The Effect of Black Medic (*Medicago lupulina* cv George) Cover Crop on Nitrogen Supplying Power of Prairie soils

BY

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A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
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Master's Thesis/Practicum Final Report

The undersigned certify that they have read the Master's Thesis/Practicum entitled:

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The Thesis/Practicum Examining Committee certifies that the thesis/practicum (and oral examination if required) is:

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ABSTRACT

Sumithira, Panniruharan, M.Sc., University of Manitoba, October 2007. The Effect of Black Medic (*Medicago lupulina* cv George) Cover Crop on Nitrogen Supplying Power of Prairie Soils. Major Professor; Dr. Martin H. Entz, Department of Plant Science, University of Manitoba.

Black medic (*Medicago lupulina,* cv George), a self-regenerating legume cover crop, was evaluated to quantify its soil nitrogen supply potential using two no-till long-term field experiments in Manitoba (established in 2000) and Saskatchewan (established in 2001) with the rotation of flax (*Linum usitatissimum*)-wheat (*Triticum aestivum*)-oat (*Avena sativa*). The main plot is presence of medic while the subplot is N fertilizer rate; two levels at Winnipeg (with and without fertilizer) and three levels at Indian Head (20%, 60% and 100% N fertilizer). No previous study has been done in a prairie no-till, continuous cropping system to assess the N benefit of black medic.

The first of two experiments was a field study conducted in 2006, to determine the effect of medic on soil NO_3^--N and on crop N content, biomass accumulation, N uptake and grain yield. The second study tested the N supply potential of surface soil (0-15 cm) from the field experiments in 2005 and 2006 using a bioassay. According to field experiment results, medic little influence was on crop performance and significant on soil NO_3^--N at tillering and maturity stages. Grain yield reduction due to medic was observed at one of three instances. At Indian Head, medic increased total N (plant + soil) available at maturity by 48 kg ha^{-1}. Lack of significant medic effect at Winnipeg was attributed to drought conditions. In the bioassay studies, medic soil from both sites showed a highly significant increase in N supply potential: Winnipeg 33 kg N ha^{-1} and 38 kg N ha^{-1} in 2005 and 2006, respectively and Indian Head 32 kg N ha^{-1} and 48 kg N ha^{-1} in 2005 and 2006, respectively. Unlike in the field experiment, medic soils from both sites showed

equal measure of N supply potential in the bioassay due to no differences in growing condition. Lack of significant interaction between medic and N fertilizer regimes demonstrated the adaptability of the black medic cover crop in cropping systems with different N fertilizer management. The major conclusion of this study is that the black medic significantly increases N-supply potential of soils by 38 kg N ha^{-1} under favorable prairie growing conditions; therefore, farmers could save a portion of N fertilizer cost.

1. INTRODUCTION

The inclusion of a legume cover crop in cereal cropping systems can improve the N availability of the soils and overall productivity of the system, particularly when it is grown outside the main crop production cycle. The legume-based system accumulates organic N over time, whereas the fertilizer-based system without cover crops lost organic N over the same period (Sarrantonio and Gallandt, 2003). The quantity of N fixed by legumes varies between 15 to 390 kg ha^{-1} yr^{-1} depending on the species and prevailing biotic and abiotic conditions (Sheaffer et al., 2002). A portion of this N will be available for subsequent non-legume crops in the rotation system. Alfalfa, clovers, lentil and peas are among the most commonly used legume cover crops in the Prairie region. However, associated annual re-seeding cost with these legumes is a limitation for their use as early or late season cover crops. Farmers may prefer self seeded cover crops for their rotation systems to reduce their seed input cost.

A self-regenerating legume species, black medic (*Medicago lupulina*), has shown promise under a wide range of environmental conditions (Turkington and Cavers, 1979; Moynihan et al., 1996; Bauchan and Scheaffer, 2002). Black medic is a cool-season crop with moderate cold tolerance (Brandsater et al., 2000) suitable for a temperate climate. Two important studies on black medic recruitment characteristics (Braul, 2004) and characteristics of seed dormancy loss (Wilson, 2005) proved its recruitment was satisfactory under Prairie growing conditions.

Previously, the suitability of black medic had been examined for intercropping or fallow replacement (Sims et al., 1985; Alford et al., 2003; Moynihan et al., 1996; Jeranmaya et al., 1998; Stopes et al., 1996; Zhu et al., 1998), forage production (Piper, 1942; De-Haan et al., 1997; James et al., 2003), and for smothering weeds (Sheaffer et al., 2002; De-Haan et al., 1997). From the earlier studies, N contribution of medics under different systems ranged from of 2.1 kg ha^{-1} (Jeranyama et al., 1998) to 80 kg ha^{-1} (Zhu et al., 1998). It was interesting and important to note in a study very similar to the present one, black medic yielded 15.1 kg N ha^{-1} during late autumn in a spring barley-black medic intercropping system in Finland (Känkänen and Ericksson, 2007). Combination of favorable characteristics that suits to prairie region such as wide adaptability for soil and climatic conditions, low growth rate at early stage, self-regeneration, and medium cold tolerance, makes black medic a desirable legume for inter-seeding in this region.

Little is known about N contribution of black medic under environmental and soil conditions in Canada. The overall purpose of the present study was to determine the effect of an understory crop, black medic, on soil N supply potential in different geographic regions and in different N fertilizer regimes. Two long-term cropping system studies with a rotation of flax (*Linum usitatissimum*)-wheat (*Triticum aestivum*)-oat (*Avena sativa*) with and without medic plots were conducted at Indian Head, SK and Winnipeg, MB. These field experiments and additional controlled environment studies (bioassays) using field soils were conducted to address the following specific objectives;

Objective 1: To examine the effect of long-term black medic on soil nitrate-N, tissue N concentration, biomass production, plant N uptake, grain yield and total available N during the growing season in a continuous no-till cropping system.

Objective 3: To understand the performance of black medic in terms of biomass production and plant density under a continuous no-till grain cropping system.

Objective 2: To evaluate the effect of long-term black medic on N availability using a plant bioassay.

2. LITERATURE REVIEW

2.1 Cover crops

The use of cover crop has a long and rich history in agriculture. Cover crops could be considered the backbone of any annual cropping system that seeks to be sustainable. Cover crops are traditionally defined as crops grown to cover the ground to protect the soil from erosion and from loss of plant nutrients through leaching and run off (Reeves, 1994). Additional reasons for growing cover crops include supply of nitrogen and other nutrients to the system, weed suppression, carbon sequestration and integrated pest management. The practice of cover cropping has re-emerged in recent decades in response to growing knowledge of ecological principles, increasing costs of agricultural inputs and the global recognition of serious and widespread soil degradation (Sarrantonio and Gallandt, 2003).

Cover crop may either be tilled into the soil as a "green manure" or used as a living or dead mulch on the soil surface. A cover crop can be any type of plant, but are generally grasses (including cereal grains), legumes, or grass/legume mixtures. Some non-legume broad-leaved plants are also used. Most farmers who use cover crops plant them in the fall and then kill them in the spring before they plant their main crop. The cover crop is then growing when the ground would otherwise be bare. But, some farmers use summer cover crops in rotation with short season vegetables or before fall- planted crops.

2.1.1 Importance in agriculture

Cover crops improve the physical, chemical, and biological quality of soil by covering the soil surface, penetrating the soil, adding organic matter to the soil, and by being involved in the soil nutrient cycle. They can also help in managing insects and disease to some extent. However, no one cover crop can give all these benefits. The inclusion of cover crops in a cropping system may provide multiple benefits towards improving overall soil quality (Doran et al., 1996). Cover crops may increase water infiltration into soil and soil water holding capacity (Reeves, 1994). If incorporated by tillage, cover crops have little impact on soil temperature. In contrast, living cover crops and mulches can significantly alter soil temperature (Dabney et al., 2001). Deep rooted cover crops such as lupin (*Lupinus angustofolius* L.) can also be effective in increasing effective root depth and subsoil water storage capacity (Reeves, 1994).

According to Dabney (1998), cover crops produce more biomass than volunteer vegetation and, therefore, transpire more water, allow more rainfall to infiltrate into the soil, as well as decrease runoff and potential erosion to a greater extent. By slowing wind and water velocities and by maintaining large aggregate size, cover crops greatly reduce wind and water erosion. Cover crops can increase the nutrient use efficiency of farming systems (Delgado, 1998). Besides reducing the loss of nutrients in eroded soil, cover crops can scavenge residual soil nitrate nitrogen after crops have matured, converting scavenged nitrogen into forage protein (Dabney, 1998). In addition to nitrogen from legumes, cover crops help recycle other nutrients such as phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S) and other minor nutrients that are accumulated by cover crops. Mycorrhizal fungal activity is a soil quality factor that has only recently become widely recognized. For example, Arbuscular mycorrhizal fungi form symbiotic relationships with plant roots that can assist with water and nutrient uptake (Galvez et al., 1995). Cover crops sometimes increase inocula of mycorrhizal fungi in soil (Harrier and Watson, 2003).

Cover crops help to increase the diversity of a cropping system through many ways. Organic matter and the roots of growing cover crops stimulate microorganisms, which help suppress disease organisms, and improve soil structure. The cover crops provide pollen, nectar and a physical location for beneficial insects to live while they search for pest insects. Laub and Luna (1992) found killed rye mulch was effective in attracting parasitoids of armyworm (*Pseudaletia unipuncta*) in a subsequent no-tillage corn crop. Also, Hunt (1998) noticed rye mulch suppressed Colarado potato beetle (*Leptinotarsa decemlineata* Say) in no-tillage tomato production.

Weed management is one of the several benefits achieved by including a cover crop into cropping systems. Cover crops can stress weed populations at multiple points: reducing or preventing propagule production, reducing seedling establishment, and minimizing the competitive ability of individual weeds that successfully establish (Gallandt et al., 1999). As some cover crop residues decay, they release phytotoxins that can cause mortality of non-emerged seedlings, an effect known as allelopathy (Sarrantonio and Gallandt, 2003). Chung and Miller (1995) determined that allelochemicals, which are autotoxic as well as inhibitory to other species, are found in various alfalfa parts in differing concentrations and also the degree of toxicity of different alfalfa plant parts can be classified in order of decreasing inhibition as follows: leaf, seed, complete plant mixture, root, flower, and stem. Soil from old alfalfa plants ranked between the complete plant mixture and the root. Also, Putnam (1994) documented that incorporated rye residues release benzoxazolinones which tend to be particularly phytotoxic to small-seeded species. *Brassica* species contain glucosinolate compounds phytotoxic to certain weed species. Incorporated residues of rapeseed (*Brassica napus*

L.), for example, reduced weed densities 73-85% in a subsequent potato crop and also yielded 17-25% more total tuber weight than fallow (Boydston and Hang, 1995). Incorporated crimson clover and hairy vetch reduced establishment of morning-glory (*Ipomea lacunose* L.), and further decreased the biomass of weeds that did establish (White et al., 1989).

Cover crops can impact disease and insect damage by changing soil chemical and physical properties, by releasing exudates and decomposition products that directly affect pathogens, by serving as hosts for competitors, parasites and predators, and by changing above and below ground environmental factors, such as moisture levels and air movement. In addition, cover crops can create mechanical barriers for movement of pests (Pickett and Bugg, 1998). Unfortunately, these same strategies can work against farmers if the cover crop attracts additional pests, or acts as an alternate host for pathogens and insects pests in the field. Cover crop impact on pathogen control can be explained by a few of following examples. Candole and Rothrock (1997) reported that a significant decrease in black rot (*Thieloviopsis basicola*) in cotton following hairy vetch incorporation was attributed to the fumigant action of ammonia release from decomposing vetch residues in the soil. Stark (1995) noticed that *Verticillium* of potato was reduced by 24-29% following sorghum-sudan grass. Hoyt and Walgenbach (1995) observed in a field trial that resulted in lower incidence of the fungus *Alternaria brassicae* in no-tillage cabbage (*Brassica oleraceae var. capitata*) production with a legume cover crop versus in a similar system with chemical fertilizer and no cover.

In some cases, the cover crop can create new pest and disease problems in the cropping system. The following examples could help to explain some unexpected problems from cover crops. Dabney et al. (1996) pointed out that the use of crimson clover preceding sorghum led to increased damage to the grain due to *Rhizoctonia solani* Kuhn. Another example is that millet used for weed control in California strawberries attracted European corn borer (*Ostrinia nubilalis* Hubner), a pest previously unreported in that crop (Mass et al., 1998). Jansson and Lecrone (1991) reported that the wireworms of four different species were higher in Florida potato crop when sorghum-sudan grass was used as a summer fallow than when the field was mechanically fallowed, leading to substantial economic losses in the cover crop system.

2.1.2 Winter cover crops

A winter cover crop is planted in late summer or fall to provide soil cover during the winter. The plant selected needs to possess enough cold tolerance to perform in the late season. Brandsaeter et al. (2002) investigated the degree of freezing resistance of nine winter annuals and biennial legumes in a growth chamber study and they found the best freezing resistance, independent of sowing time, was shown by hairy vetch (*Vicia villosa*), crimson clover (*T. incarnatum*.L.) and yellow sweet clover (*Melilotus officinalis* L.) also showed good freezing resistance. Black medic (*Medicago lupulina*) showed medium freezing resistance and barrel medic (*M. trunculata*) showed the poorest freezing resistance.

It has been known that winter cover cropping compared with bare fallow can maintain or improve organic C and N concentrations in the soil by providing additional crop residues, which increases C and N inputs to the soil. Winter cover crops use soil residual N that may leach into ground water after crop harvest in the fall and, depending on species, can sequester atmospheric C and/or N, thereby reducing the amount of N fertilizer required for summer crops (Hargrove, 1986).

2.1.3 Cover crops on the Canadian Prairies

Prairie cropping systems are dominated by annual grain crops. In the drier areas of the Canadian Prairies, a year of fallow has traditionally been used to store water for succeeding crops, despite the loss of soil quality, due to soil erosion that occurs. There are 6.5 million ha of arable land situated in the semi arid Brown soil zone of the Canadian Prairies: of this, about 2.4 M ha are summer fallowed each year (Campbell et al., 2002). Instead of summer fallow, cover crops can be grown in rotations to reduce soil erosion, while also adding nitrogen to the soil for subsequent crops to use and providing other rotational benefits too. Relay and double cropping systems provide opportunities to introduce cover crops in the Canadian Prairies without the sacrifice of main crop yield. To support the growth of late season cover crops in relay or double cropping, the availability of late season heat and moisture in the Prairie environment is very important.

Thiessen-Martens and Entz (2001) investigated the availability of late season heat and water resources for relay and double cropping with winter wheat in prairie Canada. They used long-term weather data from 21 sites across Manitoba, Saskatchewan and Alberta for analysis. From their study, south-central Manitoba appears to be the best-suited to the implementation of relay and double cropping systems involving winter wheat. Southwestern Manitoba and southern Saskatchewan receive sufficient amounts of late season thermal time, but precipitation during this time period is low. Northern and western regions of prairie Canada lack the thermal time required for conventional relay and double cropping systems with winter wheat. From the field experiments in 1998 and 1999 at two sites in Manitoba, Thiessen-Martens et al., (2001) proved that the relay and double cropping systems can be successfully established without grain yield penalties to the main crop. They reported this indicates that intensification of cropping systems with legume cover crops is agronomically feasible in southern Manitoba. Zentner et al. (2004) showed from their study that it is possible to employ an annual legume green manure crop, such as Indian Head black lentil (*Lens culinaris*), in rotation with spring wheat in the semi arid Canadian prairies without sacrificing yield or grain quality compared to conventional fallow-wheat systems.

Many grain legumes grown in western Canada do not require nitrogen fertilizer to maximize the yield potential (Hoeppner, 2001). Grain legume crops grown on the Canadian prairies include chick pea (*Cicer arietinum* L.), lentil, dry beans, faba bean (*Vicia faba* L.), pea and soybean. Various members of vetch (*Vicia*) and pea (*Pisum*) genera as well as alfalfa have been popular, as have some annual clovers, such as crimson, subterranean, and berseem (*T. alexandrinum* L.), but perennials such as red and white clover (*T. pretense* L. and *T. repens* L.) and biennial sweet clovers (*Melilotus* spp.) are the common legumes utilized, particularly in prairie cropping systems where the goal is to simultaneously improve soil health and N management. Rye, oats, oil seed radish, winter wheat, sudan grass and buckwheat are the non-legume cover crops used in the areas of Canadian prairies where N is not a primary goal.

The role of cover crops in North American farming systems is expanding to include management of weeds, disease and pests, and overall enhancement of soil quality through organic matter enrichment, improved nutrient cycling and reduction of soil compaction. While the predominant temporal niche for cover crops in North America remains the winter, other opportunities in diverse cropping systems exist for cover crops inclusion, such as summer fallow, living mulches or full-year fallow crops. To date, the use of cover crops is constrained by economic, biological and farm operational factors, but farmer education, continued research, and government policy changes can aid in overcoming existing barriers to adoption (Sarrantonio and Gallandt, 2003).

2.2 Biological nitrogen fixation

The biological fixation of atmospheric dinitrogen is a 'free' source of N for agriculture. Biological N_2 fixation contributes to productivity both directly, where the fixed N is harvested in grain or other food for human or animal consumption, or indirectly, by contributing to the maintenance or enhancement of soil fertility in the agricultural system by adding N to the soil (Giller and Cadisch, 1995). Considerable inputs of biologically-fixed N can be achieved in almost all agricultural ecosystems through the activity of many different symbiotic associations. Legumes, when effectively nodulated with rhizobia, can fix nitrogen from the atmosphere. Whereas non-leguminous plants depend on obtaining their nitrogen requirements from the soil, legumes are able to satisfy at least some of their nitrogen needs from a source that is not available to other plants. This fixed N is an input to the plant-soil system.

Black medic also has the ability to fix atmospheric dinitrogen by symbiotic relationship with *Rhizobium* bacteria through nodule formation. It should be possible to manage biological N fixation to provide a renewable source of N to supplement or replace fertilizer N, and redress the deterioration of agriculture's resource base. The final contribution of fixed N to the soil following harvest, which is determined by the difference between the amounts of N fixed and seed N removed (Peoples et al., 1995).

2.2.1 Legumes in cropping systems

There is a long history of legume use in cropping systems. Legumes are an essential component of sustainable agro-ecosystems (Sarrantonio and Gallandt, 2003). Legume cover crops can fix nitrogen from the air, supplying nitrogen to the succeeding crop. Use of legume cover crops with no-till agricultural production methods has the potential to help farmers produce grain intensively while controlling soil erosion and maintaining or improving soil productivity. The overall desired effect is to increase, or at least maintain, the long-term productivity of the soil (Frye and Blevins, 1989). Relay and double cropping represent options for incorporating legume crops into annual cropping systems without sacrificing a season of grain production (Parsch et al., 1991).

Sainju et al., (2003) found that legume cover crops may be more effective in increasing labile N pools, thereby increasing soil productivity by sequestering atmospheric N and increasing soil N mineralization, and producing summer crop yields similar to those produced by the recommended rate of N fertilization. For example, in a legume cover crop-cotton (*Gossypium hirsutum* L.) production system, hairy vetch significantly increased annual seed cotton yield by as much as 162 kg ha^{-1} compared to winter fallow (Scott et al., 1990).

In temperate regions, winter annual legumes have been most commonly used as N sources, since they can often be placed into cropping systems with the little or no interference with yield. Various members of the vetch and pea genera have been popular, as have some annual clovers, such as crimson (*Trifolium incarnatum* L.), subterranean (*Trifolium subterraneum* L.), and berseem (*Trifolium alexandrinum* L.), but perennials such as red and white clover (*T. pratenase* L. and *T. repens* L.) and biennial sweet clovers (*Melilotus* spp.) are also utilized where the goal is simultaneously to improve soil health and N management (Sarrantonio and Gallandt, 2003). The quantity of N_2 fixed by legumes varies between 15 and 390 kg N ha yr^{-1} depending on the species and prevailing biotic and abiotic conditions. In addition, legumes represent a reliable and inexpensive protein source for animal nutrition. Generally, relative to grasses, legumes are also a superior source of other essential minerals including Ca, Mg, K, Zn, Co and Cu (Sheaffer and Seguin, 2003).

2.2.2 Nitrogen benefits of legumes

Nitrogen production is a key benefit of growing cover crops and green manures. Nitrogen accumulations by leguminous cover crops range from 44 to 220 kg N ha^{-1}. Conditions that encourage good nitrogen production include getting a good stand, optimum soil nutrient level and soil pH, good nodulation, and adequate soil moisture. Forage legumes are valuable in rotations because they generate income from grazing or haying and still contribute nitrogen from re-growth and root residues. Because winter legume cover crops may provide significant quantities of N while conserving soil and water resources, the role of legumes in conservation tillage production systems warrants renewed attention (Hargrove, 1986). Nitrogen benefits in legume-cereal rotations have been attributed entirely to the transfer of biologically fixed legume N to grain production of cereals.

An estimated 7 to 72 kg N ha^{-1} was provided by hairy vetch for the cotton crop when used as green manure in a legume cover crop-cotton production system (Scott et al., 1990). Sarrantonio and Gallandt (2003) reported that the N fixing capabilities and biomass production of legumes varies by climate and soil condition, ranging between 80 and 250 kg N ha^{-1} for hairy vetch and 70 to 150 kg N ha^{-1} for most annual clovers. Ebelhar and coworkers (1982) estimated that hairy vetch supplied biologically fixed N equivalent to approximately 90 to 100 kg ha^{-1} fertilizer N annually to the no –till corn production, based on a comparison of grain yields with corn grown in corn residue and rye.

