THE EFFECTS OF LIQUID HOG MANURE APPLICATION AND TILLAGE SYSTEMS ON THE RATE OF CEREAL CROP RESIDUE DECOMPOSITION IN CLAY SOILS

BY

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A Thesis
Submitted to the Faculty of Graduate Studies
In Partial Fulfillment of the Requirements
For the Degree of

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ABSTRACT

The burning of cereal residues is a means of primary residue management often employed in the fine textured soils of the Red River Valley in southern Manitoba, Canada. Producers in the area have cited the need for residue burning to alleviate the negative effects that heavy loading rates of cereal residues can have on the subsequent growth and performance of annual cereal and oilseed crops following a cereal crop. These effects may include delayed seedling emergence, immobilization of nitrogen fertilizers or increased crop disease pressure. A suite of field and laboratory microcosm studies was completed to examine the effects of tillage system intensity and liquid manure application to these clay soils, amended with abundant quantities of cereal residue, on the resulting rate of cereal crop residue decomposition, measured as residue mass loss and soil CO_2 and N_2O respiration. One growth cabinet litterbag study, two field studies and two controlled atmosphere microcosm studies were designed to examine the effects of zero, chisel plow and V-disk primary tillage systems, with and without the application of 100 kg ha^{-1} liquid manure nitrogen on soil respiration activity. Manure application was found to have a significant positive effect on the rate of residue mass loss and soil CO_2 and N_2O respiration. Increasing tillage systems intensity was also found to stimulate soil microbial activity and increase the availability of residue carbon to soil microbial communities through incorporation, resulting in an increase in the rate of CO_2 respiration. Spring wheat and canola yields were not affected by tillage system; however, canola yield was greater when crop nutrition was supplied as liquid hog manure as opposed to commercial fertilizer. Results from this study indicate that residue management through straw burning is not necessary to maintain high annual crop yields and crop quality in the clay soil region of southern Manitoba and suggest that the prolonged use of stubble burning residue management practice may have long-term negative impacts on soil microbial activity and soil carbon and nitrogen mineralization potential.

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FOREWARD

The following thesis was prepared using the manuscript format outlined in " A Guide to Thesis Preparation For Graduate Students In The Department of Soil Science"

The nature of this MSc thesis project is unique in that it was a marriage between research and extension activities. Field work was completed on a field-scale basis to allow producers the opportunity to see research at work and provide not only sound research and crop production information but to allow producers to witness ongoing research being conducted in a system which they would employ on their own operations.

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1. INTRODUCTION

A suite of field and laboratory growth cabinet studies was initiated to examine cereal crop residue management options available to producers located in the fine-textured soil region of the Red River Valley in southern Manitoba, Canada. Current residue management practices include incorporation with tillage, straw removal through baling or grazing, and residue burning. The incorporation of large quantities of cereal straw into clay soils is considered to result in an undesirable seedbed condition due to excessive soil moisture, cold soil temperatures during the spring planting season and compromised seeding equipment performance. Crop disease proliferation and immobilization of fertilizer nitrogen have also been identified as being potential detrimental consequences of residue retention. Disposal of crop residues through burning is, therefore, an attractive residue management option for producers. However, straw burning can be stressful on persons who suffer from respiratory illness and reside in areas where straw burning is practiced. Often the smoke from straw burning can travel long distances and effect persons in who do not reside in agricultural production areas, resulting in urban public concern surrounding the issue of straw burning.

Several alternatives to burning cereal crop residues have been identified. The most extreme of these is to grow crops that produce less residue and/or residue that is less persistent. However, so long as there is a viable market for oats, producers in the Red River Valley will continue to include this crop in their rotations. Another alternative is to harvest and remove the straw from the field. This practice can be costly, however, and requires a suitable end point. Although wheat straw can be harvested and used to produce fibreboard, oat straw is currently not suitable for this purpose. A potential straw market with cattle producers, to be used for bedding or roughage in cattle rations, is unlikely to consume the amount of straw produced within the Red River Valley region.

The proper management of straw can help to alleviate its negative effects on crop production. The physical nature of crop residue can affect its decomposability, residues that are thoroughly chopped and spread with a combine harvester at harvest time will be more likely to decompose faster than residues that remain concentrated in narrow bands on the soil surface. Likewise, residues that are buried will achieve more intimate contact with soil nutrients and microbial populations, thus, theoretically, will undergo an increased rate of decomposition. Considering the effects of residue burial on the rate of decomposition, tillage operations that incorporate residues, such as chisel plow and disk-based primary tillage operations, may help to alleviate some of the negative effects of retaining cereal crop residues in the soil.

Straw burning is, however, only one of several environmental issues currently of importance in Manitoba. Agronomically effective and environmentally sustainable liquid hog manure management practices are an ever-increasing subject of debate in Manitoba as the hog industry within the Province continues to expand at a rapid rate. The past 25 years has seen the annual hog production in Manitoba increase from 0.87 to 5.35 million head; the past four years alone have seen the industry grow at an annual rate of 14 %.

Research projects that evaluate the most appropriate methods of liquid manure management within the Red River Valley of Manitoba are crucial to address public concern concerning hog manure application to agricultural soils, therefore, allowing the expansion of this profitable, value-added industry while maintaining the current high level of environmental soil and water quality within the region.

To enhance its in-field management, the application of liquid hog manure to soils amended with large quantities of cereal crop residues may increase the decomposition rate of the residues. Soils receiving abundant crop residues can become carbon-bound, as sufficient soil nitrogen is not available to sustain prolonged microbial activity, thus slowing the decomposition rate, resulting in net immobilization of soil nitrogen and the persistence of crop residues. The application of liquid hog manure to these soils may help to decrease the ratio of carbon to nitrogen in the soil, and, therefore, increase the rate of residue decomposition. If this theoretical concept holds true, producers in the Red River Valley may be able to utilize the abundant sources of liquid manure found in the region for the purpose of residue management and reduce the total number of hectares under stubble burning residue management.

