Investigation of the Blade Roller for Organic Green Manure Management

BY

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ABSTRACT

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Use of the blade roller presents organic farmers with the opportunity to reduce tillage in green manure years. The blade roller works by rolling over green manures and crimping crop stems, crushing the vascular tissue without completely cutting the stems. The green manure plant eventually desicates and is killed leaving a residue flat on the surface of the soil. Farmers can then seed their cash crop directly into the mulch. The objective of this study was to investigate the effects of using the blade roller for no-till/reduced tillage by assessing soil conservation, early wheat development, soil moisture, weed competition, green manure nitrogen dynamics, and wheat yield. The study was conducted on organically managed land at the Carman Research Station, Manitoba and on a certified organic farm near Oxbow, Saskatchewan from 2007 to 2009. In the spring, a pea (*Pisum sativum* L.) and oat (*Avena sativa* L.) intercrop was seeded as a green manure. Beginning at pea flowering, the green manure was terminated by rolling, tilling, or a combination of the two. In the following spring, Hard Red Spring Wheat (cv. 5602 HR) (*Triticum aestivum* L.) was seeded. In the year of the green manure, a biomass sample was taken just before termination. Ammonia emissions were measured following termination periodically until the fall. A soil nitrate-N sample was taken before freeze up. In the year of the wheat, soil cover and soil moisture measurements were taken before or soon after seeding the wheat. Weed competition was assessed in June after full weed emergence. Soil nitrate-N and wheat biomass were sampled at stem elongation, anthesis, and soft dough. Results showed that eliminating/reducing tillage in the green manure year a) increased soil cover in spring, b) had minimal effect on soil moisture, c) delayed wheat development in two out of three site years, d) affected weed communities, e) reduced the rate of nitrogen release, and c) reduced wheat yield in two out of three site years. Ammonia emissions were greater from the no-till green manure compared with tilled

green manures. No till green manure management can therefore provide benefits of soil conservation and nitrogen conservation but may result in decreased wheat yield.

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1. INTRODUCTION

Organic farming systems are becoming an increasingly important component of the agricultural landscape. Organic agriculture can offer numerous environmental benefits, including increased biodiversity, increased soil organic matter and reduced energy use (Mader *et al.* 2002; Teasdale *et al.* 2007). The Canadian General Standards Board (2006) defines organic agriculture as "… a holistic system designed to optimize the productivity and fitness of diverse communities within the agroecosystem, including soil organisms, plants, livestock and people." The principles of organic agriculture emphasize a holistic approach to farming and promote practices that enhance soil fertility, biological activity, diversity, recycling of materials, and the use of renewable resources. Organically managed farm acreage has been steadily on the rise in Canada in the past decade (Macey 2010). In 1999, organically managed farms accounted for 0.8% of all Canadian farms. By 2008 organic farms accounted for 1.6% of Canadian farms, equating to approximately 612 000 hectares of land under organic production (Macey 2010).

At the same time that organic agriculture aims to enhance soil fertility, tillage remains an integral part of organic management. In organic systems, tillage is the primary tool for green manure management, weed management, and seedbed preparation. Vast literature exists on the detrimental effects of using intensive tillage in agriculture. Tillage consumes large amounts of energy, leads to wind and water erosion, reduces the physical, chemical and biological quality of soil, ultimately resulting in decreased productivity (den Biggelaar *et al.* 2004; Hobbs *et al.* 2008; Pimentel and Kounang 1998).

Recent studies have investigated integrating conservation tillage practices into organic farming (Drinkwater *et al.* 2000; Krauss *et al.* 2010; Mischler *et al.* 2010; Peigne *et al.* 2007). Specifically, studies have focused on reducing tillage in green manure management. Green manures can be defined as plant material incorporated into the soil while green or at maturity (Fageria 2007). In organic systems, green manures play a key role in providing subsequent crops with nutrients, maintaining soil quality, and helping to control weeds and pests (Krauss *et al.* 2010). Thus far, some identified challenges of organic reduced tillage/no till management are weed infestations, delay in soil nitrogen mineralization in the spring, and delay in soil warming in the spring.

The blade roller is a tool that presents farmers with an opportunity to reduce tillage in organic agriculture. The blade roller - also known as the knife roller, roller crimper, and cover crop roller - was developed by farmers in South America as a mechanical method for terminating green manures (Kornecki *et al.* 2009). In the last decade, there has been an interest in adopting this technology in North America. In particular, the Rodale Institute has been promoting the adoption of the blade roller for use by organic farmers and has posted the plans for the blade roller on their website (Rodale Institute 2010). The blade roller works by rolling over green manures and crimping crop stems, crushing the vascular tissue without completely cutting the stems (Mischler *et al.* 2010). The green manure plant eventually dries and is killed leaving a root-anchored residue flat on the surface of the soil. Farmers can then seed their cash crop directly into the mulch - seeding can occur soon after rolling, or at the same time in a single operation. The residue that remains on the surface of the soil provides ground cover protecting the soil from erosion, covering the soil at the critical time between planting and canopy closure of the cash crop.

The objective of this study was to investigate the effects of using the blade roller for no-till/reduced tillage in comparison with using tillage for the management of a pea and oat green manure in an organic system, by measuring:

i) nitrogen dynamics in the year of the green manure and a subsequent wheat crop (soil nitrate-N, green manure biomass N, wheat N uptake, ammonia volatilization from the green manure),

ii) soil moisture and ground cover at the time of seeding a subsequent wheat crop,

iii) weed population density in a subsequent wheat crop,

iv) grain yield of a subsequent wheat crop.

This study aimed to answer five specific questions:

1) Is there a significant difference between a system that only uses the blade roller for green manure termination (no till) compared with the system that uses the conventional practice of only tilling the green manure?

2) Does spring tillage in the no till system significantly affect the no till system?

3) How does the no till system with spring tillage compare to only tilling the green manure?

4) What is the effect of reducing tillage by half compared with using tillage to terminate a green manure?

5) How does the frequency of tillage affect the system (i.e. N dynamics, soil moisture, soil conservation, weed populations, and wheat yield)?

2. LITERATURE REVIEW

2.1 Tillage in Agriculture

Tillage is an integral part of agriculture around the world (Lal *et al.* 2007). Tillage can be defined as ‘the mechanical manipulation of the soil and plant residues to prepare a seedbed where crop seeds are planted to produce grains for human and animal consumption’ (Reicosky and Allmaras, 2003). Tillage has provided many benefits to farmers throughout the ages, including seedbed preparation, weed management, soil nutrient release through oxidation and mineralization, residue management, amendment incorporation, temporary relief from compaction, and management of soil-borne diseases (Hobbs *et al.* 2008). At the same time, however, tillage has also led to serious environmental degradation.

2.1.1 The Detrimental Effects of Tillage

2.1.1.2 Erosion

Tillage loosens and exposes soil, leaving the soil susceptible to wind and water erosion (Lal *et al.* 2007). Soil erosion has many detrimental implications for agriculture and the surrounding environment. Eroded soils pollute waterways due to sedimentation and chemical runoff from fertilizers and pesticides, altering ecosystems, and threatening human health (Lal *et al.* 2007). Erosion leads to soil carbon loss, nutrient depletion, acidification, and salinization thereby decreasing the fertility of the soil (Lal *et al.* 2007). Globally, it is estimated that 1.6 billion ha of land is affected by erosion, resulting in soil losses estimated to be between 26 billion Mg yr^{-1} to 75 billion Mg yr^{-1} (den Biggelaar *et* *al.* 2004). Erosion is considered the most serious form of soil degradation, threatening the sustainability of agriculture around the world.

2.1.1.2 Other Effects

Tillage promotes the emission of carbon dioxide due to accelerated microbial respiration and the release of entrapped of carbon dioxide in the soil. These emissions from agricultural soils contribute to elevated atmospheric greenhouse gases (Reicosky and Allmaras 2003). Tillage machinery consumes large amounts of fossil fuel and can also lead to soil compaction (Hobbs *et al.* 2008). Furthermore, the repeated soil disturbance destroys the diversity of soil biota, including earthworms, arthropods, fungi, and bacteria (Hobbs *et al.* 2008).

2.2 Tillage in Organic Agriculture

2.2.1 Organic Agriculture

The Canadian General Standards Board (2006) defines organic agriculture as "… a holistic system designed to optimize the productivity and fitness of diverse communities within the agroecosystem, including soil organisms, plants, livestock and people". Specific regulations governing organic agriculture vary between regulatory bodies, but in general, the principles of organic agriculture emphasize a holistic approach to farming and promote practices that enhance soil fertility, biological activity, diversity, recycling of materials, and the use of renewable resources. In addition, there is a list of prohibited substances, including synthetic fertilizers and pesticides. Farmers therefore rely on non-synthetic sources to provide fertility and weed control for their agroecosystems. In both cases, tillage plays a key role.

2.2.2 Green Manures

A common practice employed by organic farmers for supplying nutrients to the soil is the use of a green manure crop. Green manures can be defined as plant material incorporated into the soil while green or at maturity (Fageria 2007). Organic farmers include green manures in their crop rotation by underseeding, overseeding, double cropping, or devoting a growing season to the green manure. The green manure is typically tilled to incorporate it into the soil, providing nutrients for subsequent crops. Both legumes and non-legumes can be used as green manures; however, legumes have the advantage of fixing atmospheric nitrogen (Frageria 2007).

The use of green manures in annual cropping systems has been shown to provide various benefits to cropping systems, including an increase in soil organic matter, less soil erosion, reduced weed densities, and water conservation. These benefits are due to the physical, chemical, and biological effects of the legumes on the soil. The roots of the legumes can stabilize the top soil, while residue can trap and slow the movement of water, leading to an overall decrease in soil erosion (Sarrantonio and Gallandt 2003). The residues also increase soil organic matter which further enhances erosion control by forming soil aggregates, and also improves nutrient availability and soil biodiversity (Fageria 2007). Green manures can also suppress weeds through competition, by forming a physical barrier and also through allelopathy (Sarrantonio and Gallandt 2003).

Studies have been conducted on various legume species available in the Canadian prairies for use as green manures. For example, Zentner *et al.* (2004) compared a summerfallow-wheat (*Triticum aestivum* L.) system (F-W) to an Indianhead black lentil (*Lens culinaris* Medikus) green manure-wheat system (LGM-W-W) by assessing yields, nitrogen economy, water use efficiency, and economic returns. Looking at the wheat following summerfallow as compared to wheat following lentil, they found that grain yield was comparable, N grain concentration was 14% greater following the lentil than summerfallow, and there was no significant difference in the water use efficiency between the systems.

Biederbeck *et al.* (1998) compared soil quality in a fallow-wheat cropping system (F-W), a continuous wheat system (W-W), and a legume green manure-wheat system (GM-W). The green manures were annual legumes - black lentil (*Lens culinaris* Medikus), tangier flatpea (*Lathyrus tingitanus* L.), chickling vetch (*Lathyrus sativus* L.), and feedpea (*Pisum sativum* L.). Soil samples taken after the wheat was harvested were tested for total organic N, wet aggregate stability (WAS), mineralizable N, mineralizable C, and light fraction organic matter. The researchers found that compared with F-W, the GM-W systems improved the aforementioned parameters on average by 7%. Of the observed green manures, lentil showed the most improved soil quality, increasing total organic N by 8% and the other attributes by 40-85%. Due to the short duration of the research (6 years), certain attributes were more influenced by the green manures, i.e. mineralizable C and N.

Bullied *et al.* (2002) compared the rotational yield and nitrogen benefits of annual legume green manures versus a canola seed crop on a subsequent wheat crop, followed by a barley crop. The legumes were: single year alfalfa (*Medicago sativa* L.), berseem (*Trifolium alexandrinum* L.) and red clovers (*T. pretense* L.), chickling vetch (*Lathyrus sativus* L.), and lentil (*Lens culinaris* Medik.). The researchers compared the total N uptake over the two years following the green manure (i.e. total N uptake in the wheat and barley crops) and found that compared to the canola-wheat-barley system, the inclusion of a green manure resulted in a cereal N uptake advantage – the clovers provided the least advantage, ranging from 10 kg ha^{-1} to 60 kg ha^{-1}, while alfalfa, chickling vetch, and lentil provided the most, ranging from 35 kg ha^{-1} to 90 kg ha^{-1}.

These studies confirm a well-established fact that legumes enhance soil fertility, increase subsequent crop yield, and minimize the need for synthetic fertilizer. The green manure's potential to contribute nitrogen to the soil is affected by rate of biological nitrogen fixation, environmental conditions, and termination technique. Optimal green manure legume species are fast growing, produce sufficient amounts of dry matter to incorporate into the soil, and requires minimal cultivation (Fageria 2007). Method and timing of termination influence the effectiveness of a green manure to provide the rotational benefits mentioned above. For example, the study by Zentner et al (2004) found that turning down the lentil in late July to early August depleted soil water, adversely affecting subsequent crops, as compared to turning down in early July.

As mentioned, the green manure crop is typically terminated and incorporated with tillage. On the Canadian Prairies, organic farmers seed legume green manures in the spring and terminate the green manure at full bloom, which occurs around mid-July. Farmers will follow up with subsequent tillage operations until freeze-up in the fall, as required to control weeds and green manure regrowth. Therefore, farmers may have up to four tillage operations following a green manure crop. These operations leave the soil bare during a critical time when soil is particularly susceptible to erosion, between planting and canopy closure (Liebman and Mohler 2001).

2.2.3 Weed Management

Weed control is considered one of the main challenges in organic farming. In a survey conducted in 2008, both Manitoba and Saskatchewan farmers ranked weed management as the third most important research issue in organic production (Organic Agriculture Centre of Canada 2008). Tillage is a primary tool for weed management in organic agriculture and is the most important direct-control method for weed management. Tillage implements vary in the amount of soil inversion and residue incorporation; examples include moldboard plow, chisel plow, sweep plow, field cultivator, tandem disks, and harrows (Reicosky and Allmaras 2003). Tillage operations can occur before seeding, pre and post crop emergence, and after harvest. Once again, these operations leave the soil bare during a critical time when soil is particularly susceptible to erosion, between planting and canopy closure (Liebman and Mohler 2001).

2.3 Reducing Tillage in Agriculture

In response to an awareness of the detrimental effects of tillage in conventional agriculture, farmers around the world have begun a movement towards soil conservation. This movement has been described by several terms that are sometimes used interchangeably and synonymously with one another, such as conservation agriculture, conservation tillage, reduced tillage, zero tillage, no-till, and sustainable farming. These terms encompass methods and techniques that aim to retain surface residue and to minimize, or eliminate, mechanical soil disturbance with the ultimate goal to conserve soil and maintain yields. Derpsch (2009) estimates that in 2007, farmers practicing some form of conservation agriculture covered 105 Mha worldwide, 13.5 Mha in Canada alone.

Due to the varying terminology regarding tillage systems, it is helpful to define the different systems. The following is a brief, general description of the tillage systems that will be discussed in this literature review. The descriptions of conventional tillage, no-till and reduced tillage are based on the definitions provided by Reicosky and Allmaras (2003):

Conventional tillage (CT) refers to a system that includes primary tillage followed by secondary tillage. Primary tillage dislodges and breaks the soil and also buries and mixes plant residues and fertilizers. Examples of tools used for primary tillage are the mold-board plow, chisel plow, and the tandem disk. These implements disturb the soil at deep depths and leave a rough surface. Secondary tillage provides additional soil breakup, but tends to be shallower than primary tillage, and also levels the soil surface. Tools used for secondary tillage include disk harrows, field cultivators, and spring tooth harrows. As a result of the tillage, only 15% of the residue remains after planting.

No-till (NT)/Zero-till refers to a system that is undisturbed from harvest to planting. Specialized seeding equipment is used to seed directly into stubble and/or residue. At least 30% of plant residue is retained after planting. Herbicides are used to control weeds.

While not always included in NT rotations, cover crops are sometimes grown and desiccated with herbicides, leaving a mulch that can be directly seeded with a cash crop.

Reduced tillage/minimum tillage tends to be a vague term. The system entails less tillage compared with conventional tillage, and leaves 15% to 30% of the residue after planting.

Organic No-Till describes a system that is organically managed with minimal to no tillage. As mentioned, NT relies on herbicides for weed management and cover crop termination; since herbicides are not an option for organic farmers, reducing/eliminating tillage from organic farming presents new challenges. Organic no till is a relatively new concept with relatively little research. The limited research has investigated different management techniques that aim to reduce/eliminate tillage under organic conditions, such as: reducing tillage intensity (Berner *et al.* 2008), growing living mulches (Teasdale *et al.* 2007), mowing cover crops (Drinkwater *et al.* 2000), and crimping cover crops (Kornecki *et al.* 2009; Mirsky *et al.* 2009; Mischler *et al.*2010). In addition, research on mulches can be useful in understanding organic no till – for example: cover crops that have been desiccated with herbicide (Mohler and Teasdale 1993; Teasdale and Mohler 1993) and applying mulch to organically managed land (Wiens *et al.* 2006).

2.3.1 The Effects of Reducing Tillage on the Soil Environment

Maintaining surface residues and minimizing soil disturbance affects the chemical, physical, and biological properties of the soil environment. The following section will review the effect of reducing tillage on the soil environment by reviewing literature on CT, NT, reduced tillage, organic no till, and mulches.

2.3.1.1 Temperature

Soil temperature is dependent upon the amount of radiant energy that reaches the soil's surface (Lafond *et al.* 1996) . As a result, soils under NT and/or mulches generally have lower temperatures compared with CT during the spring and summer due to the residue on the surface of the soil (Malhi *et al.* 2008). For example, Carter and Rennie (1985) observed soil temperatures in early spring to be 1°C to 5°C lower under ZT than CT. The residues affect the temperature by reflecting light and also by insulating the soil (Malhi *et al.* 2008) leading to a decrease in the amplitude of diurnal temperature fluctuations, which result in soils under NT experiencing lower daily maximum temperatures as compared to CT (Liebman and Mohler 2001). Mohler and Teasdale (1993) observed maximum and minimum soil temperatures under three different conditions: bare ground, natural residue level of desiccated hairy vetch, and two times the natural residue level of desiccated hairy vetch. They found the maximum temperature decreased as residue biomass increased, with temperatures of 30.2°C for bare soil, 27.6°C for natural hairy vetch residue, and 26.9°C for double the natural hairy vetch residue. However, there was no significant difference in the minimum temperatures, which averaged 21.0°C.

Soil temperature directly affects plant germination, emergence, and root growth (Lafond and Derksen 1996), as these developmental events depend on accumulation of heat (Bonhomme 2000). Therefore, lower temperatures under mulched conditions can delay the emergence of both crops and weeds under mulched conditions. For example, Hayhoe et. al. (1993) compared corn emergence under conservation tillage (ridge till and no till) with CT in Southern Ontario and found that corn under conservation tillage management required approximately 2 more days to achieve 50 % emergence than conventional tillage. The effect of delayed emergence may continue through the season, delaying development of the crop. For example, Fortin and Pierce (1991) observed that a 3.3 °C reduction in soil temperature due to surface mulch of oats delayed the vegetative growth of corn by 5 to 7 days.

2.3.1.2 Soil Moisture

Surface residues and standing stubble trap snow, reduce run-off, and minimize evaporative losses (Singh *et al.* 1998). Improved soil structure due to rooting of crops, residues, and biological activity leads to better water infiltration (Hobbs *et al.* 2008). As a result, soils under NT management and/or mulch have higher soil moisture content compared to CT (Larney *et al.* 1994). For example, in the 9th year of an established NT rotation, research conducted by Singh *et al.* (1998) observed 6-18% more total soil water in the NT system compared to a CT system at the 0 -20 cm depth. The availability of water for crop growth has been shown to contribute to increased yield of crops – Lafond *et al.* (1992) observed that increased soil water under NT and reduced tillage, in comparison to CT, resulted in 10%, 24%, and 21% higher yields for field peas, flax, and spring wheat, respectively.

2.3.1.3 Light

Surface residue reduces light transmittance to the soil environment. The light reduction varies depending on the residue composition, amount, and the level of decay of the residue. Therefore, in some cases, the residue reduces light-cued germination of weed seeds, while in other cases residues transmit adequate levels of light to stimulate germination of the weed seeds. For example, Mohler and Teasdale (1993) varied the rate of hairy vetch residue biomass and reported that *Abutilon therphrasti* emergence was not affected by residue, which the authors attributed to the species' lack of germination response to light. On the other hand, weed species that germinate in response to light, such as *Amaranthus retroflexus, Chenopodium album, Panicum capillare,* and *Echinochloa crus-galli* exhibited reduced emergence under increasing mulch, most pronounced at mulch rates of 500 g m^{-2} and more. Weed seedling growth can be delayed by residue shading due to reduced photosynthesis and energy expended on etiolated growth. On the other hand, most crop species do not require light for germination and are thus able to germinate beneath mulch, and their large seed size always for growth through the mulch without exhausting seed reserves (Liebman and Mohler 2001).

