It is difficult to say whether reduced soil splash in fall rye treatments is an effect of higher mulch biomass (soil cover) or the result of the increased bean internode length (distance from the soil surface). In 2011, beans in fall rye + NT treatments remained under the fall rye canopy longer (18 days) than beans in 2012 (11 days). This resulted in a taller bean in 2011 (although years were not compared), that may have contributed to reduced soil splash (Table 10). So, while fall rye biomass is considered to be a factor, there could also be other contributing factors to soil splash.

Fall rye mulches have previously been found to reduce levels of white mold in beans. These effects were attributed to reduced leaf area of the beans and increased soil cover (Bottenberg et al. 1997). Ferraz et al (1999) found fewer white mold spores in soils mulched with Napier grass (*Pennisetum purpureum*), which was compared for different mulch depths (0, 1, 5, 3, 6 and 9 cm). The effect was strongest at 6 and 9 cm of mulch, however at 9 cm of mulch, bean yields were reduced.

Since disease ratings were not performed, the implications of reduced soil splash can only be speculated. However, the effect of cover crop mulches on disease prevalence and severity in organic crops should be investigated since producers have limited options for reactionary disease suppression.

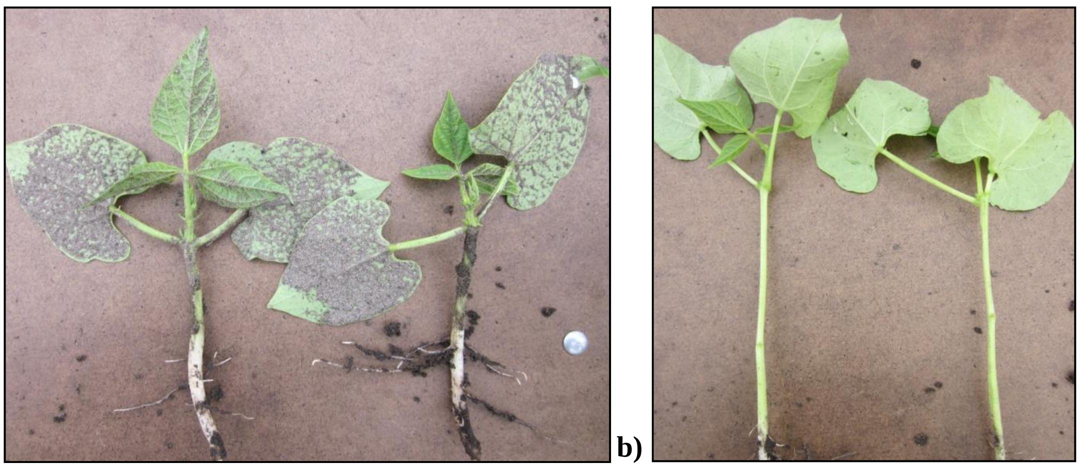



**Figure 4.** The effect of cover crop and management on the splashing of soil on the underside of bean leaves. Images are taken from beans in a) control + T and b) fall rye + NT treatments.

**Table 11**. The effect of cover crop, management and year on soil splash in 2011 and 2012. Ratings of 1 to 10 were given for low to high soil coverage on the underside of bean leaves.

| Cover crop | Management | Year | | | |
|---|---|---|---|---|---|
| | | 2011 | | 2012 | |
| | | -----------Soil Splash Rating (1 - 10)-------- | | | |
| Control | Till | 7 | **ab** | 7 | **ab** |
| Barley | | 6 | **bc** | 8 | **a** |
| Oats | | 7 | **ab** | 8 | **ab** |
| Rye | | 2 | **d** | 4 | **c** |
| | | | | | |
| Control | No-till | 2 | **d** | 7 | **ab** |
| Barley | | 5 | **c** | 5 | **ab** |
| Oats | | 4 | **c** | 7 | **ab** |
| Rye | | 0.25 | **e** | 0 | **e** |

| Source of variation | |
|---|---|
| Cover crop | <0.0001 |
| Management | <0.0001 |
| Year | <0.0001 |
| Cover crop x management | 0.0637 |
| Cover crop x year | 0.2883 |
| Management x year | 0.0206 |
| Cover crop x management x year | 0.0014 |

† Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test.

‡Sampling date 1 was 18 DAP and sampling date 2 was 30 DAP in 2011. Sampling date 1 was 20 DAP and sampling date 2 was 34 DAP in 2012.

### 3.4.5 Cover crop biomass at dry bean seeding

Cover crop biomass is an important determinant of weed control. In this study, fall rye biomass was measured at dry bean seeding in order to quantify the amount of cover crop biomass that was either incorporated (tillage plots) or as a standing crop (no-till plots). There was no significant difference in fall rye biomass between years (P value = 0.0591). Average fall rye biomass at dry bean seeding was 6921 kg $ha^{-1}$ and 4287 kg $ha^{-1}$ in 2011 and 2012, respectively.

These values are consistent with other studies on fall-seeded fall rye biomass (Blackshaw 2008, Bernstein et al. 2014). In Alberta, fall-seeded fall rye biomass at bean seeding ranged from 5520 to 7940 kg $ha^{-1}$ (Blackshaw 2008). In Wisconsin, rye biomass at seeding ranged from 4300 to 10800 kg $ha^{-1}$ depending on the year (Bernstein et al. 2014). Both studies found that the significant amount of biomass produced by fall rye was a determining factor of weed control in the subsequent bean crop.

### 3.4.6 Influence of cover crop species and tillage on weed biomass

Fall-seeded cover crop mulch systems suppress weeds physically, through nutrient, moisture and light use and chemically, through the release of allelochemicals. Cover crop life cycle (winter annual versus spring annual) and tillage management of the cover crop residues will further affect weed suppression. In the present study, weed biomass was measured at dry bean harvest to provide an indication of season long weed suppression. Cover crop species and management were then contrasted for the ability to reduce weed growth.

Weed biomass at harvest was significantly higher in 2012 compared to 2011 (Table 12).This is likely attributed to more favourable growing conditions in 2012, in both climate (Table 3) and background soil conditions especially available N (Table 2). Weed biomass at harvest was significantly lower after fall rye cover crops, 3,777.5 kg $ha^{-1}$ compared to 7,136.5 kg $ha^{-1}$ without a cover crop (Table 12). Fall rye biomass at bean seeding was 6921 and 4287 kg $ha^{-1}$ in 2011 and 2012, respectively (no analysis). This high biomass appears to be responsible for superior weed control provided by fall rye. In the mowed treatments, fall rye acted as a living mulch, directly competing with weeds in early spring prior to dry bean seeding. As well, the canopy provided by fall rye likely reduced the germination and establishment of certain weed seeds. In addition to the physical presence, the strong competitive ability of fall rye is also attributed to its allelopathic properties (Barnes and Putnam 1983). In another Manitoba field study, Flood (2008) found that 4 to 5 leaf stage fall rye reduced broadleaf weed establishment by 44 to 72% and grassy weed establishment by 43 to 88%. Flood and Entz (2009) found in bioassays that fall rye extracts significantly reduced the germination of redroot pigweed and green foxtail.

In both years, NT management of cover crops in spring significantly reduced weed biomass (4867 kg $ha^{-1}$) at harvest compared to managing cover crops with tillage (6717 kg $ha^{-1}$) (Table 12). Lack of a significant cover crop x tillage management interaction indicates that fall rye was not superior to other cover crops in terms of improving weed suppression in a no-till vs. a tilled system, i.e., all cover crops responded equally. Some studies have found that reduced tillage in organically managed rye-soybean systems can control weeds (Bernstein et al. 2014, Kruidhoff et al. 2009), while others have found variable responses of weeds to fall rye managed without tillage (Shrestha et al. 2002, Swanton et al. 1999, Teasdale et al. 1991). It is possible the timing of soil disturbance due to tillage operations in spring could have triggered a flush of summer annual weeds. Bernstein et al. (2014) found that in rye - soybean systems, tillage treatments resulted in an early flush of weeds while in NT treatments weed density peaked later in the season. As well, late mowed fall rye had reduced weed control compared to the early mowed rye.

Although fall rye produced more of a weed suppressing mulch, the timing and management of rye still requires more research.

### 3.4.7 Influence of cover crop species and management on dry bean biomass at harvest.

Cereal cover crops suppress weeds through direct competition for resources and by chemical inhibition. A significant body of research exists on determining how to manage cover crops such that cash crop yield is not compromised for weed control. However, the suitability of a cover crop and management are regionally specific. To determine if cover crops (spring annual or winter annual) and their management (till or no-till) affect dry bean growth and development, dry bean harvest biomass was measured and contrasted to a no cover crop control managed with and without tillage. This measurement is used as a indicator of the competitive effects of the cover crop and management system on the cash crop (Araujo and Teixeira 2008).

In the present study, there was a significant effect of year on dry bean harvest biomass (Table 12). Dry bean biomass at harvest was unaffected by cover crop or management, but was significantly higher in 2012 (6,615 kg $ha^{-1}$) than in 2011 (3,257 kg $ha^{-1}$). It appears that favourable background site conditions in 2012 (presumably higher soil N) led to twice the amount of accumulated biomass than in 2011. In the control treatments, soil nitrate-N was 25.6 kg $ha^{-1}$ in 2011 compared to 65 kg $ha^{-1}$ in 2012. Since dry beans are not strong N-fixers, fixing approximately 25 to 50% of their N requirement, standard practices are to not inoculate and to fertilize accordingly (Saskatchewan Pulse

Growers 2000). The location used in 2012 was previously a 3-year old alfalfa stand, which is likely responsible for the higher nitrate-N levels. Therefore, crop rotation was a determinant in dry bean biomass in the present study.

The results from this study show that cover crop species and management did not have a significant effect on dry bean biomass at harvest. Winter-killed spring annual cover crops were not expected to compete with dry beans due to low spring residue. Previous studies have found that the high biomass producing fall rye can compete with the subsequent cash crop (Liebl et al. 1992), however not in all situations (De Bruin et al. 2005, Wagner-Riddle et al. 1994). As previously discussed in Section 2.4.4, dry beans in fall rye cover crops had delayed early season development, but this did not translate into reduced harvest biomass. In Ontario, soybeans grown after fall-seeded/ spring terminated fall rye showed signs of delayed development in 1 out of 4 years but this did not translate into decreased yields at the end of the growing season (Wagner-Riddle et al. 1994).

Reduced tillage was expected to have decreased dry bean harvest biomass, however this was not observed. Bernstein et al.(2014) found that biomass of organically managed soybeans was reduced in NT fall rye cover crop systems compared to rye managed with tillage. This was attributed in part due to cooler, wetter soil conditions. Rye re-growth was also linked to reduced soybean biomass, likely because of shading and competition for nutrients. Interestingly, the authors found that an early planting date (Mid-May) had significantly higher soybean biomass than a later planting date (Early June) and that this effect was only significant in NT systems.

### 3.4.8 Yield

The adoption of cover crops is limited by the perceived ability to achieve comparable yields to standard practice (Singer et al. 2007). Previous studies have shown that fall rye cover crops can produce bean yields that are comparable to the conventional systems (Wagner-Riddle et al. 1994, Flood 2008). However, there is often a trade-off between weed control and yield in organic production systems. Results from the present study indicate that there is a significant yield penalty from growing a fall rye cover crop prior to the bean year, while bean yields in spring annual cover crop treatments were comparable to control treatments.

There were two significant two-way interactions on yield in the present study: cover crop x year and tillage x year. The first interaction showed that the yield benefit from not using fal rye was greater in 2012 than in 2011 (Table 12). For context, Manitoba average conventional white pea (cv. Envoy) bean yields in 2011 and 2012 were 2221 kg $ha^{-1}$ and 1982 kg $ha^{-1}$ (Yield Manitoba 2013).

There was a significant effect of tillage in 2012, where cover crops managed with tillage were higher yielding than NT treatments. The tillage x year interaction was attributed to no difference in till vs. no-till in 2011, but higher yield for till than no-till in 2012. In 2011, cover crop management did not have a effect on yield. No-till management of cover crop residues in this study resulted in a more competitive system for dry beans 1 year out of 2. In the case of the spring annual cover crops, increased competition is attributed to higher early season competition between weeds and dry beans.

Dry beans are uncompetitive plants and respond well to weed control (MAFRD 2011). Although fall rye provided significant weed control compared to other treatments, it appears that the competition between fall rye and dry beans early in the growing season reduced biomass and yield of dry beans. There has been extensive research on fall rye-soybean systems, with positive results. However many of these studies have not been solely organic no-till. Previous work on NT fall rye-soybean systems have found that although rye managed without tillage can provide exceptional weed control, soybean biomass was also reduced. Lower soybean yield has been attributed the cooler/ wetter conditions and regrowth in NT managed fall rye (Bernstein et al. 2011). In the present study, NT managed fall rye also produced significantly more regrowth than fall rye managed with tillage (Table 12). Additionally, rye regrowth was significantly higher in 2011 than in 2012.

Cover crop biomass is proportional to the level of weed control provided, which also increases it competitiveness with the cash crop unless it can be managed, or a more competitive cash crop is grown. Delayed development after fall rye cover crops could have contributed to lower yields in the present study. Blackshaw (2008) found that although fall-seeded cover crops delayed dry bean emergence, this did not translate into delayed maturity. Similarly, Wagner-Riddle et al. (1994) found that soybean had delayed development early in the growing season but this did not translate into differences in soybean yield. However, due to the significant difference in yields between rye and all other treatments, it could be a contributing factor.

A distinguishing feature of this study is that in NT rye treatments, fall rye and dry beans act as an intercrop for a period of time until rye is terminated with mowing. Francis et al. (1982) investigated the effects of relative planting dates in bean and maize intercropping systems by looking at competition and comparing yields of intercropping versus monocropping. Using a split-split design, the authors used intercropping or monocropping as the main plot, bean cultivar (Type I, II, III, IV) as split plot and planting date as the split-split. Planting dates were as follows: Beans 10 days before maize, beans 5 days before maize, same day, maize 5 days before beans and maize 10 days before beans. The study showed that beans seeded prior to maize had the competitive advantage regardless of cultivar. Beans seeded 10 days prior had significantly higher yields compared to planting on the same day. Conversely, beans seeded 10 days after maize had reduced yields but were only significant for Type III. This study clearly demonstrates that whenever beans had endured some level of competition, they yielded less than beans with little to no competition.

Fall rye also reduces weed biomass through the release of allelopathic plant chemicals through root and shoots (Mwaja et al. 1995). Although it is an important mechanism for weed control, the physical effect of fall rye was suspected here to have played a more significant role in lower dry bean yields than allelopathy, but it cannot be determined for certain. Flood (2008) found that fall rye exudates did not reduce the germination of dry beans (cv. Envoy), but did reduce germination of red root pigweed and green foxtail.

Nutrient availability is an important concern for organic farmers due to limited fertilizer options. Legumes, therefore, become an important component to the rotation because of the ability to supply part of its nitrate-N requirement. However, species selection must meet other criteria such as the fit into the rotation and weed control without conflicting with the nutrient supplying power of the rotation. Cover crop species did not affect the available spring soil macronutrients, however NT management of cover crop residues in spring decreased nitrate-N. It is therefore concluded that dry bean yield was correlated with available soil nitrate-N, which was higher following spring annual and no cover crop treatments. Fall rye depleted soil nitrate-N compared to the control treatment. Soil nitrate-N was also significantly higher at the 2012 location than at the 2011 location. This difference is expected to have had yield consequences. Available moisture, on the other hand, does not seem to be a limiting factor within or across treatments.