2. LITERATURE REVIEW

2.1 Residue Management

The Red River Valley of Manitoba presents a unique crop residue management challenge for producers. The clay soil that dominates the area, affords a very narrow window of opportunity for spring seedbed preparation and seeding operations. The soil incorporation of large quantities of crop residue is difficult as these soils are resistant to mixing, compared to coarser textured soils found in other areas of the province. Consequently, many producers have resorted to straw burning as a primary means of residue management. Oat crops (Avena sativa) present the greatest challenge as these crops produce large quantities of biomass compared to other small grain species. Oat straw windrows are routinely burned to alleviate plugging of seeding equipment, poor seeding depth control and resultant poor crop stands following an oat crop.

This literature review examines the processes by which crop residues are decomposed within the soil rhizosphere, with particular emphases on the effects that tillage and manure application to soils can have on the resulting soil environment and how these alterations can in turn effect the rate and extent of residue decomposition.

2.2 Straw Burning

Straw burning is a residue management technique widely used historically throughout the small grain production areas of the Great Plains region of North America. Producers throughout the area have cited a requirement for straw burning to alleviate problems associated with seedbed preparation and crop establishment, immobilization of nitrogen fertilizers, reduced spring soil drying and warming, increased weed seedling establishment and crop disease proliferation (Albrect et al. 1995; Biederbeck et al. 1980; Black 1973; Dawley et al. 1964; Dormarr et al. 1979; Emmond 1971; Unger et al. 1973). Many of these studies evaluated the effects of residue burning, using various methods of primary and secondary tillage, on the yield and quality of spring wheat and in most cases the effects were not consistently detrimental to spring wheat performance.

Many of the studies conducted in the Northern Great Plains region have identified the negative effects of straw burning on the carbon content of agricultural soils. In a review of currently available literature, Albrecht et al. (1995) reported losses of 65 %, 36 %, and 26 %, respectively, of the carbon, nitrogen and sulfur contained in crop residues when cereal residues are burned post-harvest. They further estimated that a total of only 8 % of the carbonaceous materials produced during the growing season would be assimilated into the soil organic matter pool after straw burning when a 20 % carbon use efficiency value is assumed for microbial mineralization of the remaining burned residues. This net loss of carbon from the soil system has been reported to be unsustainable by Albrect et al. (1995), Biederbeck et al. (1980), Dormarr et al. (1979) and others. Studies cited by these authors have reported an increase in wind and water erosion potential, decreased soil water infiltration rates and increased soil compaction on soils where stubble burning management is practiced.

Slight yield increases were often reported from stubble burning research trials but were most often not significantly greater than non-burned treatments. In some cases, such as a study conducted in Indian Head, Saskatchewan by Dormarr et al. (1979), long-term wheat yields from retained stubble treatments were found to be greater compared to residue burning treatments. An important consideration for analysis of this historical data is that most research in Western Canada focusing on stubble burning management systems was conducted before 1980. The production systems used on the Canadian prairies have undergone considerable change since this time, with the advent of new crop species to diversify rotations and residue management options, more effective control of weed species, more effective fertilizer management, and, perhaps most importantly, the advent of seeding equipment designed to handle large quantities of surface residue and to place seed with optimum precision into untilled seedbeds.

The commercial scale, air seeding systems now available to producers allow the simultaneous application of fertilizer and seed, and allow for the placement of fertilizer within the seed furrow or in narrow bands easily accessible to emerging seedlings. This technology allows producers to establish crops with a minimal amount of soil disturbance to discourage weed seedling germination, and reduces the potential for nitrogen fertilizers to become immobilized during microbial decomposition of crop residues as is typically the case where nitrogen fertilizers are surface broadcast and incorporated through tillage, which would have been widely practiced during the time in which early stubble burning research was conducted.

The adoption of new seeding technology, therefore, has the potential to reduce the need for producers to practice stubble burning residue management as crops can be effectively established and efficient fertilizer placement can be achieved even in the presence of appreciable quantities of crop residues. The economics of small increases in crop yield or quality of crops produced on stubble burning managed soils need to be considered in the overall bottom line for producers. Significant losses of carbon can affect long-term soil productivity and annual losses of accumulated soil nitrogen can be costly to producers and society alike (Albrect et al. 1995). This, coupled with the increased cost of tillage on compacted, organic-matter depleted soils (Unger et al. 1973), and increasing global competitive demand for natural gas to produce nitrogen fertilizers (Smil 1999), will have to be considered by producers when deciding on the most economical and responsible means of agricultural crop residue management.

2.3 Residue Decomposition

The rate of agricultural crop residue decomposition has been studied extensively. The goal of these studies is to understand and model the processes of residue decomposition, thus, providing recommendations to producers on how to manage residues in such a manner that adequate residue remains on the soil surface to control erosion but sufficient residue is decomposed to allow accurate and efficient establishment of annual crops (Aulakh et al. 1991; Collins et al. 1990a; Collins et al. 1990b; Douglas et al. 1980; Franzluebbers et al. 1996; Gilmour et al. 1998; Hu et al. 1997; Quemada and Cabrera 1995; Stroo et al. 1989). Quantifying residue decomposition has resulted in several models that describe the process (Douglas and Rickman 1992; Jenkinson et al. 1977; Parton et al. 1987).

The factors that govern the metabolic rate of soil microbes and, therefore, residue decomposition are: substrate availability, soil temperature and soil moisture (Schomberg et al. 1994; Stott et al. 1986). Moisture in the Red River Valley is seldom limiting to crop growth and, therefore, should not limit the rate of residue decomposition in most years. Assuming that adequate moisture is present after the fall harvest season in the region, substrate availability and temperature will potentially be the decomposition rate limiting factors.

Substrate availability refers to the availability of a carbon source, which requires a nitrogen source to allow for microbial straw mineralization that can be derived from the residue itself or from the soil nitrogen pool. In an attempt to overcome substrate availability limitations, a source of inorganic nitrogen could be applied to fields to which large amounts of crop residues have been added. In theory, if substrate availability and soil moisture limitations have been addressed, soil temperature will be the most important rate-limiting factor for oat residue decomposition during the fall and pre-plant spring periods in the Red River Valley. Both Gregorich et al. (1998) and Rochette and Gregorich (1998) reported that in multiple regressions with soil moisture and temperature as independent variables, the greatest predictor of soil CO_2 respiration is indeed soil temperature. Complementary results were observed by Douglas et al. (1980) who observed that the decomposition of three wheat straw samples of varying nitrogen contents ceased when soil temperatures dropped to 4°C.