Hargrove (1986) worked with the cover crops crimson clover (*Trifolium incarnatum* L.), subterranean clover (*Trifolium subterraneum* L.), hairy vetch (*Vicia villosa* Roth) and common vetch (*Vicia sativa* L.) as a N source for no-till grain sorghum. He estimated the average amount of fertilizer N replaced by the legume was 72 kg N ha^{-1} but a well adapted legume such as crimson clover can replace as much as 120 kg ha^{-1} fertilizer N. In southern Manitoba, Thiessen-Martens et al. (2001) found that late-season dry matter of red clover, alfalfa, chickling vetch and black lentil averaged 1157 kg ha^{-1}, 690 kg ha^{-1}, 746 kg ha^{-1} and 634 kg ha^{-1}, respectively and thereby, N contribution of these legumes can be estimated as 29 to 54 kg ha^{-1} for this region. The amount of N available from legumes depends on the species of legume grown, the total biomass produced, and the percentage of nitrogen in the plant tissue. Cultural and environmental conditions that limit legume growth such as a delayed planting date, poor stand establishment, and drought will reduce the amount of nitrogen produced.

2.2.3 Estimation of biologically fixed nitrogen

Symbiotic nitrogen fixation can be assessed by several methodologies. Isotope dilution is the only method that permits evaluation of the separate contributions of soil, fertilizer, and atmospheric N to total plant N (Vose and Victoria, 1986). This is an expensive procedure because of the high cost of stable isotope and instrumentation required to analyze ^{15}N. The difference method (D-method) of estimating N_2 fixation and plant growth and is less expensive that isotope dilution method, but the limitation is obtaining representative non-fixing reference crops (Zhu et al., 1998). Acetylene reduction technique has also been used to estimate the amount of nitrogen being fixed at a given time by a plant (Smith and Baltensperger, 1983) but now it has been criticized as being unreliable for quantitative field studies.

Due to the escalating cost of fertilizer N, the contribution of N from legumes to subsequent crops is of particular interest. The lack of dependable estimates of the contribution of legumes to the N cycle under specific environmental and soil conditions remains a major limitation in determining the importance and economics of legume cover crops (Hargrove, 1986). The literature with field experiment examples shows a large proportion of N fixed by legumes, often 60 to 80%. Such rates may be achieved in farmer's fields, but only where environmental factors do not operate to limit N fixation (Giller and Cadisch, 1995).

2.3 Black medic as a cover crop

Black medic (*Medicago lupulina* L.) is a member of the legume family and grows as an annual, biennial, or short-lived perennial (Turkington and Cavers, 1979; Bauchan and Scheaffer, 2002; Braul, 2004). Many varieties have been described because of the morphological diversity of the species (Turkington and Cavers, 1979). Medics have been used in drought prone and nutrient-stressed agricultural areas in Australia to maintain and improve soil fertility (Campbell, 1985). Competition between the cover crop and the main crop is, however, a serious obstacle that has to be solved before cover crop systems can be included into the farmers practices. One approach to avoid or reduce this problem is to combine a main crop and a cover crop with a synchronized onset of maximum vegetative growth. The use of winter legume such as black medic which is a poor competitor with the main crop is a good choice of such cropping systems.

The black medic cultivar "George" is a low growing self pollinated, short lived perennial legume that can be managed as annual. The seeds are borne in individual pods which turn black at maturity and closely resemble those of alfalfa (*Medicago sativa* L.) in color, size, and shape. Sims et al. (1985) found that in Montana conditions the stand density, dry matter production, and seed yields of George black medic were substantially greater than those of the Australian medics tested in the same study. Also, they reported that grain and protein yields, total N uptake, and water use efficiency were greater for spring wheat following George black medic than following the Australian medics.

Alford et al. (2003) worked on intercropping irrigated corn with annual legumes, including George black medic, in the high plains at Torrington, Wyoming. Of the species evaluated, black medic appeared to offer the greatest potential for intercropping with corn in the High plains. Black medic did not significantly reduce corn yields compared with the medic and weed free check, whereas all other cover crop species caused significant yield reductions. Black medic also produced acceptable amounts of high quality forage late in the year. This makes black medic suited to a production system utilizing fall grazing of corn stalks. Black medic suited this system because it does not grow aggressively early in the year when it could reduce corn yield. From another intercropping study by Moynihan et al. (1996) in north-central United States, black medic was found to be the least competitive medic species when it was intercropped with barley (*Hordeum vulgare* L). Also, weed suppression was usually more pronounced in barley-medic intercrops compared with either the barley or medic monocultures.

Turmel (2007) investigated the effect of the long-term black medic (*Medicago lupulina*) cover crop on arbuscular mycorrhizal fungi colonization and nutrient uptake of flax (*Linum usitatissimum*) in a no-till medic-cereal cropping system in Manitoba and Saskatchewan. She found that the long term black medic cover crop increased early phosphorus uptake, nitrogen and zinc concentration while it decreased iron and copper uptake of main crops. From the growth chamber experiment, she found that cover cropping with black medic was an effective method of increasing early AMF colonization.

2.3.1 Medics around the world

Medics have been used in the world for long time. Its extensive naturalization indicates its wide adaptation. Annual medics have proven to be highly adaptive to a wide range of environments and locations across world (Crawford et al., 1989). Black medic can be found growing from Canada to the Gulf of Mexico, and also common on Pacific coast (Piper, 1942). *M. lupulina* is widely distributed in North America as well as throughout the other temperate and subtropical regions of the world.

Black medics was likely introduced to North America in the 1600s as either a contaminant in alfalfa seed or as a constituent of general pasture mixtures, and was subsequently naturalized throughout most of North America. Black medic is typically found in disturbed areas such as roadsides, riverbanks, lawns, and fields in both temperate and subtropical regions, such as North America, Asia, North Africa and Europe (Turkington and Cavers, 1979; De-Haan et al., 1997; Wilson, 2005). In the north-central USA, annual medics have been shown to have potential as summer annual forage sources (Zhu et al., 1996), as intercrops with small grains (Moynihan et al., 1998) and smother crops in soybean (Sheaffer et al., 2002), as a source of biologically fixed N for subsequent crops and as over winter cover crops following small grains (Zhu et al., 1998).

Annual medics are important winter annual pasture legumes in southern Australia where they provide forage for livestock, improve soil fertility, and enhance subsequent crop yield (Crawford et al., 1989). Jeranyama et al. (1998) investigated on effect of medic planting date on dry matter and nitrogen accumulation when clear seeded or intercropped with corn in a Michigan State University study. They found clear seeded medics produced dry matter yields up to 3 Mg ha^{-1} and accumulated N of up to 75 kg ha^{-1}. These values are similar to other forage legumes that are adapted to the north-central USA.

2.3.2 Geographical distribution in Canada

Black medic is distributed throughout temperate and subtropical regions of the world. It is now prevalent throughout much of Canada's agricultural land although it is not common in Alberta, Saskatchewan and Manitoba. It is naturalized across southern

Canada. It is found throughout Quebec as far as north as 49° and is a common weed in settled areas of Ontario (Turkington and Cavers, 1979).

2.3.3 Importance of self-regenerating capacity of black medic

The choice of legume is often governed by the costs of establishment and the anticipated longevity of the stand. Alfalfa (*Medicago sativa* L.) is a highly productive legume capable of fixing about 170 kg N ha^{-1} in the establishment year and even more in succeeding years (Heichel et al., 1984). However, the comparatively high seed costs for alfalfa often mitigate against its use in short term stands where persistence is unimportant (Heichel et al., 1985). When considering the cost of seeding a cover crop compared to planting the grain crop into the previous year's crop residue, Frye and Blevins (1989) concluded that cost of seeding legumes usually is greater than that of small grains, and the risk of failure is also greater.

The idea behind self-regenerating cover crops is that the farmer only has to seed this crop once and it will regenerate on its own from seed in the seed bank each subsequent year. This allows the farmers to get yearly benefits of having a cover crop without having the yearly cost of reseeding it (Wilson, 2005). On the Canadian prairies, one self-regenerating species drawing particular interest is *Medicago lupulina*, due to its proven ability to regenerate well in this region of the world (Braul, 2004). A productive medic stand has regenerating plant densities between 200 to 400 plants m^{-2}. In order to achieve this density, a viable seed bank of 200 kg ha^{-1} (approximately 4000 seed m^{-2}, which is the proposed minimum level for a viable annual medic seed bank) is needed (Carter, 1981).

Pavone and Reader (1982) examined the dynamics of seed bank size and seed state of *Medicago lupulina* in Guelph, Ontario. They reported 78 to 85% of some experimentally introduced seeds germinated within twelve months, mostly in the spring. It was also estimated that normally only 30 to 40 % of the natural seed bank would germinate in a single year. They concluded that *Medicago lupulina* apparently has a persistent seed bank in this study area.

Black medic has been noted to be a prolific seed producer, often out producing many other annual medicago species (Rumbaugh and Johnson, 1986). Use of winter growing annual medics could eliminate expensive re-seeding costs, give earlier spring grazing, and add N and humus to the soil (Smith and Baltensperger, 1983). Research results of Rumbaugh and Johnson (1986) from their re-seeding studies of annual medics in Utah pastures indicated that *M.lupulina* could develop a soil seed bank more rapidly than the other species and produced abundant seedlings during the second year following seeding. They also concluded that *M. lupulina* has superior re-seeding and ground cover characteristics. The key to the success of black medic as a self-regenerating legume is its seed dormancy mechanism, hardseededness, which allows it to form long-lived seed banks (Cavers, 1995).

2.3.4 Biomass production

Black medic is especially valuable in pastures. Because of the diffuse stems and their spreading habit, black medic is usually sown in mixtures with clovers and grasses, and thus forms excellent pasturage (Piper, 1942). Black medic has superior ground cover characteristics during the second and third year after sowing. Adapted populations of

M. lupulina appear to have long-term value for forage production in Utah rangeland pastures with suitable soils and adequate precipitation (Rumbaugh and Johnson, 1986). Zhu et al. (1996) mentioned from their studies that annual medics are comparable to alfalfa in dry matter yield and forage quality. When annual medics grown in monoculture in Minnesota, the yields ranged from 0.5 to 5.7 Mg ha^{-1}, depending on harvest time and species, and had crude protein (CP) levels equal to or higher than that alfalfa. In the same study, black medic had higher CP concentration. Reported forage yields in the northern USA vary from 1 Mg ha $^{-1}$ (De-Haan et al., 1997) to 3.6 Mg ha^{-1} yr^{-1}(Zhu et al., 1996), with production concentrated in late spring. In a study in Nebraska, it was shown that black medic could produce up to 3430 kg ha^{-1} of dry matter in a year, but that annual dry matter yields tended to vary (Power and Koerner, 1994). Further, Peoples et al. (1996) found in a study in UK that medic as the green manure can produce 600 kg ha^{-1}, 9100 kg ha^{-1}, 10800 kg ha^{-1} and 20400 kg ha^{-1} in the durations of 6, 13, 18 and 25 months, respectively.

2.3.5 Nitrogen fixation capacity

Information on N fixation is important for predicting the net N contribution of annual medics in cropping systems and for selecting species with high N fixation under regional environmental conditions and farming practices. Medics increase pasture soil organic matter, enhance soil water retention and water availability, and improve soil N status due to symbiotic N_2 fixation (Puckridge and French, 1983). Information on the magnitude of N fixation by black medics is conflicting and insufficient. Jeranyama et al. (1998) found N yield of inter-seeded medics with corn ranged from 2.1 to 32 kg ha^{-1}.

Stopes et al. (1996) found *Medicago lupulina* can fix 14 kg ha^{-1} N in six months duration as a green manure crop. In a spring barley-black medic intercrop, Känkänen and Ericksson, (2007) found black medic produced 15.1 kg N ha^{-1} in the late autumn in Finland. Rates of N fixation of annual medics in Minnesota ranged from 100 to 200 kg ha^{-1} (Zhu et al., 1998). Smith and Baltensperger (1983) carried out an experiment to estimate the N fixation potential of three annual medics and found black medic and barrel medic, fix significant amount of N under green house conditions as estimated by acetylene reduction process.

Annual medic pastures in Cyprus have been estimated to fix up to 122 kg ha^{-1} N (Paspastylianou, 1987). Barley-medic intercropping frequently provided more N for soil incorporation than the unfertilized barley monoculture (Moynihan et al., 1996). According to Zhu et al. (1998) annual medics including black medic apparently fixed 40 to 86 kg N ha^{-1} if spring seeded and grown for 60 days, and 20 to 50 kg N ha^{-1} if summer seeded and grown for 43 days. Also they found herbage N of annual medics ranged from 67 to 105 kg N ha^{-1} for spring seeding and from 33 to 68 kg N ha^{-1} for summer seeding. In addition, they reported that N derived from fixation for several annual medics averaged 90% for a soil with low organic matter and N content, but only 82% for a soil with higher organic matter and N content.

2.4 Nitrogen mineralization

Soils commonly contain several thousand kilograms per hectare of organic N, but only a small fraction (1 to 3%) of it is mineralized during each growing season. Soil organic N is composed of a heterogeneous mixture of components of varying stability, including fresh crop and animal residues, microbial biomass, microbial metabolites, and very stable humic materials. Because of variation in the composition and stability of soil organic matter, total organic N generally does not give a good indication of N mineralization potential (Curtin and McCallum, 2004).

The N cycle in agro-ecosystems is complex, involving flows among biota, soil, atmosphere and hydrosphere. At the heart of the cycle is the internal exchange of N between plants and soil. In general, the N cycle processes of biological N fixation and mineralization increase plant available N. Denitrification, volatilization, immobilization, and leaching result in permanent or temporary N losses from the root zone. Because mineralization is a part of this dynamic cycle, exact measurement of mineralisable N is difficult.

Mineralization potential of soils can be affected by several factors. Mineralization of soil or organic matter and crop residue is a complex process that depends on management, soil properties, crop residue quantity or quality and environmental conditions (Mikha et al., 2006). Residue type, placement, and degree of soil incorporation, and soil water regimes largely control availability and loss of soil N from crop residues.

2.4.1 Nitrogen management in no-till systems

One of the greatest challenges in no-till systems is proper N management. With no-till systems, N may be lost by denitrification and leaching and its availability may be decreased by immobilization to a greater extent than under conventional tillage. Since the soil is not disturbed, there is a lower rate of mineralization of organic soil N and lower over all microbial activity. The combined effects of other N losses with less mineralization make N management more critical in no-till than conventional systems (Ebelhar et al., 1982). When no-till systems are initiated, surface soil organic matter increases rapidly, increasing the immobilization potential. During these first years, N management is critical. After the soil organic matter attains a new equilibrium, N mineralization may increase.

In some cases, these effects resulted in higher rates of N fertilizer being recommended for no-tillage. However, the use of legume cover crops for no-tillage systems would provide many rotational benefits and supply biologically fixed N which helps to reduce the need for more fertilizer N. According to Gentile (2002), biological tillage may help to increase the N use efficiency of no-till cropping systems through inclusion of legume cover crops. Biological tillage refers to the improvement of soil structure by biological means such as the action of plant roots, earthworms and other soil organisms (Gentile, 2002). Crop rotations that include legumes and reduced tillage are recommended methods for sustaining productivity of soils.

2.4.2 Residual nitrogen supply through mineralization

Leguminous species are often used in rotations; the biologically fixed N released during residue decomposition may reduce fertilizer N requirements for subsequent crops. Efficient N management has been difficult to achieve with regard to the synchrony of cover crop N release and N uptake by the following summer crop. During the past decade, agronomists have attempted to characterize patterns of N release from cover crops. The availability of plant-usable forms of N following a cover crop is largely microbially-mediated, and therefore dependent on moisture, temperature, microbial access to the substrate, and pH, which in turn are affected by weather, soil type , tillage and residue size and composition, among other things (Sarrantonio and Gallandt, 2003). Still, it is difficult to predict with any great certainty the quantity and timing of N availability following cover crops.

The N contribution of cover crops will not be fully realized by the subsequent crop unless the cover crop N becomes available during the period of high N demand by the summer grin crop. Power and Broadbent (1989) reported that 50% of legume N was mineralized during a subsequent summer growing season. In some cases, ^{15}N has been used to determine the N contribution of legume crop residue to a subsequent crop. Reports of N recovery from labeled legume residues have ranged from 5 to 32% of the N in the subsequent crop (Reeves, 1994). In contrast to this statement, Giller and Cadisch (1995) stated that current, limited data clearly show that recoveries of legume N in the second and later crops are generally small (2 to 15%) under both tropical and temperate conditions. Also, they reported that calculation from ^{15}N mineralization studies under field conditions suggest that in temperate regions up to 50 kg N ha^{-1}, in tropical green manures systems up to 100 kg N ha^{-1} and in agro-forestry systems even up to 300 kg N ha^{-1} of the N which is available for crop uptake is not utilized by the first catch crop. Thus, there is a large potential for improving the efficiency of use of legume N in cropping systems.

When estimating nitrogen contribution from green manure, roughly 30 kg N ha^{-1} is produced for every 1000 kg DM ha^{-1} of legume (Wiens et al., 2006). In Manitoba, legume green manure crops can produce about 3000 to 4000 kg DM ha^{-1}, which provides

90 to 120 kg N ha^{-1}. Of 120 kg N, about 60% becomes available over the following two years, or about 50 kg N in year one after green manure and 10 to 15 kg N ha^{-1} in year two. The remaining N is in soil organic matter and becomes available later (Grant and Entz, 2005). Cycling of N in a mixed legume-cereal rotation, however, is a dynamic and complex process. Many factors, including growing season duration and management practices, influence the flow of N between various above and belowground N pools and the size of these pools. The size of additional N sources such as N fixation, manure and fertilizer-N applications and external sinks such as removal of N through hay, grazing, denitrification, volatilization and leaching can further alter N cycling process.

2.4.3 Fertilizer Replacement Value (FRV)

A common method of determining the N credit from legumes to a subsequent non-legume crop is known as fertilizer replacement value (FRV). For a FRV to be both valid and useful for producer recommendations there must be a significantly higher yield following a legume than following a non legume control when no fertilizer is used in either system. Medics reduced fertilizer needs of corn in a subsequent year by 37 kg N ha^{-1} (Jeranyama et al., 1998). Hoeppner (2001) reported that the fertilizer N replacement value of relay cropped legume cover crops in Manitoba range from 0 to 70 kg ha^{-1}. Entz et al. (2005) documented that among late-season cover crops, alfalfa provided the highest FRV at Winnipeg (51 to 62 kg N ha^{-1}), followed by chickling vetch (29 to 43 kg N ha^{-1}), lentil (23 to 39 kg N ha^{-1}), and red clover (24 to 26 kg N ha^{-1}).

2.5 Evaluation of available residual nitrogen for subsequent crops

Sources of residual N for subsequent crop in rotation may come from mineralization of soil organic N, decomposition of plant residues or organic amendments such as manure and residual inorganic fertilizer. Mineralisable residual N from preceding legumes for subsequent crops in rotations can be evaluated through either field experiment or pot experiments in green house. Soil N mineralization has been shown to provide 20 to 80% of the N required by plants (Mikha et al., 2006). Considerable research has been directed toward development of N mineralization assessment methods. These methods include both field and laboratory techniques that can be applied to estimate soil N supply for crop production (Stanford and Smith, 1972). However, difficulty in predicting the contribution of mineralization continues to be obstacle to implementing best management practices for fertilizer N (Curtin and McCallum, 2004).

2.5.1 Determination of residual nitrogen

Many biological and chemical procedures have been proposed to estimate the quantity of mineralisable N in soil but none of them has found general use in N fertility testing. In the classic method of Stanford and Smith (1972), potentially mineralisable N is estimated from amounts of mineral N released during 30 weeks of aerobic incubation (Curtin and McCallum, 2004).The Stanford and Smith procedure is unsuitable for routine use, but a shortened version (e.g., 2 or 4 week incubation) may be useful (Campbell et al., 1994), even though results from short-term incubations can be sensitive to factors such as sample pretreatment and the presence of plant residues. Campbell et al. (1984) reported from their study that the approach promoted by Stanford and co-workers for estimating the N supplying power of soils may provide reasonably precise predictions while accounting for soil moisture and temperature differences. The anaerobic method of Keeney and Bremner (1966) has practical and operational advantages over aerobic incubation techniques in that the incubation period is relatively short (7 days), the need for careful adjustment and maintenance of soil moisture content is avoided, and only ammonium N needs to be measured (Curtin and McCallum, 2004).

Chang et al. (1999) pointed out that due to the high cost associated with totally field based methods to evaluate N availability and the large amount of time it takes to observe any response in plant growth rate changes due to manipulation, bioassay methods are very good alternatives to both laboratory and field based N availability evaluation methods. In contrast to this statement, Selles et al. (1999) reported that the biological and chemical procedures were accessing similar pool of mineralisable N. They concluded that hot KCl NH_4^+-N was useful for quantifying the N supplying power of the soils. However, researchers are using either one of these or both of them according to their purpose of study and the precision level that they need.

Curtin and McCallum (2004) evaluated biological tests (i.e., net mineralized in a 28 days aerobic incubation and Anaerobically Mineralisable N, (AMN)) and chemical tests (ammonium-N hydrolysis in hot 2M KCl) as predictors of N supply to a glasshouse-grown oat (*Avena sativa* L.) with 30 soils representing a range of management histories, including soils collected from long-term pastures and intensive arable cropping sites. They concluded that of the two biological tests, aerobic N was well correlated with N supplied to the oat crop by mineralization and the commercially available AMN test was less satisfactory and only provided a qualitative index of N availability. They also reported that the ammonium-N released to hot 2M KCl was not well related to plant N uptake and it cannot be recommended as an N available index.