### 3.5 Conclusions

This study showed that the cover crop/management system that provided the highest weed suppression was also competitive with the cash crop causing reduced yields. Fall rye cover crops can be a valuable tool for weed control when fall-seeded and terminated in spring. However, fall rye treatments had substantially lower dry bean yield compared to all other treatments. In contrast, spring annual cover crops did not provide any lasting weed control and were similar under most parameters as the no cover crop control. Dry bean yields were highest following no cover crop or the spring annual cover crops, where there was little to no residue to compete with dry beans. Spring annual treatments were also uncompetitive with weeds, having no effect on weed biomass compared to the control. Reduced tillage shows some potential in organic cover crop systems in Manitoba. Weed biomass was significantly lower in NT systems, however, dry bean yields were also reduced with reduced tillage in 1 out of 2 years. Other options for organic NT include exploring flame weeding for organic pulse production. Flame weeding in organic horticultural production systems in the United States is common, and can be a viable option for high value crops.

Future research should seek to establish optimum rye terminating stage for organic conditions to reduce the negative effect on the main crop. For example, earlier fall rye seeding may allow for earlier termination is spring, and therefore less competition with dry beans. The selection of a more strongly competitive main crop like soybeans may also be a way of capitalizing on the weed suppression provided by fall rye NT systems. Conversely, choosing a less competitive winter annual grass species (e.g. perennial ryegrass (*Lolium* spp.)) may also warrant investigation.

**Table 12**. The effect of cover crop species, management and year on preseason cover crop biomass, weed biomass at dry bean harvest, dry bean biomass at harvest and dry bean yield. The effect of management on fall rye regrowth (measured at bean harvest) is also included.

| Treatment | Cover crop biomass in the establishment year | | Fall rye regrowth | Harvest weed biomass | Harvest crop biomass | Yield | |
|---|---|---|---|---|---|---|---|
| | 2011 | 2012 | | | | 2011 | 2012 |
| | kg ha$^{-1}$ | | | | | | |
| **Cover crop** | | | | | | | |
| Control | 155 **b†** | 480 **b** | | 7137 **a** | 4640 | 673 **cd** | 1292 **a** |
| Barley | 325 **b** | 1687 **a** | | 6140 **a** | 5607 | 941 **bc** | 1133 **ab** |
| Oats | 395 **b** | 1488 **a** | | 6117 **a** | 5292 | 914 **bc** | 1431 **a** |
| Rye | 404 **b** | 1457 **a** | | 3778 **b** | 4204 | 515 **d** | 551 **d** |
| **Management** | | | | | | | |
| Tillage | n/a | | 1560 **b** | 6718 **a** | 4757 | 719 **bc** | 1242 **a** |
| No-till | n/a | | 3040 **a** | 4867 **b** | 5115 | 802 **c** | 961 **b** |
| **Year** | | | | | | | |
| 2011 | n/a | n/a | 2840 **a** | 4297 **b** | 3257 **b** | n/a | n/a |
| 2012 | | | 1760 **b** | 7287 **a** | 6615 **a** | | |
| **Source of variation** | | | | | | | |
| Cover crop | 0.0013 | | n/a | 0.0001 | ns | ns | |
| Management | n/a | | 0.0059 | <0.0001 | ns | ns | |
| Year | <0.0001 | | 0.0268 | <0.0001 | <0.0001 | ns | |
| Cover crop x year | 0.0089 | | n/a | ns | ns | 0.0456 | |
| Management x year | n/a | | ns | ns | ns | 0.0288 | |
| Cover crop x management | n/a | | | ns | ns | ns | |
| Cover crop x management x year | n/a | | | ns | ns | ns | |

† Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test

## 3.6 Literature cited


Agriculture and Agri-Food Canada. 2005. Crop profile for dry bean in Canada. Pest Management Centre-Pesticide Risk Reduction Program. Ottawa, Ontario.

Araujo, A.P. and M.G. Teixeira. 2008. Relationship of grain yield and accumualtion of biomass, nitrogen and phosphorus in common bean cultivars. R. Bras. Ci. Solo. 32:1977-1986.

Barnes, J.P. and A.R. Putnam. 1983. Rye residues contribute weed suppression in no-tillage cropping systems. J. Chemical Ecol. 9(8):1045-1057.

Bernstein, E.R., D.E. Stoltenberg, J.L. Posner, and J.L. Hedtcke. 2014. Weed community dynamics and suppression in tilled and no-tillage transitional organic winter rye-soybean systems. Weed Sci. 62: 125-137.

Bernstein, E.R., J.L. Posner, D.E. Stoltenberg, and J.L. Hedtcke. 2011. Organically managed no-tillage rye-soybean systems: Agronomic, economic and environmental assessment. Agron. J. 103:1169–1179

Blackshaw, R.E. 2008. Agronomic benefits of cereal cover crops in dry bean production systems in western Canada. Crop Protection. 27:208-214.

Blackshaw, R.E. and L.J. Molnar. 2008. Integration of conservation tillage and herbicides for sustainable dry bean production. Weed Technology. 22(1):168-176.

Blackshaw, R.E., L.J. Molnar, G.W. Clayton, K.N. Harker and T. Entz. 2007. Dry bean production in zero and conventional tillage. Agron. J. 99:122-126.

Blevins, R.L., D. Cook, S.H. Phillips and R.E. Phillips. 1971. Influence of no-tillage on soil moisture. Agron. J. 63:593-596.

Bottenberg, H., J.Masiunas, C. Eastman and D.Eastburn. 1997. The impact of rye cover crops on weeds, insects and diseases in snap bean cropping systems. Journal of Sustainable Agriculture. 9:131-155.

Brady, N.C. and R.R. Weil. 2002. The nature and property of soils. 13th ed. New Jersey: Pearson Education.

Burgess, J. 1985. An introduction to plant cell development. Cambridge University Press. Cambridge, United Kingdom.

Carr, P.M., R.L. Anderson, Y.E. Lawley, P.R. Miller and S.F. Zwinger. 2012. Organic zero-till in the northern US Great Plains Region: Opportunities and obstacles. Renewable Agriculture and Food Systems Renewable Agric. Food Syst. 27 (1 ): 12-20.

Carson, P. L. 1980. Recommended potassium test. p. 12-13. In W. C. Dahnke, (ed.). Recommended chemical soil test procedures for the North Central Region. North Central Region Publication 221 (revised). N.D. Agric. Exp. Stn., Fargo, N.D
Dabney, S.M., J.A. Delgado amd D.W. Reeves. 2001. Using winter cover crops to improve soil and water quality. Commun. Soil sci. plant anal. 37(7&8):1221-1250.

DeBruin, J.L., P.M.Porter and N.R.Jordan. 2005. Use of a rye cover crop following corn in rotation with soybean in the Upper Midwest. Agron. J. 97:587-598.

Diver, S. 2002. Flame weeding for vegetable crops. Approproate Technology Transfer for Rural Areas (ATTRA). [Online] Available:http://www.agrisk.umn.edu/uploads/ARL02969.pdf [2014 Dec 12].

Doran, J.W. and M.S. Smith. 1991. Role of cover crops in nitrogen cycling In: Cover crops for clean water. Soil Water Cons. Soc. P. 85-107.

Drinkwater, L.E., R.R. Janke and L. Rossoni-Longnecker. 2000. Effects of tillage intensity on nitrogen dynamics in legume-based grain systems. Plant and Soil. 227:99-113.

Duiker, S.W. 2014. Penn State Extension. Crop and Soil Management Section 10: Cover crops.[Online] Available: http://extension.psu.edu/agronomy-guide/cm/sec10

Entz, M. H., R. Guilford and R. Gulden. 2001. Crop yield and soil nutrient status on 14 organic farms in the eastern portion of the northern Great Plains. Can. J. Plant Sci. 81(2):351-354.

Ferraz, L.C.L., A.C. Filho, L.C.B. Nasser and J. Azevedo. 1999. Effects of soil moisture, organic matter and grass mulching on the carpogenic germination of sclerotia and infection of bean by Sclerotinia sclerotiorum. Plant Pathology. 48:77-82.

Flood, H. 2008. Fall rye cover crops increase sustainability of dry bean production. M.Sc. Thesis. University of Manitoba. Winnipeg, Manitoba.

Flood, H. E. and M.H. Entz. 2009. Effects of wheat, triticale and rye plant extracts on germination of navy bean (*Phaselous vulgaris*) and selected weed species. Can. J. Plant Sci. 89:999-1002.

Francis, C.A., M. Prager and G. Tejada. 1982. Effects of relative planting dates in bean (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.) intercropping patterns. Field Crops Research 5: 45-54.

Gardiner, T. R., and L.E. Craker. 1981. Bean growth and light interception in a bean-maize intercrop. Field Crops Research. 4: 313-320.

Graham, P. H. and P. Ranalli. 1997. Common bean (*Phaseolus vulgaris* L.).Field

Crops Research. 53(1): 131-146.

Halde, C., R.H. Gulden and M.H. Entz. 2014. Selecting cover crop mulches for organic rotational no-till systems in Manitoba, Canada. Agron. J. 106(4): 1193-1204.

Huffman, S. A., and K. A. Barbarick. 1981. Soil nitrate analysis by cadmium reduction 1. Communications in Soil Science & Plant Analysis 12.1: 79

Kantar, M., and P. Porter. 2014. Relationship between planting date, growing degree days and the winter rye (L.) variety "Rymin" in Minnesota. Crop Management. 13(1):

Kelner, D. J., J.K. Vessey and M.H. Entz. 1997. The nitrogen dynamics of 1-, 2-and 3-year stands of alfalfa in a cropping system. Agriculture, Ecosystems & Environment. 64(1):1-10.

Kruidhof, H. M., L. Bastiaans and M.J. Kropff. 2008. Ecological weed management by cover cropping: effects on weed growth in autumn and weed establishment in spring. Weed Research. 48(6): 492-502.

Kruidhoff, H.M., L. Bastiaans and M.J. Kropff. 2009. Cover crop residue management for optimizing weed control. Plant Soil. 318:169-184.

Lebaron, M. J. (1974). A description: Developmental stages of the common bean plant. University of Idaho, College of Agriculture, Cooperative Extension Service, Current Information Series, P. 228.

Liebl, R., F.W. Simmons, L.M. Wax and E.W. Stoller. 1992. Effect of rye (*Secale cereale*) mulch on weed control and soil moisture in soybean (*Glycine max*). Weed Tech. 6:838-846.

Lund, R.E. 1975. Tables for an approximate test for outliers in linear models. Technometrics. 17 (4): 473-476.

Malhi, S. S., R. Lemke, Z.H. Wang and B.S. Chhabra. 2006. Tillage, nitrogen and crop residue effects on crop yield, nutrient uptake, soil quality, and greenhouse gas emissions. Soil and Tillage Research. 90(1):171-183.

Manitoba Agriculture, Food and Rural Development. 2011. Field beans - Production. [Online] Available http://www.gov.mb.ca/agriculture/crops/production/field-beans.html [2011 May].

Meisinger J.J., W. L. Hargrove, R. L. Mikkelsen, J. R. Williams, and V. W. Benson. 1991. Effects of cover crops on groundwater quality. Soil Water Cons. 57-84.

Mirsky, S.B., W.S. Curran, D.A. Mortensen, M.R. Ryan, and D.L. Shumway. 2009. Control of cereal rye with a roller/crimper as influenced by cover crop phenology.

Agron. J. 101 (6): 1589 -1596.

Mwaja, V.N., J.B.Masiunas and L.A. Weston. 1995. Effects of fertility on biomass, phytotoxicity and allelochemical content of cereal rye. J. Chemical Ecol. 21(1):81-95.

Olsen, S.R. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular, March 1954. Washington, DC. 939:1-19

Ontario Ministry of Agriculture, Food and Rural Affairs. 2009. Dry Edible Beans: Planting and Crop Development. [Online] Available: http://www.omafra.gov.on.ca/english/crops/pub811/5planting.html [2014 Oct 25]

Podolsky, K. 2013. Reduced tillage implements for management of an organic green manure: effects on nitrogen, weeds and wheat yield. M.Sc. Thesis. University of Manitoba. Winnipeg, Manitoba.

Posner, J. L., J.O. Baldock and J.L. Hedtcke. 2008. Organic and conventional production systems in the Wisconsin integrated cropping systems trials: I. Productivity 1990–2002. Agron. J. 100(2): 253-260.

Putnam, A. R., M.G. Nair, J.P. Barnes, R.R. Baker and P.E. Dunn. 1990. Allelopathy: a viable weed control strategy. In New directions in biological control, alternatives for suppressing agricultural pests and diseases. Proceedings of a UCLA colloquium held at Frisco, Colorado, January 20-27, 1989. (pp. 317-322). Wiley-Liss Inc.

Reicosky, D.C.,W.D. Kemper, G.W. Langdale, C.L. Douglas, Jr., and P.E. Rasmussen. 1995. Soil organic matter changes resulting from tillage and biomass production. J. Soil and Water Cons. 50 (3):253-261.

Ruffo, M.L., D.G. Bullock and G.A. Bollero. 2004. Soybean yield as affected by biomass and nitrogen uptake of cereal rye in winter cover crop rotations. Agron.J. 96 (3): 800-805.

Sarrantonio, M. and E. Gallandt. 2003. The role of cover crops in North American cropping systems. J. Crop Prod. 8:53-74.

Sarrantonio, M., and T. W. Scott. 1988. Tillage effects on availability of nitrogen to corn following a winter green manure crop. Soil Science Society of America Journal 52.6: 1661-1668.

SAS Institute Inc. 2001. Version 9.2. SAS Institute, Cary, NC.

Saskatchewan Agriculture. 2015 [Online] Available: http://www.agriculture.gov.sk.ca/Varieties-Grain-Crops-2015

Saskatchewan Pulse Growers. 2000. Pulse Production Manual. Saskatchewan Pulse Growers. Saskatoon, SK.

Shrestha, A., S.Z. Knezevic, R.C. Roy, B.R. Ball-Coelho and C.J. Swanton. 2002. Effect of tillage, cover crop and crop rotation on the composition of weed flora in a sandy soil. Weed Research. 42:76-87.

Singer, J.W., S.M. Nusser and C.J. Alf. 2007. Are cover crops being used in the US corn belt? J. Soil and Water Cons. 62:353-358.

Swanton, C.J., A. Shrestha, R.C. Roy, B.R. Ball-Coehlo and S.Z. Knezevic. 1999. Effect of tillage systems, N, and cover crop on the composition of weed flora. Weed Sci. 47:454-461.

Teasdale, J. R., and C.L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agron. J. 85(3): 673-680.

Teasdale, J.R. 1993. Interaction of light, soil moisture and temperature with weed suppression by hairy vetch residue. Weed Sci. 41:46-51.

Teasdale, J.R. and C.L. Mohler. 2000. The quantitive relationship between weed emergence and the physical properties of mulches. Weed Sci. 48:385-392.

Teasdale, J.R., C.E. Beste and W.E. Potts. 1991. Response of weeds to tillage and cover crop residues. Weed Sci. 39:195-199.

Uchino, H., K. Iwama, Y. Jitsuyama, T. Yudate and S. Nakamura. 2009. Yield losses of soybean and maize by competition with interseeded cover crops and weeds in organic-based cropping systems. Field crops research. 113(3): 342-351.

Vaisman, I., M.H. Entz, D.N. Flaten and R.H. Gulden. 2011. Blade roller–green manure interactions on nitrogen dynamics, weeds, and organic wheat. Agron. J. 103(3): 879-889.

Varco, J. J., W.W. Frye, M.S. Smith and C.T. MacKown. 1993. Tillage effects on legume decomposition and transformation of legume and fertilizer nitrogen-15. Soil Sci. Soc. Amer. J. 57(3): 750-756.

Wagner-Riddle, C., T.J. Gillespie and C.J. Swanton. 1994. Rye cover crop management impact on soil water content, soil temperature and soybean growth. Can. J. Plant Sc. 74:485-495.

Weston, L. A.1996. Utilization of allelopathy for weed management in agroecosystems. Agron. J. 88(6):860-866.

Wilkins, E.D. and R.R. Bellinder. 1996. Mow-kill regulation of winter cereals for spring no-till crop production. Weed Tech. 10:247-252.