2.3.1 Substrate Availability

Substrate availability as it relates to residue decomposition refers to several factors. The most important is the concentration of materials found in crop residues that may be used as microbial metabolites. Other factors may include the ability of the surrounding soil environment to supply microbial decomposers to the substrate, illustrated by differences in the residue decomposition rate when residues are surface applied or buried. Much work has been conducted to provide information on how materials that comprise crop residues are decomposed, at what rates they are decomposed, and consequently which components are the most decomposable and which are the least.

Cereal straw consists of leaves and sheathes, ears, nodes and internodes in the aboveground portion; the underground root mass, albeit part of the plant, is not considered as straw. Each of the above ground portions of cereal straw are mainly comprised of varying proportions of several organic compounds, namely cellulose, hemicellulose and lignins (Staniforth 1979). The concentration and arrangement of organic compounds found in the individual components of straw will often dictate the decomposability of each component.

Cellulose is the most susceptible of the three main compounds to microbial decomposition. Cellulose is made up of glucose molecules arranged in a straight chain molecule. Hemicelluloses hold the cellulose molecules together and are composed primarily of pentose sugars. Lignins are polymers of aromatic compounds that form very stiff and rigid molecules and provide strength to the plant stems; consequently, lignins are the plant residue component least susceptible to microbial decomposition. The arrangement of lignin components can also restrict microbial access to the more bioavailable molecules contained in the plant residue. Other compounds found in small quantities in cereal straw are: proteins, waxes, sugars, salts and insoluble ash (Staniforth 1979).

According to Staniforth (1979), the proportions of compounds that comprise the al straw of several cereal species are:

Table 2.1 Proportion of chemical components of straw for several cereals

	*Cell Contents	Cell Walls	Hemi-Cellulose	Cellulose	Lignin	Silica
Barley	19	81	27	44	7	3
Oats	27	73	16	41	11	3
Rice	21	79	26	33	7	13
Wheat	20	80	36	39	10	6

*Values are % dry matter

Staniforth (1979) reports that environmental conditions have a marked effect on straw composition for the same plant species; therefore, the above information provides a guideline only.

The importance of a process known as the "feedback loop effect" on residue decomposition becomes increasingly apparent as the duration of the decomposition process increases (Swift et al. 1979). The theory behind the feedback loop is that as plant matter is decomposed, the most soluble constituents, celluloses, are mineralized first, followed by the less soluble products such as hemicelluloses and lignins. According to this theory, intense microbial activity will be induced by the initial addition of organic materials to the soil. However, as the added substrate becomes increasingly decomposed the rate of decomposition will decline in response to the reduced quality of the substrate (Swift et al. 1979). The importance of substrate quality and availability will, therefore, be discussed in more detail.

2.3.2 Carbon and Nitrogen Sources and Supply

Smith and Peckenpaugh (1986) studied several cereal species and determined that there were differences in the way that cereal species residues decompose. They concluded that the decomposability of straw decreased in the following order: hard red wheat > triticale > soft white wheat > barley, oat straw was not included in the study. Although there were distinct differences among species, the authors concluded that all cereal residues would decompose rapidly if they were buried instead of surface applied and receive sufficient moisture and adequate temperatures. Smith and Peckenpaugh (1986) also noted that further examining differences in the organic components that comprise cereal straw (lignin, celluloses and silica) may help to further distinguish differences in the decomposition rate of different cereal species.

Much of the information presented in this thesis literature review deals with the decomposition of wheat or barley; given the suggestion by Smith and Peckenpaugh (1986) that differences in cereal species are probably not critical, the data presented should be representative of most cereal species.

Trinsoutrot et al. (2000) studied the decomposition rates of several oilseed, cereal and legume species in detail, they also studied the chemical composition of the residues and the potential impact this factor can have on residue decomposition. The authors concluded that up to seven days, the decomposition rate could be attributed mainly to the soluble forms of carbon present in the residues and after this point it was thought that most of the soluble fraction had been exhausted and no longer affected the rate of decomposition. The soluble carbon fraction would have included the readily available cellulose contained in the residues and to a lesser extent the hemicelluloses as well. The authors also determined that a C:N ratio of <24 was sufficient to induce net nitrogen mineralization. Residues with C:N ratios >24 showed net nitrogen immobilization and the environment was deemed nitrogen limiting. Several studies provide similar results and will be discussed further; understanding the optimum C:N ratio for decomposition will help to form hypothesis on rates of manure which may need to be applied in order to maximize cereal residue decomposition.

Angers and Recous (1997) studied the decomposition rates of several size fractions of wheat residues and determined that the smallest size factions in wheat residues decomposed at an accelerated rate compared to larger size fractions. This acceleration is probably due to the increased surface area of the residues susceptible to microbial attack and illustrates the potential importance of straw management by harvesting equipment. Straw that is chopped and spread will likely undergo increased decomposition as compared to residues left in an unaltered, whole plant state. Reducing the particle size of residues may also reduce the extent to which lignin protects the more decomposable components, resulting in an increased rate of decomposition.

A study by Ocio et al. (1991b) studied the effect of incorporating 10 t ha^{-1} of wheat straw on microbial biomass increases. Treatments included no straw, 10 t ha^{-1} straw and 10 t ha^{-1} straw plus 100 kg ha^{-1} ammonium nitrate fertilizer. Control soils contained 340 and 76 kg biomass C and N ha^{-1}, respectively. When straw only was applied, the amount of carbon and nitrogen increased to 560 and 118 kg ha^{-1}, respectively. The treatment receiving inorganic nitrogen had 652 kg C and 149 kg N ha^{-1}. Although the difference between the control treatment and the straw only treatment was significant, the increase from the straw only treatment to the straw plus nitrogen treatment was not. The wheat straw added contained 0.91 % nitrogen (dry matter) and the authors suggested that the 91 kg of nitrogen added with the straw was important for maintaining microbial decomposition of the residues in the absence of an additional nitrogen source. According to Ocio et al. (1991b) other studies have found that incorporated straw with a C:N ratio of 132 immobilized 65 kg ha^{-1} N, where straw with a C:N ratio of 80 immobilized 45 kg ha^{-1} N. According to these results, cereal straw with a low C:N ratio can often supply sufficient nitrogen to the decomposition system, to the point where no additional nitrogen is required for the soil microbial biomass to increase. This relationship between residue C:N ratio and the associated rate of decomposition was also reported by Janzen and Kucey (1988).