2.5.2 Bioassay studies

The assessment of soil N availability by chemical extraction methods often needs to be checked by methods which directly measure plant N uptake such as a greenhouse bioassay. Compared to chemical methods, bioassay methods represent a direct measurement of soil N availability to plants under controlled environment. A comparison of chemical extraction and a greenhouse bioassay was conducted by Chang et al. (1999) to evaluate the availability of residual ^{15}N in a coniferous forest soil. They used 342 days greenhouse incubation and 2M KCl extraction method. They found that the good correlation between N obtained through extraction and plant N uptake in the greenhouse showed chemical indices can be reliably used to predict soil N availability and fertilizer N dynamics, although to exactly mimic the field situation is impossible.

A ryegrass bioassay was conducted by Palmer et al. (2007) in Switzerland to investigate the relative potential of soils with different management histories to release plant available nitrogen from added organic amendments. A pot trial was set up to estimate inherent N mineralization potential of the soils in glass house. They found native N mineralization was found to be related to total soil N content.

The residual N contribution from faba bean (*Vicia faba* L.), pea (*Pisum sativum* L.) and white lupin (*Lupinus albus* L.) to microbial biomass and subsequent wheat (*Triticum aestivum* L.) and oilseed rape (*Brassica napus* L.) was studied in a green house experiment by Mayer and his coworkers (2003). They found that the succeeding crops recovered 8.6 to 12.1% of the residue N at maturity from their ^{15}N labeled study. A bioassay was conducted in Maryland to determine the effect of hairy vetch (*Vicia villosa* Roth.) on growth, yield and leaf senescence of tomatoes, and found significant effect of hairy vetch on tomato growth performance (Kumar et al., 2005).

The plant bioassay approach provides a practical means to quantify the plant-available soil N supply in legume based cropping systems under controlled environment. The basic idea behind the plant bioassay is to grow a single or series of plants in soil samples collected from fields that has to be evaluated and extract the plant available N by using live roots of plants. Using live roots could be a better way of N extraction than the chemical extraction methods. Total mineralisable N can be calculated by measuring the total plant N uptake. In the current bioassay study, the difference in N uptake from the medic treatment minus the black medic free control treatment was used to determine the contribution of black medic N from the total extracted mineralisable N from Winnipeg and Indian Head. The plant bioassay method was preferred for this investigation because it is a simple, inexpensive, accurate and direct method of determining the N availability from black medic to subsequent crops in long term no-till cropping systems on the Canadian prairies.

2.6 Summary

Cover crops improve the overall quality of soil and environment. For farming systems to remain productive, and to be sustainable in the long-term, it will be necessary to replenish the reserves of nitrogen which are removed or lost from soil. International emphasis on environmentally sustainable development with the use of renewable resources is likely to focus attention on using legumes in cropping systems in supplying N for agriculture. In this way, environmental concerns such as nitrous oxide emission through nitrification process in the wet and bare soils, leaching of synthetic fertilizer residues into groundwater and the cost needed to purchase these fertilizers suggest that alternate sources of supplying nitrogen to soil should be considered in Canadian prairie cropping systems.

Canadian prairies are a very important agricultural area in Canada. Inclusion of a legume such as black medic may provide many rotational benefits along with N addition into the system and reduce the reliance on synthetic fertilizers. Black medic's frost resistance, ability to self-reseed, wide adoption to growing conditions, poor competition with main crop and ability to fix N make it an ideal candidate for Canadian prairies. Relay and double cropping providing opportunities to introduce black medic into the cropping systems and utilize the available late season resources in the prairies. Despite an increasing interest in the use of medics in sustainable agricultural systems, there is a lack of N benefit information on performance of medics in the Canadian prairies. The intention of this study was to evaluate the N benefits of long-term black medic in a continuous no-till grain cropping system by conducting field experiment and bioassay.

3. THE EFFECT OF LONG-TERM BLACK MEDIC COVER CROP ON NITROGEN DYNAMICS IN NO-TILL CROPPING SYSTEMS.

3.1 Abstract

The objectives of less input use and more biologically based cropping system have caused interest in the use of leguminous cover crops as sources of N in Canadian inter-cropping systems. In this study, the influence of a black medic cover crop (*Medicago lupulina* cv. George) on soil NO_3^--N, biomass, N uptake and grain yield were examined in two long-term field experiments which had the rotation flax (*Linum usitatissimum*)-wheat (*Triticum aestivum*)-oat (*Avena sativa*) established in Manitoba and Saskatchewan in 2000 and 2001, respectively. In addition, black medic biomass and density was studied to determine the medic performance in 2006. Experimental plots were arranged in a randomized complete block design with three replicates. Medic was the main plot and fertilizer rate was the sub plot. Samples for soil NO_3^--N analysis were collected from oat (Indian Head and Winnipeg) and spring wheat (Winnipeg) plots prior to planting, at tillering, at flowering and at maturity stages to the depth ranged from 0 to 120 cm (0-15, 15-60 and 60-120 cm). Above ground tissue samples were collected at tillering, at flowering and at maturity stages from both medic and non-medic plots at both sites in 2006. Medic did not significantly increase the grain yield at either site. At Winnipeg, where drought conditioned prevailed in 2006, black medic had no significant influence on tissue N content, crop biomass and N uptake and total available N for any sampling date. At Indian Head, medic significantly increased soil N and total available N at either tillering or maturity phases of oats. Medic did not increase soil NO_3^--N at both site during tillering and flowering but sub plot effect was significant for all cases. The general lack of significant in interaction between main and sub plots suggests that medic can perform well in both lower and higher fertilizer rates. The effect of medic on soil NO_3^--N was more prominent; producing an additional 48 kg ha^{-1} total N (obtained from both plant and soil) that was available at the end of season at the Indian Head site.

3.2 Introduction

For centuries, the value of legumes in crop rotation has been recognized all over the world. Relay and double cropping represent an option for incorporating legume crops into single or continuous cropping systems without sacrificing a season of grain production (Thiessen-Martens et al., 2001). In temperate regions, cereal-legume cropping systems consist of wheat, oat, flax, or barley as cereal component and field bean, vetch, clovers, alfalfa or soybean as the legume component. The main advantage of this system is legumes fix N and increase the soil N availability. The quantity of N fixed by legumes in cereal-legume system depends on the species, morphology, and density of legume in the mixture, the type of management, and the competitive abilities of the component crops (Ofori and Stern, 1987). Annual medics-barley (Moynihan et al., 1996), alfalfa-oat, alfalfa-winter wheat (Hesterman, et al., 1992), soybean-corn (Ding et al., 1998), clover-spring wheat (Garand et al., 2001), clover-barley (Känkänen et al., 2003) are some of the successful examples of legume-cereal cropping systems.

Thiessen-Martens and Entz (2001) identified the possibilities to grow late season cover crops in prairie Canada where sufficient heat and water resources are available for late season cover crop growth and N fixation. Previously, some experiments were successfully carried out using black medic as a cover crop with corn (Alford et al., 2003; Jeranyama et al., 1998), soybean (Sheaffer et al., 2002), wheat (Stopes et al., 1996) and barley (Monihan et al., 1996). In recent Finnish studies, similar to the current study, Känkänen and Eriksson (2007) found that the black medic provided 15.1 kg N ha^{-1} at late autumn undersown with spring barley (*Hordeum vulgare* L.).

In the present study, black medic (*Medicago lupulina*, cv George.) was used as potential legume cover crop in a continuous grain cropping system with wheat, oat and flax under no-till practice. George black medic was developed by the Montana Agriculture Experimental Station at Bozeman, MT. It is a low growing, self-pollinated, short lived perennial legume that can be managed as an annual. The stem is thin and 30 to 70 cm long and produces trifoliate leaves and small, yellow colored flowers. The seeds are borne in individual pods which turn black at maturity and the seeds closely resemble those of alfalfa (*Medicago sativa* L.) in color, size, and shape (Sims et al., 1985).

An important advantage of self-regenerating black medic is that it has to be seeded only once, and after that it regenerates on its own from seed in the seed bank. This is the practice that has been followed in the Winnipeg and the Indian Head experimental sites for the last five to six years under no-till management. Also, in Manitoba, Braul (2004) studied the recruitment characteristics of black medic as a self-regenerating cover crop and found that germination was related to moisture and temperature conditions in the black medic seed microsite and recruitment was greater in zero-till versus conventional tillage. The levels of recruitment (243 and 1214 plants m^{-2} at Carman and Winnipeg respectively, in 2003) obtained in his study were considered sufficient to develop black medic as a cover crop under zero-till management.

Legume residues often increase soil inorganic N concentrations, N accumulations and yield of subsequent crops (Hossain et al., 1996b). Several previous studies indicate inclusion of several legume cover crops such as alfalfa, vetches, clovers, lentils and pea (Hargrove, 1986; Entz et al., 1995; Thiessen-Martens and Entz, 2001; Sarrantonio and Gallandt, 2003; Zentner et al., 2004) into the Prairie cropping system increases the overall production due to N addition and other non-N benefits. However, no previous research has documented the N benefits of black medic as legume cover crop in a no-till continuous grain cropping system in this region. The general objective of the present study was to determine the effect of long-term black medic on soil NO_3^--N supply, biomass production, plant N uptake and grain yield in different fertilizer application rates and thereby, to examine the possibility of reducing the N fertilizer cost and improve overall performance of a no-till continuous grain cropping system. Specific hypotheses are:

1. The long-term black medic cover crop will increase the soil NO_3^--N under no-till cropping system.
2. The long-term black medic cover crop will result in more N accumulation in the main crops.
3. The long-term black medic cover crop will result in more biomass in main crops.
4. The long-term black medic cover crop will elevate the grain yield of main crops.

3.3 Materials and methods

3.3.1 Experimental site history

In this study, two previously established long-term trials with and without black medic legume cover crop were sampled in 2005 and 2006. One field was located in the Department of Plant Science Research Station (Point), University of Manitoba, Winnipeg, Manitoba (49°48'45.75"N, 97°7'21.80"W) and the other one is at the Agriculture and Agri-Food Canada Research Farm in Indian Head, Saskatchewan (50°33'53.99"N, 103°38'29.16"W). The Winnipeg site was established in 2000 and this site has a rotation of wheat, oat and flax with and without black medic crop. The Indian Head experimental site was established in 2002 with and without black medic. This trial has a crop rotation of oat-flax-winter wheat. Wheat, oat and flax are the major cereals crops in the Prairie Provinces of Canada, grown on 9.8, 2.0 and 0.8 M ha of agricultural land, respectively (Statistics Canada, 2006). Different fertilizer treatments were also included in the study. The Winnipeg site had two levels (with and without N fertilizer) and the Indian Head site had three levels (20%, 60% and 100% N fertilizer of recommended rate) as sub plot treatments.

The soil type at Winnipeg was Riverdale silty clay soil and the soil type at Indian Head was Indian Head heavy clay. Winnipeg is sub-humid climate (514 mm annual precipitation), while Indian Head is considered dry sub-humid (447 mm annual precipitation). However, during this study period, 2005 was a wet year and 2006 was a dry year for both sites. The air temperature and precipitation data were obtained from the nearest Environment Canada weather stations at Indian Head site and Campbell scientific weather station (Point) located at the Department of Plant Science Research Station

(Point), University of Manitoba, Winnipeg. Annual national temperature departures and long-term temperature and precipitation averages (1971–2000) were obtained from Environment Canada annual weather bulletins.

The George black medic was seeded at the Winnipeg site at the rate of 15 kg ha^{-1} (broadcast). At Indian Head, medic was seeded at the rate of 20 kg ha^{-1} using an Edwards drill (20 cm spacing) on May 2002 and then again re-seeded on July 2002. No re-seeding of black medic was done at either site in subsequent years and medic regenerated from the soil seed bank each year. Black medic's physical seed dormancy (i.e., impermeable seed coat) allows it to form long-lived seed banks, which is the key to the success of black medic as a self-regenerating legume, but it also controls the timing of recruitment and how much seed is available to germinate each season (Wilson, 2005). According to Pavone and Reader (1982), less than 40% of black medic seed within the soil bank germinates in any given year. Each year, at both experimental sites satisfactory medic self-regeneration was observed from the persistent seed bank in the spring and in the late autumn when the moisture and sunlight is more available due to absence of crops (Figure 3.2c).

At the time of cereal crop maturity, medic biomass and plant density was measured from five randomly selected areas within the medic plots using a quadrat with the dimension of 10×10 cm. The medic biomass was harvested and medic plants were counted in the quadrat areas. A small population of black medic was also observed during the summer along with crops. For further information about the past medic system performance at these sites, previous medic history is reported in Tables in Appendices E through K.

3.3.2 Experimental design

In both field locations, treatments were arranged in a Randomized Complete Block Design with three replicates (Appendices A and B). The main plot treatment was black medic (*Medicago lupulina* L.) cover crop and sub plot effect was N fertilizer. The Winnipeg site had two sub plot treatments: with N fertilizer application and no N fertilizer application. The Indian Head site had three sub plot treatments: application of 20%, 60% and 100% of the recommended rate of N fertilizer according to each main crop. Plot dimensions for the Winnipeg and the Indian Head sites were 4.0×8.0 m and 4.0×10.7 m, respectively. Total plot number was for the Winnipeg site was 36 and for the Indian Head site 54 (Appendices C and D).

3.3.3 Agronomic practices at the sites

At the Winnipeg site, the oat cultivar AC Assiniboia was seeded at a rate of 100 kg ha^{-1} and the spring wheat cultivar AC Barrie was seeded at a rate of 130 kg ha^{-1} using a zero-till disk drill experimental plot seeder with the row spacing of 15 cm on May 23, 2006. At the Indian Head site, the oat cultivar Pinnacle was seeded with a seeding rate of 172 kg ha^{-1} using a zero-till disk drill seeder (Conserva-pak) to 3.75 cm depth and 30 cm row spacing on 5 May, 2006. Zero-tillage management was practiced in both experimental sites. Black medic seedlings were observed during the spring and the fall in both oat and spring wheat crops. Medic growth was still observed during tillering and flowering but in lower densities.

In 2006, the Winnipeg site was sprayed with glyphosate (5L ha^{-1}) on May 19 and Poast Ultra Sethoxydim (0.47L ha^{-1}) and BuctrilM - bromoxynil + MCPA ester (1L ha^{-1})

with merge surfactant (1L $100L^{-1}$) on June 30. In 2006, the Indian Head site was sprayed with Curtail M (660 g a.i ha^{-1}) for non-medic plots. On June 1, MCPA (532.5 g a.i ha^{-1}) with merge surfactant (1L $100L^{-1}$) was applied to medic plots. At Winnipeg, spring wheat and oat 75 kg ha^{-1} N (ammonium nitrate) was broadcast applied on June 20. At Indian Head, the oat crop was fertilized with urea at 6.2 kg ha^{-1} N, 50.3 kg ha^{-1} N and 82.4 kg ha^{-1} N (20%, 60% and 100% N). In Winnipeg on 7 Sept., 2006 oat was harvested using a Kincaid experimental plot combine, dried on a forced air drying bed at 28 °C for 4 days and cleaned using an air screen seed cleaner (model Clipper M2BC) at the Department of Plant Science laboratory. At Indian Head on 22 Aug., 2006, oat was harvested using an MF-300 Combine and air dried at room temperature for a week.

3.3.4 Sample collection

Soil NO_3^--N contents were measured to a depth of 0 to 120 cm at four times: before seeding at tillering, flowering and maturity stages in all plots. Above ground tissue samples were collected to estimate the tissue N content, biomass and total N uptake of the crops at the time of soil sampling. Further, black medic biomass and density was measured and herbage N was determined in 2006.

3.3.4.1 Soil sampling

Soil samples to 120 cm (0-15, 15-60 and 60-120 cm) were collected from the oat and spring wheat plots at prior to planting at Winnipeg and from the oat plots at maturity (August) at both sites. In addition, soil samples to 60 cm (0-15 and 15-60 cm) were collected at tillering (June) and flowering (July) at both sites (Figure 3.1). All soil sampling dates coincided with tissue sampling dates except the pre-planting soil sampling in May (Figure 3.1).

Soil samples were collected using hand augers (Figure 3.2a) from five random cores per plot for each depth. In the field, bulk samples were hand-mixed and representative sub-samples were taken for analysis. All the soil samples were kept frozen (-20°C) in the Department of Plant Science freezer before nitrate analysis. Prior to analysis, samples were air dried and broken into small particles by hand, then sent for soil NO_3^--N analysis to AGVISE Laboratories (604 Hwy 15, PO Box 510, Northwood, ND 58267). The nitrate analysis was done by Cadmium Reduction Method on a Technicon autoanalyser.

3.3.4.2 Tissue sampling

Tissue samples at tillering, flowering and maturity stages were collected during the 2006 growing season at both experimental sites (Figure 3.1). At both sites, above ground cereal tissue was hand-harvested from 1 m lengths of 3 adjacent rows ($0.9m^2$ at Indian Head and $0.45\ m^2$ at Winnipeg) using sickles. The corners of sampling areas were marked by flags (Figure 3.2b) and kept free of medic plants and weeds during the growing season, so that weed or medic plants did not capture N. Tissue samples were oven dried at 65°C until constant weights were obtained (48 hours) and weighed to determine plant dry matter yield. After drying, samples were finely ground using a Willey mill and to pass through a 2 mm sieve. Representative tissue sub-samples were analyzed for total N by combustion using a LECO N analyzer (model FP528, LECO Corp., St. Joseph, Michigan, 49085) in the Department of Plant Science laboratory.

3.3.5 Statistical Analysis

The data were tested for normality and homogeneity of variance by using Proc Univariate (SAS Institute) procedure prior to ANOVA. If the data were found to be non-homogeneous they were log transformed and re-analyzed to meet the assumptions of ANOVA. An analysis of variance (ANOVA) was performed for randomized complete block design using the General Linear Model procedure (Proc GLM, SAS Institute Inc.) and means were separated using Fisher's Protected LSD at 0.05 significance level to evaluate the black medic treatment effect. *P* values less or equal to 0.05 were considered as significant in the current study.

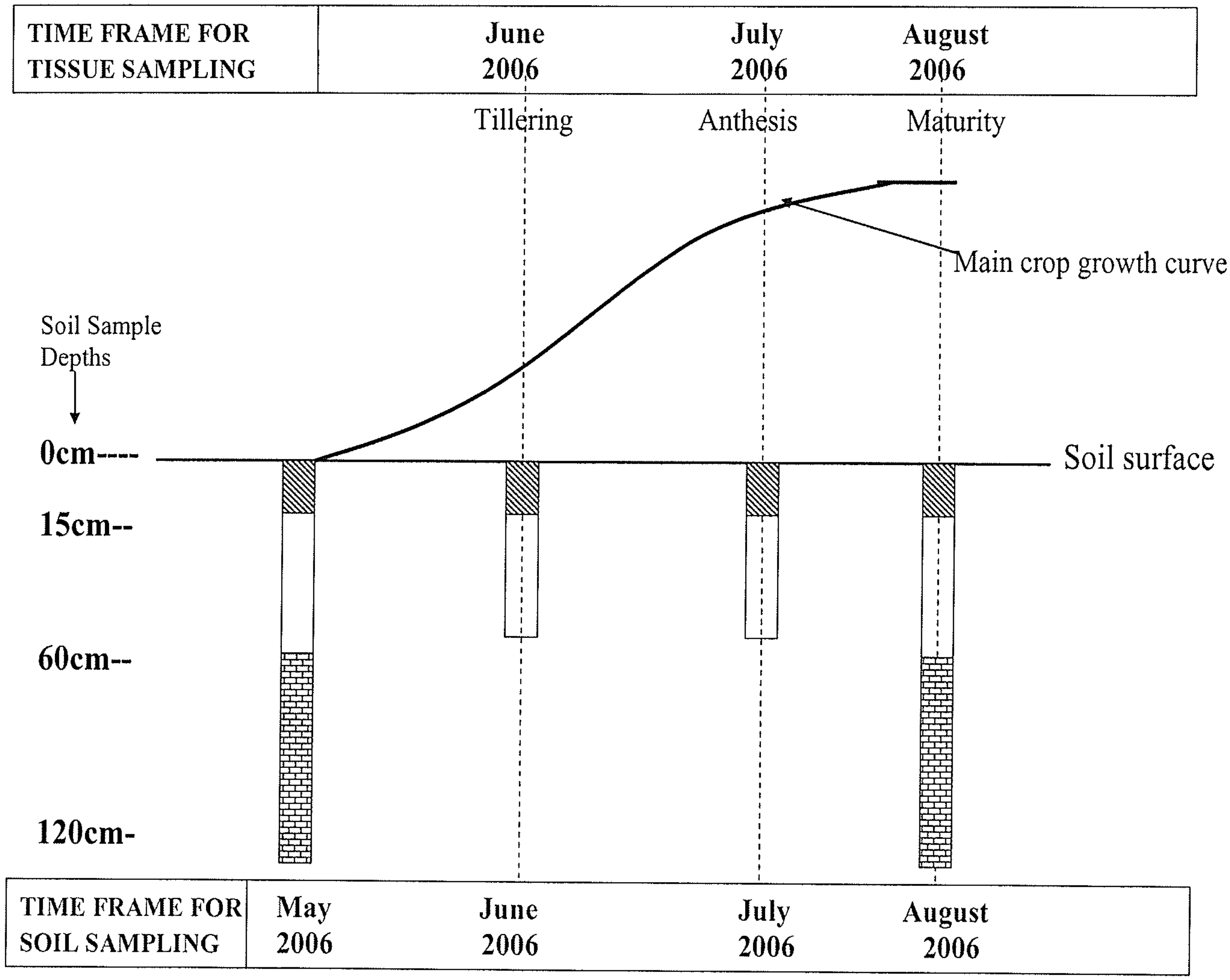

Figure 3.1. Illustration of soil and plant tissue sampling schedule for the Winnipeg and the Indian Head sites in 2006.