Wilson, J. B. 1988. Shoot competition and root competition. Journal of Applied Ecology, 279-296.

Yield Manitoba 2013 [Online] Available:
http://www.mmpp.com/mmpp.nsf/mmpp_publications.html
Zyla, L. E., R. L. Kushwaha, and A. Vandenberg. 2002. Development of a new crop lifter for direct cut harvesting dry bean. Canadian Biosystems Engineering 44: 2-9.

# 4.0 THE EFFECT OF CEREAL COVER CROPS ON EARLY SEASON WEED DENSITY AND SOIL MICROCLIMATE IN ORGANIC DRY BEANS

## 4.1 Abstract

Cover crops suppress weed establishment and growth by affecting the soil microclimate. While they are growing, cover crops compete with weeds for moisture, nutrients and light, and exude allelopathic compounds. Dead cover crops can continue to intercept light, as well as immobilize soil nitrate. Cover crop species selection and management can influence the magnitude of these processes. The present study aims at understanding the interaction between management and weed control in fall seeded cover crops. Fall rye (*Secale cereale* L.), barley (*Horedum vulgaris* L.) and oat (*Avena sativa* L.) cover crops were compared for their effect on soil microclimate parameters and weed density in bean (*Phaseolus vulgaris* L.) production. Both tillage (T) and no-till (NT) were tested. Prior to bean seeding, fall rye cover crops significantly reduced light interception and soil nitrate in the 0 - 5 cm and 5 - 15 cm soil layers. Weed density was lowest in fall rye, while weed density in oat and barley cover crops were not different than the control. Cover crops had no effect on temperature or soil moisture (0-15 cm) prior to bean seeding. Post bean seeding, fall rye cover crops reduced daily average soil temperatures compared to no cover crop. Fall rye + NT had lower maximum soil temperatures, but minimum soil temperature were unaffected by cover crop and management. Light interception was greatest in fall rye + NT treatments. In both years fall rye reduced soil nitrate compared to all other cover crops, but the magnitude of the difference was greater in 2012. Soil moisture was unaffected by cover crop in both years,

however in 2011, NT treatments had higher soil moisture than tillage treatments. Rye reduced weeds in 1 of 2 years in the post-seeding period. This study characterizes the effect of fall rye on the soil microclimate during the bean and weed emergence period in novel organic no-till production systems.

## 4.2 Introduction

Cover crops affect weed establishment and growth through a variety of mechanisms. Living cover crops interact directly with weeds via competition for resources (light, moisture, nutrients). Indirectly, cover crop mulches release germination suppressing allelopathic compounds, intercept light, reduce soil temperatures (Barnes and Putnam 1983) and immobilize soil nitrogen. Cover crop mulches can provide a light intercepting barrier, reducing the germination of light sensitive weed species such as common lamb's quarters (*Chenopodium album* L.) (Teasdale 1993). Growing cover crops can deplete the root zone of moisture for weeds and sometimes the subsequent crop (Carr et al. 2012, Vaisman et al. 2011). Conversely, cover crop mulches can reduce evaporation and result in higher soil moisture during dry periods (Wagner-Riddle et al. 1994). Cover crops are commonly used to recycle nutrients back to the root zone (Doran and Smith 1991), but can also cause nitrogen immobilization when they are in high carbon content (Wyland et al. 1995). These effects of cover crops on the soil physical environment can affect weed and crop germination.

How cover crops are managed will contribute to their influence on soil microclimate, weed germination, and growth. Decisions made to increase cover crop biomass, such as cover crop species selection and termination timing, may result in better weed suppression

(Teasdale et al. 1991). Cover crop biomass may also decrease light penetration, decrease soil moisture, or immobilize soil nitrate. These factors may negatively affect crop plants growing in these systems. Therefore, trade-offs exist when incorporating cover crops into rotations for weed control. These trade-offs are especially true of high biomass producing cover crops like fall rye. Rye terminated close to the time of main crop seeding has been found to suppress weeds but reduce soil moisture (Wagner-Riddle et al. 1994, Liebl et al. 1992) and temperature (Teasdale and Mohler 1993).

Termination method is another way of managing the influence of cover crops on the soil microclimate. There is evidence that leaving residue on the soil surface is critical for optimizing weed control from cover crops (Kruidhoff et al. 2009). Therefore, if the goal of the cover crop is to suppress weeds termination methods that retain surface cover may be advantageous. However, doing so may also reduce soil temperatures and light penetration, thereby negatively affecting subsequent crops, especially in short season growing regions. Terminating cover crops with tillage can reduce these temperature effects, but incorporation of cereal cover crops may intensify the immobilization of soil nitrate and it dramatically decreases any surface mulch layer. The trade-off between cover crop management decisions for weed control and potentially negative effects on the soil microclimate for the main crop have not been investigated in short growing season regions such as Manitoba. By better understanding how cover crop termination method affects soil and plant responses, we will be better able to plan for cover crop management strategies in organic dry bean production.

The objective of this study was to quantify the effects of tillage and no-till management of winter annual and spring annual cereal cover crops on weed establishment and soil microclimate. Parameters measured included: soil temperature, canopy light interception, soil nitrate, soil moisture and weed density in a bean production systems.

## 4.3 Materials and methods

### 4.3.1 Site description

This study was conducted in Carman, Manitoba at the University of Manitoba's Ian N. Morrison Research Station in 2011 and 2012. A site description can be found in Chapter 3.

### 4.3.2 Experimental design

The experimental design was a randomized complete block in a split plot arrangement. Each block was replicated four times. Main plot experimental units measured 4 m x 8 m and subplot experimental units measured 2 m x 8 m. Cover crop establishment and field operations are described in Chapter 3.

For this experiment, three major points in time were used for sampling and data collection. These points were chosen due to the timing of field operations required to manage the particular cover crop systems. Figure 5 illustrates the early season sampling date (Date 1), the date corresponding with dry bean seeding (Date 2) and the date corresponding with termination of NT fall rye with mowing but in spring annual treatments (Date 3). Figure 6 illustrates the same sequence of field operations in a fall rye NT treatment. The period between date 1 and date 2 is referred to as the pre-seeding period (A). The period between date 2 and date 3 is referred to as the post-seeding period (B).

Each time period has distinct features depending on the cover crop and management. In the preseeding period fall rye treatments are an upright, growing cover crop compared to the dead mulch in barley and oat treatments. Prior to dry bean seeding, tillage was applied to the till treatments. Barley and oat NT treatments received flame weeding, while NT fall rye continued to grow and develop. The final cover crop management operation was the termination of fall rye with mowing when rye reached anthesis. Sampling period, field operations, sampling parameter and their respective dates are summarized in Table 13.

### 4.3.3 Data collection

***Soil temperature***. In early spring, two soil temperature loggers were placed in each main plot, such that one logger was positioned in each subplot. Temperature loggers (TidbiT v2 Temperature Data Logger, Onset Computer Corporation 2015) were used in three of four blocks. Sensors were buried to 3 cm, measured from the centre of the sensor.  Caution was taken to have minimal disturbance to the soil above the sensor. This was achieved by cutting a straight face profile with a trowel and forming a hole under and behind where the sensor was to be placed. Sensors were programmed to log hourly. Placement was between rows (cover crops or dry beans) and approximately 3 m from one end of the plot. Loggers were removed prior to dry bean seeding and replaced after using the same methodology. Temperature loggers were in approximately the same location after dry bean seeding.

In 2012, soil temperature loggers were not replaced immediately after seeding because only soil temperature in the preseeding period was part of the original hypothesis. This meant that soil sensors were replaced immediately prior to rye mowing. Soil temperature was measured for 13 days after fall rye mowing, to June 24th which was consistent with the end date of 2011.

The hourly soil temperature data was used to calculate daily average soil temperature and soil degree days ($GDD_{soil}$). Soil degree days were calculated using the following formula:

Soil Growing Degree Day =

$$\frac{\text{Soil maximum daily temperature} + \text{Soil minimum daily temperature}}{2} - \text{Base Temperature ( 0 °C)}$$

[Eq. 2]

***Canopy light interception***. Canopy light interception was measured to quantify the effect of cover crops on the availability of incoming light to germinating beans and weeds. Photosynthetically active radiation (PAR) is defined as the wavelength between 400 nm and 700 nm and is the fraction of light important for plant growth. To measure PAR, a LICOR quantum sensor was used to take measurements above and below the canopy. Measurements were taken consecutively between 11:00 a.m. to 1:00 p.m. In order to ensure relative accuracy, readings were taken three times above, and three times below of each plot. Light interception (LI) was then calculated using the formula:

$$\text{LI} = \frac{\text{PAR above canopy}}{\text{PAR below canopy}} x\ 100$$

[Eq.3]

***Gravimetric soil moisture***. Gravimetric soil moisture was measured to a depth of 15 cm at three sampling times: early season (date 1), dry bean seeding (date 2) and fall rye mowing (date 3). However, due to an error there is no data for date 1 in 2012. Soil moisture was measured using a composite sample of two cores (5 cm diameter) per experimental unit, taken from inter row positions. In 2012, four sample bags ripped and soil was lost from the samples after being dried. Damaged samples were recorded and removed from analysis.Wet soil samples were weighed and oven dried for at least 72 hours. Oven dried soil samples were reweighed and gravimetric soil moisture was calculated using Eq. 1 (pp. 62).

***Soil nitrate***. Soil collected to measure soil nitrate was sampled using a soil probe (3.175 cm diameter) at two depths, 0 – 5 cm and 5 – 15 cm. The soil sampling regime used a "W" pattern positioned lengthwise through the plot. Once the soil had been collected, the two depths were measured with a ruler and cut into sections with a knife. In 2011, the composite sample comprised of five cores per experimental unit. In 2012, to ensure a representative sample size, this was increased to a composite sample of 8 cores per experimental unit. Soil samples were stored at 4º C until shipped to Agvise laboratories (Northwood, ND) for soil nitrate-N analysis using the cadmium reduction method.

***Weed density.*** Weed densities were determined by counting weeds within a ¼ meter quadrat twice per experimental unit. The quadrats were placed randomly from either ends of the plot and straightened to count three inter row spaces. Weeds were measured from the cotyledon stage and onwards. In the event that the number of weed seedlings approached 100 in only one quarter of the quadrat, the number of weeds was multiplied to approximate the number of weeds in the entire quadrat.

**Table 13.** Parameters and their sampling dates are listed in the respective sampling period (Pre-seeding or post-seeding) for both 2011 and 2012. The dates of field operations (E.g. Dry bean seeding) are included.

| Field Operation | Parameter | Date | | Days after planting (DAP) | |
|---|---|---|---|---|---|
| | | 2011 | 2012 | | |
| | | ---Pre-seeding period--- | | | |
| | Soil temperature | 5 May | 17 April | | |
| | Soil moisture | 5 June | n/a | | |
| | Soil nitrate | 5 June | 9 May | | |
| | Weed density | 24 May | 10 May | | |
| | Weed density | n/a | 17 May | | |
| **Dry bean seeding** | | 6 June | 1 June | | |
| | | ---Post-seeding period--- | | | |
| | Soil moisture | 8 June | 4 June | 2 DAP | 3 DAP |
| | Soil temperature | 10 June | 11 June | 4 DAP | 10 DAP |
| | Soil nitrate | 10 June | 6 June | 4 DAP | 5 DAP |
| | Weed density | 10 June | 4 June | 4 DAP | 3 DAP |
| | Canopy light interception | 23 June | 4 June | 17 DAP | 3 DAP |
| **Flame weeding of barley + NT, oat + NT and control + NT** | | 11 June | 6 June | 5 DAP | 5 DAP |
| | Weed density | 20 June | 24 June | 14 DAP | 12 DAP |
| **Mowing fall rye + NT** | | 24 June | 12 June | 18 DAP | 11 DAP |
| | Soil moisture | 28 June | 12 June | 22 DAP | 11 DAP |
| | Soil nitrate | 28 June | 12 June | 22 DAP | 11 DAP |
| | Canopy light interception | 7 July | 29 June | 31 DAP | 28 DAP |
| | Weed density | 7 June | 7 May | 30 DAP | 34 DAP |
| | Weed density | 7 June | 7 May | 30 DAP | 34 DAP |
| | Canopy light interception | 7 Nov | 25 June | 35 DAP | 25 DAP |
| | | 25 July | n/a | 49 DAP | n/a |

### 4.3.4 Statistical analysis

Analysis of variance (ANOVA) was used for evaluating the treatment effects from the present experiment. The procedures used are repeated from Chapter 3, however years were not combined since the hypothesis tested was treatment effect across the three sampling dates.

This study has two periods: pre-seeding (prior to bean seeding) and post-seeding period. In an effort to reduce Type II error, pre-seeding (Date 1) measurements were analyzed independently of post seeding measurements. This is primarily because the tillage treatment was not applied until dry bean seeding (Date 2). Post-seeding (Date 2 to Date 3) data was analyzed with an ANOVA and a repeated statement. Covariance structures were chosen based on the lowest fit statistics. In some cases, covariance structures were chosen because they resulted in normality. For example, 2012 post-seeding light interception was not normal using a compound symmetry heterogeneous covariance structure, but was normal using a compound symmetry structure. In the case of maximum and minimum soil temperatures, the repeated statement was not used because the model did not allow for the ANOVA to meet the requirements for tests of normality. Instead, ANOVA was run using daily maximum and minimum soil temperatures over the sampling period with date as a random effect. Since we would expect soil temperature to vary with sampling date, this model allowed for the interpretation of the fixed effects of cover crop and management.

If data would not conform to normality assumptions, data was transformed with log10 transformations. If log10 transformations were ineffective, log10 + 0.1 or square root (x) +0.1 were used. Transformations are indicated in subtext of relevant tables. If, after a transformation, data still did not conform to tests of normality, outliers were removed using Lund's Test (Lund 1975). Every combination of achieving normality was attempted before results were reported. If the parameter had a small sample size (n) then outliers were not removed, for example pre-seeding soil nitrate (n=12). Parameters that used a transformation are: 2011 pre-seeding soil nitrate, 2012 post seeding soil nitrate, 2011 and 2012 post seeding weed density and dominant species, 2012 post-seeding maximum and minimum soil temperatures.

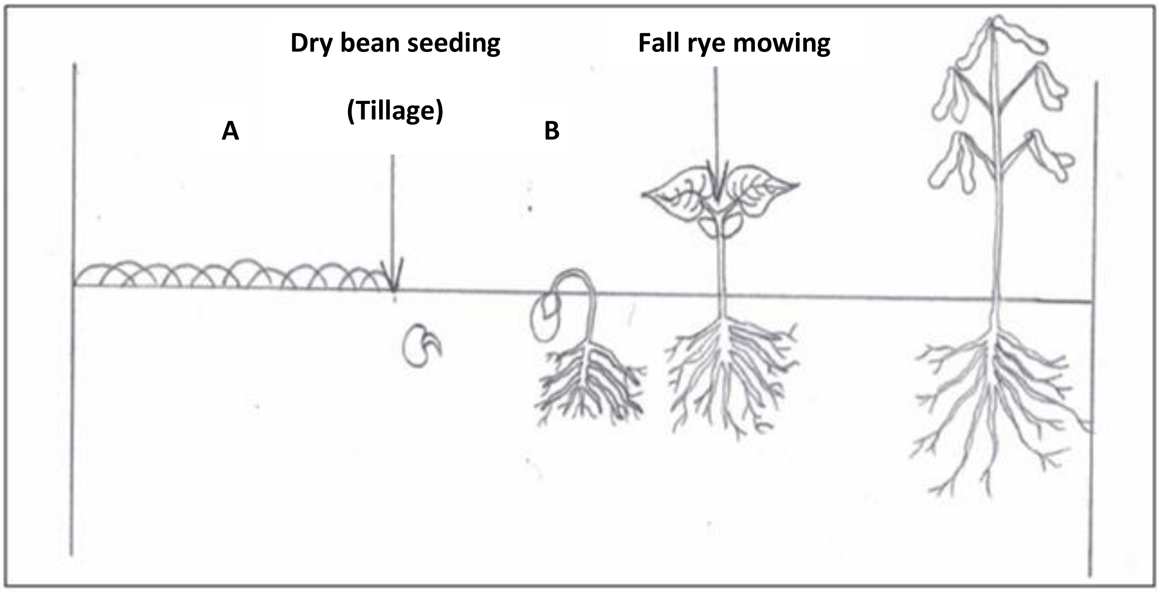



**Figure 5.** Timeline of field operations over the dry bean growing season in a spring annual cereal cover crop plot. A) Pre-seeding period prior to dry bean seeding where there is only the effect of the decomposing cover crop; B) Post-seeding period that begins with application of tillage treatments and seeding of dry beans.