Collins et al. (1990b) conducted a study where wheat residues were partitioned into their respective components, being, leaf blade, leaf sheath, stem and chaff; the chemical composition of each component was evaluated. The cumulative rate of CO_2 evolution from each fraction increased with the concentration of soluble carbon in each component. After a 30-day incubation period, the production of CO_2 from the leaf and leaf sheath components were 1.5 and 1.3 times that from the stem and chaff, respectively. By mixing the leaves, having higher N and sugar concentrations and lower lignin concentrations than the other components, with the other straw components, the overall rate of CO_2 evolution was increased. This suggests that there is a synergistic effect of the different components on residue decomposition rates and reinforces the hypothesis that high concentrations of soluble carbon and soluble sugars can induce high rates of microbial decomposition activity. Similarly, Cogle et al. (1989) found that applying the water-soluble fraction of wheat residue to the soil initially increased microbial activity, but this flush of activity was quickly exhausted owing to the high quality of the carbon source.

A study conducted in Columbia, MO by Broder and Wagner (1988) compared the decomposition rates of soybean, corn and wheat residues. After 32-days in the field, the soybean, corn and wheat residues had lost 68, 42 and 47 % of their initial mass, respectively. After 679 days, the residues had been further decomposed to 6, 15 and 18 % of the initial mass for soybean, corn and wheat, respectively. The authors hypothesized that the variation in the decomposition rate of the three residues was due to the variations in soluble carbon contents. They did not however take into account that there were likely distinct differences in the initial nitrogen concentrations of the three residues.

A study by Reinertsen et al. (1984) provides insight into the relationship between soluble carbon and the residue C:N ratio in residue decomposition Results of this study showed that as the C:N ratio was decreased, the concentration of soluble carbon and nitrogen increased. They also observed that microbial biomass will increase in the presence of an available substrate having a C:N ratio lower than 10. Further analysis indicated that the decomposition rate of the straw samples tested was dependent on the amount of soluble carbon present at the onset of the experiment. This is in agreement with other studies.

During several studies, where soluble carbon was indicated as the limiting factor for microbial decomposition, researchers observed two phases of microbial activity. The first phase was due to mineralization of the most soluble fraction and the second phase was due to the utilization of the intermediately soluble fraction of carbon. These fractions are thought to be responsible for most of the soluble nitrogen immobilization. This was observed by Allison and Klein (1962) who studied the dynamics of nitrogen immobilization and mineralization and concluded that the maximum rate of immobilization of nitrogen by soil microbes occurred within the first 20 days of a laboratory incubation study and averaged 1.7 % of the original straw weight.

Hadas et al. (1998) found that nitrogen can be an important limiting factor for residue decomposition rate. Three treatments were included in their experiment; a control treatment of soil only, a straw amended treatment with a C:N ratio of 91 and a straw plus nitrogen amended treatment with a C:N ratio of 5. The total amount of carbon released from the straw plus nitrogen treatment was 58 % of the added carbon, after a 460-day incubation period. This release was significantly greater than the treatment receiving no additional nitrogen during the first 50 days. After 150 days, however, the rate was slower than the no-nitrogen treatment, thus, the difference between the two treatments decreased significantly over time. The initial large rate of decomposition resulted from the use of the soluble and intermediately available carbon sources in the residue, which was used more quickly in the presence of abundant nitrogen.

Henriksen and Breland (1999) found that the decomposition rate of wheat straw was significantly lower after an applied inorganic nitrogen supply was depleted. Several rates of ammonium sulphate were applied; the highest application rate sustained the longest period of decomposition activity. Increasing availability of soil nitrogen significantly increased the total microbial biomass in the experimental soils as well. These results indicated that the optimal level of initial residue plus mineral nitrogen for microbial decomposition may be equivalent to 2.5 % of straw C and 1.2 % of dry matter.

Schomberg et al. (1994) found that surface applied residues tended to accumulate biomass nitrogen, indicating that the initial nitrogen content was not significant to support microbial activity in a wheat-sorghum-Fallow rotation in Bushland, TX, whereas buried residues tended to decompose more quickly and have lower levels of biomass nitrogen.

These findings are important on several agronomic levels. Burying residues will encourage accelerated nitrogen mineralization and immobilization and provide higher or lower levels of inorganic nitrogen to successive crops depending on the net effect of the mineralization and immobilization of the soil and residue nitrogen. However, burying residues will provide less protection against wind and water erosion and increase the chance for sub-surface leaching of inorganic nitrogen. This was demonstrated by Schomberg et al. (1994) where alfalfa residue, the experimental crop residue with the greatest availability of substrate in this study, decomposed at an accelerated rate reducing soil protection but increasing nitrogen availability for subsequent crops.

Some studies suggest that the addition of supplemental nitrogen can increase the initial rate of decomposition but not necessarily the overall extent of decomposition (Knapp et al. 1983). These researchers hypothesized that it was the the availability of soluble carbonaceous materials that dictated that rate of straw decomposition and that even in a nitrogen deficient system, the decomposition rate could remain at a significantly high level. This may have implications for producers wishing to encourage decomposition in the short-term, where an initial high rate of decomposition may be sufficient to reduce the volume of crop residues to a more manageable level, without complete decomposition.

Bremer et al. (1991) found that after a 98-day incubation period there was no significant difference in the amount of CO_2 evolved from wheat straw, mature and green manure lentil residues. These residues had initial nitrogen contents of 47, 21 and 5.2 mg g^{-1} residue, respectively. Adding nitrogen to the soil served to decrease the total amount of CO_2 evolved for all three-residue types as compared to the non-nitrogen amended treatments. There was, however, an effect of residue particle size on the residue decomposition rate, as an increase in total CO_2 evolution was reported when wheat straw was ground, although there was no effect of grinding on the decomposition rate of the lentil residues. The results of this study suggest that the absence of added nitrogen may not limit the decomposition rate unless the C:N ratio is greater than 40.