Figure 3. 2. a) Soil sampling at tillering at Winnipeg site. b) Flagged area for tissue sampling at Winnipeg site. c) Medic growth at maturity phase at Indian Head site. d) Indian Head oat plots at maturity stage.

3.4 Results and discussion

3.4.1 Weather condition of the sites

The 2006 season was characterized as dry with above average temperature (Tables 3.1 and 3.2). In fact, 2006 was recorded by Environment Canada as the second warmest year for Canada since 1948 (Table 3.3). During the 2006 growing season (May to September), the spring wheat and oat crops experienced mean monthly temperatures of 17.8°C (long-term average 15.8°C) and 14.8°C (long-term average 15.0°C) for the Winnipeg and the Indian Head sites, respectively (Tables 3.1 and 3.2). For the same period mean monthly precipitation was 36 mm (long-term average 69 mm) and 38 mm (long-term average 59 mm) for the Winnipeg and the Indian Head sites, respectively.

The Winnipeg site received only 50% and the Indian Head 65% of long term average precipitation during this growing season (Tables 3.1 and 3.2). Thus, the combination of higher temperature and lower precipitation of the Winnipeg site in 2006 resulted in low crop performance. On the other hand, the year 2005, was very wet for the Winnipeg site. These two totally different weather conditions for 2005 and 2006 may have some impact on soil N dynamics. Overall in 2006, the Indian Head site exhibited favorable growing conditions with optimum temperature and moderate precipitation for medic and crop growth compared to the Winnipeg site.

Table 3.1. Mean monthly air temperatures (°C) with long-term averages at Winnipeg and Indian Head sites in 2005 and 2006.

Year	Sites	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
2005	Winnipeg [y]	-18.4	-11.8	-6.2	7.6	11.0	18.1	20.9	18.7	14.9	7.3	-2.2	-8.3
	Indian Head [x]	-18.3	-11.9	-6.6	5.5	8.7	14.8	16.9	15.6	12.0	4.4	-3.8	-9.6
2006	Winnipeg [y]	-6.3	-14.4	-4.1	9.5	13.0	19.4	22.5	20.0	13.9	4.3	-3.6	-8.3
	Indian Head [x]	-6.4	-12.9	-6.5	7.3	11.2	16.0	17.9	17.4	11.6	1.2	-6.3	.
Long-term averages (Normal)													
(1971-2000)	Winnipeg [z]	-17.8	-13.6	-6.1	4.0	12.0	17.0	19.5	18.5	12.3	5.3	-5.3	-14.4
(1971-2000)	Indian Head [w]	-16.2	-12.3	-5.4	4.0	11.4	16.1	18.4	17.5	11.4	4.6	-5.4	-13.3

Table 3.2. Total monthly precipitations (mm) with long-term averages at Winnipeg and Indian Head sites in 2005 and 2006.

Year	Sites	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
2005	Winnipeg [y]	0.0	6.0	1.9	30.4	72.9	176.3	198.5	22.8	47.6	37.5	19.3	9.4
	Indian Head [x]	37.0	6.8	29.0	6.8	57.6	99.2	59.2	98.0	4.0	6.6	34.9	24.7
2006	Winnipeg [y]	9.3	0.3	32.6	7.7	22.0	22.0	15.1	76.8	42.5	13.1	5.5	5.2
	Indian Head [x]	13.1	6.3	10.6	73.2	39.0	80.4	4.4	11.6	54.8	23.5	60.3	.
Long-term averages													
(1971-2000)	Winnipeg [z]	19.7	14.9	21.5	31.9	58.8	89.5	70.6	75.1	52.3	36.0	25.0	18.5
(1971-2000)	Indian Head [w]	19.7	16.2	24.1	24.6	55.7	78.9	67.1	52.7	41.3	24.3	17.4	25.3

[x] Source: Environment Canada weather station, Indian Head
[y] Source: Point weather station, University of Manitoba, Winnipeg, Manitoba.
[z] Source: Environment Canada 30 year average for 1971-2000 at Winnipeg
[w] Source: Environment Canada 30 year average for 1971-2000 at Indian Head

Table 3.3. Annual national temperature departures (°C) and warmest ten years (1948-2006) in Canada.

Rank	Year	[n]Average T (°C)
1	1998	2.5
2	**2006**	**2.4**
3	1981	2.0
4	2001	1.7
5	1999	1.7
6	**2005**	**1.7**
7	1987	1.4
8	2003	1.1
9	1953	1.0
10	1952	1.0

[n] Source: Environment Canada national bulletins (1948 – 2006).

3.4.2 Medic system performance

3.4.2.1 Black medic biomass

The dry matter accumulation of legume cover crops is perhaps the most important factor to consider in determining the feasibility of cover cropping system in short growing season areas because the N contribution is linked to biomass (Thiessen-Martens et al., 2001). Medic biomass was determined at maturity to examine the performance of black medic at the experimental sites in 2006. At Indian Head, the N fertilizer rate had a significant influence (P=0.028) on medic biomass accumulation. Medic biomass production increased with decreased N fertilizer rates and the highest biomass was obtained at the lowest N rate treatment (20%). This result suggests that the black medic is more productive in lower N fertilizer use cropping systems. At Winnipeg, medic biomass was high in N fertilized plots compared to no N plots though the differences were not significant. The average black medic biomass at time of cereal crop maturity was 587 kg ha^{-1} in oat plots and 968 kg ha^{-1} in spring wheat plots at the Winnipeg site and 324 kg ha^{-1} in oat plots at the Indian Head site (Table 3.4).

Black medic biomass from the present study for all N rates averaged 627 kg ha^{-1}, slightly higher than the value reported by Stopes et al. (1996) and slightly lower than the value of 703 kg ha^{-1} reported by Zhu et al. (1998) in Montana. Results of the current study (average 627 kg ha^{-1}) fell in between these two past records, indicating that black medic has potential for biomass production in this study region. Also, dry matter yield of the black medic can be compared with other cover crops that are well-adapted to the Canadian cropping systems. For example, Thiessen-Martens et al. (2001) found the late season growth of red clover, alfalfa, chickling vetch and black lentil at an average of

1157 kg ha^{-1}, 690 kg ha^{-1}, 746 kg ha^{-1} and 634 kg ha^{-1}, respectively. Zhu et al. (1996) found that annual medics were comparable to alfalfa (*Medicago sativa*) in dry matter yield and forage quality and can yield 0.5 to 5.7 Mg ha^{-1} biomass under monoculture. While several studies have documented biomass production of medic (e.g., 3430 kg ha^{-1} by Power and Koerner, 1994 and 1200 to 1700 kg ha^{-1} by Carr et al., 2006), few have considered medic as a cover crop with cereals. In a Finnish study that tested medics as cover crops, similar to the present study, Känkänen and Ericksson, (2007) reported that the black medic produced 505 kg ha^{-1} dry matter in the late autumn as an undersown crop with spring barley (*Hordeum vulgare* L.). In Canada, no previous study was found that examined black medic performance as a cover crop in different fertilizer regimes. The two experimental sites used in the current study are the first long-term black medic rotation studies in Canada.

3.4.2.2 Black medic density

Medic density at the time of crop maturity was determined at both sites in 2006. The average black medic plant density was 4812 plants m^{-2} at Indian Head oat plots and 5526 plants m^{-2} and 7433 plants m^{-2} at Winnipeg oat and spring wheat plots, respectively (Table 3.4). However, the important observation from the Indian Head site was that the medic density increased with decreased N fertilizer rates and was significantly higher in the lowest N fertilizer rate treatment (20%). Also at Winnipeg higher medic densities were observed in the fertilized plots compared to non fertilized plots. Overall, the Indian Head oats showed lower medic density at maturity compared to the Winnipeg site. However, at the beginning of growing season the Indian Head site had visibly higher medic population (Figure 3.2c) compared to the Winnipeg site and then gradually decreased due to competition for resources with well-established main crops. Higher medic density at the Winnipeg site was attributed to less competition for resources due to poor main crop growth. Another possible reason for higher medic density at the Winnipeg site is that it had received an unusual high precipitation (76.8 mm) in August 2006 after dry months, resulting in late season emergence of medic seedlings. In August, the Indian Head site received only 11.6 mm precipitation (Table 3.2).

Table 3.4. Medic density and biomass at Winnipeg and Indian Head sites in 2006.

Site	Main crop	Fertilizer rates	Medic density (plants m^{-2})	Medic biomass (kg ha^{-1})
Winnipeg	Spring wheat	100% N fertilizer	8613	1335
		No N fertilizer	6253	699
		LSD($P \leq 0.05$)	3838	691
		Significance (*P*)	0.275	0.236
		CV (%)	26	55
	Oat	100% N fertilizer	5893	681
		No N fertilizer	5160	492
		LSD($P \leq 0.05$)	1758	224
		Significance (*P*)	0.371	0.195
		CV (%)	14	20
Indian Head	Oat	20% N fertilizer	2111	458
		60% N fertilizer	1865	376
		100% N fertilizer	875	134
		LSD($P \leq 0.05$)	866	210
		Significance (*P*)	0.038	0.028
		CV (%)	24	28

Rambaugh and Johnson (1986) reported that medic can produced up to 3806 plants m^{-2} in a study in southern Australia. That value is lower than the current results. However, according to their conclusion that the plant density is depending on seed bank characteristics, perhaps black medic can develop a soil seed bank more rapidly than other medic species due to its proven seed recruitment ability in the prairie region (Braul, 2004). Seed production and, therefore, seedbank establishment for regeneration are linked to the level of dry matter production (Puckridge and French, 1983). This was proved in the current study by obtaining higher density from the higher biomass production plots in the Winnipeg spring wheat (Table 3.4). Since the experimental sites were no-till systems, another important fact that has to be noted is that black medic recruitment is usually higher in no-till than conventional tillage (Braul, 2004). The study results suggest that the black medic density and biomass could be higher in the cropping systems with low fertilizer N rates.

3.4.3 Soil NO_3^--N

Soil N measurements made during spring and autumn represent an important means to evaluate the usefulness of leguminous cover crops (Känkänen and Ericksson, 2007). In the present study, soil NO_3^--N tests at pre-plant, tillering, flowering and at maturity were used to investigate the influence of black medic cover crop on the Winnipeg and the Indian Head soil N dynamics. In the present experiment, no statistically ($P \leq 0.05$) significant interactions between main plot (medic and non-medic) and sub plot treatments (N fertilizer) were observed for soil at any depth increments at either site. Thus, the main plot and the sub plot results were discussed as independent factors during different phase of sampling. Also, no interaction suggests that the medic performed well in all fertilizer regimes.

3.4.3.1 Soil NO_3^--N at prior to planting

Soil NO_3^--N tests are used in western Canada prior to planting to predict crop N requirements (Zebarth and Paul, 1997). At the Winnipeg site, medic significantly reduced pre-plant soil NO_3^--N for spring wheat (Table 3.5) but not oat (Table 3.6). Lower soil NO_3^--N in the medic treated wheat plots was attributed to black medic N uptake for their spring regeneration since more medic plants were present in spring wheat plots (table 3.4). At Indian Head site, medic significantly increased soil NO_3^--N at 0-60 cm sampling depth (P=0.0415) (Table 3.7). This additional N was found mainly in 15-60 cm zone and amounted to only 4 kg N ha^{-1}. Lack of sub plot effect in all cases was attributed to the fact that N fertilizer had not yet been added for the 2006 season.

3.4.3.2 Soil NO_3^--N at tillering and flowering

Medic did not significantly affect soil NO_3^--N at any depth at either site for the tillering or flowering phase (Tables 3.5, 3.6 and 3.7). During this time of sampling, medic growth was slow as a result of competition for resources with main crop and weeds. Very significant sub plot effects were found at all depths at both sites (Tables 3.5, 3.6 and 3.7) because of significant increase in the soil N level due to addition of fertilizer N.

3.4.3.3 Soil NO_3^--N at maturity

At maturity, medic did not significantly increase the soil NO_3^--N of the Winnipeg spring wheat and the Indian Head oat at any depth (Tables 3.5 and 3.7) but medic significantly increased soil NO_3^--N of Winnipeg oat by 26 kg ha^{-1} when the depths combined as 0-120 cm (Table 3.6). However, at maturity there was more soil NO_3^--N in all medic soils than at tillering and flowering indicating a gradual increase in mineralization and nitrification of medic residues and may also reflect a steady rate of N fixation by medics.

Growing season N dynamics depend on many factors such as prevailing environmental condition of sites, type of crops grown, amount of added fertilizer, rate of residue mineralization and type and size of microbial population. These factors correspond with various parts of N cycle such as nitrification, denitrification, immobilization, leaching, volatilization and mineralization. In the current study, black medic's influence on N dynamics varied with sites, crops, sample depths and growth stages of crop. Overall, medic did not show any consistent increase in soil NO_3^--N supply throughout the growing season.

However, interestingly, the influence of medic was observed at either the pre-planting or maturity stages of the main crops emphasizes that the medic had effects on soil N supply for the next season crop in this unique continuous cropping system. Marstorp and Kirchmann (1991) found that black medic mineralized larger amounts of N from autumn to early spring. Hypothesis for the soil NO_3^--N in this experiment under field conditions has to be rejected because significant increase in medic soil N was observed only in three out of twelve cases.

Table 3.5. Soil NO_3^--N in the soil profile of spring wheat as influenced by medic cover crop and fertilizer N rate at Winnipeg in 2006.

Sampling Time	Pre-planting (18th May 2006)					Tillering (29th June 2006)			Flowering(21st July 2006)			Maturity (14th August 2006)				
Soil Depth (cm)	0-15	15-60	60-120	0-60	0-120	0-15	15-60	0-60	0-15	15-60	0-60	0-15	15-60	60-120	0-60	0-120
	----------	kg ha^{-1}	----------													
Treatments																
Medic	15.68	20.72	13.48	36.40	49.88	36.07	33.08	69.15	37.18	48.78	85.97	66.12	31.40	37.38	97.52	134.90
Non-medic	22.03	35.32	26.15	57.35	83.50	38.12	25.25	63.37	39.22	52.68	91.90	61.47	27.48	29.17	88.95	118.12
LSD ($P\leq 0.05$)	8.19	14.71	8.59	22.40	28.39	68.19	60.50	113.57	36.22	59.38	89.88	129.84	31.32	128.25	124.96	250.08
100% N fertilizer	19.42	26.90	21.68	46.32	68.00	59.60	43.17	102.77	67.07	81.83	148.90	107.40	42.60	54.55	150.00	204.55
No N fertilizer	18.30	29.13	17.95	47.43	65.38	14.58	15.17	29.75	9.33	19.63	28.97	20.18	16.28	12.00	36.47	48.47
LSD ($P\leq 0.05$)	7.34	23.72	9.97	30.56	22.90	28.49	26.87	51.33	45.58	42.40	74.65	65.78	16.26	69.44	63.67	123.49
Significance(P)																
Replicate	0.523	[z] 0.391	0.166	0.544	0.139	[z] 0.358	[z] 0.055	[z] 0.133	[z] 0.314	[z] 0.404	[z] 0.204	[z] 0.803	0.805	0.294	0.899	[z] 0.735
Medic	0.074	0.099	0.024	0.130	0.015	0.948	0.229	0.526	0.832	0.916	0.828	0.561	0.561	0.386	0.551	0.642
N fertilizer	0.695	0.656	0.358	0.924	0.767	0.001	0.003	0.002	0.002	0.006	0.001	0.007	0.006	0.007	0.002	0.004
Medic*N ferti	0.892	0.144	0.568	0.312	0.144	0.636	0.529	0.561	0.821	0.347	0.328	0.853	0.853	0.602	0.848	0.898
CV (%)	24.29	52.80	31.41	40.67	21.43	47.93	57.40	48.30	74.40	52.10	52.30	64.30	34.40	130.20	42.60	60.90

[z] Natural log transformation was used to achieve homogeneity of variance and a normal distribution. Treatments means were presented as original, untransformed values

Table 3.6. Soil NO_3^--N in the soil profile of oat as influenced by medic cover crop and fertilizer N rate at Winnipeg in 2006.

Sampling Time	Pre- planting (18th May 2006)					Tillering (29th June 2006)			Flowering (21st July2006)			Maturity (14th August 2006)				
Soil Depth (cm)	0-15	15-60	60-120	0-60	0-120	0-15	15-60	0-60	0-15	15-60	0-60	0-15	15-60	60-120	0-60	0-120
	kg ha^{-1}															
Treatments																
Medic	21.87	26.35	25.40	48.22	73.62	42.03	30.83	72.87	37.92	51.57	89.48	36.63	20.73	18.68	57.37	76.05
Non-medic	17.95	19.05	12.73	37.00	49.73	39.80	28.60	68.40	38.10	50.43	88.53	23.17	15.17	11.98	38.33	50.32
LSD ($P \leq 0.05$)	14.76	8.62	27.95	22.35	40.67	59.47	50.28	108.54	32.29	36.08	60.47	38.48	13.36	5.58	50.81	23.72
100% N fertilizer	19.07	22.98	21.68	42.05	63.73	67.43	39.82	107.25	67.07	84.62	151.68	42.23	20.73	18.67	62.97	81.65
No N fertilizer	20.75	22.42	16.45	43.17	59.62	14.40	19.62	34.02	8.95	17.38	26.33	17.57	15.17	11.98	32.73	44.72
LSD ($P \leq 0.05$)	4.96	16.68	14.93	15.60	16.14	25.70	22.54	46.16	38.92	61.88	109.63	20.46	7.77	4.60	26.56	29.60
Significance (P)																
Replicate	0.086	^{z}0.884	0.463	^{z}0.467	0.193	^{z}0.353	^{z}0.668	0.517	0.671	^{z}0.553	^{z}0.599	0.238	^{z}0.213	^{z}0.075	0.197	0.117
Medic	0.094	0.281	0.078	0.096	0.127	0.253	0.744	0.384	0.915	0.955	0.940	0.094	0.081	0.029	0.066	0.038
N fertilizer	0.400	0.960	0.298	0.619	0.740	0.003	0.083	0.002	0.002	0.022	0.007	0.004	0.098	0.029	0.008	0.007
Medic*N ferti	0.309	0.679	0.552	0.428	0.512	0.587	0.476	0.510	0.614	0.861	0.964	0.189	0.537	0.214	0.248	0.198
CV (%)	15.56	45.84	48.87	22.84	16.33	39.18	47.31	40.76	63.89	87.92	76.83	42.69	27.01	18.73	34.62	29.23

^{z} Natural log transformation was used to achieve homogeneity of variance and a normal distribution. Treatments means were presented as original, untransformed values

Table 3.7. Soil NO_3^--N in the soil profile of oat as influenced by medic cover crop and fertilizer N rate at Indian Head in 2006.

Sampling Time	Pre-planting (6th May 2006)					Tillering (6th June 2006)			Flowering (5th July 2006)			Maturity (3rd, August 2006)				
Soil Depth(cm)	0-15	15-60	60-120	0-60	0-120	0-15	15-60	0-60	0-15	15-60	0-60	0-15	15-60	60-120	0-60	0-120
	----------	----------	----------	----------	----------	----------	----------	----------	kg ha^{-1}	----------	----------	----------	----------	----------	----------	----------
Treatments																
Medic	8.32	26.62	nd [x]	34.94	nd [x]	78.33	97.16	175.49	18.08	19.80	37.88	14.93	13.47	58.79	28.40	87.19
Non-medic	7.70	23.16	nd	30.86	nd	80.71	103.50	184.21	16.08	33.99	50.07	14.20	12.34	36.37	26.54	62.91
LSD ($P \le 0.05$)	3.77	3.15	nd	3.15	nd	91.51	131.35	222.48	5.19	43.28	40.19	8.08	2.86	88.75	10.76	89.81
20% N fertilizer	8.00	21.28	nd	29.28	nd	46.72	64.45	111.17	16.83	23.52	40.35	12.50	11.78	22.43	24.28	46.72
60% N fertilizer	6.88	20.32	nd	27.20	nd	61.27	88.57	149.83	17.02	20.75	37.77	16.25	11.78	53.80	28.03	81.83
100% N fertilizer	9.15	33.07	nd	42.22	nd	130.58	147.97	278.55	17.38	36.42	53.80	14.95	15.15	66.50	30.10	96.60
LSD ($P \le 0.05$)	1.64	5.46	nd	4.76	nd	49.08	42.65	88.90	3.10	25.18	24.44	7.35	5.63	38.02	10.56	46.36
Significance (*P*)																
Replicate	0.426	[z] 0.252	nd	0.544	nd	[z] 0.749	[z] 0.029	[z] 0.331	0.361	[z] 0.010	[z] 0.016	0.387	[z] 0.125	[z] 0.007	0.136	[z] 0.016
Medic	0.316	0.041	nd	0.042	nd	0.706	0.605	0.968	0.106	0.034	0.110	0.785	0.789	0.098	0.633	0.190
N fertilizer	0.038	0.001	nd	0.000	nd	0.002	0.001	0.001	0.918	0.241	0.222	0.519	0.378	0.011	0.471	0.049
Medic*N ferti	0.161	0.127	nd	0.106	nd	0.475	0.970	0.669	0.488	0.269	0.162	0.754	0.452	0.825	0.463	0.866
CV (%)	15.41	16.47	nd	10.87	nd	46.36	31.93	37.13	13.64	70.33	41.75	37.92	32.81	60.02	28.86	46.40

[z] Natural log transformation was used to achieve homogeneity of variance and a normal distribution. Treatments means were presented as original, untransformed values

[x] nd indicates that the value was not determined.