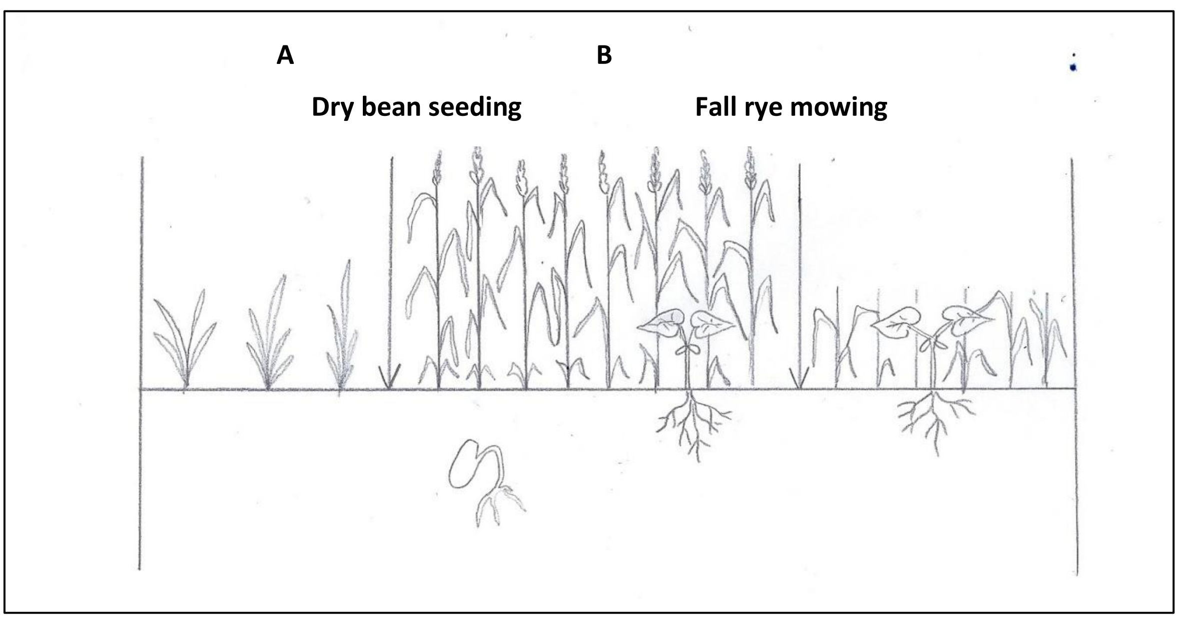



**Figure 6.** Timeline of field operations over the dry bean growing season in a fall rye NT plot. A) Pre-seeding period prior to dry bean seeding where there is only the effect of the cover crop; B) Post-seeding period that begins with application of tillage treatments and seeding of dry beans**.**

## 4.4 Results and discussion

### 4.4.1 Pre-seeding period

#### 4.4.1.1 Soil temperature

Soil temperature plays an important role in crop production with specific influence on growth, but especially development (Kaspar and Bland 1992). In Manitoba, low spring soil temperatures can often delay seeding, as producers wait for soil temperatures to rise. Optimum soil temperatures for seeding vary by species. Dry beans are considered a warm season crop, requiring soil temperatures of approximately 12$^{o}$C for optimal germination and emergence (Nleya et al. 2005).

There was no effect of cover crop on daily maximum and minimum soil temperatures in either 2011 or 2012 (Table 14). Maximum soil temperatures ranged from 16 to 17$^{o}$C and minimum soil temperatures ranged from 7 to 8$^{o}$C across both years. No-till management leaves residues on the soil surface that is often associated with lower soil temperatures (Gauer et al. 1982, Radke 1982). Similarly, cover crop residue is also linked to lowered daily maximum temperatures (Teasdale and Mohler 1993), in part due to increased soil moisture which slows soil warming (Bullied et al. 2003). Few studies can be found, however, on the effect of residues before the main crop is seeded. Therefore any practice that may delay optimal soil conditions for seeding would be considered a deterrent to adoption. To determine the effect of cover crop residue on soil warming in spring during the pre-seeding period, the accumulation of soil temperature was calculated as soil growing degree days ($GDD_{soil}$). This pre-seeding period extended for May 4 to June 4 in 2011 and from May 1 to May 31 in 2012.

Results from the present study show that there was no effect of cover crop on the accumulation of soil temperature before seeding in either 2011 or 2012 (Table 15). It was not surprising that barley and oat cover crops had spring soil temperatures that were comparable to the no cover crop control. Very little spring annual cover crop biomass was observed, such that the residue could not be collected. It was hypothesized that the high residue fall rye cover crop would cause soil to warm more slowly than either the control, oats or barley. However, the absence of differences in soil temperature under fall rye was surprising. Possible explanations are that similar soil moisture across treatments (Table 28) resulted in similar soil warming across all treatments. Soils that are wetter warm more slowly than soils that are drier (Brady and Weil 2002). Secondly, it may be that standing (i.e. growing) fall rye may have had less impact on soil temperature than rye that is laying horizontally on the soil surface. According to Facelli and Pickett (1991) plant residues affect soil temperatures, in part, through the insulation from air temperatures. As such, the insulating properties of cover crops are expected to be greater when plant material is laid down through management practice, as opposed to standing and subject to air circulation.

Since there were no treatment differences in soil temperature in either year when analysed separately, years were combined to evaluate yearly differences. Soil temperature in 2012 was warmer prior to seeding than in 2011. This is further evidence of the seasonal differences between 2011 and 2012. Warmer temperatures result in better growing conditions, and accelerated development. For example, dry beans developed more quickly relative to DAP in 2012 than in 2011 (Table 10). This illustrates the climatic variability within the study.

Results on pre-seeding accumulated $GDD_{soil}$ (Table 15) are an important finding for the promotion of fall-seeded winter annual cover crops in Manitoba. Soil temperature at seeding was 16°C in 2011, and 17°C in 2012. Thus, in both years soil temperatures were above the optimum soil temperature for germinating beans. This is an important finding of this study that would need to be confirmed. Knowing that fall rye cover crops do not significantly prevent soil temperatures from warming in early spring is an important piece of information for crop advisors and farmers.

**Table 14.** Effect of cover crop on average maximum and average minimum daily soil temperatures during the pre-seeding period in 2011 and 2012. Soil temperatures were measured between May 5 and June 5 in 2011 and between April 18 and June 10 in 2012.

| | 2011 | | | | 2012 | | | |
|---|---|---|---|---|---|---|---|---|
| Cover crop | Max | | Min | | Max‡ | | Min | |
| | ----------------------------Soil temperature (°C)------------------------ | | | | | | | |
| Control | 17.0 | **a**† | 7.8 | **a** | 16.8 | **a** | 8.0 | **a** |
| Fall rye | 16.4 | **a** | 8.5 | **a** | 16.6 | **a** | 8.4 | **a** |
| Source of Variation | | | | | | | | |
| Cover crop | ns | | ns | | ns | | 0.0655 | |

†Means within a column followed by a different letters are significantly different at $P<0.05$ according to Fischer's protected LSD test.
‡ Reported means of untransformed data. Analysis performed on log10(x) transformed data.

**Table 15.** Pre-seeding accumulated soil growing degree days ($GDD_{soil}$) above 0°C in 2011† and 2012‡. Growing degree days (Base 5°C) for air temperatures are presented for April 15 to June 6, 2011 and April 15 to June 1, 2012.

| Effect | $GDD_{soil}$ | $GDD_{Air}$ |
|---|---|---|
| Cover Crop | | |
| Control | 474.8 **a§** | |
| Barley | 469.3 **a** | |
| Oats | 478.1 **a** | |
| Rye | 473.3 **a** | |
| | | |
| Year | | |
| 2011 | 400.2 **b** | 271 |
| 2012 | 547.6 **a** | 273 |

| Source of Variation | Pr < F |
|---|---|
| Cover crop | ns |
| Year | 0.0001 |
| Cover crop x year | ns |

† 2011 pre-seeding period May 4 - June 4
‡2012 pre-seeding period May 1 - May 31
§ Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test.

#### 4.4.1.2 Canopy light interception

Cover crop residues can intercept incoming light and this can influence both crop and weed growth. Practices that increase the amount of biomass produced by the cover crop will result in higher light interception. An advantage of the life cycle of fall rye is that it can produce a large amount of weed suppressing mulch in early spring (Blackshaw 2008). To achieve a mulch that can provide season long control of weeds, no-till methods have proven to be very successful (Halde et al. 2014, Vaisman et al. 2011). Light interference by crop canopies affects light quality (i.e. red: far red light ratio), as well as quantity (Ballare and Casal 2000), therefore changes to light quality appear to have occurred in this study.

In the present study, to incorporate NT termination into a fall-seeded cover crop system the rye was mowed. Thus, in the fall rye NT system, fall rye acts as an intercrop until it reaches anthesis and is terminated. Mulch research typically measures the effect of a horizontal mulch, however in the present study rye existed as a vertical mulch for much of the time. Light interception (LI) was measured in fall rye and control treatments to quantify mulch characteristics before and after fall rye is mowed (Figure 7). Since barley and oat had winter-killed and biomass was negligible in spring, light interception was not measured in these treatments.

In 2011, canopy light interception in fall rye treatments averaged 48% reduction (of an average 1690 µmol $m^{-2}$ $s^{-1}$) incoming PAR measured above the canopy (Table 16). The proportion of LI is low compared to other studies with fall rye. Working in Manitoba in the 1990s, Thiessen-Martens (2001) found that fall rye intercepted 75 - 87% of incoming PAR early in the growing season (May 25). This is the same day that light sensor measurements were taken in the present study. Since fall rye was vertical there was some light penetration that may have radiated through the canopy, especially as wind disturbed the canopy. The lower canopy LI values could reflect lower biomass. Thiessen-Martens (2001) obtained fall rye dry matter values ranging from 10 to 15 t $ha^{-1}$ as compared to 4 to 6 t $ha^{-1}$ measured at dry bean seeding in the present study. Fall rye had to be reseeded the previous fall due to excess moisture in 2010, and was followed by cool conditions the spring of 2011. In 2011, fall rye on May 25 was at early stem elongation stage (Zadoks et al. 1974).

In 2012, LI was measured to coincide with dry bean seeding (4 DAP). At the time of dry bean seeding, rye had reached the flowering stage. No-till fall rye incepted 55% of PAR, compared to rye that had been tilled (23%). Control treatments did not intercept significant amounts of light, 0-3% of PAR (Table 16). Results from these early season measurements of

LI indicate that rye, and specifically NT rye significantly reduced incoming PAR. In this study, rye only intercepted about half the PAR.

**Table 16**. Proportion of early season light interception in fall rye cover crops measured at fall rye early stem elongation in 2011 (prior to dry bean seeding) and heading in 2012 (post dry bean seeding).

| Effect | | Light Interception (%) | |
|---|---|---|---|
| Cover crop | Management | 2011 | 2012 |
| Rye | | 49% | |
| | No till | | 55% **a†** |
| | Tillage | | 23% **b** |
| Control | | 0 | |
| | No till | | 3% **c** |
| | Tillage | | 0 **c** |
| Source of variation | | | |
| Cover crop | | n/a | Ns |
| Management | | | Ns |
| Cover crop x management | | | 0.0001 |

†Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test

a)

b)

c)

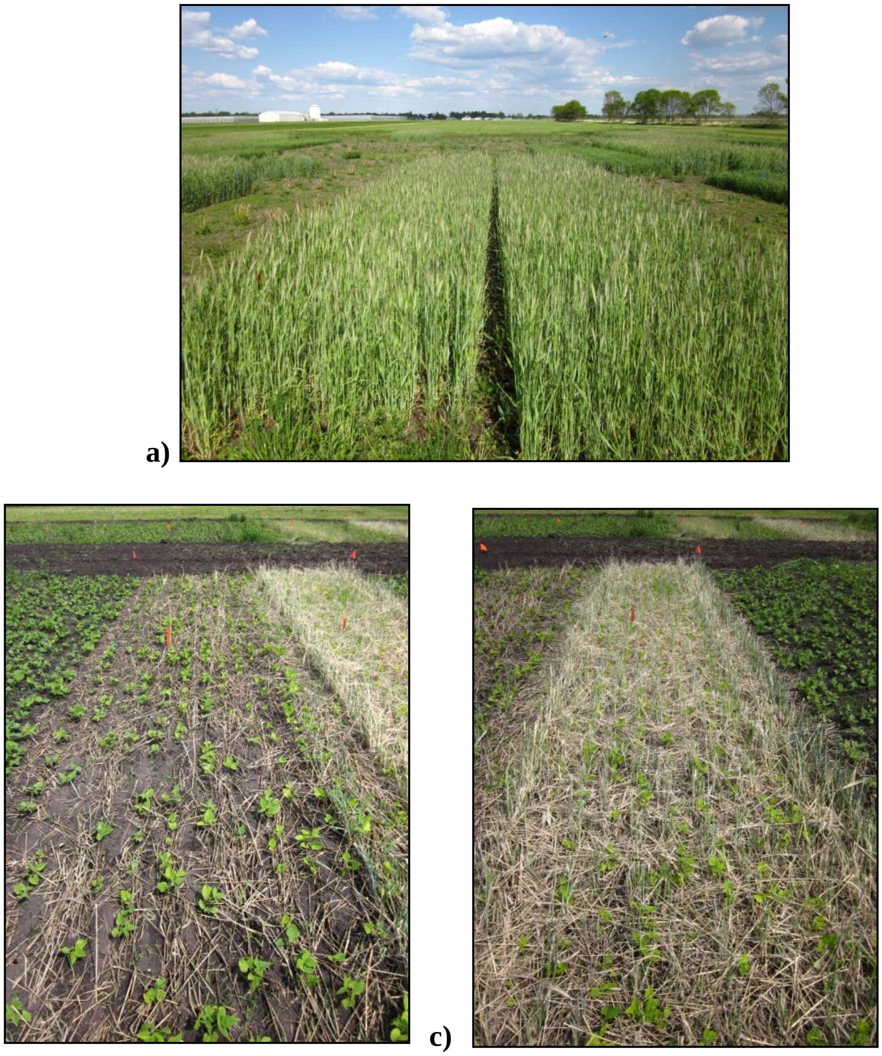


**Figure 7.** Fall rye prior to bean seeding (a) and after the application of tillage (b) and no-till (after mowing) treatment (c).

#### 4.4.1.3 Soil nitrate.

Soil nitrate-N is an important nutrient for plant growth. In organic agriculture, ensuring nutrient availability can be challenging if sources of organic manure are not available. This study aimed to evaluate the effect of fall-seeded cover crops on the soil nitrate-N status of soil in early season when weeds are germinating. Soil nitrate-N was measured in the early spring prior to dry bean seeding, in the upper 0 - 5 cm and 5 - 15 cm of soil. It was hypothesized that springtime soil nitrate-N would be lower in cover crop compared to no cover crop treatments.