Christensen (1986) conducted a study with wheat straw examining the effects of residue placement and initial straw nitrogen content on decomposition. Results from this study showed that the straw with the highest nitrogen content (0.92 % dry matter) had a significantly higher rate of decomposition than the other straws tested (0.57 %, 0.41 % dry matter). Similarly, Reinertson et al. (1984) found that the greatest soluble carbon pools were found in straw with a high nitrogen content, Christenson (1986) hypothesized that soluble carbon may have caused the initial high levels of decomposition in the high nitrogen (0.92 %) straw treatment. This elevated rate of decomposition was short lived, however, and became equal to that of the lower nitrogen content straws after a 30-day incubation period. After the first month of burial the high N straw lost 40 % of its nitrogen content as compared to 13 and 7 % for the medium and low initial N content straws, respectively. Douglas et al. (1980) also reported that the sample having the lowest initial N content of three wheat straws had the slowest rate of residue mineralization.

In an experiment aimed at identifying the source of nitrogen used by microbes after straw incorporation, Ocio et al. (1991a) found that in soils which received straw only with no additional nitrogen, about 34 % of the biomass N came from sources other than the wheat straw (0.81 % N dry matter), whereas 65 % of the resulting biomass N came from sources other than the straw when inorganic nitrogen was added with the residue. This study suggests that the system was in fact nitrogen limited to some degree and that the inorganic nitrogen increased the ability of the microbial population to mineralize the added residues. This response is likely due to wheat straw tending to have a high C:N ratio compared to residues such as alfalfa or soybean. The small relative amount of nitrogen contained in wheat straw, compared to carbon, will often result in nitrogen limiting conditions, whereas lower C:N ratio residues, when added to soils, will likely contain sufficient nitrogen to support intense microbial activity.

Recous at al. (1995) determined that nitrogen was the limiting factor for CO_2 evolution from maize residues. However, maize residue tends to have a high C:N ratio and this fact was emphasized. This study parallels others (e.g. Bremer et al. 1991), which showed that residues with low C:N ratios would not respond to additional nitrogen introduced into the system. Residues with high C:N ratios, however, tend to show a significant increase in decomposition rate when an inorganic nitrogen source is present.

Gilmour et al. (1998) determined that the decomposition rate of soybean, rice and sorghum residues could be described according to the initial residue nitrogen content, or C:N ratio, during the first two weeks of decomposition, but after this period there was little difference in decomposition between the three species. This study reinforces the fact that initial nitrogen content may prove to be a limiting factor during the early stages of decomposition, while more soluble sugars are being used as microbial metabolites. After these resources have been exhausted and the less decomposable hemicelluloses and lignins are being used, nitrogen content becomes less important, possibly due to the fact that the nitrogen remaining in the less soluble portions of the residues is sufficient to supply the needs of the soil microbes, or due to increased nitrogen availability from the mineralization of microbial biomass nitrogen.

The data presented in these studies have generally indicated that crop residue decomposition rates are in fact significantly affected by the nitrogen content of the medium in which they are placed, as well as by the initial nitrogen content of the residue itself. Several of these studies have also observed that residues with low initial C:N ratios tend to have a higher concentration of soluble carbon constituents such as celluloses, amino acids and amino sugars, which had a significant positive influence on the initial rapid rate of decomposition exhibited by these residues.

2.3.3 Impacts of Residue Burial

Many studies have been conducted to determine the relative differences in the decomposition rate of residues that have been buried and residue that remains on the soil surface, to simulate intensive and conservation tillage systems, respectively.

Brown and Dickey (1970), found that after an 18-month period, surface applied residues were 31 and 40 % decomposed at two locations in Montana, while buried residues, after the same time period, had undergone significantly higher decomposition with weight losses of 93 and 98 % at the same two locations. Numerous other studies have shown the same relationship between the rate of residue decomposition and residue placement relative to the soil surface. Parker (1962) using corn stalks as a residue source found that burying the stalks resulted in 65 % decomposition after a 20 week period while the surface placed residues were only 50 % decomposed during the same time. Douglas et al. (1980) conducted a study in the US Pacific Northwest to observe the effects of residue placement and composition on the rate of residue decomposition. During the first 45 days of the study where soil was left bare following a moldboard tillage operation, residue weight losses from standing, surface and buried wheat residues were 0, 1.8 and 22 %, respectively. Upon completion of the cropping cycle consisting of pea-fallow-winter wheat, the losses were determined to be 25, 31 and 85 % for standing, surface and buried residues, respectively. Similarly, Schomberg et al. (1994) found that there were large differences between the decomposition rate of surface applied and buried alfalfa, wheat and sorghum residues. The observed variation in the rate of decomposition was attributed to the buried residues being placed in an environment more conducive to intense microbial activity. Schomberg at al. (1994) also hypothesized that surface residues are exposed to an environment where greater leaching of soluble carbon sources is eminent, which may have been partially responsible for the reduced decomposition rate of wheat and sorghum observed in the study. Ghidey and Alberts (1993) reported similar results where the decomposition rate of buried, surface and above ground residues of wheat, corn and soybean were evaluated. Buried residues exhibited the most rapid rate of decomposition followed by surface placed and above ground level residues for all species. A study by Cogle et al. (1989) found that residue burial resulted in an initial flush of decomposition activity but was comparable to surface applied wheat residue decomposition after 15 days. Christensen (1986) compared the decomposition of buried and surface applied barley residues. He found that there was little difference in the overall decomposition of straws buried at 5, 10 and 15 cm. After a 14-month incubation period, 93-95 % of the buried straw had been decomposed, compared to residues placed on and 45 cm above the soil surface, which showed 36-37 % weight loss.

Franzluebbers et al. (1996) studied the effect of canola residue placement on decomposition rates. They found that after an accumulation of 965 growing degree days, 57 and 30 % of canola residue was lost for buried and surface applied treatments, respectively. The authors noted that initial decomposition of the highly soluble portion of the canola residue was twice as rapid as the less decomposable components and that the increased decomposition rate of buried residues was likely due to a greater soil moisture content.