3.4.4 Tissue N concentration

In the current study, in-season tissue N concentrations were measured to assess the N status of crops grown in the medic and non-medic soils. Medic and N fertilizer effects on tissue N concentration were discussed separately due to lack of significant interactions except for Winnipeg oat at flowering stage. The Winnipeg spring wheat did not show any significant fertilizer effect on tissue N concentration. However, oats at both sites showed very significant fertilizer effects (Tables 3.8, 3.9 and 3.10), agreeing with Mohr et al. (2004) who found N fertilization significantly increased whole plant oat N concentration. Surprisingly, medic had no significant influence on tissue N concentration in any cases (Tables 3.8, 3.9 and 3.10). The oat tissue N values obtained in the present study were close to the values obtained by Mohr et al. (2004) and de-Rocquigny et al. (2004). Because of the lack of significant medic effects on tissue N concentration, the hypothesis that medic would increase main crop tissue N concentration has to be rejected.

3.4.5 Biomass production

Regardless of treatment effects, all crops in the current study generally followed a similar pattern of biomass accumulation over various growth stages, with biomass increasing at early growth stages, and then reaching a maximum at late growth stages. Again, no significant interactions were observed in main crop biomass production at either site ($P \leq 0.05$). Therefore, main plot and sub-plot effects were considered as independent factors. Fertilization effect was very significant in all stages of the Indian Head oats and also for Winnipeg spring wheat at maturity stage but not for the Winnipeg oat at any stage (Tables 3.8, 3.9 and 3.10). The results for the effect of N fertilizer on biomass production resulted in no consistent trend, so no general conclusion can be made. Similar to the tissue N results, medic had little influence on biomass production, except for oats at Indian Head at the tillering stage (*P*=0.019).

Brinkman and Rho (1984) reported 9700 kg ha^{-1} and Hamill (2002) reported 10,000 kg ha^{-1} oat biomass production when oat was clear-seeded. Interestingly in the present study, under medic-oat intercropping, higher oat biomass (10,885 kg ha^{-1}) was obtained at the Indian Head site at the maturity stage. Similar to this Jeranyama et al. (1998) estimated that when medic was inter-seeded with corn, an increase of 19% in ground corn biomass increase was observed. This biomass increase could contribute to more herbage N. They also confirmed there was no biomass reduction observed in the corn-medic inter-seeded system due to medic. Similarly, no significant dry matter reduction due to the medic in the current study indicates the low competitiveness of this under story cover crop, black medic, for resources with main crop. According to de Rocquigny et al. (2004) oat dry matter accumulation under good growing conditions in Manitoba was 12,000 kg ha^{-1} at maturity. In the current study only 4,224 kg ha^{-1} oat biomass was produced in medic plots at the Winnipeg site due to unfavourable growing condition. Overall, medic had little effect on biomass production in this system.

3.4.6 Plant N uptake

Total plant N is a function of tissue N concentration and plant dry matter. Like biomass, N uptake in all crops generally increased with time, and reached a maximum at late growth stages regardless of treatment effects. Once again, there was no significant interaction effect observed between medic and N fertilizer except for the Winnipeg spring wheat N uptake at maturity stage (Tables 3.8, 3.9 and 3.10). A significant fertilizer effect was observed at all development stages for the Indian Head oats but only at maturity stage for the Winnipeg oats.

Both N fertilizer rate and medic had no significant influence on the Winnipeg spring wheat or oat N uptake at any stage (Table 3.8). This could be attributed to the low tissue N content and low biomass production of spring wheat due to drought condition in 2006. In spring wheat –clover intercropping study, Garand et al. (2001) estimated higher value than in the current study for spring wheat N uptake (137 kg N ha^{-1}) at harvesting stage. At the Indian Head site, medic significantly increased oat N uptake at tillering stage (Table 3.10); however, no differences were observed at flowering or maturity stages (Table 3.10). Of the N returned to the soil as legume residue, not all is immediately available for uptake by subsequent crops. Although the proportion of legume derived N recovered by the following crop is relatively small compared to total amount of N fixed, legumes significantly influence soil N status and the N supplying power of the soil (Campbell et al. 1994). The hypothesis of medic effect on plant N uptake under field conditions has to be rejected due to insignificant results in all cases, except Indian Head oat at tillering stage.

Table 3.8. Tissue N concentration (N%), biomass accumulation (BM) and plant N uptake (N uptake) of spring wheat as influenced by medic cover crop and fertilizer N rate at Winnipeg in 2006.

Sampling Time	Tillering (29th June 2006)			Flowering (21st July 2006)			Maturity (14th August 2006)		
	N%	BM kg ha^{-1}	N uptake kg ha^{-1}	N%	BM kg ha^{-1}	N uptake kg ha^{-1}	N%	BM kg ha^{-1}	N uptake kg ha^{-1}
Treatments									
Medic	2.06	1221	25.1	1.13	2280	25.6	1.19	3854	44.2
Non-medic	2.17	1205	26.0	1.09	2428	25.9	0.99	4027	40.5
LSD ($P \leq 0.05$)	0.62	512	17.2	0.11	83	3.9	0.84	1089	36.9
100% N fertilizer	2.03	1260	25.7	1.06	2592	27.3	1.06	4259	44.7
No N fertilizer	2.19	1165	25.4	1.16	2116	24.3	1.12	3623	40.0
LSD ($P \leq 0.05$)	0.49	180	6.3	0.12	532	3.9	0.24	459	6.2
Significance (*P*)									
Replicate	0.232	0.050	0.183	0.805	0.051	0.014	0.127	0.008	0.046
Medic	0.579	0.823	0.711	0.468	0.485	0.851	0.095	0.355	0.176
N fertilizer	0.428	0.219	0.899	0.074	0.068	0.105	0.529	0.018	0.102
Medic*N fertilizer	0.250	0.199	0.088	0.087	0.487	0.711	0.173	0.070	0.019
CV (%)	14.75	9.30	15.50	6.82	14.10	9.64	14.27	7.27	9.16

Table 3.9. Tissue N concentration (N%), biomass accumulation (BM) and plant N uptake (N uptake) of oat as influenced by medic cover crop and fertilizer N rate at Winnipeg in 2006.

Sampling Time	Tillering (29th June 2006)			Flowering (21st July 2006)			Maturity (14th August 2006)		
	N%	BM kg ha^{-1}	N uptake kg ha^{-1}	N%	BM kg ha^{-1}	N uptake kg ha^{-1}	N%	BM kg ha^{-1}	N uptake kg ha^{-1}
Treatments									
Medic	2.07	1260	26.0	0.88	2260	20.0	1.25	4223	53.3
Non-medic	1.99	1259	24.9	0.87	2603	22.6	1.26	3751	47.8
LSD ($P \leq 0.05$)	0.49	134	2.6	0.10	721	7.8	0.13	737	13.6
100% N fertilizer	2.07	1282	26.5	0.84	2406	20.4	1.48	4315	63.9
No N fertilizer	1.98	1238	24.4	0.90	2457	22.3	1.03	3659	37.2
LSD ($P \leq 0.05$)	0.17	265	3.4	0.03	1031	9.1	0.34	919	13.3
Significance (P)									
Replicate	0.863	0.330	0.177	0.263	0.219	0.238	0.628	0.249	0.643
Medic	0.235	0.991	0.427	0.275	0.408	0.472	0.960	0.227	0.317
N fertilizer	0.220	0.669	0.168	0.004	0.899	0.593	0.022	0.119	0.005
Medic*N fertilizer	0.082	0.223	0.443	0.015	0.978	0.766	0.671	0.799	0.957
CV (%)	5.28	13.17	8.51	2.09	26.45	26.66	17.06	14.39	16.48

Table 3.10. Tissue N concentration (N%), biomass accumulation (BM) and plant N uptake (N uptake) of oat as influenced by medic cover crop and fertilizer N rate at Indian Head in 2006.

Sampling Time	Tillering (6th June 2006)			Flowering (5th July 2006)			Maturity (3rd August 2006)		
	N%	BM kg ha^{-1}	N uptake kg ha^{-1}	N%	BM kg ha^{-1}	N uptake kg ha^{-1}	N%	BM kg ha^{-1}	N uptake kg ha^{-1}
Treatments									
Medic	4.85	365	17.82	1.99	5358	111.1	1.07	10885	117.62
Non-medic	4.82	294	14.17	1.86	5172	99.3	0.98	9529	94.60
LSD ($P \leq 0.05$)	0.44	143	6.01	1.10	609	67.4	0.26	4535	59.23
20% N fertilizer	3.94	318	12.62	1.40	3929	55.6	0.92	7898	73.47
60% N fertilizer	5.19	382	19.90	1.90	5914	113.4	0.94	11540	109.40
100% N fertilizer	5.37	288	15.47	2.47	5952	146.6	1.21	11181	135.46
LSD ($P \leq 0.05$)	0.21	67	3.71	0.39	436	25.9	0.23	1158	22.44
Significance (P)									
Replicate	[z] 0.070	0.142	0.099	0.708	0.008	0.203	0.051	0.452	0.021
Medic	0.716	0.019	0.024	0.361	0.262	0.237	0.302	0.327	0.236
N fertilizer	0.000	0.034	0.006	0.001	0.000	0.001	0.031	0.002	0.001
Medic*N fertilizer	0.699	0.149	0.192	0.811	0.404	0.985	0.902	0.917	0.649
CV (%)	3.27	15.39	17.42	15.18	6.22	18.54	16.68	8.52	15.88

[z] Natural log transformation was used to achieve homogeneity of variance and a normal distribution. Treatments means were presented as original, untransformed values

3.4.7 Total N at different growth stages

To determine the total N available at each crop growth stage, the N uptake (in kg ha^{-1}) of spring wheat and oat at each growth stage and soil NO_3^--N (in kg ha^{-1}) at 0-60 cm for the corresponded growth stage were combined (Tables 3.11 and 3.12). It was felt that analyzing above (crop) and below ground N (soil) at the same date could be very effective to study the role of black medic on N dynamics. Like in other cases, there was no significant interaction between medic and fertilizer rates in any instances. As expected, fertilizer application significantly increased total available N in all cases (Tables 3.11 and 3.12). Results of this analysis indicated that medic generally did not affect total N availability (Tables 3.11 and 3.12). The only and important exception was at oat maturity at Indian Head where the medic plots had 48 kg ha^{-1} greater N (Table 3.12). This observation indicates that at the only location with favourable growing conditions, black medic significantly contributed to the N supply.

Synchrony of plant N demand and N supply from various sources plays a major role in the N accumulation process. The N contribution of a cover crop will not be fully realized by the subsequent crop unless the cover crop N becomes available during the period of high N demand by the summer grain crop (Hargrove, 1986). Perhaps the lack of significant effect at the Winnipeg site was attributed to drought conditions. Delay in early precipitation for Winnipeg oat meant that early N mineralization may have been limited and N uptake of mineralized N may have been low. According to Grant et al. (2005) temperature and moisture are the two important factors that determine availability of N in the Prairie soils. The prevailed dry weather and poor crop growth of Winnipeg site may cause reduction of N mobility and root activity in the soil. Further clarification such as green house and laboratory experiments on N release pattern, influence of C:N ratio and rate of mineralization of black medic residue would be required to better understand crop N demand and residue mineralization. The increase in overall N availability due to medic was higher throughout the growing season. Also, significantly higher (48 kg ha^{-1}) at the end of growing season at Indian Head site compared to Winnipeg site where conditions were not ideal for crop performance, and N mineralization.

Table 3.11. Total N (plant + soil) at Winnipeg spring wheat and oat plots as influenced by medic cover crop and fertilizer N rate at tillering, flowering and maturity in 2006.

Crop	Spring wheat			Oat		
Sampling time	Tillering	Flowering	Maturity	Tillering	Flowering	Maturity
	--------------------	--------------------	--------------------	kg N ha^{-1} --------------------	--------------------	--------------------
Treatments						
Medic	94.2	111.6	141.7	98.9	109.5	110.7
Non-medic	89.4	117.8	129.5	93.3	111.2	86.1
LSD ($P \leq 0.05$)	130.5	92.5	119.1	107.9	56.02	62.2
100% N fertilizer	128.5	176.2	194.7	133.8	172.1	126.8
No N fertilizer	55.1	53.2	76.5	58.4	48.6	70.0
LSD ($P \leq 0.05$)	53.6	74.8	65.6	47.9	112.7	32.6
Significance (*P*)						
Replicate	0.308	0.222 [z]	0.959	0.784	0.699 [z]	0.569
Medic	0.704	0.829	0.632	0.544	0.896	0.105
N fertilizer	0.006	0.010	0.007	0.005	0.014	0.008
Medic*N ferti	0.415	0.705	0.779	0.717	0.982	0.287
CV (%)	36.44	40.7	30.21	31.09	63.7	20.7

Total N = total plant N uptake + soil NO_3^--N at 0-60cm. Both samples were collected on same dates.
[z] Natural log transformation was used to achieve homogeneity of variance and a normal distribution and treatments means were presented as original, untransformed values

Table 3.12. Total N (plant + soil) at Indian Head oat plots as influenced by medic cover crop and fertilizer N rate at tillering, flowering and maturity in 2006.

Sampling time	Tillering	Flowering	Maturity
	------------------------- kg N ha $^{-1}$ ------------------------		
Treatments			
Medic	211.1	260.1	263.6
Non-medic	212.6	248.8	215.7
LSD ($P \leq 0.05$)	210.8	101.7	27.8
20% N fertilizer	136.4	151.6	171.2
60% N fertilizer	189.6	264.7	246.8
100% N fertilizer	309.5	347.1	301.0
LSD ($P \leq 0.05$)	84.6	41.1	50.5
Significance (*P*)			
Replicate	0.219 [z]	0.008	0.019
Medic	0.840	0.361	0.028
N fertilizer	0.001	0.001	0.001
Medic*N ferti	0.760	0.426	0.569
CV (%)	30.01	12.15	15.83

Total N = total plant N uptake + soil $No3^{-}$.N at 0-60cm. Both samples were collected on same dates.
[z] Natural log transformation was used to achieve homogeneity of variance and a normal distribution. Treatments means were presented as original, untransformed values

3.4.8 Grain yield

Similar to other cases, lack of significant interaction between medic and N fertilizer application on grain yield was observed for all cases. Again, very significant fertilizer influence on grain yield was observed in all cases (Table 3.13). No significant yield increase was measured due to medic at either site in 2006. The overall yield was very poor in Winnipeg because of the drought condition. Grant and Fernando (2006) also revealed that throughout the prairies, the yield potential and therefore the amount of N required to attain optimum yield is generally determined by the amount and timing of moisture. The higher the air temperature, the lower the yields and also shortage of water can cause serious loss of the grain yield of oat (Zute, 2002). This supports the reasons for low yield in Winnipeg where average high air temperature and low precipitation during heading of oat compare to Indian Head (Tables 3.3 and 3.4). The greater difference between yields in sites indicates the influence of climatic condition on yield rather than cover crop influence.

Table 3.13. Grain yield (kg ha^{-1}) of spring wheat and oat as influenced by medic cover crop and fertilizer N rate at Winnipeg and Indian Head in 2006.

Crop	Winnipeg spring wheat	Winnipeg oat	Indian Head oat
		--------kg N ha^{-1}--------	
Treatments			
Medic	566.1	1082.7	5069.5
Non-medic	835.5	930.8	4810.3
LSD ($P\leq 0.05$)	122.7	229.4	1887.0
Significance (*P*)			
Replicate	0.020	0.005	0.128
Medic	0.040	0.096	0.614
N fertilizer	0.444	0.058	0.001
Medic*N ferti	0.138	0.348	0.052
CV (%)	22.29	12.04	6.20

Due to competition with cover crop, it is reasonable to expect lower yields when cover crops are included in the cropping systems (Moynihan et al., 1996). Medic resulted in a lower spring wheat yield at Winnipeg (Table 3.13); however, no yield reduction in oat was observed. The yield of 5070 kg ha^{-1} at Indian Head oats in medic plots is closer to the average oat yield (5140 kg ha^{-1}) reported in 2004 (Statistics Canada, 2004). No significant effect of medic on oat was observed at Indian Head (Table 3.13). In Montana, Sims and Slinkard (1991) adapted the Australian ley farming system to a conventional cropping system by replacing fallow with a rotation of annual medics, including black medic. They reported small-grain yields were doubled with medic-small grain compared to the fallow-small grain rotation. Moynihan et al. (1996) found George black medic was the least competitive with barley (*Hordeum vulgare* L.) and reduced weed biomass by 65% in a barley-medic intercropping system in North central United States. Alford et al. (2003), in Wyoming, found that there was no significant yield reduction of corn yield in corn-black medic system compared with other medics-corn and weed-free checks.

3.5 Summary and conclusions

This study evaluated the effect of long-term medic plots under very dry (Winnipeg) and more typical (Indian Head) growing conditions with different fertilizer regimes. It was hypothesized that the long-term black medic cover crop would increase soil nitrate N, plant biomass, tissue N concentration, plant N uptake and total available N under no-till management with different fertilizer rates. However, based on the mixed and conflicting results, the null hypothesis of the study has to be accepted for most of the cases.

Soil nitrate N levels were not statistically significantly different ($P \leq 0.05$) for medic and non-medic plots at any sampling date at any individual soil depths (0-15, 15-60 and 60-120 cm) at both sites. However, medic treatment showed increases in soil N when analyzed as combined depths 0-60 and 0-120 cm. This is because, the small differences on soil NO_3^--N due to medic from individual depths accumulated and statistically significant when all the depths were combined into 0-60 and 0-120 cm. The results of this study pointed out that in short-term, soil nitrate tests were not very sensitive to the black medic effect. The field performance of black medic in the current study in terms of biomass production and plant density was comparable with previous studies testing black medic and other cover crops. Also, at Indian Head significantly higher medic density and biomass was observed in low fertilizer N regime. Alford et al. (2003) concluded that George black medic appears to offer the greatest potential for intercropping because of minimal crop competition in the early season, no yield reduction and medic produces high quality forage.

In the current experiment, the general lack of significant interactions between the medic cover crop and fertilizer N application rates throughout the growing season shows that they acted independently and this suggests that the medic can perform well in both low and high fertilizer N regimes. Thereby, regardless fertilizer regimes of a system of black medic can be included in prairie cropping system as a successful cover crop. Another common feature observed in the present study was significant influence of fertilizer application throughout the growing season. The amount of soil NO_3^--N decreases during the middle of growing season and increases during early (spring) and later stages (autumn) suggests that an active fraction of medic organic matter in the soils may exist. Under favourable growing conditions at Indian Head in 2006, regardless fertilizer rates, medic increased total N supply by 48 kg N ha^{-1}.

4. THE EFFECT OF A LONG-TERM BLACK MEDIC COVER CROP ON SOIL N SUPPLY POTENTIAL

4.1 Abstract

Little previous research in North America has attempted to quantify N benefits of self-regenerating legumes when included in a continuous cropping system. The objective of this study was to determine how a black medic (*Medicago lupulina,* cv George) cover crop affects N supplying power of surface soil (0-15 cm) under different rates of N fertilization. Two no-till long-term field experiments were used for this study; one located in Department of Plant Science Research Station (Point), University of Manitoba (established in 2000) and other one located at the Agriculture and Agri-Food Canada Research Farm in Indian Head, Saskatchewan (established in 2001). The crop rotation is flax (*Linum usitatissimum*)-wheat (*Triticum aestivum*)-oat (*Avena sativa*). Main plot factor is presence of medic while the subplot effect is N fertilizer rates. In 2005 and 2006 soil samples were collected from surface soil (0-15 cm) in late autumn after main crop harvest and a series of test crops wheat (*Triticum aestivum*) - oat (*Avena sativa*) - canola (*Brassica napus*) - fall rye (*Secale cereale*) grown continuously in a growth chamber to extract plant available N. Total N uptake of test crops was determined by measuring tissue N concentration and biomass accumulation. Regardless of N fertilizer rates, N uptake increases due to black medic were 33 kg ha^{-1} and 38 kg ha^{-1} in 2005 and 2006 at Winnipeg, respectively. N uptake increase due to black medic was 32 kg ha^{-1} and 48 kg ha^{-1} in 2005 and 2006 at Indian Head, respectively. These results clearly show that in any rate of N fertilizer applications, long-term black medic contributes a significant amount of N (average of 38 kg ha^{-1}) to this unique cropping system in which the self-regenerating black medic is continuously grown along with main crops. This amount of additional N

could help farmers to save a portion of N fertilizer cost. The major conclusion is that the black medic increases soil N supplying power thereby providing farmers with the opportunity to reduce fertilizer N application.

4.2 Introduction

Achieving optimum yields without applying excessive nitrogen in the form of synthetic fertilizers is a goal to minimize cost of production as well as to protect the environment. At this juncture, the search for alternative natural sources of N is increasing and the inclusion of legumes in cropping systems is receiving more attention. In a number of experiments, the effect of various legumes on N availability to subsequent crops has been studied under different systems. The often fertilizer replacement values of annual medics, red clover (*Trifolium pretense*), alfalfa (*Medicago sativa*), hairy vetch (*Vicia villosa*), field pea (*Pisum sativa*), chick pea (*Cicer arietinum*) and soybean (*Glycine max)* were in the range of 15 to 82 kg N ha^{-1} when inter-seeded with a main crop as a N source (Hargrove, 1986; Scott et al., 1987; Zhu et al., 1998; Grand et al., 2001; Hoeppner, 2001; Thiessen-Martens et al., 2001; Mayer et al., 2003; Sarrantonio and Gallandt, 2003). Legume-derived N is reported as N credits in the calculation of fertilizer N recommendations.