2.3.1.4 Soil Structure

Residues on the soil surface form a protective barrier that minimizes the soil's exposure to the energy of wind and rain, thereby decreasing soil loss by erosion. The higher the degree of soil cover, the more protection is offered. For example, in a study by McGregor *et al.* (1990) average soil loss measured at two rates of surface straw, 1 t ha^{-1} and 3 t ha^{-1}, was 572 g m^{-2} and 289 g m^{-2}, respectively. Overall, retention of surface residues and reducing tillage has been shown to improve soil structure, ameliorating such soil properties as hydraulic conductivity, aggregate stability, and organic matter. Arshad et. al (1999) assessed the long term effects of NT in Northern British Columbia and found 50-60% greater macroaggregates and 60% greater infiltration under NT than under CT. Malhi *et. al* (2008) found the proportion of wind erodible aggregates to be 55 % less under NT than CT. The proportion of medium aggregates and large aggregates was 9 % and 14 % higher under NT as compared to CT. They also found that NT tended to have more soil organic carbon and soil organic nitrogen. This is in accordance with other research that has shown that soils under NT management have more soil organic matter (SOM). Tillage decreases SOM through aeration and the break up of organic residues, thereby accelerating microbial decomposition (Brady and Weil 2002). No-till encourages SOM accumulation due to reduced tillage, retention of residues, lower soil temperatures, and higher soil moisture (Brady and Weil 2002). Campbell *et al.* (1996) found that after 11 years of NT, soil organic carbon increased by about 4 Mg C ha^{-1} relative to that in CT.

2.3.1.5 Soil Biota

Residues left on the soil surface supply nutrients for soil organisms, while the roots of cover crops provide nourishing zones for microbial communities. The minimal disturbance also promotes above ground habitats for arthropods (Hobbs *et al.* 2008). Studies have shown that a variety of soil organisms, including rhizobacteria, actinomycetes, fungi, arthropods and earthworms, are more abundant in NT and mulched fields than CT. Evans and Miller (1990) found 42% higher colonization rate of corn roots by arbuscular mycorrhizae in undisturbed soils compared to disturbed. The authors attributed the reduction in mycorrhizal development in the disturbed soil to the destruction of the mycelia network. Working in Swtizerland, Berner *et al.* (2008) compared earthworm populations under CT and reduced tillage managed organically. While total earthworm density and biomass was not affected by tillage, horizontally burrowing earthworms were more prevalent in reduced tillage (493 individuals m^{-2}) compared to CT (342 individuals m^{-2}). Marasas *et. al* (2001) assessed arthropod communities in wheat managed under NT and CT. There was no significant difference in phytophagus and detritivorous arthropods between the two systems; however, they found significantly more predators in NT (272 individuals) than CT (136 individuals).

2.3.1.6 Residue Decomposition and Nutrient Release

Factors controlling the decomposition of residues include the quantity of residue, the chemical composition of the residue, and environmental conditions. Crop species vary in the quantity and quality of residue they produce, which determines the rate of decomposition of the crop residues. Krupinsky *et al.* (2007) found a significant difference in the amount of residue produced by different crops, ranging from 1790 kg ha^{-1} for lentils to 4571 kg ha^{-1} for sorghum. Glasener and Palm (1995) found that mulched tropical legumes with low polyphenolics tended to decompose faster, mineralizing up to 32% of their total nitrogen content within 21 days of application, whereas the legumes with higher polyphenolics tended to decompose slower, mineralizing only 21% of their total nitrogen within 21 days. Other residue characteristics that affect decomposition include C/N ratio, lignin content, and total plant nitrogen. Residue quality and quantity interact with physical, chemical, and biological processes and parameters that influence decomposition, including precipitation, microbial activity, soil temperature, soil pH, soil aeration, and soil nutrient status. Under NT, decomposition tends to proceed at a slower rate compared to CT due to cooler soils and limited residue contact with microorganisms (Krupinsky *et al.* 2007).

Residue decomposition results in a release of nutrients into the soil. These nutrients may be taken up by plants, soil microfauna and macrofauna, or become incorporated into soil compounds (Lafond *et al.* 1996). Decomposition of residues with a C:N ratio greater than 30:1, such as cereal straw, generally leads to immobilization of N by soil microbes. On the other hand, decomposition of residues with a C:N ratio less than 20:1, such as legumes, leads to an increase in plant available N (Liebman and Mohler 2001). Nutrient release from plant residues is generally slower in comparison to nutrient release from synthetic fertilizers. Stute and Posner (1995) found that application of fertilizer N (applied as ammonium-nitrate) resulted in increased mineral N concentrations, peaking within 2 weeks of application. On the other hand, incorporated hairy vetch and red clover did not significantly increase mineral N concentrations until 8 weeks later. Residues that are not incorporated into the soil release nutrients more slowly in comparison to residues that are incorporated into the soil. Malhi *et al.* (2007) found spring nitrate concentrations of 61 kg ha^{-1} in the 0 -15 cm soil depth following alfalfa incorporation in comparison to soil nitrate concentrations of 13 kg ha^{-1} where alfalfa was desiccated with herbicides and retained on the surface of the soil in the previous season.

The amount and timing of nitrogen availability from any form of fertilizer shapes uptake and synchrony. Synchrony can be defined as a dynamic balance between nutrient supply and demand, with asynchrony occurring when nutrient availability exceeds plant requirements, or when nutrient supply is insufficient to meet plant requirements at certain times (Crews and Peoples 2005). Tillage regimes can affect synchrony because tillage affects the rate of residue decomposition and nutrient availability. Residues in NT systems can act as slow release sources of nitrogen. If synchronized with crop demand the nitrogen will be taken up by subsequent crops. However other fates for the residue N are immobilization, denitrification, and ammonia volatilization (Sarrantonio and Scott 1988). Sarrantonio and Scott (1988) compared ploughed hairy vetch and NT hairy vetch as a source of N for corn. They found that under NT, 29% of the original N in the above ground vetch biomass was measured either as soil inorganic N or corn N. Under CT, 56% of the original vetch N was measured either as soil inorganic N or corn N, showing that CT provided better synchrony between nitrogen availability and crop demand.

2.3.1.7 Weed Growth

As discussed above, the NT microenvironment differs from CT in terms of light, temperature, moisture, and nutrient regime, and therefore results in different selection pressures that shape the weed community.

Surface residues can suppress weed emergence depending on the amount and origin of the mulch. Mohler and Teasdale (1993) compared weed seedling emergence under hairy vetch and rye residue applied 1 to 4 times the natural field rate. In this particular study, natural level of residue was not sufficient to suppress weed seedling germination – significant suppression occurred only at 2 to 4 times the natural rate, corresponding to 5-10 Mg ha^{-1} of residue. In comparing rye and hairy vetch residue it was observed that early in the experiment, before the residues had decayed, more weed seedlings emerged through the hairy vetch than the rye, which the authors attributed to greater soil nitrate under the hairy vetch and the greater allelophathic toxicity of rye residue. Furthermore, the hairy vetch residue decayed faster than rye residue, as a result, later on in the season a high rate of hairy vetch achieved the same degree of weed control as moderate rye.

Increased seed predation by invertebrates and vertebrates under NT can affect weed communities; while both crop and weeds are susceptible to seed predation, weed seeds are more vulnerable due to their smaller seed size in comparison to crop seed size (Liebman and Mohler 2001). Teasdale and Mohler (1993) observed more insects, slugs, snails and voles in higher residue treatments. Cromar *et al.* (1999) measured seed predation under NT, reduced tillage, and CT systems and found predation rates of 32%, 24%, and 32% , respectively - concluding that seed predation was dictated by more than soil disturbance. They indeed found more predation in corn residue (31%), compared to soybean residue (24%) and wheat residue (21%). Hence, crop rotation may also play a role in weed seed predation.

Tillage intensity also affects weed populations due to distribution of seeds in the soil profile. For example, primary tillage can result in weed seeds shifted to deep layers, while less intense tillage, like the chisel plough, results in seed distribution in the upper horizon. Gruber and Claupein (2009) investigated the effect of tillage intensity on perennial and annual weed populations in an organic system over five years. Reducing tillage by using the chisel plough resulted in a higher density of annual weeds (99 weeds m^{-2}) compared to more intense tillage deep plough, double layer plough, and shallow plough (38 m^{-2}, 59 m^{-2}, 55 m^{-2}, respectively). The authors found the same trend with the perennial weed *Cirsium arvense*, observing an increase in density as tillage intensity decreased.

A number of studies of have been conducted to compare individual weeds species' response to NT, CT and reduced tillage. Thomas *et al.* (2004) reviewed such studies from the Canadian prairies in order to identify species that are associated with specific tillage systems. The authors found that all species under investigation occurred under all three systems, but varied in relative abundance. Some weed species were strongly correlated with a tillage system. For example, field pennycress and green foxtail are associated with CT, flixweed and dandelion were associated with ZT, and Canada thistle and volunteer canola were associated with ZT/reduced tillage. Other species were ubiquitous across all three systems, such as wild buckwheat, wild mustard and wild oat. The prediction that annual weeds would be associated with CT did not prevail. The authors suggest further study of the ecophysiology of weeds will assist in making predictions about weed communities. This is in accordance with the conclusion by Teasdale and Mohler (1993) stating that species response should be observed empirically, and depends on environmental conditions and residue origin.

2.4 Nitrogen Losses from Green Manures

2.4.1 Nitrate Leaching

The incorporation of nitrogen rich green manures can result in significant losses of nitrogen due to nitrate leaching. Nitrate can be leached beyond the root zone if excess water occurs and/or if no crop is present to take up the nitrate. For example, Campbell (1994) measured 275 N kg ha^{-1} at a depth of 1.2m to 5.0 m in the spring following an incorporated sweet clover green manure. In the United Kingdom, Stopes *et al.* (1996) observed significant losses of nitrate on organically managed farm following a plowdown of a red clover green manure. Twenty seven percent of the accumulated above ground N in the red clover was lost by leaching, equating to a loss of 102 N kg ha^{-1}. The magnitude of nitrate leaching depends on soil texture, crop type, plant uptake of N, precipitation, evapotranspiration, and drainage (Campbell *et al.* 1994). Askegaard *et al.* (2005) measured nitrate leaching at various organic farms in Denmark and found the largest amount of nitrate leached from coarse sand and the lowest from sandy loam. There are several ways of mitigating nitrate leaching from green manures. Stopes *et al.* (1996) found that delaying tillage of a red clover green manure until spring resulted in a loss of 26 N kg ha^{-1}, as compared to a loss of 102 N kg ha^{-1} when the red clover was tilled in the autumn. Askegaard *et. al* (2005) found that including catch crops following a green manure decreased nitrate leaching by 38% for the coarse sand, 30% for the loamy sand, and 26% for the sandy loam.

2.4.2 Volatilization

*A*mmonia volatilization is the process by which aqueous ammonia is transformed into gaseous ammonia. This natural phenomenon results in ammonia emissions released into the atmosphere from oceans, animal manures, and soil. Anthropogenic sources of volatilized ammonia are agriculture, human and pet wastes, industrial processes, and fossil fuels. Total ammonia emissions from all sources have been estimated to be 54 Mt N yr $^{-1}$ globally (Saffigna and Freney 2002), and 559 623 t N yr $^{-1}$ in Canada (Environment Canada 2006).

2.4.2 .1 The Mechanism

Aqueous ammonium ($NH_4^+{}_{(aq)}$) exists in equilibrium with aqueous ammonia ($NH_{3(aq)}$). Alkaline conditions favour a shift towards $NH_{3(aq)}$. $NH_{3(aq)}$ is converted to gaseous ammonia ($NH_{3(g)}$) as concentrations of $NH_{3(aq)}$ and temperatures increase. Through diffusion, $NH_{3(g)}$ is released into the atmosphere from soils or plant tissue. The rate of diffusion is determined by the concentration gradient.

2.4.2 .2 Ammonia Volatilization in Agriculture

The majority of volatilized ammonia originates from agricultural sources, accounting for 70% of total global emissions and 90% of total Canadian emissions (Saffigna and Freney 2002; Environment Canada 2006). Agricultural sources of ammonia emissions are: the application of fertilizers and animal manures, biomass burning, crops, and the decomposition of plant residues. Ammonia volatilization can result in significant losses of nitrogen from an agricultural system – of the total nitrogen applied in the form of animal manure, losses of 30% -70% have been reported (Huijsmans *et al.* 2003), of the total nitrogen applied in the form of fertilizer, losses of 5% - 56% have been reported (Saffigna and Freney 2006), and of the total nitrogen applied in the form of mulch, losses of 5% - 39% have been reported (Glasener and Palm 1995; Janzen and McGinn 1991; Larsson *et al.* 1998; Whitehead *et al.* 1988). These losses have both agronomic and environmental implications. Agronomically, volatilization can decrease the fertility value of fertilizers, manures, and plant residues, leading to yield and economic losses.

Environmentally, ammonia can impact the local environment as it spreads through the atmosphere, potentially as far as 4 km from the point source. Ammonia in the atmosphere can combine with sulphates and nitrates to form particulate matter ($PM_{2.5}$), contributing to the formation of smog and visibility haze (Environment Canada 2006). Anthropogenic emissions have resulted in atmospheric N deposition 5-20 times higher than in natural conditions, resulting in increased atmospheric N deposition in natural systems. The deposited ammonia can be absorbed by vegetation through the stomata (Pitcairn *et al.* 1995). If the ammonia that has entered the plant is not assimilated, ammonia can accumulate in the plant tissues resulting in ammonia toxicity. Studies have reported evidence of toxicity near ammonia sources such as livestock farms, manure storage facilities, and fertilizer plants throughout Europe. Ammonia toxicity can hinder a plants ability to deal with stresses such as drought, frost, and pests. Ammonia deposition in soil leads to nitrogen saturation and acidification (Krupa 2003). The increased level of nitrogen in a natural ecosystem can also result in a shift in species composition (Krupa 2003).

2.4.2 .3 Ammonia Volatilization from Mulches

While animal manures are a dominant source of ammonia emissions in agriculture, contributing 21.7 Mt of emissions, studies have reported significant ammonia volatilization, 3.6 Mt, from plant material. As mentioned, of the total nitrogen applied in the form of mulch, losses of 5% - 39% have been reported (Glasener and Palm 1995; Janzen and McGinn 1991; Larsson *et al.* 1998; Whitehead *et al.* 1988).

The amount of ammonia that is emitted depends on the quality of the residue. For example, Whitehead et. al (1988) compared the ammonia volatilized from cut perennial rye grass (*Lolium perenne L.)* with high N content (3.52% N of dry matter) versus low N content (2.32%) in glass jars. They found a higher proportion of the total nitrogen was volatilized in the grass with high N content, 44%, compared to 25% from the low N rye grass. In a field study, Larsson *et al.* (1998) compared ammonia volatilization of different cut mulches: perennial rye grass (*Lolium perenne L.)* with low N content (1.15%

N of dry matter), perennial rye grass with high N content (2.12%), alfalfa (*Medicago sativa)* (4.33%), and bare soil. Similar to Whithead *et. al* (1988) they also found that with increasing N content there was an increase in the proportion of total nitrogen that was volatilized. The amount of ammonia volatilized from the perennial rye grass with low N was 2% of the total N applied as mulch, equating to a loss of 8 kg ha^{-1} N, which was comparable to emissions from the bare soil. The rye grass with high N content lost 39% of the total nitrogen through volatilization, equating to 190 kg ha^{-1} N, and the alfalfa lost 17%, equating to 170 kg ha^{-1} N. Glasener and Palm (1995) used incubation chambers to assess ammonia volatilization from ten different tropical grasses and legumes species that were cut and placed on a soil surface as mulch. The researchers tested the ten species for tissue N concentration, C to N ratio, lignin content, polyphenols, and mineralization rate. They found those species that tended to have the combination of high N content, low C to N ratio, and high lignin were more susceptible to both mineralization and ammonia volatilization. On the other hand, plants species that had low N content, high C to N ratio, and low lignin had lower mineralization rates as well as lower ammonia emissions. The proportion of total N that was volatilized ranged from 6.0% to 11.8%. Janzen and McGinn (1991) observed the ammonia losses from decomposing lentil (*Lens culinaris* cv. Indianhead) under controlled conditions in a flow through chamber. Field-grown lentil was compared to hydroponically grown lentil – it was found that the field-grown lentil had more soluble N than the hydroponically grown lentil and also exhibited higher ammonia emissions.

The incorporation of residues reduces ammonia emissions to negligible levels. Janzen and McGinn (1991) compared ammonia losses from lentil (*Lens culinaris* cv. Indianhead) that was incorporated into the soil versus lentil that was left on the surface of the soil under controlled conditions in a flow-through chamber. After 28 days of incubation, they found the accumulated ammonia emissions from incorporated lentil to be negligible, amounting to 0.05% of the total N content of the lentil. On the other hand, the lentil residue that was left on the surface of the soil resulted in 3.6% of the N content volatilized at the end of the 28 days. Glassener and Palm (1995) compared the effect of incorporating residues versus retaining residues on the surface of the soil of three different plant species, *Canavalia ensiformis, Desmodium ovaliforum,* and *Oryza sativa*, in incubation. All three species showed appreciable losses after 21 days of incubation, 10.9%, 3.4%, 3.5% of their total N, respectively. The incorporated residues had no losses.

Environmental factors that affect the rate of volatilization are wind speed, moisture, and temperature. Janzen and McGinn (1991) varied the air flow rate in flow-through chambers that contained surface applied lentil residue. They found that with higher air flow rate, more ammonia was volatilized. This is because the rate of volatilization is determined by the concentration gradient and wind promotes volatilization since it takes $NH_{3(g)}$ away from the surface. Whitehead *et al.* (1988) compared ammonia volatilization of perennial rye grass (*Lolium perenne L.)* with high N and low N in 10°C and 20°C in an incubation chamber. They found that temperature affected both the rate at which the ammonia was volatilized and the total amount of ammonia volatilized at the end of a 70 day period. At 20°C, the high N grass lost 25% of its total N through ammonia volatilization after 17 days, whereas at 10°C this amount took 33 days. At 20°C, the low N grass lost 25% of its total N through ammonia volatilization after 35 days, whereas at 10°C this amount was not reached even after 70 days. Moisture also played a critical role in the study by Whitehead at al. (1988), where ammonia losses ranged between 20% to 47% of total nitrogen in moist conditions, but only ranged from 0 -5% under dry conditions.

After plant residue application, there is an initial lag, followed by a flush of NH_3, followed by slow, continuous emissions. This pattern was observed by Glasener and Palm (1995), Janzen and McGinn (1991), Larsson *et al.* (1998), and Whitehead *et al.* (1988). The time when the NH_3 flush occurred varied with plant species and temperature, ranging from 3 days to 21 days. The initial lag can be attributed to the initial phases of decomposition. The flush occurs due to the rapid ammonification of soluble organic N converting to ammonia. The slow continuous emission is the mineralization of more recalcitrant N fractions in the plant material (Janzen and McGinn 1991).

2.4.3 Denitrifcation

No till management can lead to denitrification on poorly aerated soils - the increased bulk density and soil water resulting from NT management occurs in most soils; however, on poorly aerated soils it leads to anaerobic conditions that contribute to N_2O emissions from the soil (Rochette 2008).

2.5 The Blade roller

The blade roller - also known as the knife roller, roller crimper, and cover crop roller - was developed by farmers in South America as a mechanical method of terminating cover crops (Kornecki *et al.* 2009). In the last decade, there has been an interest in adopting this technology in North America. In particular, the Rodale Institute in Pennsylvania has been promoting the adoption of the blade roller for use by organic farmers by posting the plans for the roller on their website (Rodale Institute 2010).

The blade roller works by rolling over cover crops and crimping crop stems, crushing the vascular tissue without completely cutting the stems (Mischler *et al.* 2010). The cover crop plant eventually dries and is killed leaving a residue flat on the surface of the soil. Farmers can then seed their cash crop directly into the mulch - seeding can occur soon after rolling, or at the same time in a single operation. Examples of systems include seeding soybeans into a cover crop of black oats, seeding corn into a cover crop of hairy vetch, and seeding soybeans into a cover crop of rye. The blade roller can be an alternative to other methods of cover crop termination such as tillage, herbicides, and mowing.

When using the blade roller the residue that remains on the surface of the soil provides ground cover protecting the soil from erosion, covering the soil at the critical time between planting and canopy closure of the cash crop. The use of the roller results in a uniform distribution of residue that is still anchored to the soil, facilitating the seeding of a cash crop. Mowing on the other hand can result in patchy residue distribution and detached residue that can hinder a smooth seeding operation (Creamer and Dabney 2002). In addition, mowed cover crops decompose faster compared to rolled (Creamer and Dabney 2002). The persistence of rolled mulch provides longer erosion protection, and also contributes to weed suppression and moisture conservation. Use of the roller requires less energy than tillage, mowing or herbicides. Ashford and Reeves (2003) estimate the energy requirements for the operation of a blade roller to be one-tenth that of a rotary mower. They also assume an operating cost of \$3.73 ha^{-1} for the blade roller, in comparison to application of paraquat, \$25.61 ha^{-1}. Besides being a cheaper option, eliminating/reducing herbicide reduces environmental impact.