The studies cited here have generally presented the same conclusion that buried crop residues will undergo a more rapid rate of decomposition than when the same residues are left on the soil surface. This response to burial is attributed to the combination of an increase in potential microbiological inoculum and a more favorable environment for the growth and functioning of the biological soil communities responsible for the mineralization of crop residues.

2.3.4 Soil Environment

This section will examine the effects of cultural management on the resulting soil environment and its potential effects on residue decomposition. Of the three factors identified to control the rate of residue decomposition, substrate availability, soil moisture and soil temperature, the latter two are intimately related to the soil environment, which can be affected by climate, tillage system use and the crops included in rotation.

Douglas and Rickman (1992) used data from previous studies to develop an equation which could estimate the extent of residue decomposition using meteorological data, more specifically cumulative growing degree days. These researchers concluded that residue decomposition could be estimated with using growing degree days when information on air temperature, initial N content and placement of the residue was available.

2.3.4.1 Soil Moisture

A study by Stott et al. (1986) suggests that decomposition of crop residues will likely occur under most soil moisture regimes, although variation in the rate of decomposition is expected. Their results suggest that as environmental conditions are altered, so too are the microbial populations that dominate the decomposition system. As moist soils become dry, populations which are more drought tolerant will become the dominant decomposers, albeit these populations are less effective in breaking down residues compared to those active under moist conditions. Other work has shown, however, that severe soil drying can result in reduced aggregate stability and an increased availability of substrate upon rewetting, resulting in a flush of microbial activity (Adu and Aodes 1978).

Schomberg et al. (1994) used a line-source sprinkler system in Bushland, TX, to evaluate the rate of residue decomposition under five distinct water regimes. The results of the water regime study showed a linear trend of increased decomposition with increased application of water. The increase was more pronounced with buried residues than with surface applied residues.

Orchard and Cook (1983) showed that a small decrease in soil moisture potential, -0.01 to -0.02 MPa, caused a 10 % decrease in microbial activity, measured as CO_2 evolution. Overall, they found a linear relationship between soil moisture potential and microbial activity. Data presented in this study showed that soil which remained moist, maintained a high rate of microbial metabolism. Several treatments in the experiment allowed the moisture potential to drop below -8.5 MPa and these treatments showed a significantly lower rate of microbial activity. The authors suggested that this loss of activity was the effect of: 1) potential lethal effects of the lack of water on the microbes, and 2) a reduction in the ability of the existing microbes to mineralize the available substrate. Mayers et al. (1982) also reported a linear relationship between nitrogen mineralization and moisture content, on a percent mass basis, with a moisture tension between -0.03 and -4.0 MPa. Other findings included 34, 31, 27, 25, 18 and 11 % decomposition of buried wheat residue from soils maintained at -33 kPa, -150 kPa, -1.0, -1.5, -2.5, and -5.0 MPa water potentials. This was a linear relationship showing that as moisture potential of soils decrease so too does the ability of the microbial populations contained therein to metabolize the residues present (Stott et al. 1986).

Pal and Broadbent (1975) found similar results from studies involving the decomposition of rice straw. Measurements were collected from soil moisture regimes of 30, 60 and 150 % water holding capacity (WHC). A soil moisture content corresponding to 60 % WHC was found to provide the most favorable conditions for microbial activity. At 30 % WHC, drought tolerant microbial species were thought to be the most abundant and at 150 % WHC, less efficient anaerobic bacteria species would have become active contributing to the overall decomposition of the added rice residues but resulting in considerably less evolved CO_2 compared to the more favorable 60 % WHC treatment.

Results from these studies suggest that the decomposition rate of crop residues, although driven in part by moisture content, will occur at most moisture potentials. However, both a lack, or an excess of moisture can be an impediment to microbial activity. Mid-range soil moisture will help to maintain sufficient aeration and provide adequate moisture for decomposition of crop residues to occur.

2.3.4.2 Soil Temperature

Soil temperature has significant effects on microbial activity. Roper (1985) determined that microbial respiration can occur at virtually any soil temperature above freezing. However, the lack of respiration at temperatures below freezing is probably due to the decreased availability of soil moisture. Studies in Australia using a high clay content soil (51 % clay) with a -10 kPa water potential (38 % WHC0, found that the optimum temperature for microbial activity was in the range of 30-50 °C. The same study using a low clay content soil (17 % clay) at -10 kPa (21 % WHC), resulted in an optimum temperature range of 25-45°C. Substantial decomposition was observed in the low clay content soil down to soil temperatures of 1.4 °C, and the high clay soil to 4 °C. This study illustrates that soils differing in physical characteristics will contain different microbiological species capable of metabolism under different conditions. Stott et al. (1986) reported that when soils were maintained at -33 kPa moisture potential and soil temperatures were varied, wheat residue decomposition resulted in losses of 34, 29, 24, 17, and 12 % of the original mass of residue when straw was incorporated at temperatures of 20, 15, 10, 5 and 0 °C, respectively. In this study, higher temperatures resulted in increased decomposition, but the authors noted that decomposition can be substantial under cooler temperatures as well.

Biederbeck and Campbell (1971) studied the effect of constant and fluctuating soil temperatures and the effect on soil microbial activity. They concluded that constant cool temperatures were less lethal to the soil microbial community than fluctuating cool temperatures. This relationship was especially evident after soil had been frozen.

These studies suggest that microbial population species will vary with physical soil characteristics and that residue decomposition will occur at most soil temperatures above freezing, although the rate of decomposition may be hampered at lower temperatures.

2.4 Manure and Decomposition of Cereal Residues

It has been recognized that manure is a beneficial soil amendment in terms of organic and inorganic crop nutrients, soil microbial activity, and increased soil organic matter levels. Most of the research on manure focusing on organic matter accumulation has been conducted using solid manures, as they contain large amounts of organic materials while liquid manures tend to have much smaller amounts of solid organic matter (Gregorich et al. 1998; Lessard et al. 1996; Ritz et al. 1997; Sharpley and Sisak 1997). Most research conducted on liquid manure has focused on its ability to replace or complement commercial fertilizers rather than its ability to increase soil organic matter content. However, liquid manure often contains appreciable amounts of dissolved organic carbon, which may serve as a catalyst for soil microbial communities to initiate residue mineralization. Liquid hog manure, with its ability to supply inorganic nitrogen and soluble carbon, may prove to be an effective crop residue decomposition accelerant.