In 2011, soil nitrate-N levels were lower in fall rye (0.97 ppm) treatments than all other treatments. Soil nitrate-N for barley (4.5 ppm) and oat ( 3.7 ppm) were no different than the no cover crop control (4.5 ppm) (Table 17). In 2012, soil nitrate-N was lowest in fall rye treatments (1.6 ppm) and highest in the no cover crop control (15.9 ppm). Barley treatments (11.8 ppm) had significantly lower soil nitrate-N than the control, but were higher than fall rye. Oat cover crop treatments (12.4 ppm) were not significantly different than the control or barley treatments. Therefore, in both years the winter annual fall rye reduced soil nitrate-N status at main crop seeding.

Lower soil nitrate-N in spring following winter cover crops is well documented. In the case of winter annuals, lower soil nitrate-N is associated with longer in-field time (Jewett and Thelen 2007). Vegetative rye can contain roughly 15.8 g total N $Kg^{-1}$ in plant tissues in spring (Kuo and Sainju 1998). Fall rye (404 kg $ha^{-1}$), barley (325 kg $ha^{-1}$) and oat (395 kg $ha^{-1}$) cover crop biomass in the fall of 2010 were not significantly different than the control (Table 15). This resulted in insignificant nutrient removal by the spring annual cover crops in 2011 (Table 18). However, since fall rye continued to grow in the spring of 2011, soil nitrate-N was lower than all other treatments. In fall of 2011, spring annual cover crop biomass was not significantly different than fall rye (1457 kg $ha^{-1}$) and all cover crop treatments were significantly higher than the control (480 kg $ha^{-1}$). Average fall rye biomass at dry bean seeding was 6921 kg $ha^{-1}$ and 4287 kg $ha^{-1}$ in 2011 and 2012, respectively. Based on the study by Kuo and Sainju (1998), fall rye removed an estimated 109 and 68 kg total N $ha^{1}$.

The effect of fall cover crop biomass can be seen in spring 2012 soil nitrate-N, where barley (11.8 ppm) and fall rye (1.6 ppm) both had lowered soil nitrate-N compared to the control (15.9 ppm) (Table 17).

Soil nitrate-N in the surface layer (0 - 5 cm) was 46% and 60% higher than in subsurface soil (5 - 15 cm) in 2011 and 2012, respectively (Table 17). The lack of a significant cover crop x depth interaction indicates that all cover crops acted the same at surface and subsurface depths. In other words, fall rye was not different than all other cover crops at using soil nitrate-N at depth. Generally, surface soils are also higher in organic matter than subsurface soils. The majority (95 - 99%) of soil nitrogen exists in the organic form (R - $NH_2$) as humic substances, and are subject to microbial transformations that primarily occur in surface soils (Brady and Weil 2002). Thus it is also possible that surface soils are inherently higher in soil nitrate.

**Table 17.** Pre-seeding soil nitrate in surface and subsurface soil layers in 2011 and 2012. Sampling occurred on May 6, 2011 and May 9, 2012 which was 31 days and 23 days prior to dry bean planting, respectively.

| Effect | 2011 | 2012 |
|---|---|---|
| Cover crop | ---------------------------------ppm------------------------------- | |
| Control | 4.5 **a**† | 15.9 **a** |
| Barley | 4.5 **a** | 11.8 **b** |
| Oat | 3.7 **a** | 12.4 **ab** |
| Rye | 0.97 **b** | 1.6 **c** |
| | | |
| Depth | | |
| 0 - 5 | 4.1 **a** | 13.1 **a** |
| 5 - 15 | 2.2 **b** | 7.8 **b** |
| | | |
| Source of variation | | |
| Cover crop | <0.0001 | <0.0001 |
| Depth | <0.0001 | 0.0004 |
| Cover crop x depth | ns | ns |

†Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test.

#### 4.4.1.4 Pre-seeding weed density.

Winter cover crops can control weeds in fall and spring through direct competition for resources and physically impeding germination (Kruidhof et al. 2008). Effective early season weed control is proven to be more important for preventing yield losses than late season weed control (Gallandt 2006, Wyse 1992), and is also known as the critical weed-free period. The length of the critical weed-free period depends on the crop. For dry beans, this period can range from 3 to 6 weeks after planting (WAP) (Bernstein et al. 2014). To determine the effect of fall-seeded cover crops on late fall and early spring weed control, weed density was measured in early spring before main crop seeding.

Pre-seeding measurements indicate that there was a weak effect of cover crop on weed density in 2011 and 2012 (Table 18). In 2011, fall rye treatments had significantly fewer weeds than the spring annual cover crop treatments. The control treatment was not significantly different than any of the cover crop treatments. In 2012, there were no significant difference in weed density among all cover crops but rye had significantly fewer weeds than the control. In 2012, it was possible to take two measurements of weed density before dry bean seeding. Weed density was higher at the second date than earlier in the season but the lack of a significant date x cover crop interactions indicated no difference in performance of cover crops on weeds over time.

Fall rye can provide effective weed suppression through the exudation of allelochemicals (Putnam et al. 1983, Hoffman et al. 1996). Allelochemicals are organic compounds emitted by roots and shoots that act to inhibit weed seed germination by affecting the enzyme activities (Friebe et al. 1997). Previous research has shown that the strength of the effect is proportional to rye biomass. However, a recent study by Flood (2008) showed that rye at the 5-leaf stage effectively provided season long control of broadleaf weeds.

Living mulches have been found to reduce biomass of common lambsquarters (*Chenopodium album* L.), large crabgrass (*Digitaria sanguinalis* L.) and common ragweed (*Ambrosia artemisifolia* L.) by 98, 42 and 90 %, respectively, while having no effect on weed density (Putnam et al. 1993). Similarities can be found in this study. For example, Table 14 shows that fall rye had significantly lower weed biomass at dry bean harvest, regardless of the lack of influence on weed densities in spring. This also agrees with what was seen in the field, in the apparent stunted weed development in fall rye compared with other treatments.

**Table 18**. The effect of cover crop and sample date† on pre-seeding weed density§ in 2011 and 2012.

| Effect | 2011 | 2012 |
|---|---|---|
| Cover crop | ---plants $m^{-2}$--- | |
| Control | 46.5 **ab**‡ | 118 **a** |
| Barley | 61.4 **a** | 64.8 **ab** |
| Oat | 63.1 **a** | 89.3 **ab** |
| Rye | 33.7 **b** | 34.8 **b** |
| | | |
| Date | | |
| 1 | n/a | 33.5 **b** |
| 2 | n/a | 119.9 **a** |
| | | |
| Source of variation | | |
| Cover crop | 0.0488 | 0.0559 |
| Date | n/a | 0.0002 |
| Cover crop x date | n/a | ns |

† Only one sampling date occurred in 2011 (May24). Sampling occurred on May 10 and May 17 in 2012.
‡Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test
§Reported means of untransformed data. Analysis performed on log10(x) transformed data.

#### 4.4.1.5 Gravimetric soil moisture.

Excessive soil moisture use by cover crops is a concern commonly articulated by Manitoba producers. Previously, cover crop research was conducted in the Mid-Western and Mid-Atlantic United States which receive 508 to 1270 mm of annual precipitation compared with 500 mm in Manitoba's growing regions (Oregon State University 2006, Manitoba Agriculture, Food and Rural Development 2014). Therefore, learning how cover crops affect soil moisture use was an important goal of this study.

It was expected that gravimetric soil moisture would be lower in spring under winter cover crops because of continued moisture use. It was viewed that reduced or limited moisture use by spring annual cereals could be an added advantage in contrast to fall rye. To evaluate late fall and early season moisture use by fall-seeded cover crops, soil moisture was sampled in early spring. It was observed that there was no effect of cover crop on early season gravimetric soil moisture in 2011 (Table 19). In error, soil moisture was not sampled in 2012.

It is likely that high rainfall in the fall of 2010 and spring 2011 masked soil moisture treatment effects. The fall of 2010 was very wet, with 72 % of total growing season precipitation falling between August and October (Table 3). Working in Minnesota, De Bruin et al. (2005) found that when above normal precipitation was experienced, no differences in soil moisture were found between rye cover crops and the no cover crop control in June. Other cover crop research in Manitoba found similar results in 2011 due to excess moisture (Podolsky 2013). Without data from the second year of this study, limited conclusions can be drawn.

**Table 19.** The effect of cover crop on pre-seeding gravimetric soil moisture in 2011.

| Cover crop | g / g |
|---|---|
| Control | 0.1687 **a†** |
| Barley | 0.168 **a** |
| Oat | 0.168 **a** |
| Rye | 0.186 **a** |
| Source of variation | |
| Cover crop | ns |

†Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test

### 4.4.2 The post-seeding period (Seeding to mowing)

The following section describes the time period between dry bean seeding and fall rye mowing, what is referred to as the post-seeding period. In spring annual and control treatments, plots were tilled or flame weeded (NT) (Figures 8), and in fall rye treatments, plots were tilled or rye continued to develop until it was mowed in NT treatments (Figure 9). This period is of interest since it is the dry bean emergence period and in the NT treatment, fall rye had not yet been terminated.

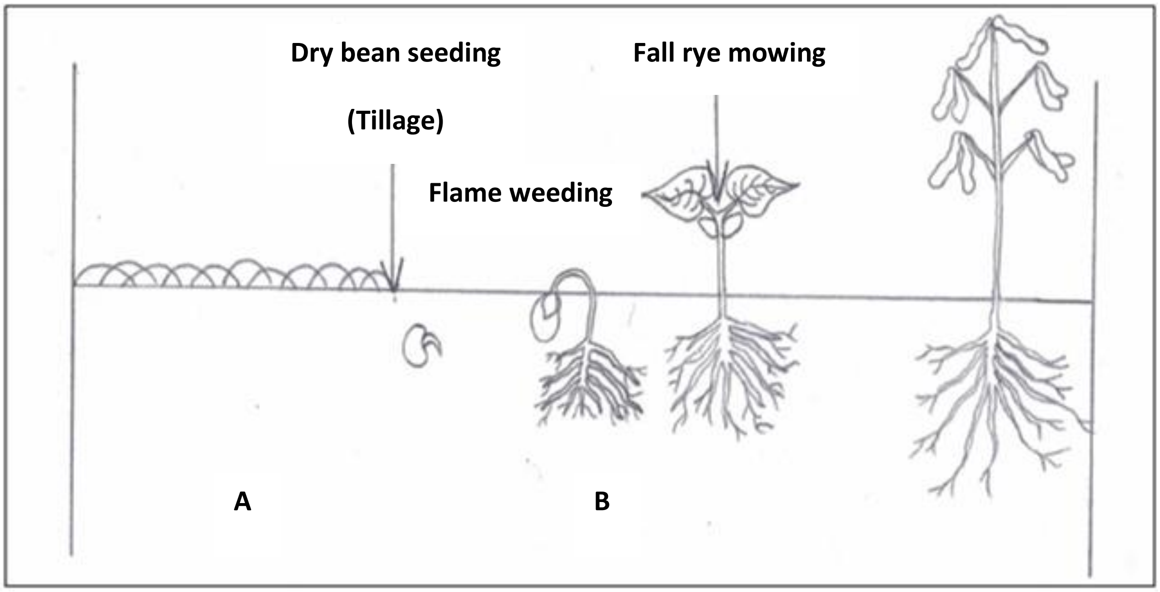



**Figure 8.** Timeline of field operations over a growing season in spring annual plot. A) Pre-seeding period prior to dry bean seeding where there is only the effect of the decomposing cover crop; B) Post-seeding period that begins with application of tillage treatments and seeding of dry beans.

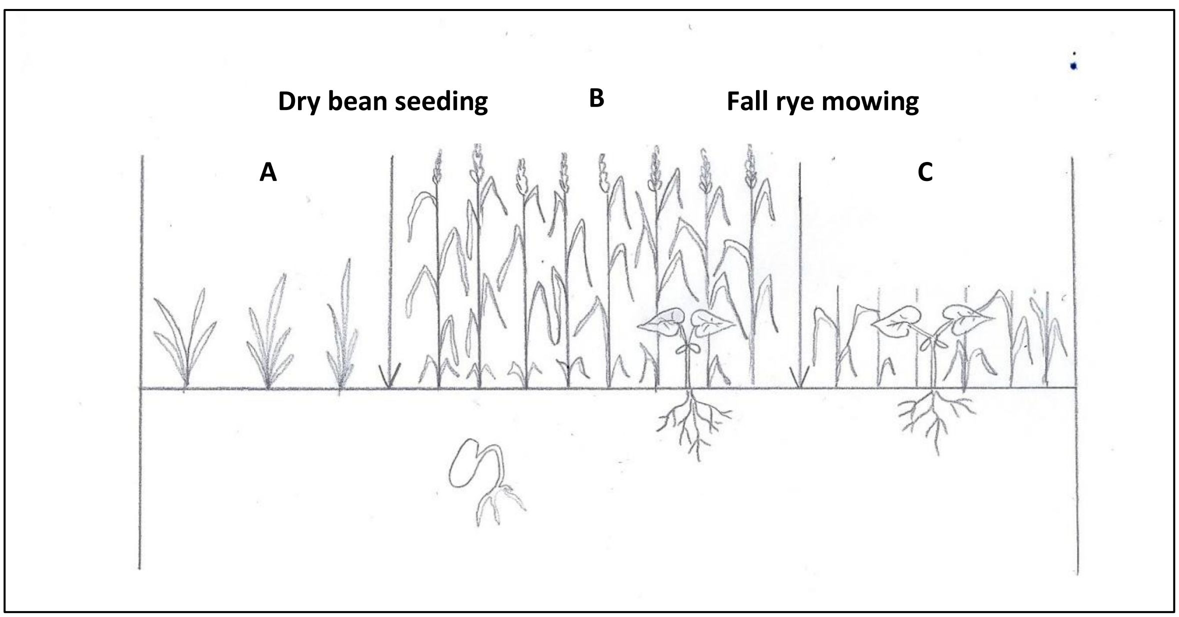



**Figure 9.** Timeline of field operations over a growing season in a fall rye NT plot. A) Pre-seeding period prior to dry bean seeding where there is only the effect of the cover crop; B) Post-seeding period that begins with application of tillage treatments and seeding of dry beans; C) post rye mowing.

#### 4.4.2.1 Soil temperature

Crop and soil management practices that maintain residue on the soil surface can influence soil temperature in agricultural lands. Past research has shown that mulches can buffer soil temperature, usually lowering soil temperature maximums and increasing soil temperature minimums. In Southern Manitoba, NT straw mulched fields were found to have lower diurnal maximum temperatures and higher soil moisture than conventional tilled fields (Gauer et al. 1982, Bullied et al. 2003).

To understand the influence of cover crop and tillage regime on soil temperature during the dry bean emergence period, daily average soil temperature was measured in all treatments. In addition, maximum and minimum soil temperatures were also investigated for fall rye and control treatments. In 2011, soil temperature was measured during the period between dry bean seeding and fall rye termination, however, due to an error in 2012, this period started the day of fall rye mowing (June 11). The end date of June 24, 2012 was decided because it is a repetition of calendar days used in 2011. In 2011, this period was 18 days and in 2012, it was 13 days.

Although significant in both years, the effect of cover crop x management on daily average soil temperature was subtle. In 2011, under tillage there was no great difference between cover crops, but in NT, daily soil temperatures were lower in rye than all other cover crops (Table 20). In 2012, there was little difference between cover crops and management. It was expected that there would be greater differences between treatments in soil temperature during this period. However, it is not solely the cover crop influencing the soil surface, but also growing beans and weeds. Other studies have found the effect of mulches on soil temperature to decline over time, although significant in the early season (Wagner-Riddle et al. 1994).

The reason we were interested in the period between dry bean seeding and the termination of NT fall rye is because it coincides with dry bean emergence. The optimal soil temperatures for bean emergence are considered to be 15°C and higher, while temperatures below 9°C are considered sub-optimal for emergence (Kolasinska et al. 2000). Therefore, to investigate fall rye treatment effects on daily average maximum and minimum soil temperatures, fall rye + tillage and fall rye + NT treatments were compared to the control with and without tillage (Table 21).