Several designs of the roller exist in North and South America. A study by Kornecki *et al.* (2009) assessed six different roller designs to determine which design resulted in the least vibrations, as vibrations can result in uneven rolling and an uncomfortable and unhealthy situation for the operator. They concluded a straight blade roller had significantly higher vibrations than a roller with curved bars. The vibrations resulting from the straight blade were deemed 'fairly uncomfortable' and exceeded the health limit based on Australian safety standards. The roller promoted by the Rodale Institute has chevron shaped blades for the same purpose of avoiding vibrations.

The efficacy of the roller (i.e., adequate weed suppression, moisture conservation, and cash crop yield) is determined by successful termination of the cover crop as well as the amount of cover crop biomass at termination. Timing of termination plays a key role in both successful termination and biomass production. In general, studies have shown the most successful termination is at late bloom growth stages of the cover crop (Ashford and Reeves 2003; Creamer and Dabney 2002; Mirsky 2009). For example, Mischler et. al (2010) found that by rolling at the 100% flowering stage of hairy vetch they were able to consistently achieve 100% kill. Rolling at earlier stages, varying from 40% flowering to 60% flowering, resulted in only 70% to 90% kill. Ashford and Reeves (2003) attained complete kill of rye, wheat, and black oat at early milk, but not at earlier stages such as anthesis. Seeding date of the cover crop can also play a role in successful termination as earlier planting dates result in increased rye maturity at termination. Mirsky *et al.* (2009)

observed 79% control rate for a rye cover crop planted in late August, 70% for a mid - September planting, and 73% for a mid-October planting. In addition, they found an interaction between termination date and rye cultivar early in early spring – the early May termination date resulted in 41 % kill for the Aroostook cultivar, significantly more than the 21 % kill achieved with the Wheeler cultivar. The authors concluded that early spring environmental conditions resulted in cultivar specific responses that affect rye maturity. Delaying termination until late bloom growth stages of the cover crop also increases the amount of cover biomass present at termination. For example, hairy vetch biomass can increase by 50 to 60% from late May to mid-June (Mischler *et al.* 2010). Furthermore, Ashford and Reeves (2003) found that delaying termination can also affect residue quality - as rye, wheat, and black oat increase in maturity there was an increase in the C:N ratio. Delayed termination also improves weed control (Mischler *et al.* 2010).It is important to note that while delaying termination may result in successful termination and increased biomass production, the delay can also result in soil water depletion and a late seeding date of the cash crop, both of which can decrease the yield of cash crops (Ashford and Reeves 2003; Mirsky 2009).

Preliminary investigations using the blade roller in southern Manitoba showed that the blade roller was effective in terminating a pea and oat green manure intercrop (OACC 2008). The N uptake of wheat following the rolled green manure was 20% lower than the N uptake of wheat following a tilled green manure. It appeared that rolling the green manure had slowed the rate of nitrogen release.

2.6 Pea

Pea (*Pisum sativum*) is an annual with viney growth. Field pea can be grown on a wide range of soil types but requires good drainage as it does not tolerate wet or water logged conditions. Field pea germinates best in cool moist soils and needs a cool growing season for optimal growth. Field pea can be used for forage, hay, silage, grain and green manure. Peas can produce approximately 1400 kg ha^{-1} to 4600 kg ha^{-1} in above ground biomass (Biederbeck *et al.* 1996; Biederbeck *et al.* 1993) and above ground nitrogen content ranging from approximately 30 kg ha^{-1} to 90 kg ha^{-1} (Biederbeck *et al.* 1996). When grown as a green manure, field peas are sometime intercropped with a supporting crop, like oats or rye. At Carman, Manitoba the average dry matter yield of a pea and oat intercrop grown organically between 2007 and 2009 was 5756 kg ha^{-1} (Natural Systems 2010).

2.7 Wheat

Wheat is the most commonly grown food crop in the world, providing more nutrients for humans than any other source of food (Curtis 2002). Worldwide, the FAO (2010) estimates that 681.4 million tonnes of wheat was produced in 2008/2009. Wheat is also the most commonly grown food crop in Canada, with approximately 9.5 million hectares harvested in 2009, yielding approximately 26.5 million tonnes (Statistics Canada 2008). Canadian wheat grown under organic management in 2005 totaled 75, 816 hectares (Statistics Canada 2008).

Wheat development is shaped by an interaction among various factors, including sowing date, sowing depth, location, cultivar, photoperiod, radiation efficiency, nutrient availability, temperature, and water availability. These factors have varying effects on crop physiology throughout the different developmental stages, ultimately affecting grain quantity and quality. This literature review will discuss the effect temperature, nitrogen availability, and water availability have on wheat development, as these are factors that differ between CT and NT systems and pertain to this research project.

2.7.1 Temperature and Wheat Development

Temperature affects wheat development from seeding to maturity – however, certain stages are more dependant on temperature than others. The effect of temperature on development is based on thermal time, which is an expression of the summation of differences between daily mean temperature and base temperature (Miralles and Slafer 1999). The period between emergence and floral initiation is highly dependant on temperature – the more thermal time is accumulated, the faster development proceeds (Miralles and Slafer 1999).

2.7.2 Nitrogen and Wheat Development

Nitrogen is the most important nutrient in determining yield potential and is the limiting factor for the productivity of most agroecosystems (Frageria *et al.* 2006). Nitrogen taken up by wheat roots, mostly in the form of nitrate, is assimilated into the plant to form organic compounds, mainly proteins, essential for plant structure and function (Miralles and Slafer 1999). The effect of nitrogen availability on wheat development begins at tillering and continues until mid milk. Malhi *et. al* (2006) quantified nutrient (N,P,K,and S) uptake and biomass accumulation during the different growth stages of wheat. Their results showed that both biomass accumulation and nitrogen uptake increased with time, reaching a maximum at late growth stages. Maximum nutrient accumulation rate occurred between tillering and stem elongation, reaching a rate of 5.7 kg ha^{-1} d^{-1}. This was followed by maximum biomass accumulation rate during late boot, reaching a rate of 204 kg ha^{-1} d^{-1}. Afterwards, maximum nutrient uptake was reached between flowering and mid milk, at 161 kg ha^{-1}. And finally, maximum biomass amount was achieved at ripening, totaling 7614 kg ha^{-1}.

The effects of nitrogen deficiency on wheat development vary depending on the developmental stage. If a deficiency occurs during tillering, there is a decrease in the number of tillers (Miralles and Slafer 1999). A deficiency during terminal spikelet initiation results in a decrease in the number of spikelets per spike and the number of kernels per spike (Miralles and Slafer 1999). The terminal spikelet stage is especially sensitive to nitrogen and has been suggested as an ideal stage for a second dose of fertilizer nitrogen (Acevedo *et al.* 2002). A deficiency during flowering, would result in a decrease in seed setting. During grain filling, there is limited nitrogen uptake and enough nitrogen is provided from soil mineralization. Nitrogen is remobilized from senescing vegetative tissue to reproductive organs (Miralles and Slafer 1999). Roughly 75% of the nitrogen found in the vegetative organs is relocated to the grain (Frageria *et al.* 2006).

2.7.3 Water Availability

Water availability affects wheat development from seeding to maturity. As with nitrogen, the effects of water deficiency on wheat development vary depending on the developmental stage. Water stress can lead to poor germination and emergence. Water stress after emergence, decreases leaf growth, decreases tillering, and decrease number of spikelets. The most critical stage for water stress is during the reproductive phase. Water deficits during this phase decreases photosynthetic activity and decreases number of grain. Water stress during grain filling accelerates senescence, resulting in decreased grain weight (Frageria *et al.* 2006).

3. MATERIALS AND METHODS

3.1 Site Description

Field plots were located at the Organic Field Laboratory on the Ian N. Morrison Research Farm in Carman, Manitoba and at Moose Creek Organic Farm near Oxbow, Saskatchewan from 2007 to 2009. Carman is located 70 km southwest of Winnipeg, Manitoba. Climate data was obtained from a weather monitoring station at Carman and summarized in (Table 1). The soil is an Orthic Black Chernozem fine sandy loam soil of the Hibisin series (Mills and Haluschak 1993). The Organic Field Laboratory has been under organic management since 2004. The six year crop rotation practiced at Carman follows the sequence of: 1) green manure – 2) cereal – 3) pulse crop - 4) green manure – 5) oilseed – 6) cereal. The field plots for this research took place in years 1 and 2 of the rotation. See Table 2 for nutrient status of fields.

Moose Creek Organic Farm is a 1456 ha certified organic farm located 10 km northwest of Oxbow, Saskatchewan. The farm has been under organic management since 1985. The soil is a loam of the Oxbow series. Climate data was obtained from the nearest Environment Canada Station in Estevan, Saskatchewan and summarized in Table 1. See Table 2 for nutrient status of the fields.

3.2 Experimental Design

In year 1 of the experiment, a green manure crop was seeded in early May. At Carman, the green manure was an intercrop of peas (cv. 4010) and oats (cv. HiFi) and a monocrop of peas (cv. Trapper) at Oxbow. See Table 3 for seeding dates and seeding rates. The peas at Carman were inoculated with liquid inoculant (Nodulator®) at the manufacturer's recommended application rate of 75 mL of inoculant per 27 kg of seed. The peas at Oxbow were inoculated with a powder inoculant (Nitrastik®). Six different

Table 1. Mean monthly temperature and precipitation during the growing season (MAFRI 2010, Environment Canada 2010) and long term averages (Environment Canada 2004) at each experimental site.

Research Site	May	June	July	August	Growing Season
Air temperature (°C)					
Carman (2008)	8.85	15.50	18.18	19.05	15.40
Carman (2009)	8.48	15.38	18.00	17.06	14.73
Long Term Average[1]	12.40	17.20	19.70	18.10	16.85
Oxbow (2009)	9.90	15.10	16.50	17.00	14.63
Long Term Average[1]	12.10	16.80	19.50	18.60	16.75
Precipitation (mm)					
Carman (2008)	33.60	84.40	37.60	54.80	210.40
Carman (2009)	69.20	126.80	68.40	52.60	317.00
Long Term Average[1]	59.80	75.50	73.50	66.80	275.60
Oxbow (2009)	6.00	66.40	37.60	71.60	181.60
Long Term Average[1]	52.10	76.20	65.00	49.50	242.80

[1] 30 year averages.

Table 2. The pH, organic matter content, and nutrient status at the experimental sites.

Location	Soil Depth (cm)	pH	Organic Matter (%)	N*	P**	K	S***
					----------ppm ----------		
Carman	0-30	5.9	3.6	14	11.5	147	5.0
	30-60	7.4	2.1	10	5	146	7.0
	60-120	8.4	1.9	8.0	2.5	173	35
Oxbow	0-30	7.8	3.7	14	3.5	293	8.5
	30-60	8.2	1.2	27	2.0	111	60
	60-120	8.4	0.4	16	2.5	89.5	55

* nitrate-N, **Olsen-P, *** sulfate-S

termination treatments were applied to the green manure beginning when the peas were at full bloom around mid-July (Table 4). The treatments were applied in the experimental design of a randomized complete block with 4 repetitions. Plot sizes at Carman were 4 m by 8m and at Oxbow were 6 m by 8 m. At Carman, a tandem disc was used for all tillage operations. At Oxbow, a tandem offset disc (Hutchmaster) was used for the first tillage operation of each treatment and subsequent tillage operations were conducted with a cultivator. The dates of the rolling/tillage operations were based on green manure regrowth and weed growth.

‘Rolling’ was accomplished with the blade roller (Figure 1). The blade roller was constructed based on the plans provided by the Rodale Institute (Rodale Institute 2010). The blade roller consists of a 2 m wide drum with chevron shaped blades attached to the drum. The weight can be adjusted by adding water to the drum. For this study water was added to the drum, resulting in a total drum weight of approximately 730 kg. An additional 360 kg of steel weights were added to the roller, resulting in a total weight of approximately 1090 kg. A John Deere 5210 tractor was used to pull the roller on a three point hitch, at a speed of approximately 6 – 7 km h^{-1}. The blade roller works by rolling over cover crops and crimping crop stems, crushing the vascular tissue without completely cutting the stems. At the first rolling date, the green manure was rolled twice in opposite directions to ensure proper termination.

Figure 1. The blade roller (left) and the blade roller crimping a pea and oat intercrop (right).

Table 3. Year and location of the green manure and subsequent spring wheat, seeding rates are in parentheses, and seeding dates are in italics.

Location	2007	2008	2009
Carman Research Station	Peas (124 kg ha^{-1}) and oats (40 kg ha^{-1}) *n/a*	Spring wheat (128 kg ha^{-1}) *May 2*	-
	-	Peas (127 kg ha^{-1}) and oats (26 kg ha^{-1}) *May 6*	Spring wheat (128 kg ha^{-1}) *May 4*
		-	Peas (125 kg ha^{-1}) and oats (25 kg ha^{-1}) *May 15*
Moose Creek Organic Farm	-	Peas (145 kg ha^{-1}) *n/a*	Spring wheat (128 kg ha^{-1}) *May 21*

n/a seeding date not available

Table 4. Description of the rolling and tilling operations for each treatment.

		Green Manure				Spring wheat
		July[a]	August[b]	September[c]	October[d]	May[e]
	Treatment	-- Field operation --				
1	Rolled only (no-till)	Roll	Roll	Roll	Roll	no operation
2	Spring tilled no-till	Roll	Roll	Roll	Roll	Till
3	Rolled three times	Roll	Roll	Roll	Till	Till
4	Rolled two times	Roll	Roll	Till	Till	Till
5	Rolled once	Roll	Till	Till	Till	Till
6	Tilled only (conventional tillage)	Till	Till	Till	Till	Till

[a] At Carman (2007), Carman (2008) and Oxbow (2008) the field operations took place on July 12, July 15, and July 16, respectively.

[b] At Carman (2007), Carman (2008) and Oxbow (2008) the field operations took place on Aug 7, July 25, and July 30, respectively.

[c] At Carman (2007), Carman (2008) and Oxbow (2008) the field operations took place on Sep 7, Aug 18, and Aug 28, respectively.

[d] At Carman (2007), Carman (2008) and Oxbow (2008) the field operations took place on Oct 16, Sep 18, and Oct 3 respectively.

[e] Tillage operations took place before spring wheat seeding, see Table 3 for dates.

In year 2 of the experiment, spring wheat was seeded into the green manure plots (Table 3). At Carman the variety 5602 HR was used. At Oxbow the variety AC Cadillac was used since that was the variety the farmer used. All treatments, except for treatment 1, were disked before seeding (Table 4). The wheat was seeded using a no-till disc drill (Fabro Enterprises Ltd., Swift Current, SK) at a row spacing of 15 cm and a depth of roughly 4 cm.

3.3 Data Collection

3.3.1 Data Collection in the Year of the Green Manure

Soil nitrate. Soil samples were collected three times in the year of the green manure, at: 1) seeding of the green manure, 2) at the first termination date, and 3) in the fall. Soil samples were taken using a hand auger at depths of 0 - 30 cm, 30 cm – 60 cm, 60 cm – 120 cm. At seeding and termination, six random samples were taken from the entire green manure field and bulked. In the fall, two samples were taken from each plot and bulked. Samples were refrigerated until they were sent to Agvise Laboratories (Northwood, ND) for soil nitrate-N analysis using the cadmium reduction method.

Green manure biomass and biomass nitrogen. A biomass sample of the peas and oats was taken on the day of the first termination date. Six random samples of 1.0 m^2 were taken from the alleyways between the plots of the aboveground biomass of the peas and oats just before rolling/disking. The samples were dried at 70°C for at least 48 hours and then weighed. The samples were then ground using a Wiley Mill No.1 (Arthur H.Thomas Co., Philadelphia). The ground samples were subsampled for nitrogen concentration analysis using a LECO FP-528 (LECO, St. Joseph).

Ammonia emissions. Ammonia volatilization from the green manure crop was measured in the rolled only treatments and tilled only treatments at Carman (Table 4). In 2008, ammonia volatilization was measured from the plots that were used for the study that subsequently had wheat grown in 2009. Measurements were taken again in 2009 on a site that was established solely for volatilization measurements. The experimental design of this additional experiment was a randomized complete block with 4 repetitions and plot sizes were 4 m by 8m. Measurements began right after the first termination date and continued until the fall. A total of 13 measurements were taken in 2008, and a total of 11 measurements were taken in 2009. Measurements were approximately one week apart.

Ammonia emissions were measured using the technique described by Grant *et al.* (1996). In summary, a polyvinyl chloride tube 20 cm long and 15 cm in diameter was inserted into the soil to a depth of about 5 cm (Figure 2). A foam disk that had been presoaked in a glycerol-phosphoric acid trapping solution was placed inside the chamber about 5 cm above the ground to absorb ammonia emitted within the chamber. Another presoaked foam was placed at the top of the chamber to stop the entry of ammonia from outside of the chamber, while still allowing for exchange of air between inside and outside the chamber. A plastic canopy was placed above each chamber to protect the foam disks from rain washing away the acid. At each sampling date, the foams were collected. The solution in the ammonia-trapping foam disks was extracted procedure to remove the trapped ammonia. The ammonia was extracted by soaking the disk in 0.5 M KCl for half an hour. After the half hour, the foams were wrung out of all liquid. The liquid extracts were placed in the freezer until they were analyzed for ammonia, using an AutoAnalyzer (Technicon Instruments Corporation, New York).

It was discovered that the chambers had to be moved at each sampling date due to some observed fungal growth in the chamber. Therefore, at each sampling date the chambers were moved to a new location within the same plot, reinserted into the ground and equipped with two freshly soaked foam disks. In 2008, two chambers were used per plot and in 2009 three chambers were used per plot.

Figure 2. Polyvinyl chloride tube fitted with foam disks and a plastic canopy.

3.3.2 Data Collection in the Year of the Spring Wheat

Ground cover. Before or soon after wheat seeding, pictures were taken of the land surface to estimate the percent of the ground covered by residues for each of the six treatments.

Wheat population density and Haun stage. Wheat development and plant density were measured at roughly the 4 leaf stage at Carman and the 3 leaf stage at Oxbow. Wheat development was determined by measuring the Haun scale (Haun 1973) on ten wheat plants along a 1 m length of row per treatment. Plant density was measured by counting plants in a 1 m length along 3 rows of wheat per treatment.

Weed population density. Weed density was determined in mid June after most weeds had emerged. Individual weed species were counted in two randomly selected 0.25 m^2 quadrats per treatment.

Soil moisture content. Soil moisture was measured shortly after wheat seeding. At Carman (2008), volumetric soil moisture was measured to a depth of 120 cm using a Troxler Neutron Moisture Meter. To utilize the Troxler Neutron Meter, aluminum tubes were inserted in the centre of each plot. Measurements were taken at depth intervals of 10-30 cm, 30-50 cm, 50-70 cm, 70 – 90 cm, 90-110 cm, and 110-130 cm. Due to the design of the Troxler Neutron Meter, the top 0-10 cm cannot be measured by the meter. The soil moisture in the top 0-10 cm of soil was determined by using a soil punch. Five soil samples were collected from each plot with the soil punch and bulked. The samples were weighed and then dried in the oven at 80°C for at least 48 hours and weighed again. The gravimetric soil moisture was determined, as follows:

$$\textit{gravimetric moisture} = (\textit{wet weight-dry weight})/(\textit{dry weight}) \qquad \text{[eq. 1]}$$

The gravimetric moisture was converted to volumetric soil moisture by assuming a bulk density of 1 g cm^{-3}. Volumetric moisture was calculated as follows:

$$\textit{volumetric moisture} = (\textit{gravimetric moisture})*(\textit{bulk density}) \qquad \text{[eq. 2]}$$

At Carman (2009) and Oxbow (2009) soil moisture was determined by using subsamples from the soil collected for soil nitrate testing at the time of spring wheat seeding. Samples were taken using a Dutch auger at depths of 0 - 30 cm, 30 cm – 60 cm, 60 cm – 120 cm. The samples were weighed and then dried in the oven at 80°C for at least 48 hours. The gravimetric soil moisture was determined and then converted to volumetric soil moisture content using eq. 2.

Soil nitrate-N. Soil samples were taken three times in the year of spring wheat at: 1) seeding of the wheat, 2) stem elongation, and 3) soft dough. One extra soil sample was taken in the spring of 2009 following the wheat crop in Carman in 2008. Soil samples were taken using a hand auger at depths of 0-30 cm, 30 cm – 60 cm, 60 cm – 120 cm. Two samples were collected and bulked for each plot. Samples were refrigerated until they were sent to Agvise Laboratories (Northwood, ND) for soil nitrate-N analysis using the cadmium reduction method.