During the autumn period after harvest of the main crop, temperature and light conditions allow some plant growth, though not enough to produce commercial crops. Many attempts have been made to use this period to grow plants, which reduce nutrient leaching or improve the soil in various other ways (Thorup-Kristensen et al., 2003). Such crops are often termed catch crops, cover crops or green manures. According to Thiessen-

Martens and Entz (2001) the availability of late season heat and water resources for relay and double cropping to include cover crops such as black medic is possible in Prairie Canada.

Black medic offers many agricultural applications. Black medic (*Medicago lupulina* L.) as a new legume cover crop with proven self-regenerating capacity could be a potential alternative for Canadian prairies to reduce annual re-seeding cost along with its N benefit (Braul, 2004).The self-regenerating ability of black medic from the soil seed bank was well documented by previous studies (Carr et al., 2005; Wilson, 2005; Braul, 2004). This distinct nature of black medic will help to reduce the annual re-seeding cost for farmers. Black medic can serve as a cover crop (Moynihan et al., 1996; Entz et al., 2002; Alford et al., 2003), a forage crop (Zhu et al., 1996; Zhu et al., 1998; Sheaffer et al., 2003; James et al., 2003) and a smother crop (De-Haan et al., 1997; Sheaffer et al., 2002). Also black medic is a cold tolerant crop, suitable for temperate region. Cold tolerance is also increasingly important when cover crops are grown later in the season, as their N effect then depends more on their ability to continue growth into the colder periods (Brandsaeter et al., 2002). Sims and Slinkard (1991) stated that black medic had the potential to replace summer fallow in a wheat-fallow cropping system in Montana. This past research highlights the importance of black medic and suggests the possibility to use black medic in Canadian cropping systems.

Estimation of N supplying power of black medic would help farmers design a successful self-seeded cover cropping system with less N fertilizer requirement, thereby allowing maximization of net returns. A few studies to determine the dry matter and N production of black medic have been done in North America (Zhu et al., 1998; Jeranyama et al., 1998; Carr et al., 2005). The purpose of this study was to determine the N benefit of black medic in a unique cropping system at Winnipeg and Indian Head where black medic has been continuously grown along with cereals under no-till practice.

There are a number of chemical and biological laboratory and/or field methods to assess the N mineralization potential of soils which have grown legumes. For example, laboratory incubations, chemical extractions, measurements of N mineralization in the field, and N^{15} labeled techniques have all been used previously (Charoulis et al., 2005). Amongst these approaches, plant bioassay is considered an efficient method to measure N supplying power of legume-amended soils (Mohr, 1996). A plant bioassay is a simple, inexpensive, accurate, easy to perform and a direct method to determine the plant available nitrogen (Palmer et al., 2007). As the soil microbial community plays a major role in N-transformations, especially in mineralization, biological assays where live plant roots extract N may be more reliable than chemical methods.

The main objective of this study was to quantify the N contribution of black medic that could be useful for subsequent crops. Bioassays were carried out using soils from two long-term black medic rotation experiments with different N fertilizer regimes in dry sub humid (Indian Head) and sub humid (Winnipeg) regions of Canada. In the previous field experiment (Chapter 3), medic and oats were grown simultaneously. In that case, the medic presence was not completely eliminated. The present study provided more controlled conditions. The following hypothesis was established:

Tissue N concentration, biomass accumulation, N uptake and cumulative N uptake of test crops will be higher in black medic treated soils than the control treatment.

4.3 Materials and method

4.3.1 Soil sample collection and preparation

Two long-term, no-till, continuous grain cropping systems located in Indian Head, Saskatchewan and Winnipeg, Manitoba were used in this study. The experimental sites were each designed as a randomized complete block with three replicates and had a rotation of flax (*Linum usitatissimum*)-wheat (*Triticum aestivum*)-oat (*Avena sativa*) with and without black medic as main plot treatment. The Winnipeg site had two N fertility levels (with and without N fertilizer) and the Indian Head site had three N fertility treatments (20%, 60% and 100% N fertilizer of recommended rate) as sub plot treatments.

In both sites, soils were sampled from the plots where flax was previously grown. Soil samples were collected in late autumn from surface soil (0-15 cm) using hand augers. For each sample, 5 kg of soil was collected from ten randomly selected cores within each plot. Soil was air dried at room temperature (22°C) and prepared by hand breaking to avoid big pieces. For each pot 3200 g (dry basis) soil was used in this experiment. This amount of soil was much greater than that of Palmer et al. (2007) who used only 300 g soil (dry basis) per pot to study the effect of soil management history on nitrogen mineralisation.

To obtain 3200 g dry soil, fresh soil needed for each pot was calculated using the moisture contents of soils. Gravimetric water contents of both soils (Winnipeg 42.4% and Indian Head 32.68%) were determined in the laboratory by drying sub-samples in the oven for 24 hours at 105 °C. From each soil, fresh soil (equal to 3200 g dry weight) was placed into pots with a dimension of 20 cm in height and 25 cm in diameter. Pots were well-cleaned and lined with plastic bags to prevent any leaching of soil/nutrients with water. All pots were properly labeled and randomly placed into a growth chamber (Figure 4.1a).

4.3.2 Growth chamber experiment

Bioassays were conducted in both 2005 and 2006 to determine the plant available mineral N from long term black medic experimental sites by growing a series of non legume crops in each pot in the growth chamber (model GRV36, serial 81A2, Enconaire systems Ltd.). A total of 18 pots were used from the Indian Head rotation representing six treatment combination (two main plot effects × three sub plot effects) with three replicates and a total of 12 pots were used from the Winnipeg rotation representing four treatment combination (two main plot effects × two subplot effects) with three replicates. All 30 pots were arranged randomly and rotated twice a week during each watering to reduce the variation of light and heat in the growth chamber.

The field capacity of Winnipeg soil (64.9%) and Indian Head soil (63.3%) was determined. According to field capacities of soils, the watering schedule was prepared for each pot to maintain average of 80% field capacity levels according to crop performance. In cases where crops had showed wilting or over watering sign, watering regime was slightly adjusted between 70 to 90% field capacities (wetter than the field conditions). However, all pots within the experiment always had a similar watering regime. The amount of water added for each pot to reach different field capacities was calculated in grams. Then the final weights (Appendix L) corresponded to field capacity levels calculated by adding soil, empty pot and needed water weights. Pots were placed on top of the balance (Mettler digital scale, model PE11) and water was carefully added using a small water can till the corresponded final weights were reached.

4.3.3 Crop establishment and management in the growth chamber

In the 2005 bioassay, three consecutive non legumes, wheat (cv. AC Barrie), oat (cv. AC Assiniboia) and canola (cv. Reston) which are popular crops grown in the prairies were planted and in the 2006 bioassay instead of canola, fall rye (cv. AC Remington) was planted as the third crop. Also re-growth of fall rye was used as one of the test crops in the 2006 bioassay. Rye demonstrated quick growth response to N that could be helpful in extractions maximum plant available N. It was impossible to extract greater amount of N by growing only one crop because crops had showed variation to response to N under controlled environment; some are quick and some others are slow. Also it take time to release N from medic residues through the mineralization process. These are the reasons for growing a series of test crops in this experiment.

Shortly after emergence, crops were thinned to 14 wheat, 12 oats, 4 canola or 12 rye plants per pot according to the spacing and number of plants germinated (Figure 4b). Weed and black medic seedlings were removed upon emergence to avoid competition with the main crop growing in the pots. Pots were weighed periodically, to determine the soil moisture content and water was added three times a week for the first two weeks to facilitate germination, then , twice a week up to harvest to maintain soil moisture content. Frequent observation was done for soil borne pest and disease outbreak. According to each crop type, day and night temperatures in the growth chamber were maintained as for wheat 22 and 18 ^{o}C, for oat 21 and 18 ^{o}C, for canola 20 and 15 ^{o}C and for fall rye 22 and 17 ^{o}C (warmer than field conditions). The total incubation period of bioassays were 110 and 130 days in 2005 and 2006, respectively which is slightly longer than a summer growing period (slightly longer than field summer growing season).

4.3.4 Measurements

The crops were grown up to the flowering stage to capture the maximum plant available N, at which point above ground biomass of each crop was harvested (Figure 4.1d). After each crop, the soils in the pots were well mixed by folks. The top growth was cut at the soil surface using a scissor or a knife and biomass amount per pot was determined after drying samples for 48 hours at 65°C. Then plant tissue samples were ground by a Willey mill, sieved through a 2 mm sieve. Processed tissue samples were analyzed for total nitrogen concentration by combustion using Leco N analyzer (model LECO-FP528, Leco Corp., St. Joseph, Michigan, 49085) in the Department of Plant Science laboratory.

Cumulative N uptake by all crops was calculated as the sum of N uptake by each individual crop such that the final cumulative value was the sum of N uptake of all (three in 2005 and four in 2006) consecutive crops. Root N was not measured due to practical difficulties. However, the top growth contains 80 to 90% of the total N compared to roots (Hargrove, 1986). Before seeding the pots, initial soil nitrate test was done by cadmium reduction method on a Technicon autoanalyser. (AGVISE Laboratories, 604 Hwy 15, PO Box 510, Northwood, ND 58267).

4.3.5 Statistical analysis

The data was tested for normality and homogeneity of variance by using Proc Univariate (SAS Institute) procedure prior to ANOVA. If the data were found to be non-homogeneous they were log transformed and re-analyzed to meet the assumptions of ANOVA. An analysis of variance was performed for randomized complete block design using the general linear model procedure (Proc GLM, SAS Institute Inc.) *P* values less than or equal to 0.05 were considered as significant effects in the current experiment.

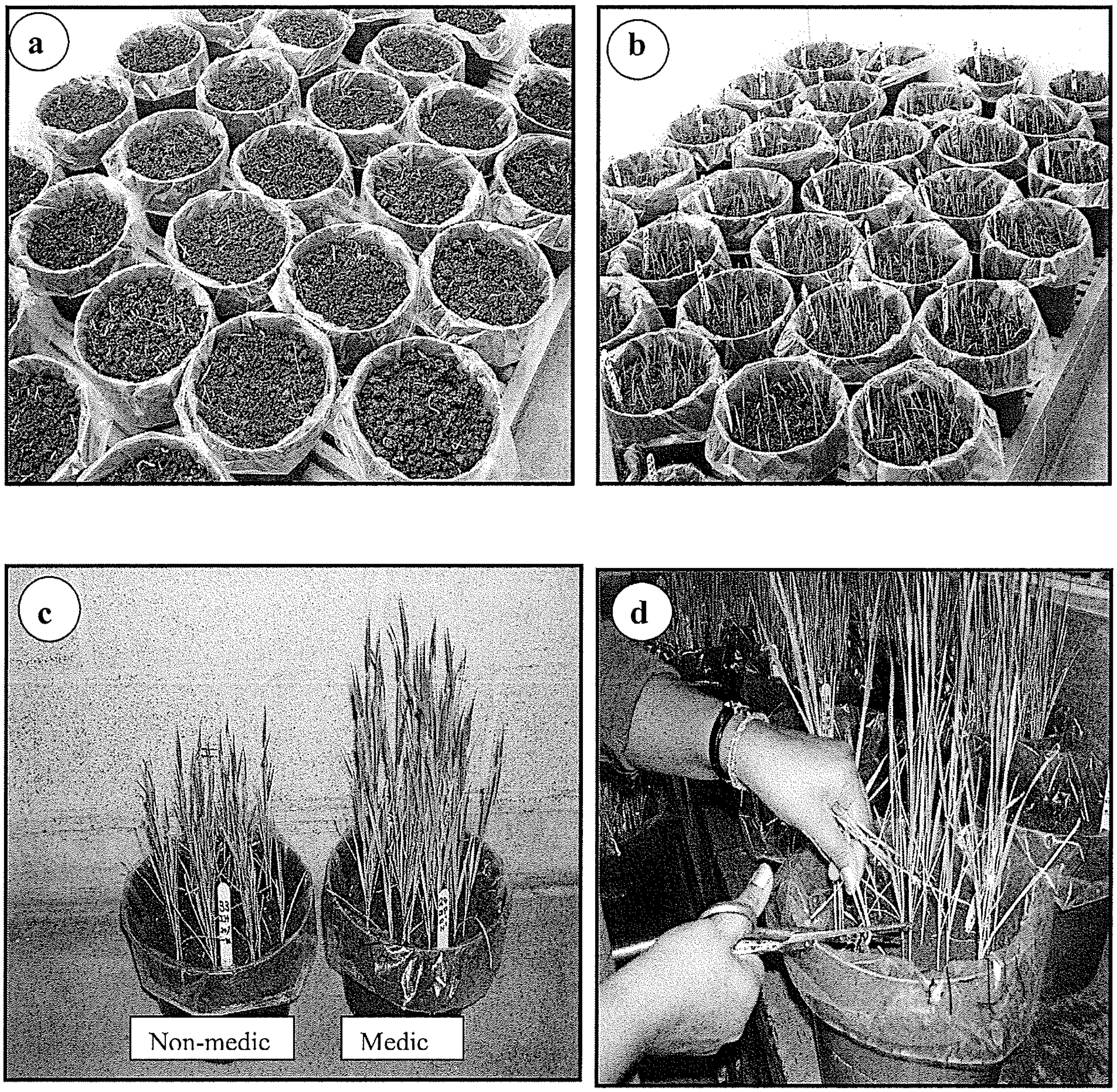

Figure 4.1. a) Prepared soil placed in the pots and ready for planting in the growth chamber. b) Wheat germination in pots in the growth chamber. c) Growth differences in plants between medic and non-medic treatment. d) Harvesting above ground biomass of bioassay wheat.

4.4 Results and discussion

4.4.1 Initial soil nitrate N at the beginning of bioassays

The soils for this experiment were sampled from the depth of 0-15 cm in late autumn 2005 and 2006 from Indian Head and Winnipeg sites. Initially, a soil nitrate N test was done to determine the N status of medic and non-medic soils at the beginning of bioassays. At three of four site-years, soil nitrate N was significantly higher in the medic compared with non-medic plots (Table 4.1). Average increases in N available due to medic at the beginning of 2005 and 2006 bioassays were 5 kg ha^{-1} and 11 kg ha^{-1}, respectively (Table 4.1). No significant fertilizer residual N effect was found in this test suggesting that the majority of readily available fertilizer N used by the crops during the summer. The only exception was Winnipeg 2006 (P=0.0143) where higher available soil N was attributed to the fact that the crop performance was not enough to use the fertilizer N due to the dry summer. Meanwhile, the lowest amount of soil residual N found in Indian Head 2006 after main crop harvesting showed oats had been efficiently used fertilizer N at this site and this was confirmed by the good oat biomass production obtained in 2006 field experiment. These results clearly show that medic within the cropping system increased the amount of available N in the soil. Also, the medic effect was stronger in three site years than the fertilizer effect which confirms that the medic helps to sustain this cropping system through continuous recycling of mineral N.

Soil N present in the late autumn is partially the result of what happened during the summer growing season. After the main crop harvest, N mineralization of crop and medic residues can take place until late autumn. There are some benefits and risks associated with this extra N from mineralisation. For example, during this period because of no main crop, mineralized N can be utilized by late season or early spring medics and weeds. This N can also be leached out during the autumn and spring due to precipitation or during snowmelt. For example in 2006, for Winnipeg spring wheat at maturity higher soil N (0-15 cm) was observed in the fertilizer N treated plots (table 3.5). But, at autumn in surface soil samples lower residual N observed for the same plots (table 4.1). The reason is Winnipeg site had received higher precipitation (table 3.2) in August after dry summer months may leached out the N from the surface.

Table 4.1. Initial soil NO_3^-- N (kg ha^{-1}) for 2005 and 2006 bioassay soils collected from 0-15 cm depth at Winnipeg and Indian Head.

	Winnipeg		Indian Head	
	2005	2006	2005	2006
Treatments				
Medic	33.92	34.22	39.60	22.73
Non-medic	24.38	20.88	38.86	14.86
LSD ($P \leq 0.05$)	2.84	11.86	14.91	6.60
100% N fertilizer	31.72	38.60	-	-
No N fertilizer	26.58	16.50	-	-
LSD (P=0.05)	7.72	17.53	-	-
20% N fertilizer	-	-	39.05	19.25
60% N fertilizer	-	-	36.85	19.06
100% N fertilizer	-	-	41.80	21.08
LSD ($P \leq 0.05$)	-	-	9.11	5.53
Significance (P)				
Replicate	0.171	0.369 [z]	0.175	0.269
Medic	0.027	0.049	0.826	0.017
N fertilizer	0.139	0.014	0.488	0.663
Medic*N ferti	0.119	0.535	0.657	0.485
CV (%)	16.52	10.92	17.45	20.97

z Natural log transformation was used to achieve homogeneity of variance and a normal distribution. Treatments means were presented as original, untransformed values

The rest of the N after the losses can remain in the soil and some of this can still be available in the next season. De-Haan et al. (1997) found that black medic has a low N requirement, thus did not use much N. So, when the samples were collected in the late autumn for the bioassay study, the higher N levels medic plots was likely due to medic N from fall mineralization. Consequently, this medic N could be used by the first test crop (wheat) that was grown in the bioassays. N uptake results from the bioassay agree with this concept.

4.4.2 Tissue N concentration of bioassay crops

Plant N content is an indicator of the plant's ability to accumulate N from soil. In the current study, tissue N concentration of all individual test crops of 2005 and 2006 bioassays were measured to determine N availability of medic and non-medic soils. Tissue N concentrations for test crops are shown in Tables 4.2 and 4.3. No significant interactions were found between main plot effect and sub plot effect except for 2006 Indian Head canola, indicating that the main plot (Black medic treatment) and sub plot (N fertilizer application) effects were mostly independent in this study. Therefore, main plot and sub plot effects will be discussed individually. No significant differences were observed between N fertilizer treatments in both sites for both years (Tables 4.2 and 4.3). Since the soils were collected in autumn after crops used applied N fertilizer during the summer, significant N fertilizer residues were not expected in the samples. Hence, the discussion here will focus on the main plot, or the medic effect.

In this experiment, tissue N concentration range between 0.73 - 0.85, 0.64 - 0.84, 0.86 - 1.30 and 0.76 - 1.93 % for wheat, oat, canola and fall rye, respectively (Tables 4.2 and 4.3). The influence of black medic on tissue N concentration varied in this bioassay.

In some cases black medic significantly increased tissue N (i.e., for Winnipeg oat 2005 and in both years canola for Indian Head) but in other instances, N tissue concentrations were not significantly different.

Table 4.2. Tissue N concentrations (%) of wheat, oat canola and fall rye in 2005 and 2006 bioassays for Winnipeg.

	2005			2006			
	Wheat	Oat	Canola	Wheat	Canola	Rye	Rye re-growth
Treatments							
Medic	0.82	0.84	0.86	0.77	1.30	0.84	1.81
Non-medic	0.81	0.64	0.88	0.73	1.21	0.76	1.67
LSD ($P \leq 0.05$)	0.24	0.06	0.17	0.12	0.30	0.31	0.60
100% N fertilizer	0.83	0.71	0.89	0.76	1.29	0.81	1.78
No N fertilizer	0.80	0.77	0.85	0.74	1.22	0.79	1.70
LSD ($P \leq 0.05$)	0.15	0.16	0.07	0.19	0.193	0.18	0.15
Significance (*P*)							
Replicate	0.646	0.495	0.098	0.819	0.513	0.318	0.296
Medic	0.898	0.026	0.677	0.546	0.286	0.274	0.060
N fertilizer	0.640	0.373	0.185	0.766	0.421	0.756	0.209
Medic*N ferti	0.971	0.809	0.952	0.759	0.680	0.429	0.275
CV (%)	11.70	13.59	5.19	15.79	9.58	13.67	5.30

Table 4.3. Tissue N concentration (%) of wheat, oat canola and fall rye in 2005 and 2006 bioassays for Indian Head.

	2005			2006			
	Wheat	Oat	Canola	Wheat	Canola	Rye	Rye re-growth
Treatments							
Medic	0.82	0.72	0.93	0.85	1.30	0.88	1.93
Non-medic	0.75	0.64	0.88	0.81	1.09	0.94	1.83
LSD ($P \leq 0.05$)	0.07	0.09	0.04	0.12	0.17	0.15	0.19
20% N fertilizer	0.77	0.67	0.87	0.80	1.23	0.92	1.95
60% N fertilizer	0.80	0.73	0.93	0.84	1.18	0.89	1.82
100% N fertilizer	0.79	0.65	0.92	0.86	1.16	0.92	1.86
LSD ($P \leq 0.05$)	0.09	0.17	0.14	0.13	0.14	0.18	0.35
Significance (*P*)							
Replicate	0.262	0.458	0.008	0.107	0.080	0.283	0.938
Medic	0.074	0.214	0.038	0.422	0.003	0.425	0.466
N fertilizer	0.665	0.587	0.542	0.623	0.599	0.906	0.682
Medic*N ferti	0.323	0.458	0.949	0.624	0.044	0.995	0.999
CV (%)	8.62	18.44	11.34	11.79	8.73	15.13	14.12

There was no negative effect observed in tissue N concentration due to medic at both sites. According to the hypothesis, higher tissue N concentration was expected for medic treatment but this was not observed in most cases.