During the 2011 and 2012 post-seeding periods, there was a significant cover crop x management interaction for both maximum and minimum soil temperatures (Table 21). In both years, NT alone (i.e., control treatments) did not result in differences in maximum soil temperatures, but in fall rye + NT there were lower soil maximum temperature (21°C in 2011 and 22°C in 2012). Wilkins and Bellinder (1996) found that rye killed at kernel filling reduced growing season soil temperatures by 6°C compared to bare soil. The maximum temperatures of the rye + T treatments were rarely significantly different than the control treatments. In both years, no-till management resulted in lower minimum soil temperatures with the exception of fall rye + NT treatments in 2012. Results are similar to other studies by Wagner-Riddle et al. (1994) and Teasdale and Mohler (1993) that found that mulches had a buffering effect on soil temperatures. Cover crops buffer soil temperature by lower soil maximum temperatures and raising soil minimum temperatures, which means that daily soil temperature amplitudes were reduced (Teasdale and Mohler 1993).

**Table 20.** Daily mean post-seeding soil temperature until fall rye mowing in 2011 and 2012. In 2011, this period was June 10 to June 24. In 2012, the daily average for June 11 to June 24 was used. ). In 2011, fall rye +NT has not been mowed (Mowing occurred on June 24, 2011) In 2012, fall rye +NT has been mowed (Mowing occurred on June 11, 2012).

| Treatment | | Year | | | |
|---|---|---|---|---|---|
| Cover crop | Management | 2011 | | 2012 | |
| Control | Till | 19.46 | **a†** | 21.34 | **ab** |
| Barley | | 19.19 | **ab** | 21.31 | **b** |
| Oats | | 19.44 | **ab** | 21.31 | **b** |
| Fall rye | | 19.31 | **ab** | 21.31 | **b** |
| Control | No-till | 19.19 | **b** | 21.32 | **b** |
| Barley | | 19.26 | **ab** | 21.37 | **a** |
| Oats | | 19.54 | **ab** | 21.27 | **c** |
| Fall rye | | 17.41 | **c** | 21.34 | **ab** |
| Source of variation | | | | | |
| Cover crop | | 0.0134 | | 0.0220 | |
| Tillage | | <0.0001 | | ns | |
| Cover crop x tillage | | <0.0001 | | 0.0025 | |

†Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test.

**Table 21**. The effect of cover crop and management on maximum and minimum soil temperatures during the post-seeding period (June 11 - June 24 in 2011 and 2012). In 2011, fall rye +NT has not been mowed (Mowing occurred on June 24, 2011) In 2012, fall rye +NT has been mowed (Mowing occurred on June 11, 2012).

| Cover crop | Management | Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | | | 2012 | | | |
| | | Max | | Min | | Max‡ | | Min‡ | |
| | | ------------------------------Average soil temperature ($^{o}$C)------------------------ | | | | | | | |
| Control | Till | 24.16 | **a†** | 15.56 | **b** | 23.53 | **b** | 14.56 | **b** |
| | No-till | 24.1 | **a** | 15.24 | **c** | 24.10 | **a** | 14.21 | **c** |
| Fall rye | Till | 23.28 | **a** | 16.05 | **a** | 23.50 | **ab** | 14.45 | **b** |
| | No-till | 20.69 | **b** | 14.90 | **c** | 21.67 | **c** | 15.58 | **a** |
| Source of variation | | | | | | | | | |
| Cover crop | | 0.0766 | | 0.745 | | 0.0398 | | 0.0174 | |
| Tillage | | <0.0001 | | <.0001 | | <.0001 | | <.0001 | |
| Cover crop x tillage | | <0.0001 | | <.0001 | | <.0001 | | <.0001 | |

†Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test.
‡ Reported means of untransformed data. Analysis performed on log10(x) transformed data.

#### 4.4.2.2 Light interception

Light interception is an important mechanism contributing to weed suppression by fall rye mulches (Teasdale and Mohler 1993). However this may also have a negative effect on the main crop by reducing available incoming PAR. To evaluate the effect of termination method (with or without tillage) on light interception by fall rye, LI was measured before and after fall rye mowing. In 2011, light was first measured 17 DAP (unmowed rye) and 31 DAP (mowed rye). In 2012, light was measured 11 DAP (unmowed rye) and 28 DAP (mowed rye). Mowing occurred 18 DAP and 11 DAP in 2011 and 2012, respectively. It is important to note that light was measured on the soil surface, therefore also capturing light interception from growing beans and any rye plant material.

In 2011, there were two, two-way interactions; cover crop x management and management x date. There was no effect of tillage in the control, but in the rye treatment, the no-till system intercepted significantly more light than the tilled system (Table 22). The control + tillage had the least effect on light interception, and any interception recorded in this treatment was the combined effect of the dry bean canopy and/or weed canopy. Tillage treatments at dry bean seeding (Date 1) had the lowest light interception, since plots had just been tilled. There was no difference between no-till treatments at either date and this was comparable to tillage treatments at the mid season sampling date. By the second date (FR mowing), sufficient weed biomass was present in tillage treatments to reduce incoming light by 34 %.

In 2012, there were two, two-way interactions; cover crop x management and cover crop x date. Similar to 2011, light interception in 2012 was greatest under fall rye + NT, intercepting 54% of incoming PAR (Table 21). Fall rye + tillage and the control + NT were statistically similar, intercepting 28% and 19%, respectively. This indicates that soil incorporated fall rye residue and any weeds present in control + NT had a similar effect on LI. Control + tillage treatments had the lowest light interception (14%). Light interception was negligible in the control at dry bean seeding (Date 1). By comparison, light interception in fall rye treatments was not different between the two sampling dates, and was statistically similar to the control midseason. This means that rye intercepted a similar amount of light, regardless if it was standing, or if it had been mowed and residue left on the plot. It also means that there was sufficient weed biomass to compete with beans for incoming light. In other words, rye was replaced by weeds as an agent of light interception.

Results from this study indicate that light interception could be an important mechanism for weed control, but may contribute to lower dry bean yield. Rye managed without tillage had on average 50% less available PAR for weed and bean germination and growth. These numbers are relatively consistent with the literature where 60 % to 70 % interception of PAR with rye has been recorded (Wilkins and Bellinder 1996, Thiessen-Martens et al. 2001). Results also indicate that across both years, there was no significant effect of sampling date on LI in fall rye. This could also be interpreted to mean that at the time of seeding (Date 1), rye has already accumulated enough biomass to substantially reduce available light, such that when rye is terminated (Date 2) there has been little change in biomass. It also means that standing rye intercepts as much light as mowed rye.

**Table 22**. The effect of cover crop, management and date† on light interception (%) during the period between dry bean seeding (Date 1) and the termination of no-till fall rye by mowing (Date 2).

| | | 2011 | | | | 2012 | |
|---|---|---|---|---|---|---|---|
| Effect | | | | | | | |
| Cover crop | Management | Date | Light Interception (%) | Cover crop | Management | Date | Light Interception (%) |
| | No-till | 2 | 41 **a**‡ | Rye | | 1 | 43 **a** |
| | No-till | 1 | 40 **a** | | | 2 | 39 **a** |
| | Till | 2 | 34 **a** | Control | | 1 | 1 b |
| | Till | 1 | 13 **b** | | | 2 | 31 **a** |
| Rye | No-till | | 59 **a** | Rye | No-till | | 54 **a** |
| | Till | | 29 **b** | | Tillage | | 28 **b** |
| Control | No-till | | 22 **bc** | Control | No-till | | 19 **bc** |
| | Till | | 18 **c** | | Tillage | | 14 **c** |
| Sources of variation | | | | | | | |
| Cover crop | | | ns | | | | ns |
| Management | | | ns | | | | ns |
| Date | | | ns | | | | ns |
| Cover crop x management | | | 0.0009 | | | | 0.0002 |
| Cover crop x date | | | ns | | | | < 0.0001 |
| Management x date | | | 0.0032 | | | | ns |
| Cover crop x management x date | | | ns | | | | ns |

† Sampling date in 2011: Date 1 was June 23 Date 2 July 7. Sampling date in 2012: Date 1 was June 12 Date 2 June 29

‡Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer’s protected LSD test.

### 4.4.2.3 Soil nitrate

Incorporating cereal cover crops into crop rotations can put stress on already limited available soil nitrogen in organic systems. It is important to understand the effect of cover crops and residue management on soil nitrate-N in order to maximize the benefit of the cover crop and minimize the negative impact on the main crop. The effect of cereal cover crops is twofold. First, cereal cover crops use available soil N, due to their high C/N ratio. Second, the incorporation of residues can facilitate microbial activity and immobilization of soil nitrate-N due to the high C:N ratio of cereal crops. Therefore, from a soil nitrate-N perspective it is beneficial to leave residues on the soil surface. In addition to the effect on nitrate cycling, cover crop residue can also have stimulatory effects on the germination of certain weed species (Teasdale and Pillai 2005). Soil nitrate-N status of surface and subsurface soil was investigated here in order to detect any difference in these zones of germination for beans or weeds. Soil nitrate-N was measured at two depths (0 - 5 cm and 5 - 15 cm) and two sampling dates (dry bean seeding and rye mowing).

In 2011, there was a significant two-way interaction between soil depth and sampling date. Soil nitrate-N was significantly higher in the surface soil than subsurface at dry bean seeding. At fall rye mowing (Date 2), soil nitrate-N was significantly higher in the subsurface soil than soil. This effect is attributed to high precipitation in this period causing leaching of nitrates deeper into the soil profile. Spring 2011 was wet, the month of May having 72 mm of rainfall and 52 mm in June (MAFRD Ag-Weather Program 2014). Due to this, any treatment differences were probably masked which is possible to say since there were effects in 2012.

Cover crop treatment significantly affected soil nitrate-N in 2011. Soil nitrate-N was significantly lower in fall rye treatments (2.1 ppm) than all other treatments, while barley (5.1 ppm) and oat (4.2 ppm) cover crops had similar nitrate-N levels as the control (4.7 ppm) (Table 23). Higher nitrate-N after spring annual cover crops compared with rye was not surprising since little residue was observed in the field at the time of dry bean seeding. It was concluded that the lower soil nitrate in fall rye treatments was explained by N uptake. As a winter annual, fall rye continued to remove nitrate-N when all other treatments were not.

In 2011, no-till management of cover crops reduced soil nitrate-N by 20 % compared to tillage (Table 23). It was expected that incorporation of high residue fall rye would reduce spring soil nitrate-N but the opposite was observed here. This is contrary to the hypothesis that tillage would reduce soil N in spring. Previous research has indicated fall-seeded rye has a spring C:N ratio of approximately 23 (Kuo and Sainju 1998). A C:N ratio of 23 is above the threshold for N immobilization (20 :1) according to Brady and Weil (2002). Therefore, at the time of sampling, spring soil nitrate-N in fall rye + NT treatments was more affected by the continued removal by fall rye. The time between dry bean seeding (Date 1) and fall rye mowing (Date 2) means that rye was still actively growing for 18 DAP. The lower soil nitrate-N found in all other NT treatments is likely due to continued uptake by weeds present.

In 2012, there was a three-way interaction of tillage management x date x depth on soil nitrate (Table 24). Regardless of date, soil nitrate was higher in the surface soil layer under tillage management than in NT. In general, soil nitrate was lower at depth than in surface soil. Previous research has shown that tillage increases soil mineralization of indigenous soil organic matter (Drinkwater et al. 2000). Drinkwater et al. (2000) found that the N-mineralization potential of surface soils (0 - 5 cm) were two to three-fold higher than for subsurface soils (5–20 cm soil), which were not significantly different across treatments. Surface soils are also warmer than subsurface soils, which accelerates soil microbial mineralization processes (Brady and Weil 2002).

The effect of cover crop varied across management regime (Cover crop x management) and sampling depth (Cover crop x depth) in 2012. Not only did fall rye reduce soil nitrate-N more than any other treatment, but the difference was greater under no-till management and at depth. Although this could be beneficial for weed competition, it places stress on resources for the germinating main crop. Bean development, biomass and yield were consistently lower in fall rye + NT treatments, even though weed biomass was also lower in these treatments

(Table 12). It is apparent that fall rye and NT management places additional stress on soil nitrate-N. Cereal cover crops are excellent N scavengers that can improve N cycling in situations where there is an excess of N and a risk of N leaching (Weinert et al 2002). However, they may not be suitable for cropping systems where nitrogen is a limiting resource.

**Table 23.** The effect of cover crop, management, depth and sampling date† on post-seeding soil nitrate in 2011 during the period between dry bean seeding (Date 1) and the termination of no till fall rye by mowing (Date 2).

| Effect | | Soil $N0_3$ |
|---|---|---|
| Cover crop | | ----------------------ppm---------------------- |
| Control | | 4.7 **a** |
| Barley | | 5.1 **a** |
| Oat | | 4.2 **a** |
| Fall rye | | 2.1 **b** |
| | | |
| Management | | |
| Till | | 5.0 **a** |
| No till | | 3.1 **b** |
| | | |
| Depth (cm) | | |
| 0 - 5 | Date 1 | 4.5 **a** |
| | Date 2 | 3.5 **b** |
| 5 - 15 | Date 1 | 3.5 **b** |
| | Date 2 | 4.5 **a** |
| Source of variation | | |
| Cover crop | | 0.0033 |
| Management | | <0.0001 |
| Depth | | ns |
| Date | | ns |
| Cover crop x management | | ns |
| Management x depth | | ns |
| Depth x date | | 0.0026 |
| Cover crop x date | | ns |
| Cover crop x depth | | ns |
| Management x date | | ns |
| Cover crop x management x depth x date | | ns |

† Sampling occurred on June 10 and June 28 in 2011. Sampling occurred on June 6 and June 12 in 2012.
‡Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test

**Table 24.** The effect of cover crop, management, sampling date† and depth on soil nitrate-N‡ during the post-seeding period in 2012 during the period between dry bean seeding (Date 1) and the termination of no till fall rye by mowing (Date 2).

| Effect | Management | | Depth | |
|---|---|---|---|---|
| Cover crop | Tillage | No-till | 0 - 5 cm | 5 - 15 cm |
| | ppm | | | |
| Control | 15.4 **a§** | 11.2 **c** | 13.2 **ab** | 13.0 **ab** |
| Barley | 13.5 **ab** | 12.2 **bc** | 13.6 **ab** | 12.2 **b** |
| Oat | 14.2 **ab** | 12.6 **bc** | 14.6 **a** | 12.3 **b** |
| Fall rye | 4.4 **d** | 1.9 **e** | 4.5 **c** | 1.9 **d** |

| | Date 1 | | Date 2 | |
|---|---|---|---|---|
| Management | 0 - 5 cm | 5 - 15 cm | 0 - 5 cm | 5 - 15 cm |
| Till | 12.63 **a** | 7.19 **c** | 12.51 **a** | 11.51 **a** |
| No-till | 8.70 **b** | 6.55 **c** | 8.54 **b** | 6.73 **c** |

| Source of variation | |
|---|---|
| Cover crop | ns |
| Management | ns |
| Depth | ns |
| Date | ns |
| Cover crop x management | <0.0001 |
| Cover crop x depth | <0.0001 |
| Date x managment | 0.0032 |
| Date x depth | 0.0007 |
| Cover crop x date | ns |
| Cover crop x depth | ns |
| Management x date x depth | 0.0045 |
| Cover crop x management x depth x date | ns |

† Sampling occurred on June 10 and June 28 in 2011. Sampling occurred on June 6 and June 12 in 2012.
‡ Reported means of untransformed data. Analysis performed on log 10(x) transformed data
§ Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test

### 4.4.2.4 Weed density

Cover cropping affects weed populations through the influence on soil N, soil moisture, soil temperature, light and soil chemical changes. All of these parameters, except allelopathy, were examined in this study, and have been explained in previous sections. Ultimately, the ability of a cover crop to suppress weeds depends on the timing and method of cover crop residue management. In this study, weed density was measured over three sampling dates during the period between dry bean seeding and fall rye mowing. The objective was to compare spring annual cover crops to the winter annual cover crop, and their management in spring on weed plant population density.