Wheat biomass and wheat biomass N. Wheat biomass samples were taken at three wheat developmental stages: 1) stem elongation, 2) anthesis, and 3) soft dough. At stem elongation and anthesis, two 1 m rows of above ground wheat only biomass were taken using a sickle, cutting plants about 2 cm from the soil surface. At soft dough, two samples of 0.25 m^{-2} quadrats per plot of all above ground biomass (weeds and wheat) were sampled. At Carman (2008) and Oxbow (2009) the samples were not sorted between weeds and wheat. At Carman (2009), the samples were sorted between weeds and wheat. The samples were dried at 70°C for at least 48 hours. The samples were weighed to determine biomass weight. The samples were then ground using a Wiley Mill No.1 (Arthur H.Thomas Co., Philadelphia). The ground samples were subsampled for nitrogen concentration analysis using a LECO FP-528 (LECO, St. Joseph).

Wheat grain yield and grain protein. At Carman, grain yield was collected from each plot with a Massey Ferguson 80XP plot combine (Table 5). The samples were cleaned and weighed. At Oxbow (2009), a combine was not used, but instead three randomly selected 1 m^2 quadrats of wheat were collected (Table 5). The collected samples were later threshed using a stationary Wintersteiger combine. Grain protein was determined by grinding subsamples of the grain. The ground samples were subsampled, and then analyzed for nitrogen concentration using a LECO FP-528 (LECO, St. Joseph). Grain protein was calculated by multiplying grain nitrogen concentrations by a factor of 5.7.

Table 5. Harvest dates of spring wheat at Carman in 2008 and 2009, and Oxbow in 2009.

Site-year	Date
Carman (2008)	August 19th
Carman (2009)	September 2nd
Oxbow (2009)	August 27th

Nitrogen Indices. Two different indices were used to assess effects of tillage regime on N supply: 1) available nitrogen and 2) nitrogen use efficiency (NUE). In this study, available nitrogen was calculated as the total measured nitrogen at soft dough in the system:

$$\textit{Available nitrogen (N kg ha}^{-1}\textit{) = Wheat biomass nitrogen (N kg ha}^{-1}\textit{) + Total soil profile nitrate-N (N kg ha}^{-1}\textit{)} \qquad \text{[eq. 3]}$$

Nitrogen use efficiency was calculated as the percentage of wheat biomass nitrogen ‘derived’ from the green manure shoot biomass:

$$\text{NUE (\%)} = \frac{\textit{Wheat biomass nitrogen (N kg ha}^{-1}\textit{)}}{\textit{Green manure shoot biomass nitrogen (N kg ha}^{-1}\textit{)}} \times 100 \qquad \text{[eq. 4]}$$

3.4 Statistical Analysis

Treatment effects were tested using analysis of variance for all measurements. Data were analyzed using the PROC Mixed procedure with the Statistical Analysis Software program (SAS Institute 2001). The protected Least Square Difference was used to determine significant differences ($p > 0.05$). Assumptions of ANOVA were tested by using the PROC Univariate procedure to test for normality of the residuals and also by using the PROC Plot procedure for a visual diagnostic of the scatter of the residuals. Outliers were removed based on critical values of internal studentized residuals of Lund’s test (Lund 1975). Contrasts were used to answer to answer four of the questions of interest: 1) is there a significant difference between a system that only uses the blade roller for green manure termination (no till) compared with the system that uses the conventional practice of only tilling the green manure (trt 1 vs. trt 6), 2) does spring tillage in the no till system significantly affect the no till system (trt 1 vs. trt 2), 3) how does the no till system with spring tillage compare to only tilling the green manure (trt 2 vs. trt 6), and 4) is there a significant difference between reducing tillage in half and only using tillage to terminate a green manure (trt 4 vs. trt 6)?

4. RESULTS AND DISCUSSION

4.1 Ground Cover

Ground cover was assessed to determine the degree to which the soil was protected from erosion. At wheat seeding, the no till treatment had the most ground cover compared with the other treatments across all three site years, ranging from approximately 50% at Oxbow to 90% at Carman (App 1 Fig 1 and Fig 2). The tilled only treatment had the least ground cover ranging from 2 % at Oxbow to 5% at Carman. The spring tilled no till treatment had approximately 20% ground cover at both Oxbow and Carman. The reduced tillage treatments (rolled three times, rolled twice, and rolled once) had similar ground cover, ranging from 15% to 20%.

Soil erosion rates have been shown to decrease with increased ground cover (Trimble and Mendel 1995). Therefore, the no till treatment clearly provided the most protection from soil erosion, followed by the spring tilled no-till treatment. The tilled only system was at the greatest risk of soil erosion since the system had the least ground cover both in the year of the green manure and at wheat seeding.

4.2 Wheat Plant Population Density

Wheat plant population density was measured to determine the effect of the different tillage regimes on crop establishment. Wheat plant population density ranged from 237 plants m^{-2} to 407 plants m^{-2} at the Carman sites and 253 plants m^{-2} to 315 plants m^{-2} at the Oxbow site (Table 6). Plant population density was greater than the 230-280 plants m $^{-2}$ recommended by Manitoba Agriculture, Food and Rural Initiatives (2001) because of the increased seeding rate recommended for organic production. At all three site years tillage regime had no significant overall effect on wheat plant population density. Wiens *et al.* (2006) also found no difference in wheat plant population density between zero mulch and plots mulched with alfalfa at rates ranging from 0.97 t ha^{-1} to 3.94 t ha^{-1}. However, contrast analysis showed that at Oxbow (2009) the no-till treatment had 20% fewer plants than the tilled only treatment. This reduced wheat plant population may be attributed to the greater weed pressure present at time of seeding in the no till treatment compared to the tilled only treatment at time of seeding. Both wild mustard (*Brassic kaber*) and green foxtail (*Setaria viridis*) were beyond the seedling stage at the time of seeding in the no-till treatment, and potentially competed with the wheat.

Table 6. The effect of tillage regime on wheat plant density and Haun stage at Carman in 2008 and 2009, and at Oxbow in 2009.

	Carman				Oxbow	
	2008		2009		2009	
	Haun stage	plant population	Haun stage	plant population	Haun stage	plant population
Treatment		-----plant m^{-2}-----		-----plant m^{-2}-----		-----plant m^{-2}-----
1 - Rolled only (no-till)	3.4 **c**[Y]	479	2.9 **b**	486	2.5	505
2 - Spring tilled no-till	3.8 **ab**	472	3.2 **ab**	472	2.4	584
3 - Rolled three times	4.0 **b**	610	3.6 **a**	505	2.3	577
4 - Rolled two times	3.6 **bc**	486	3.6 **a**	518	2.5	630
5 - Rolled once	3.7 **bc**	531	3.5 **a**	486	2.4	617
6 - Tilled only	4.0 **a**	499	3.5 **a**	486	2.5	630
P > F	0.0044	0.5419	0.0206	0.8965	0.1448	0.0905
Contrasts	-----------------------------	-----------------------------	------------- *P > F*	------------------------------	-----------------------------	-----------------------------
Trt 1 vs. Trt 6	**0.0008**	0.7640	**0.0090**	0.9021	0.5523	**0.0125**
Trt 1 vs. Trt 2	**0.0204**	0.9520	0.1546	0.8376	0.2428	0.1110
Trt 2 vs. Trt 6	0.1314	0.7188	0.1546	0.7432	0.0882	0.2716
Trt 4 vs. Trt 6	**0.0091**	0.8884	0.5728	0.4891	0.5523	0.9423

[Y] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

4.3 Wheat Development

Wheat Haun stage was measured to determine the effect of the different tillage regimes on early wheat development. Plant development rate in the period between wheat emergence and floral initiation is highly dependent on temperature; the more thermal time is accumulated, the faster development proceeds (Miralles and Slafer 1999). It was therefore expected that wheat Haun stage would be affected by cooler soil temperatures observed under no-till conditions. Results of the present study showed that Haun stage was in fact affected by tillage at both years in Carman (Table 6). In Carman (2008), the no-till wheat was less developed than most tillage treatments, and significantly less developed than the tilled only treatment. In Carman (2009), the no-till treatment was significantly less developed than all treatments that were tilled the previous year. Kabakci *et al.* (1993) also reported slower wheat development when wheat was grown where residues were not removed as compared with complete residue removal. In their study, the Haun stage at 4 weeks after planting was 5.5 where residues were not removed and 5.9 where residues were removed. In the present study, at Carman (2008) the Haun stage of the wheat in the no-till system was 3.4 and 4.0 in the tilled only system. In Carman (2009), the Haun stage of the wheat in the no-till system was 2.9 and 3.5 in the tilled only system. One specific question of interest in this study was whether spring tillage immediately before spring wheat seeding would change plant development rate. Results from Carman (2008) demonstrated that this one tillage eliminated the development delay. A similar, but non-significant trend was observed at Carman (2009). No significant effect of tillage on wheat development was observed at Oxbow. One reason for this observation may be lower overall soil surface mulch at the Saskatchewan site, which was drier than the Carman site. The above ground biomass of the green manure at time of termination was 5800 kg ha^{-1} at Carman compared with only 1447 kg ha^{-1} at Oxbow. Also, the Carman green manure contained a combination of peas and oats, while the green manure at Oxbow was a pea monoculture. The pea and oat mulch would be expected to decompose more slowly than a pea only mulch due to higher C:N ratios (Krupinsky *et al.* 2007).

4.4 Soil Moisture

Reducing tillage has been shown to conserve soil moisture in comparison to conventional tillage (Larney *et al.* 1994). For example, Lafond *et. al* (1992) measured total spring water to a soil depth of 1.2 m and reported 42.4 cm of water under no-till and 40.2 cm under conventional tillage (Larney *et al.* 1994). Soil moisture was measured at time of wheat seeding to determine if reducing tillage with the blade roller would result in soil moisture conservation. Tillage regime significantly affected total profile soil moisture only at Carman (2009)(Table 7). The spring tillage in the no till treatment reduced total soil profile moisture by 5% compared with the no till system (p>0.0494). It was also interesting to observe that the treatments which differed in total profile soil water at Carman (2009) were the rolled three times treatment and the spring tilled no-till treatment (Table 7)These are the treatments that also differed in surface soil water content at the Oxbow site in the 0-15 cm depth. One possible explanation for the lower water content in soils that were rolled three times is that the plots had significant green manure regrowth following each rolling event, which would have depleted soil water resources. Similar regrowth occurred in the no till system, but this treatment benefited from a continuous mulch cover which likely conserved water.

Under the conditions of this study, only minimal soil water conservation was observed with reduced tillage. Both Malhi *et al.* (2007) and Mohr *et al.* (1999) assessed spring soil moisture following alfalfa terminated by either tillage or herbicide, and while Malhi *et al.* (2007) found no effect of termination method on soil water, Mohr et. al (1999) found increased surface (0-30cm) soil moisture in herbicide treatments. In the present study, the lack of dramatic treatment effects of no tillage at Carman may be attributed to adequate precipitation (Table 1). Lack of dramatic treatment effects at Oxbow may be attributed to a low mulch mass in the no till treatments (Table 11) as well as weed growth early in the season.

4.5 Weed Population Density

Tillage is a primary tool for weed management in organic agriculture and is the most important direct weed control method. Consequently, weed control has been reported as a major challenge in implementing reduced tillage or no till management in organic systems (Berner *et al.* 2008; Drinkwater *et al.* 2000; Krauss *et al.* 2010; Peigne *et al.* 2007). It was therefore important to understand how using the blade roller affected the weed community. Weeds were assessed in two ways: total weed density and densities of individual predominant weed species observed.

Table 7. The effect of tillage regime on volumetric water content in the soil profile at time of wheat seeding at Carman in 2008 and 2009, and at Oxbow in 2009.

	Carman (2008)								Carman (2009)					Oxbow (2009)				
	Depth (cm)								Depth (cm)					Depth (cm)				
Treatment	0-10	10 -30	30-50	50-70	70-90	90-110	110-130	total	0-15	15-30	30-60	60-120	total	0-15	15-30	30-60	60-120	total
	$m^3 m^{-3}$																	
1 - Rolled only (no-till)	0.127	0.323	0.271	0.254	0.285	0.407	0.456	0.303	0.241	0.249	0.238	0.237	0.240 **a**[Y]	0.143 **a**	0.116	0.114	0.047	0.104
2 - Spring tilled no-till	0.124	0.356	0.311	0.321	0.410	0.453	0.436	0.344	0.267	0.230	0.223	0.236	0.227 **bc**	0.127 **a**	0.127	0.097	0.064	0.099
3 - Rolled three times	0.121	0.301	0.276	0.270	0.340	0.443	0.447	0.314	0.207	0.211	0.239	0.217	0.219 **c**	0.067 **b**	0.096	0.101	0.054	0.081
4 - Rolled two times	0.120	0.350	0.298	0.272	0.347	0.400	0.440	0.318	0.208	0.232	0.225	0.228	0.224 **bc**	0.126 **a**	0.126	0.110	0.049	0.082
5 - Rolled once	0.120	0.310	0.304	0.240	0.319	0.415	0.393	0.300	0.201	0.247	0.237	0.239	0.233 **ab**	0.100 **a**	0.095	0.112	0.019	0.082
6 - Tilled only	0.123	0.287	0.256	0.239	0.267	0.365	0.464	0.286	0.217	0.225	0.232	0.253	0.237 **ab**	0.108 **a**	0.107	0.082	0.046	0.084
P > F	0.8388	0.3060	0.8372	0.3256	0.2207	0.5292	0.3043	0.2338	0.7011	0.0795	0.4645	0.2194	0.0313	0.018	0.602	0.746	0.153	0.325
Contrasts	*P > F*																	
Trt 1 vs. Trt 6	0.5661	0.3006	0.7548	0.6855	0.7541	0.4004	0.7836	0.4530	0.3525	0.0785	0.5074	0.2748	0.6318	0.0866	0.7132	0.1904	0.9533	0.1333
Trt 1 vs. Trt 2	0.6932	0.3510	0.4172	0.1029	**0.0438**	0.3532	0.5283	0.0904	0.3519	0.1444	0.1470	0.9238	**0.0494**	0.4222	0.6767	0.4711	0.2954	0.7424
Trt 2 vs. Trt 6	0.8560	0.0600	0.2672	**0.0483**	**0.0236**	0.0882	0.3695	**0.0209**	0.9991	0.7327	0.4087	0.2374	0.1200	0.3291	0.3996	0.5369	0.2706	0.2288
Trt 4 vs. Trt 6	0.6187	0.0845	0.3963	0.3999	0.1806	0.4721	0.4288	0.1780	0.7543	0.5718	0.5212	0.0870	0.0544	0.3656	0.4259	0.2514	0.8408	0.9176

[Y] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

At Carman (2008), there was no overall tillage effect on total weed density (Table 8). However, contrast analysis showed that the tilled only treatment had more than two times ($p<0.01$) the total weed density than the no till treatment. This significant difference may be due to weed suppression from the mulch present in the no-till treatment (Figure 5). Tillage regime had a significant effect on two out of three predominant species in Carman (2008). Redroot pigweed (*Amaranthus retroflexus* L.) was significantly more prevalent in treatments with more tillage – which would be expected since redroot pigweed is known to germinate in response to tillage (Mohler and Liebman 2010). Wild buckwheat (*Polygonum convolvulus* L.) was most prevalent in the no-till treatment with spring tillage, potentially due to nitrogen mineralized from the mulch from spring tillage (Mohler and Liebman 2010). Contrast analysis showed that the green foxtail population was significantly less in the no till treatment than the tilled only treatment, which may be attributed to a number of factors including seed predation of the large, palatable green foxtail seed (Mohler and Liebman 2010). Previous research at Carman , MB showed that green foxtail germinates in response to tillage (Ominski and Entz 2001).

At Carman (2009), there was no overall tillage effect on total weed density (Table 8). Only one out of four of the predominant species was significantly affected by tillage regime. Wild buckwheat density was significantly higher in the no-till treatment compared to the tilled only treatment. At Oxbow (2009), total weed population density was significantly affected by tillage (Table 10). The no till treatment with spring tillage had a significantly greater total weed density compared to all other tillage regimes. Green foxtail appeared to be the main weed species driving the weed population differences among treatments. Green foxtail was significantly greater in the no till treatment with the spring tillage and the rolled three times treatments compared with all other treatments. Wild mustard density was also significantly greater in the no-till treatment with spring tillage than the tilled only treatment. It appeared that the spring tillage in the no-till treatments stimulated green foxtail and wild mustard recruitment, potentially by burying seeds and creating more favourable conditions for germination. Ominski and Entz (2001) also reported that eliminating soil disturbance in the alfalfa termination process significantly reduced weeds, including green foxtail, wild mustard, lamb's quarters (*Chenopodium album* L.), and redroot pigweed. In fact, aeration from tillage has been shown to initiate wild mustard germination (Mohler and Liebman 2010).

The no till treatment at Oxbow (2009) had the same total weed population as the tilled only and rolled once treatments. The tilled treatments most likely benefited from weed control due to the repeated tillage in the green manure year, while the no-till treatment may have benefited from seed predation and perhaps some weed control from the rolling itself. It is unlikely the mulch contributed to weed suppression in the no-till treatments since the ground cover was not significant (Figure 5). Studies indicate a mulch of at least 5-10 Mg ha^{-1} is required for significant weed suppression (Teasdale and Mohler 1993), which was not the case at Oxbow (2009).

The weed densities were measured to assess the effect tillage regime had on total weed densities and the predominant weed species densities, ultimately to determine weed competition with wheat. It is important however to note that weed density alone may not provide an accurate picture of weed competition. First, the counts taken to determine weed densities do not take into account the weed biomass and hence the competitiveness of the weed plant. For example, at the time of the weed counts at Carman (2009), the winter annual weeds species shepherd's-purse (*Capsella bursa-pastoris* L.) and stinkweed (*Thlapsi arvense* L.) were already mature in the rolled only treatments and potentially more detrimental to the crop than the sheppard's-purse and stinkweed seedlings in the tilled treatments. Another reason why weed population counts are not necessarily accurate in describing weed competition is that the counts are taken early in the season and do not reflect the final biomass of weeds. For example, while wild mustard was very prevalent at Oxbow (2009), wheat is a good competitor against wild mustard, and therefore, the competition by wild mustard might be misrepresented with weed counts alone. A more accurate assessment would be to collect a biomass sample of wheat and weeds at the end of the season and sort out the weeds. This was done for Carman (2009) (see section 4.6.2.2). It was not deemed necessary for Carman (2008) and

Oxbow (2009) since it was estimated that weeds composed substantially less than 10% of the total biomass.

Table 8. The effect of tillage regime on total weed density and the three predominant weed species in the spring wheat at Carman (2008).

Treatment	Total	Green foxtail	Redroot pigweed	Wild buckwheat
	-------------------- plant m^{-2}			--------------------
1 - Rolled only (no-till)	298	194	27 **b**[Y]	62 **b**
2 - Spring tilled no-till	542	272	30 **b**	233 **a**
3 - Rolled three times	552	366	99 **ab**	39 **b**
4 - Rolled two times	692	451	150 **a**	68 **b**
5 - Rolled once	755	582	86 **ab**	37 **b**
6 - Tilled only	687	499	145 **a**	15 **b**
P > F	0.1811	0.1262	0.0170	0.0053
Contrasts	----------------------	*P > F*		----------------------
Trt 1 vs. Trt 6	**0.0426**	**0.0494**	**0.0070**	0.3547
Trt 1 vs. Trt 2	0.1845	0.5920	0.9278	**0.0031**
Trt 2 vs. Trt 6	0.4223	0.1326	**0.0085**	**0.0005**
Trt 4 vs. Trt 6	0.9799	0.7434	0.8971	0.2979

[Y] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

Table 9. The effect of tillage regime on total weed density and the four predominant weed species in the spring wheat at Carman (2009).

Treatment	Total	Green foxtail	Redroot pigweed	Wild buckwheat	Sheppard's purse
	----------------------------	plant m^{-2}	----------------------------		
1 - Rolled only (no-till)	381	33	79	166 **ab**[Y]	40
2 - Spring tilled no-till	502	4	121	133 **bc**	39
3 - Rolled three times	648	178	60	296 **a**	14
4 - Rolled two times	364	91	51	92 **bc**	45
5 - Rolled once	361	99	39	102 **bc**	37
6 - Tilled only	361	79	21	20 **c**	238
P > F	0.0958	0.1522	0.6598	0.0257	0.5648
Contrasts	----------------------------	*P > F*	----------------------------		
Trt 1 vs. Trt 6	0.8459	0.4475	0.3602	0.0458	0.1613
Trt 1 vs. Trt 2	0.2711	0.6377	0.5080	0.6211	0.9960
Trt 2 vs. Trt 6	0.2024	0.2307	0.1309	0.1073	0.1600
Trt 4 vs. Trt 6	0.9700	0.8430	0.6345	0.2872	0.1700

[Y] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

Table 10. The effect of tillage regime on total weed density and the three predominant weed species in the spring wheat at Oxbow (2009).