4.4.3 Dry matter production of bioassay crops

Nitrogen is one of the important nutrients for biomass production. Biomass accumulation will increase when soils have more plant available N (Stopes et al., 1996). In this study, biomass accumulation of test crops was determined to differentiate the N availability of medic and non-medic soils. Once again, there was no significant interaction between main plot and sub plot observed in statistical analysis. Main plot (black medic treatment) and sub plot (N fertilizer rate) effects were independent (Tables 4.4 and 4.5) in all cases for the Indian Head and at four out of seven cases for Winnipeg. Since soils were sampled in autumn, very few chances for N fertilizer residues in sampled soils could be the reason for non-significant sub-plot effects except 2006 Winnipeg wheat (Table 4.4). Higher biomass production for the medic treatment was expected for all test crops. The concept behind this expectation is that the presence of a black medic legume cover crop will supply more N to test crops compare to non-medic and, therefore, this additional medic N would increase biomass accumulation of test crops.

Table 4.4. Biomass (g pot^{-1}) of wheat, oat canola and fall rye in 2005 and 2006 bioassay for Winnipeg soil.

	2005			2006			
	Wheat	Oat	Canola	Wheat	Canola	Rye	Rye re-growth
Treatments							
Medic	3.78	9.28	20.83	11.72	17.52	14.02	5.05
Non-medic	2.53	7.18	18.03	8.93	16.08	13.03	4.33
LSD ($P \leq 0.05$)	1.10	1.22	2.49	2.60	0.19	2.41	0.60
100% N fertilizer	3.03	8.35	19.33	11.20	16.70	13.62	4.62
No N fertilizer	3.28	8.12	19.53	9.45	16.90	13.42	4.77
LSD ($P \leq 0.05$)	1.30	0.27	3.72	0.89	0.54	1.74	0.19
Significance (*P*)							
Replicate	0.302 [z]	0.082	0.840 [z]	0.078	0.936	0.430	0.002
Medic	0.034	0.000	0.040	0.001	0.002	0.188	0.001
N fertilizer	0.815	0.074	0.903	0.005	0.359	0.766	0.094
Medic*N ferti	0.423	0.027	0.900	0.034	0.088	0.952	0.029
CV (%)	25.62	2.04	11.94	5.36	1.99	8.03	2.54

[z] Natural log transformation was used to achieve homogeneity of variance and a normal distribution and treatments means were presented as original, untransformed values

Table 4.5. Biomass (g pot^{-1}) of wheat, oat canola and fall rye in 2005 and 2006 bioassays for Indian Head soil.

	2005			2006			
	Wheat	Oat	Canola	Wheat	Canola	Rye	Rye re-growth
Treatments							
Medic	5.52	8.89	22.89	10.26	18.42	14.89	4.98
Non-medic	5.23	6.83	20.01	8.54	17.42	13.26	4.17
LSD ($P \leq 0.05$)	3.16	0.50	1.81	1.49	0.63	0.97	0.71
20% N fertilizer	5.25	7.73	21.73	9.43	18.05	14.09	4.70
60% N fertilizer	4.97	7.85	21.05	9.22	17.63	14.05	4.32
100% N fertilizer	5.92	8.00	21.57	9.55	18.08	14.10	4.70
LSD ($P \leq 0.05$)	1.61	0.46	1.28	0.70	1.04	1.22	0.83
Significance (*P*)							
Replicate	0.465	0.480	0.486	0.113	0.852	0.724	0.894
Medic	0.626	0.000	0.001	0.001	0.027	0.005	0.034
N fertilizer	0.418	0.448	0.475	0.562	0.565	0.994	0.497
Medic*N ferti	0.966	0.367	0.763	0.706	0.451	0.932	0.333
CV (%)	22.49	4.42	4.49	5.60	4.37	6.49	13.56

Results of ANOVA indicate that presence of black medic significantly increased biomass production of several bioassay crops. Figure 4.1c clearly exhibits the higher growth of medic treated crops compared to non-medic crops. The only exceptions were 2005 Indian Head wheat and 2006 Winnipeg rye (Tables 4.4 and 4.5). According to the overall results, the hypothesis for this study could be accepted. It can be concluded that the presence of long-term black medic will increase biomass accumulation of following crops under no-till cropping system.

4.4.4 N uptake of bioassay crops

Plant N uptake is the product of plant tissue N concentration and biomass production. Non-legume crops in rotation systems obtain N primarily from mineralization of various N sources such as soil organic matter, fertilizer residues, manures, and legume residues (Mayer et al., 2003), but the availability of each resource varies with time. In this bioassay study, soils were sampled at late autumn after harvest of the main crop. N uptake of all test crops (non-legumes) was measured to investigate the N supplying power of medic soils compared to non-medic soils.

The only significant interaction for plant N uptake between the main-plot and sub-plot was for canola grown in Indian Head soil in 2006. Otherwise the main plot and sub plot effects acted upon N uptake independently. As anticipated, no significant fertilizer treatment (sub plot) effect was observed in any instance (Tables 4.6 and 4.7) because there were no large amounts of fertilizer residues left in these soils at the time of sampling. Soils were sampled after main crop harvested in late autumn, when readily available fertilizer N had been utilized during the summer growing season by both main crops and medics. Significant medic treatment effects were observed at both sites and in both years (Tables 4.6 and 4.7). As no N was added during the experiment, test crops grown in pots were totally depended on residual N supplied by the soils which were collected from medic and non-medic plots. The difference in N uptake between the medic and control treatment (non-medic) was used to determine the residual N derived from the black medic cover crop plants.

The availability of N under black medic cover crop depends on the quantity of N in the biomass, the resources quality or chemical composition of residues (C:N) and the rate of N mineralization during decomposition. The mineralization of N from legume residues may vary considerably depending upon their chemical composition, with a low C:N ratio promoting rapid residue decomposition when the available N is low. Mineralization-immobilization turnover could alter the net plant available N controlled by C: N ratio of crop residue in the low level of available N. Net immobilization is favored at C:N ratios above 20:1, and net mineralization is favored when residues have C:N ratios below 20:1 (Havlin et al., 1999). According to Baggs et al. (2000) C: N ratio of black medic is 14:1. This value is within the range (8:1 to15:1) for other legumes such as red clover (*Trifolium pretense*), hairy vetch (*Vicia villosa*), and alfalfa (*Medicago sativa*) (Sullivan et al., 1991). These results suggest that black medic has a C:N ratio that is low enough for rapid mineralization of N in the later stages of bioassay when the available N become low, since no fertilizer is added.

The overall plant N uptake of individual crops was higher for both sites in 2006 than in 2005. The first year of the study (2005) was much wetter than the second year (2006) (Tables 3.1, 3.2 and 3.4). When comparing the sites, the Indian Head site showed more significant results of medic compared to the Winnipeg site. In general, rye, canola and rye re-growth had more N uptake, for both sites (Tables 4.6 and 4.7).

Table 4.6. Total N uptake (g pot^{-1}) of wheat, oat canola and fall rye in 2005 and 2006 bioassays for Winnipeg.

	2005			2006			
	Wheat	Oat	Canola	Wheat	Canola	Rye	Rye re-growth
Treatments							
Medic	0.030	0.078	0.180	0.091	0.227	0.107	0.093
Non-medic	0.020	0.045	0.156	0.065	0.195	0.110	0.072
LSD ($P \leq 0.05$)	0.009	0.006	0.023	0.015	0.020	0.048	0.011
100% N fertilizer	0.025	0.060	0.171	0.086	0.215	0.110	0.083
No N fertilizer	0.026	0.063	0.165	0.070	0.207	0.107	0.082
LSD ($P \leq 0.05$)	0.007	0.014	0.023	0.025	0.031	0.029	0.009
Significance (*P*)							
Replicate	0.169	0.631	0.328	0.819	0.525	0.535	0.017
Medic	0.020	0.004	0.050	0.046	0.048	0.814	0.006
N fertilizer	0.846	0.563	0.549	0.141	0.526	0.747	0.786
Medic*N ferti	0.324	0.787	0.751	0.281	0.989	0.601	0.276
CV (%)	17.85	14.58	8.54	20.20	9.28	16.89	7.21

Table 4.7. Total N uptakes (g pot^{-1}) of wheat, oat canola and fall rye in 2005 and 2006 bioassays for Indian Head

	2005			2006			
	Wheat	Oat	Canola	Wheat	Canola	Rye	Rye re-growth
Treatments							
Medic	0.045	0.065	0.213	0.087	0.239	0.132	0.095
Non-medic	0.040	0.044	0.175	0.069	0.188	0.125	0.077
LSD ($P \leq 0.05$)	0.023	0.005	0.024	0.013	0.037	0.021	0.018
20% N fertilizer	0.040	0.052	0.188	0.076	0.222	0.129	0.092
60% N fertilizer	0.040	0.059	0.195	0.078	0.209	0.125	0.079
100% N fertilizer	0.047	0.052	0.199	0.082	0.211	0.130	0.088
LSD ($P \leq 0.05$)	0.013	0.013	0.024	0.012	0.022	0.027	0.018
Significance (*P*)							
Replicate	0.188	0.615	0.132	0.132	0.060	0.277	0.985
Medic	0.292	0.002	0.021	0.003	0.002	0.486	0.048
N fertilizer	0.361	0.423	0.598	0.552	0.357	0.893	0.298
Medic*N ferti	0.806	0.497	0.996	0.728	0.012	0.989	0.456
CV (%)	22.94	17.54	9.21	11.59	7.65	15.86	15.79

For the Winnipeg site, a significantly higher N uptake due to medic effect was observed in six of seven cases. For the Indian Head site significantly higher N uptake due to medic was observed in five of seven cases. The positive results on N uptake of test crops support a firm conclusion that the black medic as an undersown cover crop strongly influenced the N supplying power of these soils. As expected, significant results observed in N uptake of test crops in medic soils supports the original hypothesis.

4.4.5 Cumulative N uptake of bioassay crops

The effect of black medic on N supplying power of soils, as determined by the difference in cumulative N uptake of all individual crops grown in the bioassay, showed a significant positive effect of medic compared to the control in both sites and years (Tables 4.8 and 4.9). The total N accumulated for the black medic treatments were significantly higher than the control treatments at all four site-years (Tables 4.8 and 4.9). This highly significant results proved the strong influence of black medic on N dynamics of soils in this unique cropping system. Medic in this system is continuously growing along with main crops and thus utilizes a portion of soil N for their growth at the same time adding extra N into the system through N-fixation. The medic residue decomposes in the late autumn or early spring could provide N for associated crops during the summer growing season which is the basic idea behind this unique medic cropping system. The significant results of all site-years suggest that this system is working well in the Prairie region.

Table 4.8. Cumulative N uptake (g pot $^{-1}$) of wheat, oat canola and fall rye in 2005 and 2006 bioassay for Winnipeg.

	2005		2006	
	g pot^{-1}	kg ha^{-1}	g pot^{-1}	kg ha^{-1}
Treatments				
Medic	0.288	148.6	0.517	266.8
Non-medic	0.223	115.2	0.442	228.0
LSD ($P \leq 0.05$)	0.026	13.4	0.048	24.7
100% N fertilizer	0.257	132.3	0.494	254.9
No N fertilizer	0.255	131.5	0.465	239.9
LSD ($P \leq 0.05$)	0.035	18.0	0.053	27.3
Significance (*P*)				
Replicate	0.339		0.254	
Medic	0.007		0.017	
N fertilizer	0.907		0.201	
Medic*N ferti	0.904		0.532	
CV (%)	8.64		6.87	

Table 4.9. Cumulative N uptake (g pot-1) of wheat, oat canola and fall rye in 2005 and 2006 bioassay for Indian Head.

	2005		2006	
	g pot^{-1}	kg ha^{-1}	g pot^{-1}	kg ha^{-1}
Treatments				
Medic	0.323	166.3	0.553	285.3
Non-medic	0.259	133.5	0.459	236.8
LSD ($P \leq 0.05$)	0.034	17.6	0.027	14.0
20% N fertilizer	0.281	144.7	0.519	267.5
60% N fertilizer	0.294	151.4	0.490	252.6
100% N fertilizer	0.298	153.6	0.510	263.1
LSD ($P \leq 0.05$)	0.032	16.6	0.055	28.4
Significance (*P*)				
Replicate	0.121		0.521	
Medic	0.001		0.001	
N fertilizer	0.469		0.492	
Medic*N ferti	0.827		0.364	
CV (%)	8.31		8.19	

When comparing the years, in 2006 (dry year) cumulative N uptake for both sites in 2006 (dry year) were higher compared to 2005 (wet year). When comparing the sites, the Winnipeg site had slightly higher medic N (0.001 g pot^{-1}) in the 2005 bioassay, but the Indian Head site had higher medic N (0.019 g pot^{-1}) in the 2006 bioassay. The slight differences between years and sites could be attributed to growing condition variations because crop and medic growth performances and N transformation process mainly depend on environmental condition of the sites. Higher amounts of N are available in surface soils in dry years because chances for N losses are very low and thus available N for following crops is high (Grant and Fernando, 2006). Their statement supports the results of the current study where more N available for test crops in 2006 that was comparatively a dry year.

The values obtained from the bioassay were converted to kg ha^{-1} for field level recommendations by using the bulk densities of the experimental sites (1.1 g cm^{-3}) and depth of sampling (0-15 cm). Based on these calculations, the total additional N from the black medic was 33 and 38 kg ha^{-1} for the Winnipeg site and 32 and 48 kg ha^{-1} for the Indian Head site in 2005 and 2006, respectively. However, the temperature, moisture level and mineralization time length used under growth chamber conditions to grow test crops were higher than those under field conditions. Due to this variation, N supply potential of black medic found in this study may slightly vary in the fields according to prevailing weather conditions. Recently, very similar to the current study, Känkänen and Ericksson (2007) also obtained positive results regarding N benefits in their work with legumes in Finland during 1995-1999. They found that black medic at a standard seeding rate (600 seeds m^{-2}) as an under-sown crop with spring barley (*Hordeum vulgare* L.) supplied 15.1 kg N ha^{-1} and produced 505 kg ha^{-1} biomass in the late autumn. From the same study they found that the white and red clovers are also suitable N-fixing crops for under-sowing with low N leaching risk and able to produce 18 kg N ha^{-1} and 12.6 kg N ha^{-1} in the late autumn.

Previous documentation of N contribution by medics shows higher and lower values compared to the current study. In Minnesota, N from medic in the range 100 to 200 kg N ha^{-1} (Zhu et al., 1998) was recorded and in Cyprus N contribution has been estimated up to 122 kg ha^{-1} N (Paspastylianou, 1987). Further, Moynihan et al., (1996) observed barley-medic intercropping frequently provided more N than the unfertilized barley monoculture. In addition to N, medic can provide superior ground cover characteristics and quality forage (Rumbaugh and Johnson, 1986; Zhu et al., 1996). Similar to black medic, other legumes also supply N to following crops in different cropping systems. For example, contribution of annual medics 37 kg N ha^{-1} (Jeranyama et al., 1998), crimson clover (*Trifolium incarnatum)* 72 kg N ha^{-1} (Hargrove, 1986), alfalfa (*Medicago sativa*) 51-62 kg N ha^{-1}, chickling vetch (*Lathyrus sativus* L.) 29-43 kg N ha^{-1}, lentil (*Lens culinaris*) 23-39 kg N ha^{-1} and red clover 24-26 kg N ha^{-1} (Entz et al., 2005). In another study, Guldan et al., (1996) found when five legumes, hairy vetch, barrel medic (*Medicago truncatula*), alfalfa (*Medicago sativa* L.), black lentil and red clover were inter-seeded into sweet corn (*Zea mays* L.), corn yield was not affected by legume inter-seeding and the average N yield was ranged between 12 to 83 kg ha^{-1}. Black medic N from the current study (average 38 kg N ha^{-1}) falls within these N ranges of other legumes indicates that it could also be a successful legume cover crop in intercropping systems.

The results of the current study reveal that significant amounts of N were added by the black medic to build-up the N level of this system and the amount of N added (average 38 kg ha^{-1}) is of sufficient quantity to offset significant fertilizer N. Also, the fact that the available medic N was significantly greater and persistent over each of the two sample years provides the evidence for the strong existence of medic treatment effect at the autumn compared to fertilizer N residual effect. Though, one important question remains, and that regards the amount of N provided by black medic each year. This will depend on prevailing growing condition of the sites that could be varied with year. And another possible reason is that when medic is grown continuously, the effects from different years on soil N can also be mixed, because sometimes the release of N from organic residues takes longer than one growing season.

4.5 Summary and conclusions

Cover crops are grown for many purposes, but most of the recent interest is in their N effects. Long-term N contribution of black medic in a continuous cropping system with different rate of N fertilizer application has not been studied in detail before. As the soil microbial community plays a major role in N transformations, bioassays are more reliable than chemical methods for measuring plant available N from legume-amended soils. Under growth chamber conditions, the N supplying power of black medic can be estimated without the interference of weather (temperature and moisture) and pests. The incubation periods were 110 and 130 days for 2005 and 2006, respectively which is slightly longer than the normal (90 to 100 days) summer growing season.

Bioassay results from these long-term trials clearly confirmed that a self-regenerating black medic cover crop increased the N supplying power of the soil. The soil test determined that a portion of N due to medic was available at the beginning of the bioassays (i.e., 5 to 11 kg N ha^{-1} and this can be averaged 8 kg N ha^{-1}). At the end of bioassay, the amount of black medic N available to associated crops in this system was very considerable, averaging 38 kg ha^{-1}. This suggests that 30 kg ha^{-1} of N derived from mineralization process during the incubation period. At this point, it is not clear whether the same amount of N (38 kg ha^{-}1) will be available every year for following crops.

One of the challenges in this unique cropping system is to find out the exact amount of annual medic N contribution which is often difficult to determine due to the microbial mediated complex N transformation process and weather variation in fields. However, the amount of N supplied by the medics represents a portion of fertilizer N. For farmers, this represents a reasonable portion in their N fertilizer cost. In addition to this, using a self-seeding black medic in their cropping system, they also can eliminate the annual cover crop re-seeding cost.

In summary, the results from this bioassay experiment have strongly demonstrated the potential of black medic as a legume cover crop to increase soil N supplying power. As a new cover crop to the Canadian prairies, black medic proved that it could be equally comparable to other commonly used legume cover crops in this region such as alfalfa, clovers, lentils and vetches in regards to N supply and crop establishment. The fact that the medic effect was relatively consistent between years for the different soils, contrasting weather conditions and for different N fertilizer management indicates the consistency of the black medic N contribution. In addition, because of its self-regenerating capacity, black medic can produce crops for several seasons from a single seeding make it a potentially valuable companion crop for a cereal-legume rotation under no-till cropping system.

The results of the current study provide strong evidence of the productivity and effectiveness of black medic towards N supplying capacity. Also, medic effect was significant in all N fertilizer rates at either site suggests that medic can be utilized as a cover crop in either low or high or medium or no N fertilizer cropping systems. Thus, both commercial and organic farmers have the opportunity to use medic in their cropping systems. Because of its proven performance in different geographic regions and in different fertilizer N levels, self-seeded black medic could be a viable option for prairie farmers to reduce cost of production.

5. GENERAL DISCUSSION

5.1 Importance of self-regenerating medic cropping systems in the prairies

Current crop production systems in the prairies depend on high levels of energy input and have negative impact on the environment due to lack of species diversity. This project evaluates the use of a self-regenerating legume cover crop black medic (*Medicago lupulina* cv George) as a source of N in a continuous no-till cropping system under prairie growing conditions. A number of experiments with different legume cover crops (alfalfa, clovers, soybean, pea and lentils) have been already discussed to understand their role in N supply. However, the difference in the present unique system is that medic was growing continuously with main crops without re-seeding. The long-term impacts on soil N dynamics of such permanent self-regenerating cover crops have received only very limited research attention. There is no doubt that black medic improves the N economy of the Prairie soils and help to reduce the fertilizer cost because the present study provides a strong evidence of medic N supply under prairie growing condition.

5.2 Mineral N supply potential of black medic and fertilizer N savings

The field study showed that the increase in N due to medic (both in plant and soil) was 48 kg ha^{-1} at Indian Head but only 23 kg ha^{-1} at Winnipeg. Low N supply at Winnipeg was attributed to drought conditions which may have limited N fixation and mineralization. The 48 kg N ha^{-1} recorded at Indian Head was thought to represent the annual medic N supply under more typical field conditions. Meanwhile, the average measure of potential medic N supply from the two controlled environment studies was for both sites which were 36 kg ha^{-1} at Winnipeg soil and 40 kg ha^{-1} at Indian Head soil.

Therefore, it is concluded that both soils have a similar potential for medic N supply under similar environmental conditions.

A frequent comment is that the fertilizer requirement should gradually be reduced in a legume cover crop system as the N supplying power of the soil increases. The gains in yield of subsequent crops and reduction in N fertilizer cost often compensate for the legume establishment cost. This results in a lack of financial incentive for farmers to use legume cover crops. But in the case of black medic, there is an additional advantage to producers, since no reseeding costs are required because of medic's proven self-regenerating ability in this region (Braul, 2004). Therefore, it is logical to assume that the economic benefit of medic cover crops could in fact occur at lower N supply rates than the N contribution required to make seeded cover crops economical. In the current study, for farmers, medics help to save a portion of fertilizer N cost.

5.3 Field study vs controlled environment study

Accurate measurement of the gain and loss of N by plants and soil under field conditions is difficult because all aspects of the N pathway have to be monitored at the same time. Another important problem in a field study with different sites is variations in the weed infestation and environmental conditions. Because it eliminated growing season variation, the plant bioassay under controlled environment was considered a more appropriate method to measure the potential of medic soil N supply. This concept has been successfully proved by the equal measure of N potential obtained for both soils under growth chamber conditions unlike field study.