In 2011, there was a significant cover crop x management effect on weed density (Table 25). There was little effect of cover crop in the tilled system, but under NT management fall rye significantly reduced weed density. Therefore, results from this study indicate fall rye provides the most effective weed control when managed without tillage. The strong weed suppression provided by fall rye is well documented, and has been attributed to its strong physical presence and its allelopathic properties (Barnes and Putnam 1983, Blackshaw 2008, Liebl et al. 1992). As reported in previous sections, fall rye + NT has had a significant effect on the soil microclimate, e.g., reduced soil temperature during dry bean emergence period, reduced soil moisture, reduced incoming PAR and reduced soil nitrate-N. Since there is little effect of fall rye cover crop alone (i.e. fall rye + tillage), it is logical to conclude that it was the physical presence of fall rye that reduced weed establishment. This result is contrary to another Manitoba study of fall rye cover crops which found that rye provided season long weed control when chemically desiccated at the 5-leaf stage (Flood 2008). In that study, weed control by fall rye was attributed to allelopathy.

Weeds increased over time, regardless of cover crop and management regime (Table 25).

**Table 25**. The effect of cover crop, management and sampling date† on weed density‡ during the post-seeding period in 2011 and 2012. Sampling occurred during the period between dry bean seeding (Date 1), fall rye mowing (Date 2) and post-mowing (Date 3).

| Effect | | | | | |
|---|---|---|---|---|---|
| Cover crop | Management | 2011 | Management | Date | 2012 |
| | | plants/m$^{-2}$ | | | plants/m$^{-2}$ |
| Control | Till | 71 **a**§ | Till | 1 | 1 **d** |
| Barley | | 80 **a** | | 2 | 40 **ab** |
| Oat | | 67 **ab** | | 3 | 54 **a** |
| Rye | | 69 **ab** | | | |
| Control | No-till | 58 **b** | No-till | 1 | 33 **bc** |
| Barley | | 69 **ab** | | 2 | 26 **c** |
| Oat | | 63 **ab** | | 3 | 40 **ab** |
| Rye | | 26 **c** | | | |
| Date | Timing | | | | |
| 1 | Dry bean seeding | 54 **b** | | | |
| 2 | Rye mowing | 62 **a** | | | |
| 3 | Post-mowing | 66 **a** | | | |
| Source of variation | | | | | |
| Cover crop | | ns | | | ns |
| Management | | ns | | | ns |
| Date | | 0.0038 | | | ns |
| Cover crop x management | | <0.0001 | | | ns |
| Cover crop x date | | ns | | | ns |
| Management x date | | ns | | | <0.0001 |
| Cover crop x management x date | | ns | | | ns |

† Sampling occurred on June 10, June 28 and July 11 in 2011. Sampling occurred on June 4, June 12 and July 11 in 2012.
‡ Reported means of untransformed data. Analysis performed on log 10(x) transformed data
§ Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test.

In 2012, there was a significant management x date effect on weed density. There was no significant effect of cover crop during the sampling period (Table 25). At dry bean seeding (Date 1), tillage treatments had the lowest weed density. At the second sampling date, tillage treatments had higher weed density than in NT treatments. However, at the third sampling, date tillage and NT treatments had statistically similar weed density. Although cover crop did not significantly reduce weed recruitment, weed biomass at harvest was significantly lower in rye treatments and under NT management (Table 15). This can be confirmed with field observations, which documented that weeds were stunted in rye cover crops. Other studies on rye cover crops have shown reduced weed biomass without affecting the number of weeds (Bernstein et al. 2014). In addition, due to higher background soil nitrate-N levels that were characteristic of the site in 2012, weed biomass was 41% higher in 2012 than in 2011 (Table 15). Therefore, the effect of fall rye on weed recruitment was more pronounced in already stressed, low fertility scenarios as experienced in the 2011 site (Table 25).

In 2011, dominant weed species were foxtail (*Setaria* spp.), Shepherd's purse (*Capsella bursa-pastoris*), dandelion (*Taraxacum officinale*) and wild buckwheat (*Fallopia convolvulus*). Fall rye + NT systems reduced foxtail species by 93% to 96% in 2011. Liebl et al. (1992) also found that fall rye reduced weed densities by 90%. Fall rye reduced Shepherd's purse by 33% to 86% compared to all other treatments in 2011. There was no significant effect of cover crop or management on dandelion or wild buckwheat (Table 26).

In 2012, dominant weed species were foxtail (*Setaria* spp.), barnyard grass (*Echinochloa crus-galli*), dandelion and redroot pigweed (*Amaranthus retroflexus*). Fall rye + NT significantly reduced foxtail species by 73% to 88%. No-till systems significantly reduced barnyard grass and redroot pigweed densities by 30% and 69%, respectively (Table 27). There was no significant effect of cover crop or management on dandelion. Other studies have found fall rye reduced green foxtail, wild buckwheat, redroot pigweed and barnyard grass (Teasdale and Mohler 2000, Barnes and Putnam 1983, Putnam et al. 1983, Teasdale and Pillai 2005).

There were varying responses of dominant weed densities to combinations of fall rye and tillage. Individual weed life cycles are attributed to the differences in responses to weed control measures examined in this experiment. Shepherd's purse is a winter annual and was prevalent across treatments early in the 2011 growing season. As such, it is logical that fall rye would have reduced weed densities beginning early in the season since fall rye would have been competing with early spring shepards's purse rosettes. Summer annual weeds like foxtail spp., barnyard grass and redroot pigweed are known to be responsive to changes in tillage (McPherson 1994). Following a disturbance, summer annual weeds begin to emerge in mid-May, and are promoted by warmer, drier conditions (Bullied et al. 2003). This could be why barnyard grass and redroot pigweed were dominant in 2012, which experienced warmer, drier conditions relative to 2011. Thus, cooler soil temperature found in NT treatments (Table 20) may partially explain why these species were reduced in NT treatments. No-till practices generally favour a shift to perennial weeds (Blackshaw et al. 1994, Thomas and Dale 1991), which explains the unaffected dandelion populations. In addition, when weed populations are high fall rye cover crops have been found to be insufficient at reducing weed pressure (DeBruin et al. 2005). Other studies have found inconsistent relationships between weed density and tillage system (DeBruin et al. 2005, Nord et al. 2001, Swanton et al. 1999).

**Table 26**. The effect of cover crop and management on predominant weed species in organic dry beans at the fourth trifoliate stage (35 DAP) in 2011.

| | | Foxtail Spp. | | Shepard's Purse | | Dandelion‡ | Wild Buckwheat‡ |
|---|---|---|---|---|---|---|---|
| Cover crop | | ------------------------------------ | | plants $m^{-2}$ | | ------------------------------------ | |
| Control | Till | 40† | **ab** | 6 | **bc** | 27 | 43 |
| Barley | Till | 47 | **ab** | 12 | **ab** | 34 | 14 |
| Oat | Till | 27 | **b** | 14 | **a** | 34 | 27 |
| Rye | Till | 44 | **ab** | 2 | **c** | 69 | 36 |
| | | | | | | | |
| Control | No-till | 32 | **ab** | | | | |
| Barley | No-till | 41 | **ab** | | | | |
| Oat | No-till | 50 | **a** | | | | |
| Rye | No-till | 2 | **c** | | | | |
| Source of variation | | | | | | | |
| Cover crop | | ns | | 0.0244 | | ns | ns |
| Management | | ns | | ns | | ns | ns |
| Cover crop x management | | 0.0052 | | ns | | ns | ns |

† Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test.

‡ Reported means of untransformed data. Analysis performed on log 10(x)+0.1 transformed data

**Table 27.** The effect of cover crop and management on predominant weed species in organic dry beans at the bush stage (25 DAP) in 2012.

| | | Foxtail Spp. | | Barnyard Grass‡ | | Dandelion§ | Redroot Pigweed¶ | |
|---|---|---|---|---|---|---|---|---|
| Cover crop | | ----------------------- | ------------ | plants $m^{-2}$ | ------------ | ------------ | ------------ | ------------ |
| Control | Till | 51† | ab | 34 | | 96 | 32 | |
| Barley | Till | 56 | ab | 29 | | 39 | 43 | |
| Oat | Till | 50 | ab | 24 | | 55 | 23 | |
| Rye | Till | 47 | ab | 15 | | 59 | 23 | |
| | | | | | | | | |
| Control | No-till | 28 | ab | | | | | |
| Barley | No-till | 31 | a | | | | | |
| Oat | No-till | 26 | b | | | | | |
| Rye | No-till | 7 | c | | | | | |
| | | | | | | | | |
| Management | | | | | | | | |
| Till | | | | 30 | a | | 121 | a |
| No-till | | | | 21 | b | | 37 | b |
| **Source of variation** | | | | | | | | |
| Cover crop | | 0.0134 | | ns | | ns | ns | |
| Management | | 0.0014 | | 0.0306 | | ns | <0.0001 | |
| Cover crop x management | | 0.0022 | | ns | | ns | ns | |

† Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test.
‡ Reported means of untransformed data. Analysis performed on log 10(x) transformed data.
§ Reported means of untransformed data. Analysis performed on log 10(x)+0.1 transformed data.
¶ Reported means of untransformed data. Analysis performed on sqrt (x)+0.1 transformed data.

### 4.4.2.5 Gravimetric soil moisture.

Cover crops in a crop rotation affect soil moisture in two ways; through direct moisture use and by reducing evaporation from the soil surface. The magnitude and mechanism of this effect depends on the type of cover crop (i.e. life cycle), the amount of residue cover, and how long the cover crop is able to draw on soil moisture. In this study, soil moisture was examined at various stages in the production system. In this section, soil moisture during the period between dry bean seeding and the termination of NT rye is compared. Since the interest is in the impact on dry bean and weed germination, gravimetric soil moisture was measured in the upper 15 cm of soil. The objective was to quantify any differences in surface soil moisture between cover crop and tillage management.

Gravimetric soil moisture was affected by cover crop management in 2011. Tillage treatments were significantly lower than NT treatments (Table 28). Since mulches reduce evaporation, they can result in wetter conditions than bare soil in periods of excess moisture (Liebl et al 1992, Teasdale and Mohler 1993). Soil moisture was also affected by sampling date. In 2011, soil moisture was higher at the later sampling date. It is expected that precipitation between sampling dates contributed to the higher moisture levels; total precipitation was 51 mm between June 10 and July 11 (MAFRD Ag-Weather Program 2014).

In 2012, gravimetric soil moisture was unaffected by cover crop and management across the post-seeding period. However, soil moisture was lower at the second sampling date (rye mowing) than at the first sampling date (dry bean seeding). The lack of a significant cover crop or cover crop x management interaction means that in this study, NT rye did not significantly affect soil moisture compared to all other treatments. This is contrary to the hypothesis of this study, which predicted that fall rye would reduce soil moisture. For example, other studies have found late-killed rye will have lower soil moisture than early killed rye due to depletion by growing rye (Liebl et al. 1992, Wagner-Riddle et al. 1994). Future studies should aim to confirm the effect of fall-seeded fall rye on soil moisture through repeated studies in a wider range of moisture conditions.

**Table 28.** The effect of cover crop, management and sampling date on gravimetric soil water content (GWC) (0-15 cm) during the post-seeding period in 2011 and 2012.

| Effect | | | |
|---|---|---|---|
| Cover crop | | 2011 ‡ | 2012 |
| | Control | 0.2 | 0.25 |
| | Barley | 0.2 | 0.26 |
| | Oat | 0.2 | 0.26 |
| | Fall rye | 0.2 | 0.26 |
| Management | | | |
| | Till | 0.19 **b** | 0.26 |
| | No-till | 0.20 **a** | 0.26 |
| Date | | | |
| | 1 | 0.18 **b** | 0.29 **a** |
| | 2 | 0.21 **a** | 0.22 **b** |
| Source of variation | | | |
| Cover crop | | ns | ns |
| Management | | 0.005 | ns |
| Date | | <0.0001 | <0.0001 |
| Cover crop x till | | ns | ns |
| Cover crop x date | | ns | ns |
| Till x date | | ns | ns |
| Cover crop x till x date | | ns | ns |

† Sampling occurred on June 10 and June 28 in 2011. Sampling occurred on June 4 and June 12 in 2012.
‡ Reported means of untransformed data. Analysis performed on log 10(x) transformed data
§ Means within a column followed by a different letters are significantly different at P<0.05 according to Fischer's protected LSD test.

## 4.5 Conclusions

The goal of this experiment was to characterize soil microclimate parameters as affected by cover crops and management in two periods: between spring thaw and main crop seeding and the period between bean seeding and the termination of NT fall rye. Primarily, the research question was: How do cover crops and their management affect the soil zone for bean and weed germination? This study found that regardless of parameter, e.g., soil temperature, light interception, soil moisture, soil nitrate, weed density, the results followed a pattern: fall rye had an effect but only in NT management, while all other treatments were generally not statistically different.

Results from this research provide further support for the weed suppression provided by fall rye. Although allelopathy is often cited as a strong contributor to the weed control provided by fall rye, this study highlights some important physical effects of fall rye on the soil microclimate, such as interception of PAR by the canopy, reduced soil temperature after dry bean seeding and reduced soil nitrate-N. However since these effects are documented during the period around dry bean seeding and germination, it is also possible to say that they are contributing factors to the poor bean yields in fall rye treatments, especially in the system where fall rye was managed in the novel organic no-till system.

This research also shows some more novel features of the physical effects of these systems as they are applied in Manitoba. For example, early season soil temperature data indicated that there was no effect of cover crop on early season soil warming, which is a concern in warm season crops like dry beans. In 2011, when growing conditions were cooler, soil temperature after bean seeding was only depressed by fall rye + NT. Results showed that light interception under fall rye was not different whether rye was standing or mulched after mowing. In addition, it was observed that in a year of adequate precipitation cover crops did not lower gravimetric soil moisture.

Finally, this research provides further support for NT management of weeds in organic production systems. Weed densities were lower in NT management than when treatments were managed with tillage in the early season, and this also translated to lower weed biomass at the end of the growing season. This is likely due to the lack of tillage to stimulate weeds and the use of flame weeding as secondary weed control, this points to potential for flame weeding as a NT organic weed management option. However some caution is necessary, since conventional NT research demonstrates that a weed shift will occur from spring annual weeds that respond to tillage to perennial weeds that do well in reduced tillage systems (Froud-Williams et al. 1981).

## 4.6 Literature Cited


Ballaré, C.L., and J.J. Casal. 2000. Light signals perceived by crop and weed plants. Field Crops Research 67.2: 149

Barnes, J.P. and A.R. Putnam. 1983. Rye residues contribute weed suppression in no-tillage cropping systems. J. Chemical Ecol. 9(8):1045-1057.

Bernstein, E.R., D.E. Stoltenberg, J.L. Posner, and J.L. Hedtcke. 2014. Weed community dynamics and suppression in tilled and no-tillage transitional organic winter rye-soybean systems. Weed Sci. 62: 125-137.

Blackshaw, R. E., F.O. Larney, C.W. Lindwall and G.C. Kozub. 1994. Crop rotation and tillage effects on weed populations on the semi-arid Canadian prairies. Weed technology, 231-237.

Blackshaw, R.E. 2008. Agronomic benefits of cereal cover crops in dry bean production systems in western Canada. Crop Protection. 27:208-214.

Brady, N.C. and R.R. Weil. 2002. The nature and property of soils. 13th ed. New Jersey: Pearson Education.