Treatment	Total	Green foxtail	Wild mustard	Lamb's qaurters
	-------------------- plant m^{-2}			-------------------
1 - Rolled only (no-till)	495 **c**[Y]	240 **c**	222	15
2 - Spring tilled no-till	1291 **a**	951 **a**	314	18
3 - Rolled three times	986 **b**	705 **ab**	220	36
4 - Rolled two times	814 **b**	484 **bc**	277	38
5 - Rolled once	380 **c**	165 **c**	181	26
6 - Tilled only	367 **c**	160 **c**	151	33
P > F	0.0001	0.0006	0.2410	0.2633
Contrasts	---------------------- *P > F*			------------------------
Trt 1 vs. Trt 6	0.3729	0.6275	0.3180	0.1308
Trt 1 vs. Trt 2	**<0.0001**	**0.0005**	0.2030	0.7990
Trt 2 vs. Trt 6	**0.0001**	**0.0002**	**0.0320**	0.2004
Trt 4 vs. Trt 6	**0.0060**	0.0603	0.0867	0.6719

[Y] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

4.6 Nitrogen

A major objective of this study was to investigate the effect of rolling a green manure on nitrogen dynamics. The effect of tillage regime on nitrogen dynamics was assessed in the year of the green manure by measuring green manure biomass nitrogen, soil nitrate-N, and ammonia volatilization. In the year of the spring wheat, the effect of tillage regime on nitrogen dynamics was assessed by measuring soil nitrate-N, wheat biomass nitrogen, available nitrogen and nitrogen use efficiency.

4.6.1 Green Manure Year

4.6.1.1 Green Manure Shoot Biomass

The shoot biomass of the pea and oat green manure at Carman in 2008 was 5800 kg ha^{-1} and had a biomass nitrogen content of 126 kg ha^{-1} (Table 11). At Oxbow, there appeared to be large weed pressure from wild mustard; therefore the green manure biomass was analyzed by separating peas and weeds. The biomass of the peas alone was 1447 kg ha^{-1} and had a biomass nitrogen content of 50 kg ha^{-1}. The biomass of the weeds was 386 kg ha^{-1} and had biomass nitrogen content of 10 kg ha^{-1}. The green manure crop at Oxbow had less biomass and biomass nitrogen than Carman because at Oxbow a pea monocrop was used, compared to the pea and oat intercrop at Carman. In addition, Oxbow was drier than Carman (Table 1), resulting in less biomass production. Previous studies have shown that peas produce approximately 1400 kg ha^{-1} to 4600 kg ha^{-1} biomass (Biederbeck *et al.* 1996; Biederbeck *et al.* 1993) and have above ground nitrogen content ranging from approximately 30 kg ha^{-1} to 90 kg ha^{-1} (Biederbeck *et al.* 1996). The biomass production of the green manure pea and oat intercrop has ranged from 5380 kg ha^{-1} to 8474 kg ha^{-1} in the past six years at the Organic Crops Field Laboratory (Natural Systems Agriculture 2010).

Table 11. Green manure biomass and biomass nitrogen on the first termination date at Carman and Oxbow in 2008.

	Biomass			Biomass Nitrogen		
Location	Green manure [Y]	Weed	Total	Green manure	Weed	Total
	------------------ kg ha^{-1}	----------------		--------------- N kg ha^{-1}	------------------	
Carman	5800	- [Z]	5800	126	-	126
Oxbow	1447	386	1746	50	10	58

[Y] The green manure at Carman was a pea and oat intercrop and the green manure at Oxbow was a monocrop of peas.

[Z] Weeds were neglible at Carman and therefore not measured separately

4.6.1.2 Soil Nitrogen

Soil nitrate concentrations were high at the time of green manure seeding at both Carman (2009) and Oxbow (2009) (Carman (2008) was not measured) (Table 12). The Manitoba Water Stewardship residual soil nitrate-N limit within the top 60 cm of soil is 157 kg ha^{-1} (Manitoba Water Stewardship 2010). Entz et. al (2001) found that soil N in organic farms ranged from 60 kg ha^{-1} to 131 kg ha^{-1} in the 0-60 cm depth.

Table 12. Soil nitrate-N at the time of seeding the green manure at the depths 0-30 cm, 30 -60 cm, 60 -120 cm, and total (0-120 cm) in 2008.

Location	0-30	30 - 60	60-120	Total
	--------------- N kg ha^{-1}			--------------------
Carman	63	45	67	175
Oxbow	63	119	139	320

Nitrate concentrations were measured in the fall after green manure termination using the different tillage regimes. These fall nitrate-N values serve as an indication of the amount of nitrate that can potentially be available to a crop the following year, but also as an indication of potential losses, since green manure nitrogen is susceptible to volatilization, leaching, and denitrification (Campbell *et al.* 1994; Janzen and McGinn 1991). Soil nitrate measurements was measured at three depths: shallow (0-30 cm), middle (30 cm-60 cm), and deep (60 cm-120 cm).

In the fall of the green manure crop, treatment effects were similar at Carman in both years, with significantly more nitrate in the depth of 0-60 cm in the tilled only treatment than the no-till treatment (Table 13 and Table 14). There was 56 kg ha^{-1} and 88 kg ha^{-1} more nitrate in the tilled only system compared to the no-till system at Carman (2008) and Carman (2009), respectively. However, no significant treatment effects between 60 cm -120 cm were observed in either year. At Carman (2009), soil nitrate was also measured in the rolled twice treatment. Results showed that soil nitrate in the 0 - 30 cm depth in the rolled twice treatment was similar to both the no till and the tilled only treatments. However, at 30 cm - 60 cm the rolled twice treatment had significantly more nitrate-N than the no till treatment and significantly less than the tilled only treatment. These results demonstrate a positive relationship between amount of tillage and soil nitrate concentrations. Analyzing total nitrate throughout the profile, Carman (2009) showed that eliminating tillage decreased total soil nitrate by half and reducing the tillage to half reduced total soil nitrate by almost 40%.

The observation of greater nitrate concentrations in the tilled systems are consistent with many other studies comparing incorporated green manures to surface applied green manures (Drinkwater *et al.* 2000; Janzen and McGinn 1991; Sarrantonio and Scott 1988; Varco *et al.* 1993). There are several possible reasons for this observation. First, incorporating the green manure stimulates mineralization of the green manure material due to increased temperatures and exposure to soil microbial populations (Varco *et al.* 1993). Furthermore, tillage stimulates the mineralization of indigenous soil organic matter (Drinkwater *et al.* 2000). Lower nitrate concentrations in the NT system maybe also be the result of immobilization (Sarrantonio and Scott 1988) or losses from denitrification (Ball *et al.* 2008). In addition, the no till treatment may have lost nitrogen to volatilization after each rolling event, since decaying plant material that is not incorporated is susceptible to ammonia volatilization (Glasener and Palm 1995; Janzen and McGinn 1991)

The nitrogen that is mineralized after the incorporation of a legume is susceptible to leaching if no crop is present to take it up and if excess water occurs. For example, Campbell *et al.* (1994) observed 275 N kg ha^{-1} in the 1.2 m – 5.0 m depth in the spring following a sweet clover (*Melilotus officinalis* L.) green manure plowdown and 280 N kg ha^{-1} after a alfalfa (*Medicago sativa* L.) -bromegrass (*Bromus inermis* Leyss) hay plowdown. Stopes *et al.* (1996) observed significant losses of nitrate on an organically managed farm following a plowdown of a red clover green manure. Twenty seven percent of the accumulated above ground N in the red clover was lost by leaching, equating to a loss of 102 N kg ha^{-1}. The greater amounts of soil nitrates in the tilled system therefore represent a greater risk of nitrate leaching than the rolled systems.

Carman (2009) in fact displayed evidence of downward movement of nitrate with a significant accumulation of nitrate in the 30-60 cm depth in both the tilled only and rolled twice treatments, compared with the no till treatment (Table 14).

At Oxbow (2009), there was no significant difference between treatments (Table 15). The nitrogen contribution of the pea green manure to the soil may have not been detectable due to the high background soil nitrate. The green manure biomass was only 1447 kg ha^{-1} and the biomass nitrogen was 58 kg ha^{-1}, while the soil nitrate at the time of green manure seeding was 320 kg ha^{-1}.

Table 13. The effect of tillage regime on soil nitrate-N in the depths 0-30 cm, 30 -60 cm, 60 -120 cm, and total (0-120 cm) for Carman (2008) wheat production year.

	Fall 2007				May 2008				July 2008				August 2008				May 2009			
	Peas and Oats				Wheat				Wheat				Wheat				-			
	fall				seeding				anthesis				soft dough				-			
Treatment	0-30	30-60	60-120	Total	0-30	30-60	60-120	Total	0 -30	30 - 60	60-120	Total	0 -30	30 - 60	60-120	Total	0 -30	30 - 60	60-120	Total
	N kg ha^{-1}																			
1 - Rolled only (no-till)	103	39	27	208	88	41	51	180	16	10	31	58	22 **b**[Y]	10 **b**	16	48 **b**	45 **bc**	20 **b**	66	131
2 - Spring tilled no-till	103	39	27	208	101	38	54	193	14	10	22	46	22 **b**	8 **b**	19	49 **b**	57 **a**	36 **a**	65	157
3 - Rolled three times	n/a	n/a	n/a	n/a	111	40	67	219	18	12	31	61	30 **b**	11 **b**	21	62 **b**	52 **ab**	38 **a**	70	160
4 - Rolled two times	n/a	n/a	n/a	n/a	129	40	73	242	19	15	35	69	26 **b**	13 **a**	27	66 **ab**	45 **bc**	37 **a**	78	159
5 - Rolled once	n/a	n/a	n/a	n/a	122	39	55	216	18	14	30	62	25 **b**	10 **b**	21	56 **b**	39 **c**	34 **a**	76	149
6 - Tilled only	144	54	30	264	112	43	70	225	16	16	29	61	42 **a**	19 **a**	26	87 **a**	39 **c**	23 **b**	98	159
P > F	0.0451	0.0124	0.9646	0.0713	0.0606	0.9706	0.2420	0.1421	0.2999	0.4920	0.9082	0.7743	0.0158	0.0087	0.4058	0.0283	0.0291	0.0041	0.1925	0.4007
Contrasts	*P > F*																			
Trt 1 vs. Trt 6	-	-	-	-	0.0747	0.7227	0.0995	0.0629	0.8065	0.1665	0.8370	0.8562	**0.0017**	**0.0026**	0.1075	**0.0029**	0.2809	0.5601	**0.0278**	0.0888
Trt 1 vs. Trt 2	-	-	-	-	0.3219	0.6578	0.7998	0.5768	0.3345	0.8863	0.4156	0.4506	0.9170	0.5437	0.6748	0.9193	**0.0496**	**0.0045**	0.9318	0.1086
Trt 2 vs. Trt 6	-	-	-	-	0.3871	0.4287	0.1550	0.1708	0.4661	0.1305	0.5395	0.3528	**0.0021**	**0.0007**	0.2187	**0.0035**	**0.0053**	**0.0152**	**0.0234**	0.9109
Trt 4 vs. Trt 6	-	-	-	-	0.2014	0.5956	0.7998	0.4830	0.1554	0.8863	0.6084	0.5882	**0.0078**	0.0513	0.8335	0.0758	0.2809	**0.0073**	0.1382	0.9745

[Y] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

n/a = not analyzed.

Table 14. The effect of tillage regime on soil nitrate-N in the depths 0-30 cm, 30 -60 cm, 60 -120 cm, and total (0-120 cm) for Carman (2009) wheat production year.

	October 2008				May 2009				August 2009			
	Peas and Oats				Wheat				Wheat			
	fall				seeding				soft dough			
Treatment	0-30	30 - 60	60-120	Total	0 -30	30 - 60	60-120	Total	0 -30	30 - 60	60-120	Total
	---------- N kg ha^{-1} ----------											
1 - Rolled only (no-till)	29 **b**[Y]	25 **c**	47	101 **b**	45	44	58 **bc**	148 **c**	38	20	20	78
2 - Spring tilled no-till	29 **b**	26 **c**	47	102 **b**	57	28	71 **bc**	155 **bc**	45	24	28	96
3 - Rolled three times	n/a	n/a	n/a	n/a	49	33	63 **bc**	145 **c**	n/a	n/a	n/a	n/a
4 - Rolled two times	40 **ab**	41 **b**	48	129 **b**	80	39	110 **b**	229 **ab**	42	24	40	107
5 - Rolled once	n/a	n/a	n/a	n/a	60	43	50 **c**	153 **c**	n/a	n/a	n/a	n/a
6 - Tilled only	50 **a**	92 **a**	63	205 **a**	62	65	124 **a**	250 **a**	47	32	32	105
P > F	0.0148	0.0001	0.776	0.0327	0.2724	0.373	0.0484	0.0276	0.5277	0.1431	0.5822	0.4024
Contrasts	---------- *P > F* ----------											
Trt 1 vs. Trt 6	**0.0052**	**0.0001**	0.5332	**0.0136**	0.2687	0.2456	**0.0191**	**0.0113**	0.1746	**0.0443**	0.4041	0.1892
Trt 1 vs. Trt 2	-	-	-	-	0.4426	0.3334	0.6293	0.8460	0.2936	0.1889	0.5803	0.3301
Trt 2 vs. Trt 6	**0.0052**	**0.0001**	0.5332	**0.0136**	0.7239	**0.0432**	**0.0499**	**0.0169**	0.7282	0.3243	0.7461	0.6478
Trt 4 vs. Trt 6	0.0963	**0.0002**	0.5751	**0.0453**	0.2299	0.1526	0.5883	0.5622	0.4916	0.4665	0.6476	0.9236

[Y] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

n/a = not analyzed.

Table 15. The effect of tillage regime on soil nitrate-N n the depths 0-30 cm, 30 -60 cm, 60 -120 cm, and total (0-120 cm) for Oxbow (2009) wheat production year.

	October 2008				May 2009				August 2009			
	Peas and Oats				Wheat				Wheat			
	fall				seeding				soft dough			
Treatment	0-30	30 - 60	60-120	Total	0 -30	30 - 60	60-120	Total	0 -30	30 - 60	60-120	Total
	------------ N kg ha^{-1} ------------											
1 - Rolled only (no-till)	72	77	72	221	89	114	181	384	32	62	103	197
2 - Spring tilled no-till	72	77	72	221	83	63	151	298	46	61	86	193
3 - Rolled three times	n/a	n/a	n/a	n/a	98	86	129	313	n/a	n/a	n/a	n/a
4 - Rolled two times	86	46	50	183	83	64	119	266	39	83	158	280
5 - Rolled once	n/a	n/a	n/a	n/a	98	115	123	336	n/a	n/a	n/a	n/a
6 - Tilled only	104	69	59	231	107	100	191	397	39	78	145	261
P > F	0.3371	0.1006	0.2974	0.4607	0.7006	0.1781	0.2905	0.3517	0.3477	0.7218	0.1607	0.2412
Contrasts	------------ *P > F* ------------											
Trt 1 vs. Trt 6	0.1577	0.5400	0.3323	0.8031	0.3231	0.5790	0.8072	0.8451	0.3925	0.5142	0.2342	0.2194
Trt 1 vs. Trt 2	-	-	-	-	0.7371	0.0576	0.4330	0.2058	0.0850	0.9595	0.6140	0.9363
Trt 2 vs. Trt 6	0.1600	0.5400	0.3320	0.8030	0.1915	0.1573	0.3085	0.1490	0.3270	0.4832	0.1058	0.1944
Trt 4 vs. Trt 6	0.3921	0.1099	0.5343	0.2546	0.1915	0.1653	0.0732	0.0627	0.9197	0.8391	0.6880	0.7107

n/a = data not collected

4.6.1.3 Ammonia Volatilization

Previous studies have reported that legume residues that remain on the soil surface and are not incorporated into the soil are susceptible to ammonia volatilization (Glasener and Palm 1995; Janzen and McGinn 1991; Larsson *et al.* 1998; Whitehead *et al.* 1988). Ammonia emissions were measured in the present study to compare volatilization rates from peas and oats that were rolled (the no-till treatment) to peas and oats that were tilled (the tilled only treatment).

Seasonal emissions of ammonia from green manure crops grown at Carman in 2008 and 2009 were determined by measuring emissions periodically from the time of the first termination event and until fall. In 2008, tillage had a significant effect on ammonia volatilization in 4 out of 13 sampling dates (Figure 3). In 2009, tillage had a significant effect in 7 out of 11 sampling dates (Figure 4). In both years, the rolled system always emitted significantly more ammonia than the tilled system. While the other sampling dates do not have significant differences, it was always the case that more ammonia was emitted from the rolled system than the tilled system.

The pattern of ammonia emission from the rolled system was similar in both years (Figure 3 and Figure 4). In 2009, there was an initial lag in emissions after the first rolling event. This was followed by a rapid flush of ammonia, which was followed by slow continuous emissions. In 2008, an initial lag in emissions was also observed; however, the next rolling event was just two weeks later, and as a result a slow continuous emission was not observed before the second rolling event. Following the second rolling event, both site years had the same pattern of ammonia emission. In the week following each rolling event there was a flux of ammonia emissions, followed by a period of slow, continuous emissions. The flushes observed following each rolling event were a result of ammonia emissions from freshly rolled green plant material of pea, oat and weed regrowth.

The pattern of ammonia emissions observed in the rolled system was similar to those reported by Glasener and Palm (1995), Janzen and McGinn (1991), Larsson *et al.* (1998), and Whitehead *et al.* (1988). The initial lag may be attributed to the initial phases of decomposition. The flush occurs due to the rapid ammonification of soluble organic N converting to ammonia and the slow continuous emission is the mineralization of more recalcitrant N fractions in the plant material (Janzen and McGinn 1991).

In both years, the pattern of ammonia emission from the tilled system was a flush at the beginning, followed by a continuous slow emission for the remainder of the season. The initial flush may be the result of the incomplete incorporation of the pea and oat green manure after the first tillage event. The peas and oats that were retained on the surface after the first tillage event appear to have produced ammonia emissions. With each subsequent tillage event, more plant material was incorporated, resulting in fewer ammonia emissions. Previous studies have shown that incorporation of residues reduces ammonia emissions to negligible levels, ranging in losses of 0% - 0.5% of total legume nitrogen (Glasener and Palm 1995; Janzen and McGinn 1991; Mohr *et al.* 1998). Furthermore, unlike the rolled treatments, the tilled treatments had minimal weed growth. Weeds that did grow were easily incorporated, leaving no plant material on the surface of the soil susceptible to ammonia volatilization.

Total seasonal ammonia emissions were greater in rolled peas and oats compared to tilled peas and oats in both 2008 and 2009. Total seasonal ammonia emitted from the rolled system in 2008 was 6.2 kg ha^{-1} compared with 1.8 kg ha^{-1} from the tilled system. This represents 4.9% and 1.5 %, respectively, of the original pea and oat shoot biomass N. Total seasonal ammonia emitted from the rolled system in 2009 was 13.4 kg ha^{-1} compared with 1.5 kg ha^{-1} from the tilled system. This represents 8.3% and 0.09 %, respectively, of the original pea and oat biomass N.

Previous studies have reported ammonia losses of 5% - 39% of total plant nitrogen applied in the form of mulch (Glasener and Palm 1995; Janzen and McGinn 1991; Larsson *et al.* 1998; Whitehead *et al.* 1988) and losses of 0%- 0.5% when plants are incorporated into the soil (Glasener and Palm 1995; Janzen and McGinn 1991; Mohr *et al.* 1998). The process of ammonia volatilization is driven by the concentration gradient between ammonia gas in the soil and ammonia in the atmosphere (Saffigna and Freney 2002). Therefore, any factors that favour increased gaseous ammonia in the soil will increase ammonia volatilization rates. For example, ammonia emissions from mulched plants tend to be greater with increased plant N content (Glasener and Palm 1995; Larsson *et al.* 1988; Whitehead *et al.* 1988). Ammonia emissions also increase with increased wind speeds(Janzen and McGinn 1991), increased temperature (Whitehead *et al.* 1988), and increased moisture (Whitehead *et al.* 1988). In the present study, these environmental factors (wind speed, temperature, and moisture) were altered due to the nature of the chambers that were used in the experiment. The chambers were closed off from the surrounding environment due to the two layers of sponges at the top of the chambers and the roof that covered the entire chamber (Figure 1). As a result, in the chamber there is no wind, potentially reducing ammonia emissions in comparison to outside of the chamber. Temperatures in the chamber may have been either be lower or higher than the temperatures outside of the chamber, thereby increasing or decreasing the ammonia volatilization taking place inside the chamber. The inside of the chamber was also not subject to the wetting and drying cycles that occur outside of the chamber, which may result in an increase or decrease of ammonia emissions.