Manures with a high organic matter content can be expected to have a positive effect on the rate of soil respiration, as they are simultaneously a source of abundant carbon and nitrogen. Gregorich et al. (1998) found that the addition of high rates of solid dairy manure to soil resulted in elevated rates of soil respiration, measured as CO_2 evolution. The accumulated emissions of CO_2 were used to calculate total carbon loss from the high and low application rates as well as a control soil. Total carbon loss was determined to be 8076, 6063 and 3507 kg ha^{-1}, for high rate, low rate and control soils, respectively. Manure on these three treatments was applied at 21300, 10600 and 0 kg ha^{-1}, dry matter equivalent. This study indicated that the application of solid manures increases the rate of respiration but higher application rates do not necessarily cause a proportional increase. Gregorich et al. (1998) postulated that the highest application rate caused a decrease in the rate of oxygen diffusion sufficient to reduce microbial respiration, or that soil moisture may have remained at an elevated level resulting in decreased soil temperature conditions, thus reducing respiration. The single factor found to effectively predict respiration rate was soil temperature; this result is in agreement with studies discussed previously. The increased respiration rates reported by Gregorich et al. (1998) were probably due to the mineralization of organic matter found in the manure itself and not the soil to which the manure was added. However, this study offers an interesting perspective for cereal residue decomposition that if a source of nutrients and microbial inoculants, such as liquid hog manure, is added to a soil receiving high levels of organic matter as cereal straw, the additions may result in increased organic matter decomposition as was reported by Gregorich et al. (1998). Weil and Kroontje (1979) found that the addition of solid poultry manure to soils increased the CO_2 respiration rate from 0.024 mg C g soil^{-1} day^{-1} in the control treatment to 0.101 and decreased the respiration rate to 0.069 in soils receiving 85 and 110 Mt ha^{-1}, respectively. Included in the experiment was a litterbag study where there was statistically no difference in the disappearance of leaf matter from any of the three treatments mentioned above. This demonstrates the importance of adding a carbon source with manure or crop residue amendments. The addition of poultry manure adds both nutrients and organic matter to the soil ecosystem.

In this study there was a trend for less decomposition of the plant matter contained in litterbags, as manure application rates were increased. This was probably due to the carbon sources added with the manure being preferentially metabolized by the soil microbial population instead of the crop residues already present at the time of manure application.

Lessard et al. (1996) reported elevated levels of nitrous oxide flux from soils amended with solid dairy manure in Ottawa, Ontario. This study was a continuation of the Gregorich et al. (1998) study discussed previously; the same treatments were applied and the elevated rates of N_2O were again attributed to increased microbial activity. The increases in N_2O flux were observed within the first 7 days of the experiment, further reinforcing the fact that large flux increases are short lived after manure application due to the rapid decomposition of the soluble carbon sources.

Fauci and Dick (1994) reported a greenhouse study where the addition of organic nitrogen increased microbial activity compared to inorganic inputs of nitrogen. Hog manure, being essentially a liquid ammonium fertilizer may induce the same trend when applied to soils already containing high levels of organic materials. Similarly, Fraser et al. (1988) evaluating the difference between conventional and organic cropping systems for grain production, showed higher soil respiration rates in soils receiving feedlot manure compared to soils receiving inorganic nitrogen fertilizers. Other observed benefits of manure application were increased phosphorus and potassium reserves, increased water holding capacity and increased soil carbon levels. The increase in microbial activity, associated with the increase in CO_2 evolution, was also deemed to be a positive effect of manure applications due to increased soil health and mineralization potential.

Both solid and slurry manure applications to soil can increase the rate of soil microbial population activity, measured as soil CO_2 respiration. This suggests that manure additions stimulate microbial activity through the simultaneous additions of carbon and nitrogen. These findings suggest that there may be merit to the simultaneous application of cereal crop residues and liquid hog manure on the rate of soil respiration observed and the subsequent rate of residue decomposition.

2.5 Tillage and Decomposition of Cereal Residues

The adoption of conservation tillage systems to combat soil movement by wind and water has resulted in an increase in crop residues being retained either at the soil surface or within the top 10 cm of soil (Schomberg et al. 1994). In conventional or inversion tillage, such as moldboard plow systems, crop residues are completely buried, providing a clean soil surface free of crop residues. These systems, however, can result in a decrease in soil organic matter content and intensive tillage can result in poor soil aggregation and poor soil structure. An increased rate of soil drying resulting from increased evaporation potential and a decrease in the moisture holding capacity of soils is also evident when comparing conventional to conservation, or reduced tillage systems. Perhaps most importantly, intensively tilled fields leave soil particles very susceptible to movement by wind and/or water.

Tillage is an important part of crop production in the Red River Valley of Manitoba. High rates of annual precipitation in Red River Valley and the fine texture of the soils that dominate the area have prompted producers to employ tillage as a means of reducing excess soil moisture. Soils are often tilled in the fall to encourage the infiltration of spring melt water and to provide a means for soil drying and aeration. Spring tillage is usually minimized to direct seeding operations as intensive tillage prior to seeding can promote very rapid soil drying and result in an undesirable seedbed condition.

The direct effects of tillage on residue decomposition are relatively simplistic when the three driving factors for organic matter mineralization are considered. Angers and Recous (1997) reported that ground wheat residues showed increased rates of disappearance when compared to intact straw. Intensive tillage will effectively reduce the size of residues through mechanical manipulation. Straw management often requires harrowing operations, which serve to distribute straw evenly across a field and reduce the size of the straw through physical disturbance, possibly increasing straw availability to decomposing organisms. Tanaka (1986) studied the effects of chemical and mechanical fallow on wheat residue retention on the soil surface after spring and winter wheat production in Montana. Chemical fallow plots received four herbicide applications to control weed populations while mechanical fallow plots received sweep and rod weeder tillage passes for weed control. After 426 days of fallow, the chemical and mechanical fallowed plots retained 72 and 28 % of the initial residue, respectively. Blackshaw and Lindwall (1995) found similar results where mechanical fallow systems retained significantly less surface residue than chemical fallowed plots. Franzluebbers et al. (1995) studied the effects of conventional and no-till practices on the decomposition of soybean, sorghum and wheat residues. They found large differences in the potential mineralization of crop residues between the two systems. The conservation tillage (no-till) systems resulted in much lower rates of carbon mineralization, after harvest, for soybean and sorghum residues. Wheat showed little difference in potential carbon mineralization between the cropping season and post-harvest periods. This may have been due to the high C:N ratio of the wheat straw relative to soybean and sorghum residues.