Bullied, W. J., A.M. Marginet and R.C. Van Acker. 2003. Conventional-and conservation-tillage systems influence emergence periodicity of annual weed species in canola. Weed science:51(6): 886-897.

Carr, P.M., R.L. Anderson, Y.E. Lawley, P.R. Miller and S.F. Zwinger. 2012. Organic zero-till in the northern US Great Plains Region: Opportunities and obstacles. Renewable Agriculture and Food Systems Renewable Agric. Food Syst. 27 (1): 12-20.

DeBruin, J.L., P.M.Porter and N.R.Jordan. 2005. Use of a rye cover crop following corn in rotation with soybean in the Upper Midwest. Agron. J. 97:587-598.

Doran, J.W. and M.S. Smith. 1991. Role of cover crops in nitrogen cycling In: Cover crops for clean water. Soil Water Cons. Soc. Pp. 85-107.

Drinkwater, L.E., R.R. Janke and L. Rossoni-Longnecker. 2000. Effects of tillage intensity on nitrogen dynamics in legume-based grain systems. Plant and Soil. 227:99-113.

Facelli, J. M., and S.T. Pickett. 1991. Plant litter: its dynamics and effects on plant community structure. The Botanical Review. 57(1): 1-32.

Flood, H. 2008. Fall rye cover crops increase sustainability of dry bean production. M.Sc. Thesis. University of Manitoba. Winnipeg, Manitoba.

Friebe, A., U. Roth, P. Kuck, H. Shnabl and M. Schulz. 1997. Effects of 2,4-Dihydroxy-1,4-Bezoxazin-3-ones on the activity of plasma membrane H+-ATPase. Phytochemistry. 44:979-983.

Froud-Williams, R. J., R. J. Chancellor, and D. S. H. Drennan. 1981. Potential changes in weed floras associated with reduced-cultivation Systems for cereal production in temperate regions. Weed Research 21.2: 99

Gallandt, E. R. 2006. How can we target the weed seedbank?. Weed Science. 54(3): 588-596.

Gauer, E., C.F. Shaykewich and E.H. Stobbe. 1982. Soil temperature and soil water under zero tillage in Manitoba. *Can. J. Soil Sci. 62(*2): 311-325.

Halde, C., R.H. Gulden and M.H. Entz. 2014. Selecting cover crop mulches for organic rotational no-till systems in Manitoba, Canada. Agron. J. 106(4): 1193-1204.

Hoffman, M. L., L.A.Weston, J.C. Snyder and E.E. Regnier. 1996. Allelopathic influence of germinating seeds and seedlings of cover crops on weed species. Weed Science, 579-584.

Jewett, M. R., and K.D. Thelen. 2007. Winter cereal cover crop removal strategy affects spring soil nitrate levels. Journal of Sustainable Agriculture. 29(3):55-67.

Kaspar, T. C., and W.L. Bland. 1992. Soil temperature and root growth. Soil Science. 154(4): 290-299.

Kolasinska, K., J. Szyrmer and S. Dul. (2000). Relationship between laboratory seed quality tests and field emergence of common bean seed.470-475.

Kruidhof, H. M., L. Bastiaans and M.J. Kropff. 2008. Ecological weed management by cover cropping: effects on weed growth in autumn and weed establishment in spring. Weed Research. 48(6): 492-502.

Kruidhoff, H.M., L. Bastiaans and M.J. Kropff. 2009. Cover crop residue management for optimizing weed control. Plant Soil. 318:169-184.

Kuo, S., and U.M. Sainju. 1998. Nitrogen mineralization and availability of mixed leguminous and non-leguminous cover crop residues in soil. Biology and Fertility of Soils. 26(4): 346-353.

Liebl, R., F.W. Simmons, L.M. Wax and E.W. Stoller. 1992. Effect of rye (*Secale cereale*) mulch on weed control and soil moisture in soybean (*Glycine max*). Weed Tech. 6:838-846.

Lund, R.E. 1975. Tables for an approximate test for outliers in linear models. Technometrics. 17 (4): 473-476.

Manitoba Agriculture, Food and Rural Developmen- Ag-Weather Program. 2014. [Online]

Available:http://tgs.gov.mb.ca/climate/DailyReport.aspx

Thiessen-Martens, J. R. T., J.W. Hoeppner and M.H. Entz. 2001. Legume cover crops with winter cereals in Southern Manitoba. *Agron J. 93*(5): 1086-1096.

McPherson, G. R. 1994. Response of annual plants and communities to tilling in a semi-arid temperate savanna. Journal of Vegetation Science, 5(3): 415-420.

Nleya, T., R.A. Ball and A. Vandenberg. 2005. Germination of common bean under constant and alternating cool temperatures. Canadian J. Plant Sci. 85(3): 577-585.

Nord, E.A., M.R. Ryan, W.S. Curran, D.A. Mortensen and S.B. Mirsky. 2001. Effects of management type and timing on weed suppression in soybean no-till planted into rolled-crimped cereal rye. Weed Sci. 60:624-633.

Oregon State University. 2006. 30-year precipitation normals:1981-2010. PRISM Climate Group. [Online] Available: http://www.prism.oregonstate.edu/normals/

Podolsky, K. 2013. Reduced tillage implements for management of an organic green manure: effects on nitrogen, weeds and wheat yield. M.Sc. Thesis. University of Manitoba. Winnipeg, Manitoba.

Putnam, A.R., J. Defrank and J.R. Barnes. 1983. Exploitation of allelopathy for weed control in annual and perennial cropping systems. J. Chemical Ecol. 9(8):1001-1009.

Radke, J.K. 1982. Managing early season soil temperatures in the Northern corn belt using configured soil surfaces and mulches. Soil Sci. Soc. Amer. J. 46 (5):1067-1071.

Swanton, C.J., A. Shrestha, R.C. Roy, B.R. Ball-Coehlo and S.Z. Knezevic. 1999. Effect of tillage systems, N, and cover crop on the composition of weed flora. Weed Sci. 47:454-461.

Teasdale, J.R. 1993. Interaction of light, soil moisture and temperature with weed suppression by hairy vetch residue. Weed Sci. 41:46-51.

Teasdale, J. R., and C.L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agron. J.*85*(3): 673-680.

Teasdale, J.R. and C.L. Mohler. 2000. The quantitive relationship between weed emergence and the physical properties of mulches. Weed Sci. 48:385-392.

Teasdale, J. R., and P. Pillai. 2005. Contribution of ammonium to stimulation of smooth pigweed (Amaranthus hybridus L.) germination by extracts of hairy vetch (Vicia villosa Roth) residue. Weed Biology and Management. 5(1): 19-25.

Teasdale, J.R., C.E. Beste and W.E. Potts. 1991. Response of weeds to tillage and cover crop residues. Weed Sci. 39:195-199.

Thomas, A. G. and M.R.T. Dale. 1991. Weed community structure in spring-seeded crops in Manitoba. Can. J. Plant Sci.71(4): 1069-1080.

Vaisman, I., M.H. Entz, D.N. Flaten and R.H. Gulden. 2011. Blade roller–green manure interactions on nitrogen dynamics, weeds, and organic wheat. Agron. J. 103(3): 879-889.

Wagner-Riddle, C., T.J. Gillespie and C.J. Swanton. 1994. Rye cover crop management impact on soil water content, soil temperature and soybean growth. Can. J. Plant Sc. 74:485-495.

Weinert, T. L., W.L. Pan, M.R. Moneymaker, G.S. Santo and R.G. Stevens. 2002. Nitrogen recycling by nonleguminous winter cover crops to reduce leaching in potato rotations. Agron. J. 94(2):365-372.

Wilkins, E.D. and R.R. Bellinder. 1996. Mow-kill regulation of winter cereals for spring no-till crop production. Weed Tech. 10:247-252.

Wyland, L.J., L.E. Jackson, W.E. Chaney, K. Klonsky, S.T. Koike and B. Kimple. 1995. Winter cover crops in a vegetable cropping system: Impacts on nitrate leaching, soil water, crop yield,pest and management costs. Agriculture, Ecosystems and Environment. 59:1-17.

Wyse, D. L. 1992. Future of weed science research. Weed Technology, 162-165.

Zadoks, J. C., T.T. Chang and C.F. Konzak. 1974. A decimal code for the growth stages of cereals. Weed research. 14(6): 415-421.

## 5.0 GENERAL DISCUSSION

This study aimed to evaluate the overall agronomic impact of cover crop systems in organic bean production, as well as the influence of cover crops on soil microclimate factors. More specifically, to evaluate whether winter cereals like fall rye can provide an alternative to tillage in organic dry bean production. Organic no-till (NT) fall rye/soybean systems have been shown to be successful in the Mid-western United States, but no previous studies have evaluated their performance in Western Canada. In this study, NT fall rye termination was adapted for Manitoba conditions such that dry beans were direct seeded into standing fall rye. Once fall rye anthesis had been reached, fall rye was mowed above the growing beans below. This termination technique is unique to this study, conducted to allow timely dry bean seeding without compromising the efficacy of fall rye termination. Previous research on NT fall rye/pulse systems seed directly into rye biomass that has already been terminated, either through herbicides, mowing or with the more novel blade roller (Blackshaw 2008, De Bruin et al. 2005, Bernstein et al. 2014). Two spring annual cereal cover crops (barley and oat) were also compared as an alternative to the winter annual. No-till plots where spring annual cover crops winter-killed were flame weeded immediately after bean seeding to provide secondary weed control.

*The effect of cover crops on weeds and dry beans in organic production systems*

An important research question of this experiment was: Do fall-seeded cover crops control weeds in organic dry beans, and how do spring annual cover crops compare to a winter annual? In regards to weed suppression, there were consistent trends in the data across treatments. Fall rye provided the strongest weed control, in the early season and at harvest, while spring annual cereals behaved similarly to having no cover crop. This is not surprising due to almost complete decomposition of the cover crop residues by the time of bean seeding. Blackshaw (2008) also found using spring annual cereals used as fall-seeded cover crops in pulse production resulted in insufficient weed control and yield losses compared to fall rye cover crops. Alternatively, high biomass producing fall rye reduced weed density and biomass. However, the trade-off for weed control meant fall rye also reduced soil nitrate, soil temperature, light interception, bean development and bean yield.

Main crop yield penalties have been documented in previous studies on fall rye / soybean systems. In some cases, there have been no negative effects of fall rye but in others there were reductions in main crop yield. The difference usually lies in management timing, fertility and available moisture. Simply, when the main crop is given the competitive disadvantage it is negatively affected. In the present study, rye had not reached flowering when dry beans were seeded, and in NT treatments, rye continued to develop until anthesis. Without the use of herbicides for NT termination, waiting until rye has reached anthesis is proven to be the optimum timing of NT rye termination. However, this study indicates that applying this management practice in Manitoba may not be suitable since NT rye termination occurs approximately two weeks after main crop seeding. Choosing earlier maturing varieties of fall rye or other early maturing winter annual cereals may improve this system. Contrary to another Manitoba study (Flood 2008), which showed that rye terminated and incorporated at the four leaf stage provided the same level of control as when terminated at heading, soil incorporated fall rye in this experiment did not result in the same level of weed control as did NT systems.

*The effect of no-till management on weeds and beans*

A major finding of this study was that regardless of cover crop species and year, weed biomass at harvest was significantly lower under NT management than in tillage management. This is not uncommon, considering the transition from tillage to NT management generally coincides with a decrease in annual weeds in favour of a transition towards perennial weeds. Tillage exposes weed seeds to light, breaking dormancy for some weed species (Grime et al. 1981). Teasdale and Mohler (2000) determined that light reduction was one of the most important ways cover crop mulches reduce weed pressure.

Cover crops are an integral part of combining NT management with organic production. In conventional NT, herbicides act to control weeds, without disturbing soil. However, there are no such options in organic production. Instead, producers must rely on actively growing cover crops or cover crop mulches to impede weed colonization. Fall rye is well suited to NT organic production due to its high biomass production, allelopathic qualities and ease of incorporating into crop rotations. However termination of fall rye still proves challenging, especially when efficacy of fall rye termination and seeding conditions for the main crop are being weighed against one another as in the present study. In other climatic regions, fall rye cover crop establishment/ development is weighed against other factors, such as available soil moisture for the main crop (Carr et al. 2014).

Results indicated that background soil fertility was an important determining factor of bean yield. In low indigenous soil nitrate-N conditions (2011), yield was unaffected by tillage management, however, in high indigenous soil nitrate-N conditions (2012), NT resulted in significantly lower dry bean yields. Although the production of organic dry bean stands to benefit from fall rye cover crops due to low competitive ability, further research is needed on the timing of NT rye management, and rotational effects to determine if this system can be profitable.

*The effect of cover crops and management on early season microclimate conditions.*

Early season growing conditions were affected by cover crop species and management. Interestingly, fall-seeded cover crops did not reduced soil temperatures during early spring. Reduced soil warming in Manitoba's short growing season would have offset any weed control to producers due to potential impacts on the main crop. However, once rye continued to develop in NT treatments there were reduced daily average soil temperatures after dry bean seeding. Overall cooler temperatures during the germination and early development of beans could be detrimental. While the buffering effect of maximum and minimum soil temperatures may reduce weed germination. It was documented that light interception by the rye canopy in NT treatments had caused etiolation, a symptom of depleted available incoming light. As well, bean development was delayed compared to control treatment during the first three weeks of growth. These are two important pieces of evidence that describe the reduced bean biomass and yield found in rye + NT treatments.

This experiment demonstrated that fall-seeded spring annual cereal cover crops have little effect on soil microclimate and did not result in significant reductions in weed density and biomass. However, this study does indicate that flame weeding could be an important tool in organic weed management. The lack of significant cover crop x management interaction means that regardless of cover crop, NT management resulted in fewer weeds.

*Conclusions and recommendations*

In conclusion, these findings suggest that there is an opportunity for NT fall rye in organically managed cropping systems. This initial characterization of fall-seeded fall rye/ organic bean production systems highlights where challenges and trade-offs exist. Future research should investigate more optimum termination timing to reduce light interception and nitrogen uptake. Based on this research, two ways of improving this system would be to ensure that nitrogen is not a limiting factor, for example, using a main crop with higher fixation capacity like soybean and to reduce the time between seeding and terminating fall rye. The latter may mean mowing twice, to remove any competitive fall rye regrowth. To provide long term benefits of a rye + NT organic system could, conceptually, be achieved by a repeat pass of a modified flail mower or stripper header that could remove weed seed heads prior to filling, eventually exhausting the weed seed bank.

**5.1 Literature cited**

Bernstein, E.R., D.E. Stoltenberg, J.L. Posner, and J.L. Hedtcke. 2014. Weed community dynamics and suppression in tilled and no-tillage transitional organic winter rye-soybean systems. Weed Sci. 62: 125-137.

Blackshaw, R.E. 2008. Agronomic benefits of cereal cover crops in dry bean production systems in western Canada. Crop Protection. 27:208-214.

Carr, P.M., R.L. Anderson, Y.E. Lawley, P.R. Miller and S.F. Zwinger. 2012. Organic zero-till in the northern US Great Plains Region: Opportunities and obstacles. Renewable Agriculture and Food Systems Renewable Agric. Food Syst. 27 (1 ): 12-20.

DeBruin, J.L., P.M.Porter and N.R.Jordan. 2005. Use of a rye cover crop following corn in rotation with soybean in the Upper Midwest. Agron. J. 97:587-598.

Flood, H. 2008. Fall rye cover crops increase sustainability of dry bean production. M.Sc. Thesis. University of Manitoba. Winnipeg, Manitoba.

Grime, J. P., G. Mason, A. Curtis, J. Rodman and S.R. Band, S. R. 1981. A comparative study of germination characteristics in a local flora. The Journal of Ecology, 1017-1059.

Teasdale, J.R. and C.L. Mohler. 2000. The quantitive relationship between weed emergence and the physical properties of mulches. Weed Sci. 48:385-392.