Due to the altered environment within the chamber, the findings of the present study provide ammonia emission values that are not necessarily absolute, but are rather comparative values of emissions in rolled and tilled peas and oats. Nonetheless, the values provide useful information on the two different systems. The findings clearly show more ammonia is emitted from the rolled system than the tilled system. The loss of nitrogen to ammonia volatilization in the rolled system has both agronomic and environmental implications**.** Agronomically, ammonia volatilization represents a loss in the fertility value of the green manure crop. In the present study, volatilization may help explain the decreased soil nitrate concentrations observed in the rolled system compared to the tilled system (Table 13 and Table 14) as well as the decreased wheat nitrogen uptake in the no-till and reduced till systems compared to the tilled systems (Table 16). Environmentally, ammonia contributes to smog and alters the nitrogen dynamics of natural systems (Environment Canada 2006; Pitcairn *et al.* 1995).

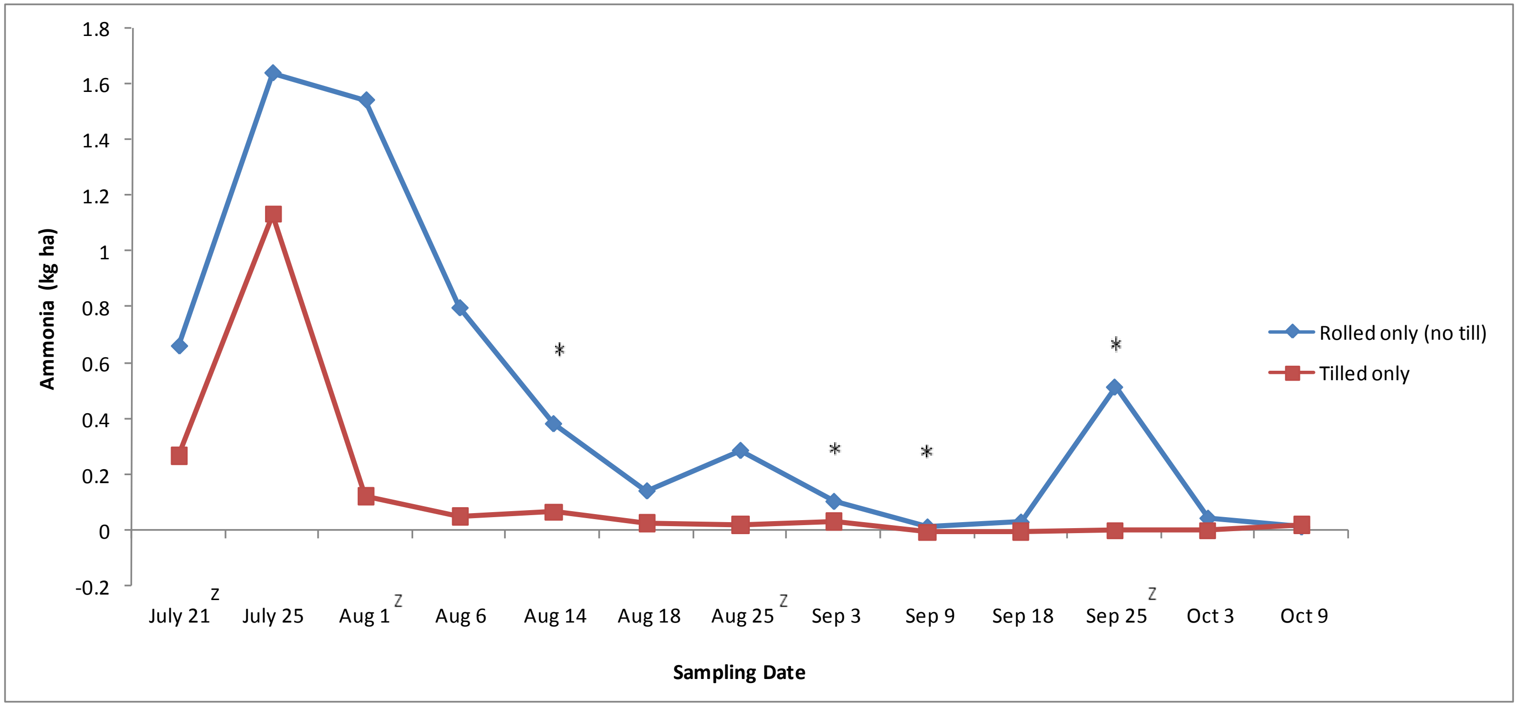

Figure 3. Ammonia emissions from the peas and oat green manure in the rolled only and tilled only treatments at Carman in 2008.

^{z} Sampling dates following a rolling and tilling operation.

* Significantly different treatment means according to Fisher's protected LSD at the 0.05 level of significance.

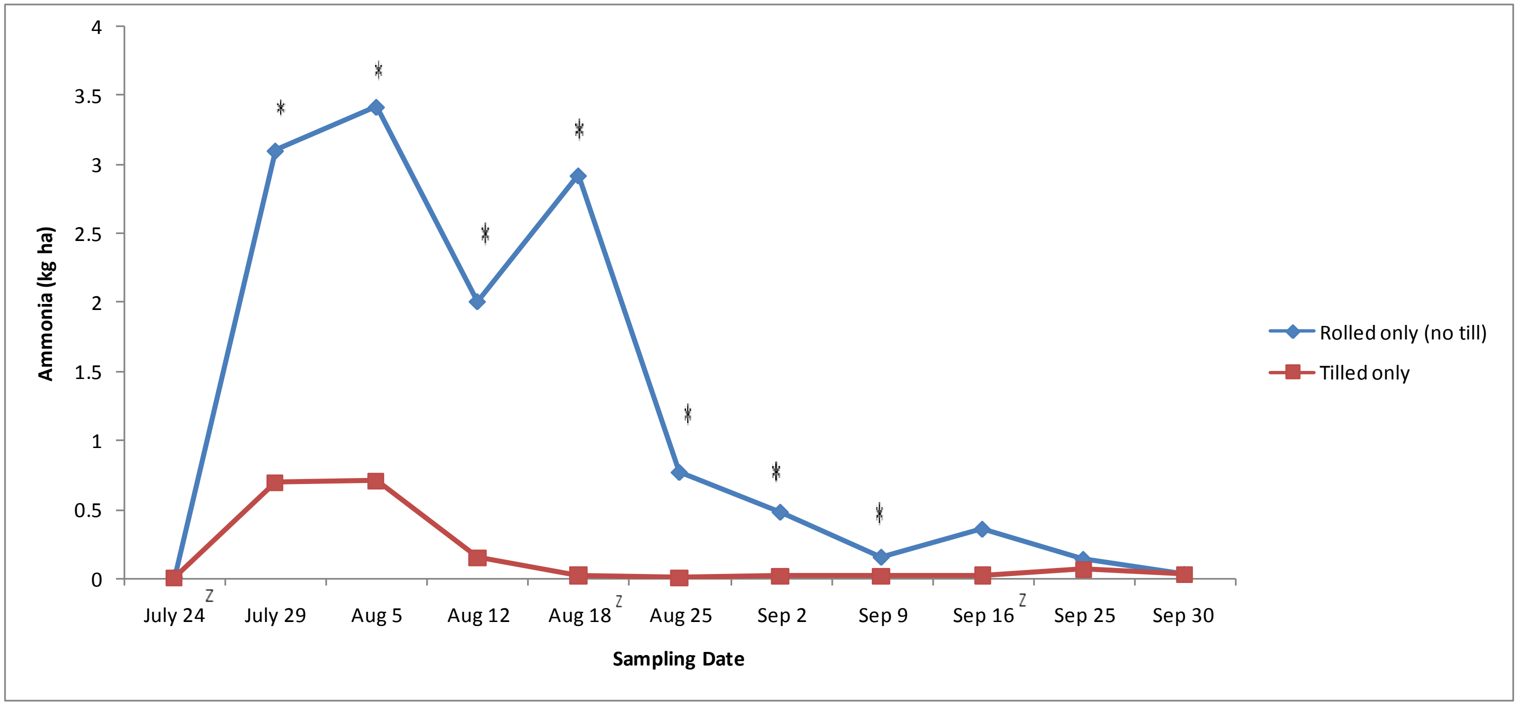

Figure 4. Ammonia emissions from the peas and oat green manure in the rolled only and tilled only treatments at Carman in 2008.

Z Sampling dates following a rolling and tilling operation.

*** Significantly different treatment means according to Fisher's protected LSD at the 0.05 level of significance.**

4.6.2 Spring Wheat

4.6.2.1 Soil Nitrogen

Nitrogen mineralization under organic no till has been observed to proceed at a slower rate than in tilled systems (Berner *et al.* 2008; Drinkwater *et al.* 2000; Peigne *et al.* 2007). This has implications for subsequent crop nitrogen uptake and susceptibility of nitrogen loss. Soil nitrate-N was measured to determine the amount of nitrogen throughout the soil profile under the different tillage regimes. The measurements were taken at three different depths: shallow (0-30 cm), middle (30 cm-60 cm), and deep (60 cm-120 cm).

Carman (2008)

At Carman (2008) soil nitrate-N concentrations were not significantly affected by tillage regime at seeding or at anthesis (Table 13). The lack of a significant effect at seeding was inconsistent with previous studies that reported increased soil nitrate-N concentrations in the spring following soil-incorporated legumes in comparison to a legume that had not been incorporated (Malhi *et al.* 2007; Mohr *et al.* 1999; Soon *et al.* 2001). The lack of a difference in spring soil nitrate-N concentrations at this site may be the result of nitrate leaching, with more nitrate lost from the tilled systems, since more nitrate-N was present in the tilled system in the previous fall. Campbell *et al.* (1984) found significant amounts of nitrate beyond 120 cm, though nitrate at this depth was not measured in this study. The lack of a significant effect of tillage on soil nitrate concentrations at anthesis, in conjunction with the lack of significant differences in wheat biomass nitrogen (Table 16), suggests there was an equal amount of plant available nitrate in all systems.

The effect of tillage regime on soil nitrate-N became significant at soft dough (Table 13). Total profile soil nitrate-N (0 to 120 cm) was significantly greater in the tilled only system compared to both the no-till and spring tilled no till systems. The spring tillage in the no till system did not change nitrate-N concentrations compared to the no till system. Reducing tillage in half resulted in the same total soil nitrate-N as tilling only. The greater amounts of soil nitrate observed in the tilled only system may be the result of greater mineralization rates in the tilled only system compared to the systems that were only rolled in the year of the green manure. Soon et. al (2001) reported opposite results, observing higher soil nitrate in NT treatments than in CT treatments at the soft dough stage in the top 15 cm of soil. The authors attributed this difference to higher N mineralization during the growing season under NT.

The greater nitrate-N concentrations in the tilled only treatment at soft dough may have implications both for the wheat crop and for potential N loss. While the majority of nitrogen uptake has already occurred by soft dough, wheat can still take up nitrogen at this stage, which can increase biomass and seed nitrogen content (Miralles and Slafer 1999). However, since the majority of uptake has occurred, excess nitrate that is not taken up has the potential to be leached in late fall or the following spring. In fact, some evidence of nitrate leaching is present at the next sampling date, which was in May 2009 (i.e., the spring following the 2008 wheat crop).

In May 2009, following the wheat crop, total soil profile nitrate-N was not affected overall by tillage; however, treatment effects were observed at individual depths (Table 13). The effect of spring tillage in the no-till treatment became significant for the first time at this site. The spring tilled no till system had 28 kg ha^{-1} more ($p<0.05$) nitrate-N than the no till system in the top 60 cm of soil. This observation may be due to several reasons such as higher rates of mineralization from spring tillage, higher rates of immobilization in the no till system, or higher N losses in the no till system to volatilization and denitrification. The spring tilled no till system also had 31 kg ha^{-1} more nitrate-N than the tilled only system in the top 60 cm of soil. The observation may be due to greater leaching loss in the tilled only system. Evidence of leaching appeared to exist in the deep depth (60 -120 cm), where the tilled only treatment had significantly more nitrate-N than both the no till and spring tilled no till systems. These differences were present earlier at soft dough of wheat in the previous year in the 0 – 60 cm depth and appear to have moved down. Reducing tillage in half had a significant effect only in the 30 cm – 60 cm depth, where the rolled twice treatment had 14 kg ha^{-1} more nitrate-N than the tilled only treatment.

The soil nitrate-N concentrations in May 2009 indicate that the spring tilled no till system has more available nitrogen available to a second crop than the other tillage regimes. It appears that replacing tillage with rolling in the year of the green manure can provide the benefit of soil conservation in the year of the green manure as well as nitrogen conservation for the system. On the other hand, the tilled only system appears to have 'run out' of nitrate, probably due to leaching. Reducing tillage in half was essentially the same as only tilling at Carman (2008), indicating that reducing tillage in half resulted in the same availability of nitrogen to crops, as well as the same risk of nitrate leaching. Therefore, the results from Carman (2008) suggest that a significant reduction in tillage was required to significantly alter soil nitrate-N. Furthermore, tillage reduction needed to go beyond halving the tillage frequency in order to achieve nitrogen conservation in the second year following the green manure.

Carman (2009)

Reducing tillage in the year of the green manure significantly reduced total soil nitrate-N at wheat seeding at Carman (2009) (Table 14). It appears that the effects observed in fall 2008 persisted into the spring, with more soil nitrate-N in the tilled only treatment compared to the rolled only system. For example, the no till system had 102 N kg ha^{-1} less total soil nitrate-N compared to the tilled only system and the spring tilled no till system had 95 N kg ha^{-1} less than the tilled only system. Adding a spring tillage in the no till system did not affect nitrate-N. This observation may be due to the soil sampling date being soon after spring tillage, and therefore not enough time elapsed for significant mineralization to occur. Reducing tillage frequency by half was not sufficient to lower soil nitrate-N compared to intensive tillage but was in fact the same as intensive tillage.

The presence of more total soil nitrate-N at seeding in the tilled only system compared to the other systems may translate to more available nitrogen to the crop, but also increases risk of nitrate losses. Until the wheat crop begins developing, excess nitrates and nitrates beyond the rooting system have the potential to be leached (Campbell *et al.* 1994). At Carman (2009) at seeding, the tilled only system had 124 kg ha^{-1} in the 60 cm -120 cm depth, while the no till and the spring tilled no till systems had significantly less nitrate-N (58 kg ha^{-1} and 71 kg ha^{-1}, respectively). These findings suggest that the risk for soil nitrate leaching was higher for the tilled only system because of the significantly larger amounts of nitrate-N found in the 60 cm – 120 cm depth compared to the other systems. There is an indication that leaching may have already occurred between the fall soil measurement and seeding since the significant treatment differences seen in the fall have moved down the soil profile to the bottom depth. Stopes et. al (1996) reported similar findings in the United Kingdom where spring cultivation of red clover reduced the total quantity of nitrate leached to 26 kg ha^{-1} from 102 kg ha^{-1} nitrate leached from autumn cultivation.

The next sampling date was at the soft dough stage at which point soil nitrate-N amounts were the same across all treatments (Table 14). Only one significant treatment difference was observed. This difference occurred in the 30 cm – 60 cm depth where the tilled only treatment had 12 kg ha^{-1} more nitrate-N than the no till treatment. One explanation for this difference is more nitrate was available in the tilled only system compared to the no till system throughout the season, more nitrate than the wheat could take up. The general lack of tillage effect at soft dough may be due to wheat taking up available nitrogen in each treatment leaving the same soil nitrate across the systems. In fact, there is evidence from the wheat biomass nitrogen data that more nitrate was taken up in the systems with more tillage, which could result in the same soil nitrate across all treatments.

Oxbow (2009)

Oxbow (2009) continued to show no significant differences in soil nitrate-N throughout the year of the wheat. This may be a result of several factors. The nitrogen contribution of the pea green manure to the soil may have not been detectable due to the high background soil nitrate. The green manure biomass was only 1447 kg ha^{-1} and the biomass nitrogen was 58 kg ha^{-1}, while the soil nitrate-N at the time of green manure seeding was 320 kg ha^{-1}. There may have in fact been an effect from tillage with more nitrogen mineralized in the tilled treatments; however, the nitrogen uptake by the wheat obscured any significant differences.

4.6.2.2 Wheat Biomass Nitrogen

The primary role of a green manure is to supply subsequent crops with nutrients. Therefore a question of interest in this study was how rolling a green manure affects nitrogen availability and uptake throughout the growing season of a subsequent wheat crop. Wheat biomass nitrogen was measured to determine how much of the nitrogen was taken up by wheat under the different tillage regimes. Biomass nitrogen was measured at three wheat developmental stages: stem elongation, anthesis, and soft dough.

The wheat biomass nitrogen values observed at Carman over the two years (Table 16) were greater than values found in previous studies. For example, at soft dough, biomass nitrogen ranged from 95 - 205 kg N ha^{-1}, while previous studies ranged from 69 to 135 N kg ha^{-1} (Soon *et al.* 2006; Wiens *et al.* 2006). At Oxbow, the biomass nitrogen values were within range of previous studies, ranging from 60 to 90 kg N ha^{-1} at soft dough.

At Carman (2008), increasing tillage intensity resulted in increased wheat N uptake at stem elongation (Table 16). The wheat in the no till treatment had significantly less biomass N than all other treatments. The biomass N in the no till treatment was 40 % less than the biomass N in the tilled only treatment, while the spring tilled no-till treatment was only 13% less than the tilled only treatment. These observations suggest that spring tillage most likely stimulated nitrogen mineralization, resulting in more nitrogen availability and uptake. Reducing tillage in half did not result in a significant difference in biomass N at stem elongation compared to only tilling. While reducing tillage in half may be expected to decrease nitrogen availability because of potentially less mineralization, the rolled twice treatment may have the same N uptake as only tilling because of a reduction in the amount of nitrogen losses due to volatilization and denitrification associated with no till.

Table 16. The effect of tillage on wheat biomass nitrogen uptake at stem elongation, anthesis, and soft dough at Carman in 2008 and 2009, and at Oxbow in 2009.

	Carman						Oxbow		
	2008			2009			2009		
Treatment	stem elongation	anthesis	soft dough	stem elongation	anthesis	soft dough	stem elongation	anthesis	soft dough
	N kg ha^{-1}								
1 - Rolled only (no-till)	66 **d**^{Y}	105	162	23 **c**	51 **c**	95	27	42 **c**	60 **b**
2 - Spring tilled no-till	92 **c**	115	161	25 **c**	72 **bc**	111	30	49 **bc**	63 **b**
3 - Rolled three times	93 **bc**	116	177	32 **bc**	64 **bc**	n/a	32	n/a	n/a
4 - Rolled two times	106 **ab**	122	174	46 **a**	91 **ab**	137	40	64 **ab**	79 **ab**
5 - Rolled once	110 **a**	135	170	42 **ab**	92 **ab**	n/a	38	n/a	n/a
6 - Tilled only	106 **abc**	129	205	42 **ab**	112 **a**	155	46	72 **a**	91 **a**
P > F	0.0001	0.4850	0.6406	0.0037	0.0167	0.2751	0.0719	0.0409	0.0184
Contrasts	*P > F*								
Trt 1 vs. Trt 6	**<0.0001**	0.1448	0.1387	**0.0048**	**0.0015**	0.0828	**0.0091**	**0.0107**	**0.0054**
Trt 1 vs. Trt 2	**0.0012**	0.5220	0.9628	0.7926	0.2027	0.6237	0.6649	0.4280	0.7163
Trt 2 vs. Trt 6	0.0511	0.3691	0.1279	**0.0100**	**0.0221**	0.1827	**0.0221**	**0.0414**	**0.0098**
Trt 4 vs. Trt 6	0.9895	0.6497	0.2657	0.4921	0.2079	0.5767	0.3886	0.4127	0.1753

^{Y} Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

n/a = not analyzed.

No further significant differences in N uptake were observed at anthesis or soft dough at Carman (2008). The lack of a significant difference in biomass N and soil nitrate-N at anthesis suggests that treatment effects have ceased to occur. Blackshaw et. al (2010) also reported equal spring wheat N concentrations following sweet clover that had been either mowed, disked, or plowed. The loss in tillage treatment effects over time may be due to equal availability of soil nitrate across all treatments. While at stem elongation it appeared more nitrate was available under the systems with more tillage, with time, more nitrogen may have been mineralized from the systems with less tillage. The significant differences in soil nitrate-N observed at soft dough did not appear to affect biomass N, potentially because the majority of plant nitrogen uptake had already occurred.

The results from Carman (2008) suggest that one can choose to reduce/eliminate tillage and still maintain comparable N uptake as the usual practice of tillage, thereby maintaining comparable yield potential. An added advantage to eliminating tillage at Carman (2008) appears to be better synchrony between N availability and N uptake. All the systems had the same N uptake for two thirds of the season, yet at the soft dough sampling date there was significantly more total soil N in the tilled only system i.e. N became available in the tilled only system when the wheat was mostly finished taking up N. The extra N in the system is susceptible to loss via denitrification, volatilization, and leaching.