5.4 Black medic cover crop for all cropping systems

The general lack of significant interaction between medic and N fertilizer rates in the present study indicates that the medic has the ability to perform similarly in any N fertilizer management system. The observation that N fertilization rate did not affect the medic performance suggests that the medic can be included in cropping systems with either low or medium or high rates of N fertilization.

Sheaffer et al. (2002) suggests that the use of black medic as an intercrop may be most advantageous in organic production systems where synthetic fertilizers and pesticides cannot be used and where a premium is paid for grain production. Premiums for organic grain may offset the cost associated with black medic establishment though it is only a one time investment and thus low in cost compared to other legume cover crops.

For example, one farmer conducted an on-farm research project intercropping black medic with wheat (SARE, Jess Alger, 1999). He compared his conventional small grains rotation to a rotation incorporating black medic instead of fallow. Also, in the black medic trial he eliminated agri-chemicals and included 30 head of cattle. He observed low cost of production for medic plots (organic plots) compare to conventional plots. Over 10 years of growing black medic, Alger measured an increase in organic matter of 1.8% (from 2.8% to 4.6%). While this is not a rigorous scientific study, these preliminary findings suggest that medic has soil benefits beyond N. A comment often made is that farmers are conservative and not ready to adopt new ideas. However, this example showed that some farmers are willing to adopt novel practices such as using self-regenerating medics in organic cropping systems. Farmers will be more interested in adopting new innovations when the benefits can clearly be demonstrated.

5.5 Competitive ability of black medic

Although this study has mainly focused on the positive aspects of black medic, especially on N-economy of soils, it must also be pointed out that because of its persistent seed bank, medic itself may compete with crops in some instances. However, Moynihan et al. (1996) found that George was the least competitive with barley and reduced 65% of weed biomass in a barley-medic intercropping. In fact, farmers may face difficulty in terminating black medic if and when they choose no longer to use it as a cover crop. However, in situations where black medic is a concern, it can be terminated with some herbicides such as broadleaf herbicides bromoxynil at the rate of 280 g a.i. ha^{-1} and glyphosphate at the rate of 623 or 879 g a.i. ha^{-1} with appropriate tillage and N management practices (Braul, 2004).

5.6 Recommendations for future studies

Using black medic in cropping systems is in the initial stages in the Canadian prairies because it is a new crop to this region. Other than its proven self-regenerating capacity and N benefit, additional research needs to be done to get complete benefit of black medic in this region.

5.6.1 Extension work on black medic

Since black medic is a new crop to the prairie region, it needs some introduction. This could be achieved through farmers meeting, field demonstrations and field visits. Also extension work help to minimize gap exists between medic N yield from experiments and farmer's fields by providing more information on management practices. Meanwhile, it is important to gather information on how many farmers are already using black medic in their systems, what are their observations on growth and morphology, what is their opinion on inclusion of medic in the rotation systems, if they have any problem due to medic in the field, how they are controlling medic in the fields, crop yield data with medics and their cost of production with medic. Positive and negative information on medic under actual field conditions will help to design a better medic cropping system in this region. Since it is not a popular crop in this region, proper extension work needs be done to get farmers' attention on black medic.

5.6.2 Suitability of black medic for forage production

Annual and perennial forages in cereal cropping systems are used on the prairies of Western Canada for silage and pasture production. Generally, relative to grasses, legumes represent a reliable and inexpensive protein source for animal nutrition and also a superior source of other essential minerals including Ca, Mg, K, Zn, Co and Cu (Sheaffer and Seguin, 2003). Alford et al. (2003) found that black medic was the most desirable species for late season grazing among eight legumes tested. Zhu et al. (1996) stated that among other annual medics, black medic was one of the species producing the higher crude protein concentration levels and, it produced forage similar quality of alfalfa. These studies show a promise that black medic could be used as a forage crop. Further experiments are needed on medic forage production under different Prairie growing conditions to determine the production potential in terms of biomass accumulation. At the same time its nutritional quality needs to be analyzed in laboratory experiments.

5.6.3 Development of commercial hybrid cultivar of black medic

Plant breeders have already accelerated the development of germplasm and cultivars of a few species to meet exacting adaptive requirements and uses. It is anticipated that this trend will continue to new beneficial species, also. Research by Li and Dermarly (1995) regarding characterization of factors affecting plant regeneration frequency of *Medicago lupilina* L. pointed out that cytokinin is the essential hormone for shoot differentiation from immature inflorescence of black medic. This could be an effective step in the asexual re-production of black medic. Accordingly, black medic could be the most suitable one due to its proven self-regeneration and N fixation which could be upgraded through breeding program. For example the genes responsible for more biomass production can be selected from other medics (e.g., 'Mogul' barrel medic, Moynihan et al., (1996) proved Mogul produced more biomass in a barley-Mogul intercropping study) to increase black medic biomass production from medium level to higher level and thus in turns more herbage N production.

5.6.4 Quantification of non-N benefits of black medic

Usually legume cover crops increase the overall productivity of the cropping system through their N and non-N benefits such as weed suppression, breaking disease cycles, increase water and land use efficiency, increase soil microorganism, reduce soil erosion and adding micronutrients in to the soil. Quantification of non-N benefits of black medic needs to be done in this region with different cropping systems to add more value to this new crop.

5.6.5 Improve the N fixation capacity and nodulation of black medic

Since medic is a legume cover crop, the N fixation could be increased by increasing the nodule formation treating with different type, form and amount of commercial *Rhizobium* inoculums. However, the effectiveness of each type of inoculums and possible preference for black medic was unknown. To find out the most effective inoculum and specific strain to the George black medic further studies are needed in the field and laboratory and thereby would increase the N fixation capacity of medic.

5.6.6 Experiment the black medic performance with other crops in diverse environment and management

Field and laboratory experiments on medic effect on N availability to commonly grown crops in the Prairies such as canola, sunflower and barley should be conducted because medic may supply different quantity of N according to companion crops. Also, studies on the effect of different medic seeding rates and seeding dates on grain yield of main crops would be helpful to obtain maximum benefit of this new crop. The role of medic in an Integrated Pest Management (IPM) system needs investigation to design sustainable cropping systems. The productivity of black medic in different soil types also needs to assess to know its better adaption for different regions.

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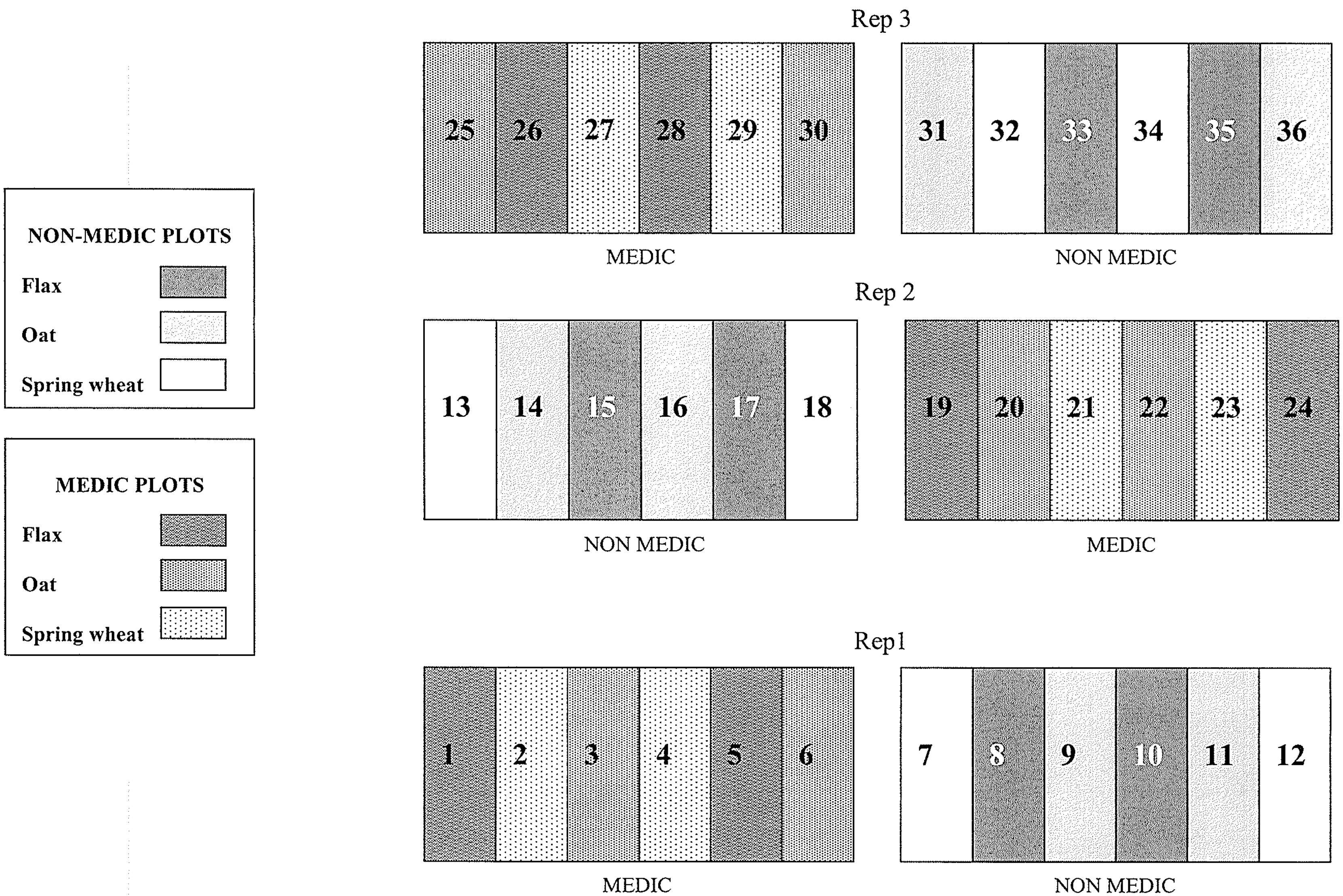
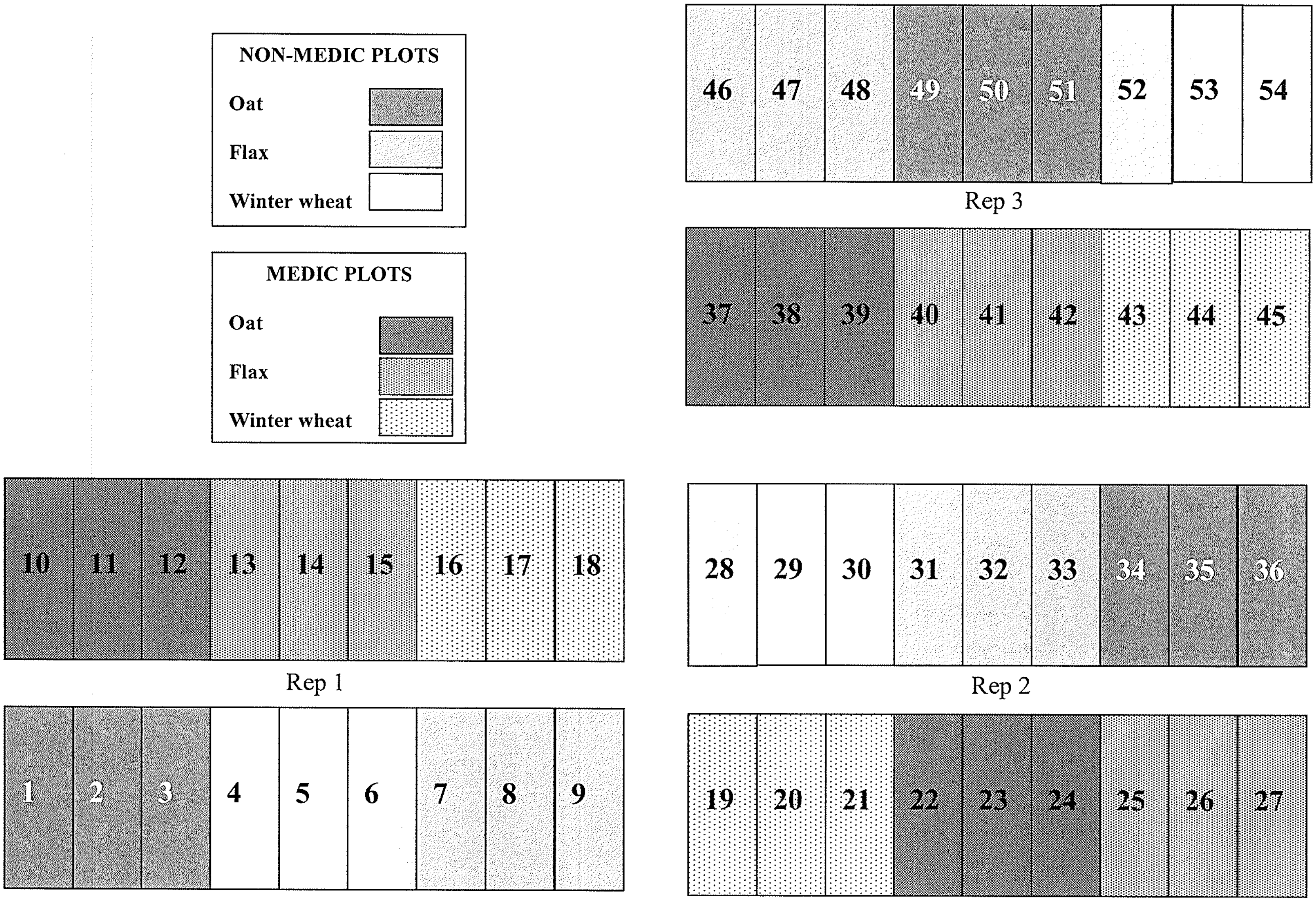
APPENDICES

Appendix A. Winnipeg field plot plan in 2006.



Appendix B. Indian Head field plot plan in 2006.



Appendix C. Treatment combinations for Winnipeg experimental site, 2006.

Treatment/crop	Wheat	Oat	Flax	Total plots
Medic + 100% N	3	3	3	9
Medic + No N	3	3	3	9
Non-medic + 100% N	3	3	3	9
Non-medic + No N	3	3	3	9
Total	12	12	12	36

Appendix D. Treatment combinations for Indian Head experimental site, 2006.

Treatment/crop	Wheat	Oat	Flax	Total plots
Medic + 20% N	3	3	3	9
Medic + 60%N	3	3	3	9
Medic + 100% N	3	3	3	9
Non-medic + 20% N	3	3	3	9
Non-medic + 60% N	3	3	3	9
Non-medic + 100%	3	3	3	9
Total	18	18	18	54

Appendix E. Medic density, medic biomass, main crop yield and main crop biomass at Winnipeg in 2002

Crop	Fertilizer N	Medic density	Medic biomass	Crop yield	Crop biomass
		plants ha^{-1}	----------------kg ha^{-1}----------------		
Oat	No N	2987	-	2353	-
	100% N	1214	-	3930	-
Flax	No N	209	-	528	-
	100% N	7	-	1136	-
Winter wheat	No N	1347	-	1738	-
	100% N	434	-	4452	-
Average		1033	-	2356	-

Appendix F. Medic density, medic biomass, main crop yield and main crop biomass at Winnipeg in 2003

Crop	Fertilizer N	Medic density	Medic biomass	Crop yield	Crop biomass
		plants ha^{-1}	----------------kgha^{-1}----------------		
Oat	No N	-	168	1382	5940
	100% N	-	63	2591	9719
Flax	No N	-	653	650	1699
	100% N	-	484	1717	2739
Winter wheat	No N	-	-	-	-
	100% N	-	-	-	-
Average		-	228	1057	3349

Appendix G. Medic density, medic biomass, main crop yield and main crop biomass at Winnipeg in 2004

Crop	Fertilizer N	Medic density	Medic biomass	Crop yield	Crop biomass
		plants ha^{-1}	----------------kgha^{-1}----------------		
Oat	No N	971	46	-	2121
	100% N	1013	128	-	2384
Flax	No N	404	39	295	6288
	100% N	227	73	658	9064
Winter wheat	No N	410	-	-	-
	100% N	299	-	-	-
Average		554	48	159	3310

Appendix H. Medic density, medic biomass, main crop yield and main crop biomass at Winnipeg in 2005

Crop	Fertilizer N	Medic density	Medic biomass	Crop yield	Crop biomass
		plants ha^{-1}	----------------kgha^{-1}----------------		
Oat	No N	5602	280	-	-
	100% N	3207	160	-	-
Flax	No N	6508	326	1367	6052
	100% N	6979	349	1754	8918
Winter wheat	No N	2641	132	-	-
	100% N	1151	58	-	-
Average		4348	217	520	2495

Appendix I. Medic density, medic biomass, main crop yield and main crop biomass at Indian Head in 2003

Crop	Fertilizer N rate	Medic density	Medic biomass	Crop yield	Crop biomass
	(%)	plants ha^{-1}	----------------kgha^{-1}----------------		
Oat	20	-	-	1427	-
	60	-	-	1414	-
	100	-	-	1578	-
Flax	20	-	-	386	-
	60	-	-	370	-
	100	-	-	337	-
Winter wheat	20	-	-	1784	-
	60	-	-	2323	-
	100	-	-	2097	-
Average		-	-	1302	-

Appendix J. Medic density, medic biomass, main crop yield and main crop biomass at Indian Head in 2004

Crop	Fertilizer N rate	Medic density	Medic biomass	Crop yield	Crop biomass
	(%)	plants ha^{-1}	-----------------kgha^{-1}-----------------		
Oat	20	-	1589	4692	-
	60	-	797	5629	-
	100	-	259	5903	-
Flax	20	-	3289	1283	-
	60	-	3388	1593	-
	100	-	2781	1637	-
Winter wheat	20	-	1877	3377	-
	60	-	1536	3503	-
	100	-	1483	3774	-
Average		-	1889	3488	-

Appendix K. Medic density, medic biomass, main crop yield and main crop biomass at Indian Head in 2005

Crop	Fertilizer N rate	Medic density	Medic biomass	Crop yield	Crop biomass
	(%)	plants ha^{-1}	--------------kgha^{-1}	----------------	
Oat	20	-	275	4768	-
	60	-	227	5260	-
	100	-	92	5774	-
Flax	20	-	368	1387	11912
	60	-	303	1687	11472
	100	-	224	1945	14348
Winter wheat	20	-	240	3239	-
	60	-	104	3710	-
	100	-	49	3648	-
Average		-	209	3491	4192

Appendix L. Water amounts needed for 2005 and 2006 bioassay pots to reach different field capacity levels.

Pot No.	Pot wgt(g)	Soil dry wgt(g)	Field capacity	Final weights for watering to different field capacity levels (g)							
				80%FC	75%FC	70%FC	60%FC	65%FC	50%FC	40%FC	30%FC
WP 1	260.3	3200	64.9	5120	5017	4913	4705	4809	4498	4290	4083
WP 2	262.0	3200	64.9	5122	5018	4915	4707	4811	4500	4292	4085
WP 3	263.2	3200	64.9	5123	5020	4916	4708	4812	4501	4293	4086
WP 4	262.5	3200	64.9	5123	5019	4915	4708	4811	4500	4293	4085
WP 5	266.1	3200	64.9	5126	5023	4919	4711	4815	4504	4296	4089
WP 6	267.3	3200	64.9	5127	5024	4920	4712	4816	4505	4297	4090
WP 7	251.4	3200	64.9	5112	5008	4904	4697	4800	4489	4281	4074
WP 8	256.4	3200	64.9	5117	5013	4909	4702	4805	4494	4286	4079
WP 9	253.0	3200	64.9	5113	5009	4906	4698	4802	4491	4283	4076
WP 10	265.2	3200	64.9	5125	5022	4918	4710	4814	4503	4295	4088
WP 11	253.6	3200	64.9	5114	5010	4906	4699	4802	4491	4284	4076
WP 12	254.0	3200	64.9	5114	5010	4907	4699	4803	4492	4284	4077
IH 13	254.0	3200	63.3	5073	4972	4871	4669	4770	4466	4264	4061
IH 14	266.0	3200	63.3	5085	4984	4883	4681	4782	4478	4276	4073
IH 15	264.6	3200	63.3	5084	4983	4882	4679	4780	4477	4274	4072
IH 16	265.9	3200	63.3	5085	4984	4883	4680	4782	4478	4276	4073
IH 17	262.6	3200	63.3	5082	4981	4880	4677	4778	4475	4272	4070
IH 18	264.3	3200	63.3	5084	4983	4881	4679	4780	4476	4274	4072
IH 19	261.5	3200	63.3	5081	4980	4879	4676	4777	4474	4271	4069
IH 20	265.8	3200	63.3	5085	4984	4883	4680	4782	4478	4276	4073
IH 21	266.4	3200	63.3	5086	4985	4883	4681	4782	4479	4276	4074
IH 22	266.8	3200	63.3	5086	4985	4884	4681	4783	4479	4277	4074
IH 23	262.9	3200	63.3	5082	4981	4880	4677	4779	4475	4273	4070
IH 24	259.9	3200	63.3	5079	4978	4877	4674	4776	4472	4270	4067
IH 25	261.6	3200	63.3	5081	4980	4879	4676	4777	4474	4271	4069
IH 26	267.8	3200	63.3	5087	4986	4885	4682	4784	4480	4278	4075
IH 27	266.3	3200	63.3	5086	4985	4883	4681	4782	4478	4276	4074
IH 28	266.1	3200	63.3	5086	4984	4883	4681	4782	4478	4276	4073
IH 29	265.4	3200	63.3	5085	4984	4882	4680	4781	4478	4275	4073
IH 30	257.4	3200	63.3	5077	4976	4874	4672	4773	4470	4267	4065