At Carman (2009), replacing tillage with rolling in the year of the green manure resulted in significantly less wheat nitrogen uptake at stem elongation (Table 16). Wheat in the no till system had 45% less biomass nitrogen than the tilled only system. Spring tillage in the no till system did not significantly affect biomass nitrogen compared to the no till system, and had 41% less biomass nitrogen than the tilled only system. Reducing tillage in half resulted in the same nitrogen uptake as only tilling. Reducing tillage to just one tillage operation before fall also resulted in the same nitrogen uptake as only tilling. It appeared that as tillage frequency increased more nitrogen became available, possibly due to more mineralized N from tillage and/or greater N volatilization in the systems with less tillage. The soil nitrate test from seeding at Carman (2009) showed a trend similar to biomass N at stem elongation, with significantly more nitrate-N in the tilled only system compared to both the no till and spring tilled no till system, and the rolled twice system had the same soil nitrate-N as the tilled only.

A similar biomass N trend was observed at anthesis. However, the difference between biomass N in the no till system and tilled only system became larger – the wheat in the no till system had 55% less biomass N than the wheat in the tilled only system. Conversely, the difference between the spring tilled no till system and the tilled only system became smaller – the wheat in the spring tilled no till system had 35% less biomass N than the wheat in the tilled only system. This trend suggests that a significant amount of nitrogen was liberated between stem elongation and anthesis as a result of spring tillage. In fact, the wheat in spring tilled no till system had the same biomass N as the wheat in the system that was rolled only once in the year of the green manure. Once again, reducing tillage in half resulted in the same wheat biomass N as tilling only.

By soft dough, all the systems had the same wheat biomass nitrogen. Similar N uptake at soft dough may be attributed to more nitrate mineralized in the no till and spring tilled no till systems. Soon *et. al* (2001) also observed more soil N becoming available later in the growing season following no till management of sweet clover compared with conventional till. However, the authors had opposite results from the present study observing N uptake of wheat was 1.3 times greater with no till compared with CT at maturity.

While total nitrogen uptake was the same at soft dough, the differences that occurred earlier in the season have implications for grain yield, since the more nitrogen is accumulated, the more can be translocated to the grain, and translocation starts immediately after anthesis (Fageria and Baligar 2005). Therefore, the slower mineralization observed in the no till treatments at Carman (2009) would be expected to reduce grain yield potential.

From field observations, weeds appeared to account for more than 10% of total plant biomass in several plots. There was a concern that the weed competition in these plots would result in substantial amounts of N uptake by the weeds such that it would affect wheat N uptake. Therefore, at soft dough, weeds were sorted from the wheat crop sample and analyzed separately for biomass N. Results showed that neither weed biomass nor weed biomass nitrogen were significantly affected by tillage regime (Table 17). Therefore, weeds did not appear to affect treatment differences in wheat N uptake in this study. Previous studies have shown that weeds can significantly impact crop yield in organic no till systems (Berner *et al.* 2008; Drinkwater *et al.* 2000; Peigne *et al.* 2007). For example, Drinkwater *et al.* (2000) found that maize biomass in organic management was significantly reduced under no till management in comparison with conventional tillage. The total above ground plant biomass was dominated by weeds at the end of the growing season, resulting in 6010 kg ha^{-1} weed biomass and 3320 kg ha^{-1} maize biomass. In the present study, weed biomass never exceeded 1143 kg ha^{-1}.

Table 17. The effect of tillage regime on wheat and weed biomass and biomass nitrogen at the soft dough stage of wheat at Carman 2009.

	Biomass				Biomass Nitrogen			
Treatment	Wheat	Weed	Total ^{V}	Weed percent of	Wheat	Weed	Total ^{X}	Weed percent of
	-------------- kg ha^{-1} ----------------			------- % -------	------------- N kg ha^{-1} ------------			------- % -------
1 - Rolled only (no-till)	6561 **c** ^{z}	1002	7562 **c**	13	95	14	109	13
2 - Spring tilled no-till	7946 **bc**	1143	9089 **bc**	14	111	17	127	14
3 - Rolled three times	8505 **abc**	478	8984 **abc**	6	n/a	n/a	n/a	n/a
4 - Rolled two times	10053 **a**	919	10972 **a**	9	137	12	148	9
5 - Rolled once	9431 **ab**	974	10406 **ab**	10	n/a	n/a	n/a	n/a
6 - Tilled only	9899 **ab**	811	10710 **ab**	8	155	9	163	6
P > F	0.0191	0.6201	0.0349	0.3750	0.2751	0.6689	0.4468	0.2626
Contrasts	------------------------------				*P > F* ------------------------------			
Trt 1 vs. Trt 6	**0.0035**	0.6235	**0.0079**	0.2092	0.0828	0.4228	0.1440	0.1279
Trt 1 vs. Trt 2	0.1718	0.7151	0.1577	0.8849	0.6237	0.6704	0.5978	0.8569
Trt 2 vs. Trt 6	0.0613	0.3963	0.1354	0.1651	0.1827	0.2327	0.3196	0.0955
Trt 4 vs. Trt 6	0.8761	0.7800	0.8026	0.7865	0.5767	0.6704	0.6743	0.5106

^{V}Total was calculated by adding wheat biomass and weed biomass.

^{W}weed percent of total was calculated by divding weed biomass by total biomass.

^{X} Total was calculated by adding wheat biomass nitrogen and weed biomass nitrogen.

^{Y}Weed percent of total was calculated by dividing weed biomass by total biomass.

^{Z}Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

n/a = not analyzed.

At Oxbow (2009), tillage regime affected wheat nitrogen uptake for the entire season (Table 16). Contrast analysis revealed that the treatment effects were the consistent for the entire season. First, biomass N was significantly greater in the tilled only treatment compared to both the no till and the spring tilled no till treatments. Second, there was no significant difference between the no till and the spring tilled no till systems. And finally, there was no difference between the rolled twice and tilled only treatments. These observations indicated that replacing tillage entirely with rolling resulted in significantly less wheat nitrogen uptake from the beginning of the growing season until the end, ultimately resulting in 34% less wheat biomass N in the no till treatment compared to the tilled only treatment. Unlike Carman (2008) and (2009), the no till and spring tilled no till systems did not catch up to the rolled twice and tilled only systems, suggesting that tillage regime strongly affected nitrogen availability for the entire season .

At Oxbow (2009), soil nitrate -N was not affected by tillage regime at any sampling date (Table 15), while wheat N uptake was affected by tillage regime for the entire season. The results for wheat biomass N suggest that more N was indeed available in tilled systems; however, it was not reflected in the soil tests because the available nitrogen was taken up by the wheat. Drinkwater *et al.* (2000) observed the same phenomenon where soil mineral N was the same following cultivated hairy vetch (CT) and mowed hairy vetch (NT), but at maturity, corn N uptake was three to five times higher in the cultivated in CT system than the NT treatments.

4.6.2.3 Grain Protein

Grain protein concentration is an important measure of wheat economic performance. The Canadian Wheat Board creates price spreads according to the value of protein in a particular year, with farmers receiving more income for higher protein.

At Carman (2008), grain protein tended to increase with increasing tillage frequency (Table 18). Replacing tillage completely with rolling significantly reduced wheat grain protein by 1.1% protein. The spring tillage in the no till treatment did not significantly affect grain protein compared to the no till treatment, and was significantly less than the tilled only system by 0.8% protein. Reducing tillage in half resulted in the same grain protein as tilling only, but decreasing tillage frequency by more than half resulted in a significant decrease in grain protein compared with only tilling.

Previous studies have also shown increased wheat grain protein following incorporated legumes compared to no till managed legumes (Blackshaw *et al.* 2010; Malhi *et al.* 2007; Mohr *et al.* 1999). For example, Blackshaw *et. al* (2010) found significant differences in spring wheat grain protein concentration following sweet clover with varying intensities of tillage. The study reported grain protein concentrations following mowed, disked and plowed sweet clover of 159 g kg^{-1}, 164 g kg^{-1}, and 171 g kg^{-1}, respectively. The authors attributed the greater grain protein in wheat following incorporated legumes to the greater amount of soil nitrogen available due to greater mineralization rates. In the present study, the differences in grain protein between treatments were most likely attributable to different nitrogen availability between the tillage regimes. This is evidenced at stem elongation where increasing tillage resulted in increased biomass nitrogen (Table 16). Nutrient availability at early developmental stages is positively correlated with wheat grain protein content (Malhi *et al.* 2006). Furthermore, at the soft dough stage there was more soil nitrate-N in the tilled treatments, potentially contributing to more grain protein in this system. While nitrogen remobilization is considered the most important source of grain N, seed nitrogen originates from both the remobilization of vegetative tissue nitrogen and from soil nitrogen uptake during grain fill (Miralles and Slafer 1999).

The results from Carman (2008) indicate that there is a tradeoff between completely eliminating tillage and grain protein. However, it was interesting to note that all the ‘reduced tillage’ treatments (i.e., spring tilled no till, rolled thrice, rolled twice and rolled once) had the same grain protein, suggesting that if one is interested in reducing tillage there are several options. Specifically, to maximize the soil conservation benefits of ground cover, one can wait until the spring to till without detrimental effects to grain protein content. Furthermore, tillage can be reduced by half and still maintain the same grain protein as only tilling. Therefore, some soil conservation benefits can be achieved while maintaining the same grain protein as only tilling.

At Carman (2009), tillage regime did not affect grain protein content (Table 18)The absence of a tillage effect was unexpected since the wheat nitrogen uptake trend observed at stem elongation and anthesis indicated increased nitrogen uptake with increasing tillage frequency (Table 16). One possible explanation for the lack of tillage effect is that the increased nitrogen uptake observed with increasing tillage resulted in higher grain yield but resulted in protein dilution. Another possible explanation is more soil nitrogen was mineralized after anthesis in the no-till and the reduced tillage systems, resulting in increased wheat nitrogen uptake. Therefore, the lack of tillage regime effect on grain protein may be due to the timing of N availability throughout the season.

The results from Oxbow (2009) also indicate that there is a tradeoff between reducing tillage and maintaining a high concentration of grain protein (Table 18). The tilled only system had the highest grain protein percentage of all treatments. Reducing tillage in half reduced grain protein by 1.0% compared to the tilled only system. The spring tilled no till system had the lowest protein, and was significantly lower than the no till system by 0.9% protein and lower than the tilled only system by 2.0% protein. The differences in grain protein between treatments were most likely attributable to the different nitrogen availability between the tillage regimes. This was evidenced at all sampling dates throughout the growing season where increased tillage frequency resulted in increased biomass nitrogen, which was the general trend observed for grain protein. However, weed competition may have also played a significant role at Oxbow (2009). The comparatively lower grain protein concentrations observed in the spring tilled no till system and rolled once system may be attributed to the high weed pressure in these treatments (Table 10). The weeds in those treatments may have robbed the wheat crop of soil moisture.

In the present study, the effect of tillage on grain protein varied between site years. This is because grain protein concentration is dependent on growing season conditions including weather conditions, nitrogen availability and water availability (Campbell *et al.* 1997; Soon *et al.* 2006). On average, the grain protein content at Carman (2009) was less than Carman (2008) potentially due to a cooler, wetter year (Table 1) that would result in less mineralization and more nitrate leaching.

Table 18. The effect of tillage regime on wheat yield and wheat grain protein at Carman in 2008 and 2009, and Oxbow 2009.

	Carman				Oxbow	
	2008		2009		2009	
	Yield	Grain protein	Yield	Grain protein	Yield	Grain protein
Treatment	---kg ha^{-1}---	--- % ---	---kg ha^{-1}---	--- % ---	---kg ha^{-1}---	--- % ---
1 - Rolled only (no-till)	3816	14.7 **c**[Y]	3096 **c**	14.2	1843	14 **b**
2 - Spring tilled no-till	4216	15 **bc**	3877 **bc**	14.7	1892	13.1 **c**
3 - Rolled three times	3463	15.1 **bc**	3900 **abc**	13.6	1969	13.6 **bc**
4 - Rolled two times	3782	15.4 **ab**	4606 **ab**	14.1	1944	14.1 **b**
5 - Rolled once	3396	15.4 **ab**	4229 **ab**	13.8	2064	13.8 **b**
6 - Tilled only	3553	15.8 **a**	4931 **a**	14.8	2364	15.1 **a**
P > F	0.6306	0.0419	0.0336	0.3600	0.1843	0.0012
Contrasts	-- *P > F* --					
Trt 1 vs. Trt 6	0.6127	**0.0027**	**0.0023**	0.5035	**0.0202**	**0.0066**
Trt 1 vs. Trt 2	0.4454	0.3498	0.1400	0.8223	0.8097	**0.0197**
Trt 2 vs. Trt 6	0.2130	**0.0192**	0.0527	0.6542	**0.0328**	**<0.0001**
Trt 4 vs. Trt 6	0.6590	0.2137	0.5262	0.2887	0.0538	0.0120

[Y] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

4.6.2.4 Nitrogen Availability Indices

Two different indices were used to assess effects of tillage regime on N supply: 1) available nitrogen and 2) nitrogen use efficiency (NUE). In this study, available nitrogen was calculated as the total measured nitrogen at soft dough in the system, i.e. soil nitrate-N at soft dough plus wheat biomass nitrogen at soft dough. Nitrogen use efficiency was calculated as the percentage of wheat biomass nitrogen ‘derived’ from the green manure, i.e. wheat biomass nitrogen at soft dough divided by green manure biomass nitrogen at time of green manure termination.

At Carman (2008), reducing tillage resulted in less available nitrogen (Table 19). Completely eliminating tillage resulted in half as much available nitrogen compared with only tilling. This large difference may be due to higher mineralization rates of both the incorporated green manure and indigenous soil organic matter from repeated tillage. Furthermore, there may be less available nitrogen in the no till treatment due to volatilization, denitrification, and immobilization. The spring tillage in the no till system did not significantly affect available nitrogen compared with the no till system, indicating that a single tillage operation in the spring did not significantly alter available nitrogen. It is interesting to note that while not statistically significant ($p>0.0821$), the spring tilled no till system had 40% less available nitrogen than the tilled only system, suggesting that indeed some nitrogen was mineralized by the single event, but not a substantial amount. Reducing tillage in half significantly reduced available nitrogen by 45% compared with the tilled only system. Once again, this large difference was attributed to higher mineralization rates in the tilled only system. Furthermore, the rolled twice treatment may have lost nitrogen to volatilization after each of the two rolling events.

At Carman (2009), the only significant difference observed in available nitrogen was between the no till and tilled only treatments (Table 19). Replacing tillage entirely with rolling resulted in 38% less available nitrogen. One potential reason that no other significant differences were observed at Carman (2009) was because of the cool weather. The cool, wet weather may have resulted in less mineralization in the tilled only system, resulting in less pronounced differences between the systems (i.e. 50% at 2008 and 38% in 2009).

Nitrogen use efficiency was not significantly affected by tillage regime at Carman (2009). The NUE for the no till system was below 100% suggesting that some green manure nitrogen was either immobilized or lost due to volatilization or denitrification. The NUE for the tilled only system was over 100% suggesting that indigenous soil nitrogen was mineralized and taken up by the wheat. This observation may indicate that the tilled only system may be less sustainable than a system with an NUE below 100%, because indigenous nitrogen is being utilized and potentially not replenished.

At Oxbow (2009), tillage regime did not affect total available nitrogen but did significantly affect NUE (Table 19). All the systems had NUE values that were over 100% suggesting that all the systems had indigenous nitrogen mineralized. Replacing tillage with rolling resulted in 55% lower NUE than tilling only. Once again, the reason for this observation is probably attributable to higher mineralization rates from repeated tillage and less available nitrogen in the no till treatment due to volatilization, denitrification, and immobilization. The spring tillage in the no till system did not significantly increase NUE compared with the no till system. The spring tilled no till system had a 49% lower NUE than the tilled only system. Reducing tillage by half resulted in the same NUE as tilling only, suggesting that similar amounts of nitrogen were mineralized under the two tillage regimes.

While not always statistically significant, the trend across all three site years was that increased tillage resulted in an increase in both available nitrogen and NUE. These findings suggest that no-till and reduced till management of the green manure reduced short term plant available nitrogen at all three site years. This phenomenon is consistent with past studies. For example, Mohr *et al.* (1999) also observed higher available nitrogen in wheat following tillage-terminated alfalfa, compared to herbicide-terminated alfalfa. Drinkwater *et al.* (2000) reported that nitrogen captured in the aboveground biomass of maize following tillage terminated hairy vetch was significantly greater than the nitrogen content of vetch at the time of incorporation. The nitrogen content of maize following NT and reduced till hairy vetch was significantly lower than the nitrogen content of the hairy vetch at termination. The authors attributed these observations to significant mineralization of nitrogen from soil organic matter under conventional tillage. On the other hand, the mineralization of the hairy vetch under the no-till treatments was reduced, resulting in less nitrogen capture by the maize. Evidence in the present study for lower mineralization rates under NT was seen in soil nitrate tests in the fall of the green manure. Lower nitrate-N concentrations were observed in no till and rolled twice systems at both Carman (2008) (Table 13) and Carman (2009) (Table 14). Decreased mineralization rates and nitrogen availability were also deduced from the general trend of lower wheat N uptake in the no-till and reduced till systems observed across all three site years throughout the growing season (Table 16).

Sarrantonio and Scott (1988) also reported that corn following NT-vetch contained 29% of the original N contained in the aboveground hairy vetch tissue, and 55% following CT hairy vetch. The authors concluded that the overall net accumulation of mineralized N from vetch was less in the NT system compared to the CT system. Once again, the authors attributed this conclusion to less mineralization rates under NT. The authors also suggest that the lower nitrate under NT may be a result of immobilization of nitrogen under NT and the loss of nitrogen under NT due to leaching, volatilization, and denitrification. The lower soil and plant nitrogen observed under NT and reduced till in the present study not only indicate decreased mineralization, but may also indicate some losses due to denitrification, volatilization and immobilization. Immobilization of N would represent a short term loss, and may result in N release in subsequent seasons. In fact, there is some evidence of that occurring in the spring following the wheat at Carman (2008). The soil nitrate-N concentrations were significantly greater in the spring tilled no till system and the rolled three times system compared to all the other systems (Table 13). On the question of volatilization, nitrogen loss through ammonia was measured for this study and there was in fact significantly more ammonia lost from the rolled only system compared to the tilled only system (Figure 3 and Figure 4).

Table 19. The effect of tillage regime on total nitrogen and nitrogen use efficiency at the soft dough stage of the wheat at Carman in 2008 and 2009, and Oxbow 2009.

	Carman			Oxbow	
	2008	2009		2009	
	Total N ^{W}	Total N	NUE ^{Y}	Total N	NUE
Treatment	---kg ha^{-1}---	---kg ha^{-1}---	--- % ---	---kg ha^{-1}---	--- % ---
1 - Rolled only (no-till)	183	178	69	256	103 **b** ^{Z}
2 - Spring tilled no-till	223	212	80	256	109 **b**
3 - Rolled three times	219	n/a	n/a	n/a	n/a
4 - Rolled two times	200	242	99	359	136 **ab**
5 - Rolled once	213	n/a	n/a	n/a	n/a
6 - Tilled only	366	288	112	352	158 **a**
P > F	0.1737	0.1853	0.2794	0.1459	0.0191
Contrasts	---------- *P > F* ----------				
Trt 1 vs. Trt 6	**0.0289**	**0.0428**	0.0842	0.1066	**0.0055**
Trt 1 vs. Trt 2	0.4316	0.4785	0.6246	0.9928	0.6978
Trt 2 vs. Trt 6	0.0821	0.1403	0.1854	0.1050	**0.0104**
Trt 4 vs. Trt 6	**0.0405**	0.1403	0.5785	0.9096	0.1756

[W] Total nitrogen was calculated by adding total soil nitrogen (0-120 cm) and wheat biomass nitrogen at soft dough. See Table _ and Table _ .

[Y] NUE = nitrogen use efficiency calculated by dividing wheat biomass nitrogen at soft dough (Table _) and green manure biomass at termination (Table _) .

[Z] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

n/a = not analyzed.

4.7 Wheat Grain Yield

A main objective of this study was to determine if rolling can replace tillage in organic green manure management. Seed yield is an important measurement for ultimately determining the economic viability of using the blade roller approach. It is also an important measurement for the final development stage of wheat.

Tillage regime had no significant effect on wheat grain yield at Carman (2008) (Table 18). Conversely, previous studies have shown that reducing tillage can increase wheat yield due to moisture conservation (Larney *et al.* 1994) or decrease wheat yield due to lack of nitrogen availability (Berner *et al.* 2008; Blackshaw *et al.* 2010). In the present study, it appears that the tillage regime effects that were observed early in the season did not affect yield. For example, at the four leaf stage, the no till treatment was significantly delayed compared to other treatments, and the tilled only treatment was developmentally ahead (Table 6). These differences continued until stem elongation where the no till treatment had significantly less biomass than all the other treatments (Table 16). Also at stem elongation, nitrogen uptake significantly increased with increasing tillage intensity. The lack of tillage effect on yield may be related to nitrogen availability. More nitrogen was potentially lost from the tilled only system or more N became available later in the growing season for the no till system, generating equal amounts of available nitrogen across all treatments at maturity. Another reason for the lack of treatment effect was low weed pressure across all plots and equal moisture availability across all treatments (contrast analysis did show that that spring tilled no till system had more moisture than the tilled only system at seeding; however, this difference was driven by the 70-90 cm depth, which would not have affected wheat growth that early in the season) (Table 7 and Table 8).

At Carman (2008), frequency of tillage therefore did not affect grain yield and tillage could in fact be completely eliminated without affecting yield. These findings suggest that farmers can eliminate tillage without a detriment to their yield.

At Carman (2009), grain yield tended to increase with increasing tillage frequency (Table 18). The yield in the no till treatment was only 63% of the yield in the tilled only treatment. The spring tillage in the no till treatment did not significantly affect yield compared to the no till treatment. Reducing tillage in half resulted in the same grain yield as tilling only, but decreasing tillage frequency by more than half resulted in a significant decrease in grain protein compared with only tilling. Previous studies have also shown higher wheat yield following incorporated green manures compared wheat yield following no till/reduced tillage green manures. For example, Blackshaw *et al.* (2010) reported higher spring wheat yields following disked and plowed sweet clover compared to mowed sweet clover. Berner *et al.* (2008) working in Switzerland found that under an organic reduced tillage system, the grain yield of winter wheat was 14% lower than under conventional tillage. The authors attributed this difference to lack of synchrony of N availability in the reduced tillage system.

In the present study, it appears that early season weather and N availability may be the reason for the observed yield differences. Early in the season, at the four leaf stage, the wheat in the no till treatment was significantly delayed compared to all the other treatments (Table 6). The delay in wheat development appears to have continued for the remainder of the season as the wheat biomass in the no till system was consistently lower compared to the tilled only system (Table 16). The cooler weather in the summer of 2009 at Carman (Table 1) may have resulted in an extension of this delay. In addition, wheat nitrogen uptake also increased with increasing tillage frequency at stem elongation and anthesis. While there was no treatment effect at soft dough, translocation of assimilates was already taking place and the availability of soil nitrate had already affected yield. Grain yield therefore appears to be strongly affected by the availability of nitrogen through the growing season. Weed pressure and moisture do not appear to have played a significant role in grain yield at Carman (2009). The weed count at the beginning of the season was similar across all treatments (Table 9) and weed biomass and nitrogen uptake were deemed to have no affect on wheat biomass and wheat nitrogen uptake at soft dough (Table 17).

The results from Carman (2009) suggest that there is a tradeoff between tillage reduction and grain yield. Completely eliminating tillage resulted in a major reduction in yield. However, it was interesting to note that all the ‘reduced tillage’ treatments (i.e., spring tilled no till, rolled thrice, rolled twice and rolled once) had the same grain yield, suggesting that if one is interested in reducing tillage there are several options.

Specifically, to maximize the soil conservation benefits of ground cover, one can wait until the spring to till without being detrimental to grain yield. Another interesting observation at Carman (2009) was that one could roll the green manure up to 3 times and still maintain the same yields as the traditional practice of only tilling, suggesting that as long as one tills the green manure at least once in the year of the green manure at the end of the season, the same yield as tilling only can be achieved. This may be related to nitrogen availability resulting from mineralization of the incorporated green manure, or mineralization of soil N, or both.

At Oxbow (2009) tillage regime had a significant effect on grain yield (Table 18). The no till treatment was 78% of the yield in the tilled only treatment. The spring tillage in the no till treatment did not significantly affect yield compared to the no till treatment, and was 80% of the yield in tilled only system. These observations for grain yield were consistent with wheat biomass and wheat biomass nitrogen trends throughout the growing season, suggesting that the yield differences were related to the different nitrogen availability between the systems. However, one difference to note is that the wheat biomass and nitrogen trend for the season indicated that reducing tillage in half was the same as only tilling, while the grain yield in the rolled twice treatment was 80% of the tilled only treatment. This observation may be due to weed competition as there was significantly more weeds in the rolled twice system compared to the tilled only system (Table 10), resulting in lower yields in the spring tilled no till system and the rolled twice system.

The effect of tillage regime on wheat yield varied between site years. Previous studies have also shown varied effects of tillage on yield. Some have shown that tillage has no affect on yield (Mohr *et al.* 1999), while other studies have shown reduced yield in reduced tillage systems (Berner *et al.* 2008; Blackshaw *et al.* 2010). On the Canadian prairies, previous studies have often shown no till stubble management to be beneficial for wheat yield due to moisture conservation (Lafond *et al.* 2006). The benefits are most pronounced during years of inadequate precipitation, as adequate rainfall results in minimal differences between yields under no till, reduced tillage, and conventional tillage. In the present study, reducing tillage resulted in reduced yields in two site years, and had no effect in one site year. It appears that the effect of tillage regime on wheat yields was influenced by the site year. Soon *et al.* (2006), assessed the relative effects of growing season conditions, nitrogen fertilization, and tillage system on spring wheat yields. The authors concluded that growing season conditions had the strongest influence on available soil N, wheat N uptake, and yield of spring wheat. Carman (2009) and Oxbow (2009) were both cooler compared to Carman (2008) (Table 1) resulting in delayed wheat development in the no till wheat at Carman (2009) and potentially contributing to delayed nitrogen mineralization in the no-till and reduced tillage systems at both Carman (2009) and Oxbow (2009). Oxbow is a drier site compared to Carman and it was expected that the Oxbow site would benefit from moisture conservation from the reduced tillage, which would subsequently benefit yield. This was not the case, potentially because there was insufficient mulch for moisture conservation (App Fig 2). Furthermore, the rolled system is different from traditional no-till stubble management due to regrowth of both the green manure and weeds following rolling, resulting in more soil moisture use and loss.

It is interesting to note that spring tillage in the no till system had no significant affect on yield in comparison to the no till system at all three site years. While spring tillage was speculated to stimulate mineralization based on observations from biomass and nitrogen uptake, it did not have an effect on yield.

5. CONCLUSIONS

There were significant agronomic differences between using the blade roller and using the current practice of tillage for green manure termination. The differences varied depending on frequency of tillage, the agronomic measurement, and location.

1) On the question of the effect of frequency of tillage on the system, several conclusions were drawn. Firstly, as the frequency of tillage increased, the availability of nitrogen tended to increase as well. This was evidenced by wheat N uptake and soil nitrate-N tests. In the short term, the increased availability is beneficial since increased N availability generally results in increased grain yield and grain protein. However, the increased N availability also represents a higher risk for nitrate loss through leaching. Furthermore, in the long term, the benefit may diminish since there was evidence that indigenous soil N is being mineralized and utilized, which will ultimately be exported in the form of grain from the wheat from the system.

Another conclusion on the effect of frequency of tillage is that grain yield and grain protein tended to decrease with decreasing tillage and increasing rolling frequency. Nonetheless, the grain yield and the grain protein produced in the reduced tillage systems can still be considered profitable. There appears to be some trade off between soil conservation practices and profit.

2) On the question of the difference between only using the blade roller for green manure termination compared with only tilling, it was found that the two systems were frequently significantly different (Table 20). The rolled only system and the tilled only system were two very different systems due to the distinct difference in tillage and ground cover, and as a result the two systems behaved differently. The prevailing trend was that the no till system had less N availability, less yield, and less protein compared with the tilled only system. These findings indicate a trade off between completely eliminating tillage and profit. The benefit of higher grain yield and grain protein in the tilled system must be weighed against the benefits of soil conservation and N conservation in the rolled only system.

3) On the question of whether spring tillage in the no till system significantly affected the no till system, it was found that for the most part, the two systems were not significantly different (Table 20). The spring tillage was expected to stimulate mineralization and liberate a significant amount of nitrogen, but it appears it was rarely enough to make a significant difference compared with the no till system. Since the spring tillage was rarely beneficial, these findings suggest that it is unnecessary to have a tillage operation in spring. This is useful information since the risk of wind erosion is high in the period between seeding in the spring and canopy closure, therefore maintaining a soil cover in this period would be beneficial for soil conservation. It is also interesting to note that the spring tillage appeared to stimulate weed germination at Oxbow, which is suspected to have negatively affected both yield and protein.

4) On the question of how the no till system with spring tillage compared to only tilling the green manure, it was found that the two systems were frequently significantly different (Table 20). The prevailing trend was that the spring tilled no till system had less N availability, less yield, and less protein compared with the tilled only system. However, it was interesting to note that the spring tilled no till system was significantly different from the tilled only system less frequently than the no till system was significantly different from the tilled only system. This observation suggests that the spring tillage in the no till system did have some detectable effects, such as soil warming, stimulating mineralization, and stimulating weed growth.

5) On the question of the effect of reducing tillage in half in comparison with only using tillage to terminate a green manure, it was found that on the most part, the two systems were not significantly different (Table 20). Therefore, tillage can be reduced by half and maintain comparable nitrogen availability, grain yield and grain protein to the current practice of only tilling. A reduction in tillage by half means energy savings for the farmer and that the soil will be covered for longer than if the green manure is only tilled. In the case of this study, the soil was covered until September.

Table 20. Summary of contrasts for measurements taken in the year of the spring wheat at Carman in 2008 and 2009, and Oxbow 2009.

Contrast	wheat Count	Haun stage	Moisture	Total weed count	Wheat Biomass			Grain Yield	Total Soil Nitrogen					Wheat Biomass			Grain Protein	Nitrogen Index	
					SE	ANT	SD		Fall	SPR	ANT	SD	SPR'	SE	ANT	SD		Total N	NUE
Carman 2008																			
1 vs. 6	NS	1<6	NS	1<6	1<6	NS	NS	NS	NS	NS	NS	1<6	NS	1<6	NS	NS	1<6	1<6	-
1 vs. 2	NS	1<2	NS	NS	1<2	NS	NS	NS	-	NS	NS	NS	NS	1<2	NS	NS	NS	NS	-
2 vs. 6	NS	NS	2>6	NS	NS	NS	NS	NS	-	NS	NS	2<6	NS	2<6	NS	NS	2<6	NS	-
4 vs. 6	NS	4<6	NS	NS	NS	NS	NS	NS	-	NS	NS	NS	NS	NS	NS	NS	NS	4<6	-
Carman 2009																			
1 vs. 6	NS	1<6	NS	NS	1<6	1<6	1<6	1<6	1<6	1<6	-	NS	-	1<6	1<6	NS	NS	1<6	NS
1 vs. 2	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	-	NS	-	NS	NS	NS	NS	NS	NS
2 vs. 6	NS	NS	NS	NS	2<6	NS	NS	2<6	2<6	2<6	-	NS	-	2<6	2<6	NS	NS	NS	NS
4 vs. 6	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	-	NS	NS	NS	NS	NS	NS
Oxbow 2009																			
1 vs. 6	1<6	NS	NS	NS	1<6	1<6	1<6	1<6	NS	NS	-	NS	-	1<6	1<6	1<6	1<6	NS	1<6
1 vs. 2	NS	NS	NS	1<2	NS	NS	NS	NS	-	NS	-	NS	-	NS	NS	NS	1>2	NS	NS
2 vs. 6	NS	NS	NS	2<6	2<6	2<6	2<6	2<6	NS	NS	-	NS	-	2<6	2<6	2<6	2<6	NS	2<6
4 vs. 6	NS	NS	NS	4<6	NS	NS	NS	4<6	NS	NS	-	NS	-	NS	NS	NS	4<6	NS	NS

SE = stem elongation
ANT= anthesis
SD= soft dough
SPR = spring (wheat seeding)
SPR^{1} = spring (following spring wheat)
- not analyzed

6. GENERAL DISCUSSION

The objective of this study was to investigate the effects of using the blade roller for no-till/reduced tillage in comparison with using only tillage for the management of a green manure in an organic system. The findings of this study show that the blade roller is a viable alternative to tillage for organic no till green manure management on the Canadian Prairies. The adoption of the blade roller can provide the benefits of both soil conservation and agronomic profitability. In addition, the blade roller requires less energy than the conventional practice of tillage, which can translate into substantial savings for a farmer. However, simply replacing tillage with rolling will not necessarily have beneficial outcomes. Use of the blade roller must be coupled with other management decisions such as choosing an appropriate green manure, terminating the green manure at on optimal time, determining how many times to roll and deciding when tillage must in fact be used. Therefore, the blade roller must be integrated into a holistic approach to organic farming. The blade roller also has the potential to be integrated into non-organic farming. With the unstable costs of energy, synthetic fertilizers, and herbicides, conventional farmers can turn to cover crops and use the blade roller for its management.

Previous studies on tillage reduction in organic systems have cited weed infestations as a major challenge for the implementation of organic no till/reduced tillage system. In the present study, weeds did not play a significant role at Carman, but did at Oxbow. The reason for the lack of weed impact may be due to relatively low pre-existing weed populations at Carman compared with Oxbow. Furthermore, the lack of effect at Carman may be due to the short term duration of this study. From field observations, there did appear to be more perennials in the no till systems. While few in numbers during this study, in the long term, these perennials can ultimately pose a serious threat to cash crop yield. Some solutions to this problem would be to use other management techniques in conjunction with the roller, such as grazing, thistle clipper, spot tillage, use of allelopathic crops, competitive rotations, competitive varieties, higher seeding rates, closer row spacing, and flaming.

The findings of this study show that an organic no till system can be viable on the prairies. However, due to the short duration of this study it is difficult to predict the long term success of an organic no till system. With time, more challenges will arise and become significant such as weed control, a delay in crop development due to mulch, and increased ammonia emissions from the green manure. The blade roller was developed, and is being successfully used, in tropical and warm temperature regions. Liebman and Mohler (2001) point out that a mulch based system is a more viable in tropical and warm temperature regions than in cool temperate regions because the warm fallow season results in production of more mulch biomass, there is a greater range of cover crops that are winter hardy in warmer regions, and in cooler climates, mulch can lower soil temperatures and delay crop development. Therefore, a truly organic no till system might prove to be challenging to maintain over many growing seasons. While other management options can be used in conjunction with the roller, however, a reality is that tillage operations might be necessary every few years. It is therefore important to view organic no till or reduced tillage on the Canadian prairies as a unique system.

The present study was the first to assess the use of the blade roller on the Canadian Prairies. There are several directions in which future research can proceed. For example, a more detailed investigation of nitrogen dynamics can be conducted. Nitrogen-15 can be used to track the fate of green manure N in the system to determine how much is taken up by wheat, what form it is in the soil, and how much has been lost. Lysimeters can be used to have a better picture of how much nitrate is indeed lost to leaching, since in this study leaching is suspected to have occurred. Another loss that can be investigated in better detail is denitrification. And finally, other studies can measure other forms of N in the system, such as microbial N or ammonium-N.

Another future direction for research can explore the impact of ammonia volatilization from no-till green manures on the environment. The results of this study show that there was significantly more ammonia emissions from the no-till green manures compared with the tilled green manures, but the magnitude and the potential effects on the environment are unclear. Techniques to mitigate the effects of ammonia volatilization can also be investigated, such as tree windbreaks in order to decrease wind (and thereby volatilization) and to potentially absorb ammonia emissions.

Identifying promising green manure species to be rolled would be another option for future research. A key to successful adoption of the blade roller is utilizing a green manure that produces sufficient biomass so that it is competitive with weeds while it is growing and can also create a suppressive mulch after it is rolled. Therefore, legumes that are currently being grown as green manures can be tested with the roller, or novel legumes can be assessed.

Further research can also focus on use of the roller under different climates. In the present study, there were different treatment responses at Carman compared with the drier and cooler Oxbow site. Certain management decisions therefore would differ from location to location. For example, in drier areas, green manures may rob subsequent crops of precious soil water; therefore, timing of termination would important in conserving soil moisture. In wetter areas, no-till management may retain too much moisture; therefore, an alternate option may be to reduce tillage.

And finally a long term organic no till trial should be established to identify how to integrate the blade roller into a successful organic no till system and to identify further challenges.

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7. APPENDIX

Table 1. The effect of tillage regime on wheat biomass at Carman in 2008 and 2009, and Oxbow 2009.

	Carman						Oxbow		
	2008			2009			2009		
Treatment	stem elongation	anthesis	soft dough	stem elongation	anthesis	soft dough	stem elongation	anthesis	soft dough
	kg ha^{-1}								
1 - Rolled only (no-till)	2010 **b**[Y]	4806	10603	658 **c**	3471 **c**	6561 **c**	675	2671 **bc**	4458 **c**
2 - Spring tilled no-till	3067 **a**	5712	11257	750 **c**	4845 **bc**	7946 **bc**	785	3542 **bc**	5071 **bc**
3 - Rolled three times	2901 **a**	5717	11934	1037 **b**	4444 **bc**	8505 **abc**	776	2946 **b**	4532 **c**
4 - Rolled two times	3223 **a**	5354	11193	1367 **a**	5575 **ab**	10053 **a**	996	3904 **ab**	5571 **ab**
5 - Rolled once	3324 **a**	6066	11359	1307 **ab**	6175 **ab**	9431 **ab**	940	3273 **b**	4911 **bc**
6 - Tilled only	3032 **a**	5614	13040	1196 **ab**	5896 **ab**	9899 **ab**	1142	4605 **a**	6281 **a**
P > F	0.0004	0.5576	0.7464	0.0005	0.0202	0.0191	0.0670	0.0142	0.0126
Contrasts	*P > F*								
Trt 1 vs. Trt 6	**0.0004**	0.2471	0.1532	**0.0016**	**0.0050**	**0.0035**	**0.0070**	**0.0012**	**0.0015**
Trt 1 vs. Trt 2	**0.0003**	0.1971	0.6919	0.5191	0.0819	0.1718	0.4734	0.0976	0.2122
Trt 2 vs. Trt 6	0.8800	0.8862	0.2884	**0.0062**	0.1746	0.0613	**0.0308**	**0.0409**	**0.0212**
Trt 4 vs. Trt 6	0.4075	0.7029	0.2720	0.2418	0.6699	0.8761	0.3461	0.1670	0.1518

[Y] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

Table 2. The effect of tillage regime on wheat biomass nitrogen concentration at Carman in 2008 and 2009, and Oxbow 2009.

	Carman						Oxbow		
	2008			2009			2009		
Treatment	stem elongation	anthesis	soft dough	stem elongation	anthesis	soft dough	stem elongation	anthesis	soft dough
	%								
1 - Rolled only (no-till)	3.281 **ab**[Y]	2.160 **abc**	1.523	3.312	1.404 **b**	1.377	4.081 **a**	1.596	1.342 **b**
2 - Spring tilled no-till	3.003 **c**	2.003 **c**	1.442	3.311	1.450 **b**	1.394	3.793 **b**	1.389	1.247 **c**
3 - Rolled three times	3.210 **bc**	2.035 **bc**	1.467	2.993	1.424 **b**	n/a	4.110 **a**	n/a	n/a
4 - Rolled two times	3.318 **ab**	2.280 **a**	1.542	3.345	1.628 **ab**	1.333	4.042 **a**	1.679	1.420 **ab**
5 - Rolled once	3.314 **ab**	2.223 **ab**	1.525	3.191	1.461 **b**	n/a	4.003 **a**	n/a	n/a
6 - Tilled only	3.541 **a**	3.000 **a**	1.5406	3.458	1.894 **a**	1.535	3.987 **a**	1.565	1.471 **a**
P > F	0.0196	0.0445	0.9430	0.3257	0.0154	0.8379	0.0043	0.0849	0.0024
Contrasts	*P > F*								
Trt 1 vs. Trt 6	0.0568	0.1998	0.8887	0.4790	**0.0015**	0.0828	0.1872	0.7613	**0.0134**
Trt 1 vs. Trt 2	**0.0438**	0.1413	0.5201	0.9951	0.2027	0.6237	**0.0007**	0.0656	0.4940
Trt 2 vs. Trt 6	**0.0007**	**0.0111**	0.4357	0.4753	**0.0221**	0.1827	**0.0116**	0.1083	**0.0005**
Trt 4 vs. Trt 6	0.0972	0.8802	0.9920	0.5822	0.2079	0.5767	0.4269	0.2802	0.2498

[Y] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

n/a = not analyzed.

Figure 1. Carman (2008) shortly after spring wheat seeding. The spring tilled no till treatment and rolled only (no till) treatment (top), the rolled twice treatment (middle), and the tilled only treatment (bottom).

Figure 2 Oxbow (2009) on the day of spring wheat seeding. The rolled only (no till) treatment (top left), the spring tilled no till treatment (top right), the rolled twice treatment (bottom left) and the tilled only treatment (bottom right).