The effect of tillage systems can have a marked effect on the potential for soils to mineralize crop residues. Studies by Christensen (1986), Douglas et al. (1980) Franzluebbers et al. (1996) and Ghidey and Alberts (1993) have all demonstrated the impact of burying crop residues on potential decomposition. Tillage acts as a mechanical means for inoculating crop residues with the soil's diverse population of decomposing organisms. Conservation tillage systems will serve to maintain the maximum amount of crop residues on the soil surface as possible, without reducing crop yields, in order to control erosion by wind and water. Residues retained on the soil surface will not be exposed to intensive microbial activity, which buried residues will undoubtedly encounter. While the theories supporting conservation tillage adoption are paramount to maintaining a sustainable agri-ecosystem, by reducing the degradation of non-renewable soil resource quality, the need for increased carbon mineralization to manage crop residues in the Red River Valley may require special attention.

Wuest et al. (2000) studied the effect of wheat straw mixed with soil, placed on the soil surface or below the seed and found that residues mixed with the soil resulted in delayed seed emergence compared to the other treatments. After a 12-day period all treatments were equal in emergence and the authors concluded that the delay in emergence was due to the physical impediment of the straw to coleoptile growth towards the soil surface and not a chemical hindrance. The researchers did not include final yield in the measured data, but hypothesized that the uneven emergence may have resulted in uneven crop growth and potential uneven ripening. Their suggestions for alleviating this problem included using low disturbance seeding equipment to minimize seed to residue contact and removing unweathered crop residues from the seeding area.

Intensive tillage, even on the gently undulating topography present in the Red River Valley, can increase the severity of tillage erosion, as compared to reduced tillage systems. The retention of surface residues is also beneficial for protecting soils against water and wind erosion. Chisel tillage and disk tillage systems will both incorporate appreciable amounts of crop residues in order to inoculate straw with soil bacteria resulting in stimulated microbial activity, while maintaining sufficient surface cover and a rough field surface which is effective in reducing wind erosion. With careful consideration of tillage intensities, the management of crop residues using cultural methods, excluding residue burning, can be potentially viable and sustainable practices while soil health and crop productivity will not be compromised.

2.6 Summary and Conclusions

The decomposition of cereal crop residues by microbial action has been widely documented, as has been shown with this literature review. Most of the research on this topic has been established in order to quantify the effects of conservation tillage on surface crop residue persistence. However, the aim of this review has not been to study how to maintain residues, but rather how to increase the rate at which surface applied and incorporated residues are decomposed. Typically, heavy loading rates of annual crop residues in the Red River Valley of southern Manitoba have prompted producers to use straw burning as a means for disposing of excess residues. Straw management by burning post-harvest crop residues is neither a sustainable production practice nor a sustainable practice in terms of environmental quality. Further to issues surrounding sustainability, health concerns for the residents of southern Manitoba, arising from elevated levels of suspended particulate matter in the atmosphere which follow a residue burning event, have prompted government officials to consider the appropriateness of such management practices.

Straw burning is a cultural practice which may have been important for maintaining crop productivity before the advent of modern highly efficient seeding implements designed to accurately place seed and fertilizers optimally with respect to the soil surface to promote timely and even crop emergence even in the high residue seedbed conditions that dominate the Red River Valley. The small increase in crop yields associated with straw burning can be negated by an annual net loss of soil carbon and nitrogen, which, if considered in an economic feasibility study for the annual crop production costs associated with alternative residue management systems, may be found to have negative economic implications.

Research presented in this review has demonstrated that there is potential to decrease the need for straw burning by increasing microbial decomposition of crop residues using cultural methods of residue management. Cereal straw, having a high C:N ratio, may decompose more rapidly when an abundant nitrogen source is made available within an environment conducive to microbial activity. The nitrogen and carbon contained in liquid hog manure could prove to be an effective catalyst to increase in the rate of crop residue decomposition. Liquid manure will provide valuable moisture, microbes and both organic and inorganic nutrients to the soil, all required for sustained microbial activity. Small particle size residues have been shown to be decomposed at accelerated rates when additional nitrogen is added to the soil system. Using tillage for physical disintegration of the cereal residues should also theoretically increase the rate of decomposition by providing more potential surface area for microbial colonization. By using both biological and mechanical means of accelerating residue decomposition, the need for straw burning in the Red River Valley may be decreased, while providing incentive to using hog manure as a valuable resource with a potential to increase the sustainability of agricultural ecosystems.

3. A GROWTH CHAMBER STUDY TO EVALUATE THE EFFECT OF OAT RESIDUE PLACEMENT AND LIQUID HOG MANURE APPLICATION ON THE RATE OF RESIDUE USING MASS LOSS USING MESH LITTER BAGS

3.1 Abstract

In order to evaluate the effects of residue placement relative to the soil surface and liquid manure application to soil on the rate of oat residue mass loss, a controlled atmosphere growth cabinet study was conducted. Mesh bags were constructed and either buried or surface applied to control soils and soils that had received a manure application rate equivalent to 98 kg NH_4^+-N ha^{-1}. Three replications each of the four treatments were established and these sets of treatments were established in triplicate in order to evaluate the effects of incubation time on residue mass loss; one set of litterbags was removed after a 3, 6 and 9-week incubation period. Statistical analysis was completed to identify significant manure application, residue placement and incubation duration effects.

Manure application was found to have a significant positive effect on the rate of oat residue mass loss after the 9-week incubation period only; no significant manure effect was observed during the 3 and 6-week incubation periods. Residue placement was found to have a significant effect on mass loss after each incubation period; in each case the buried residues were observed to decompose at a much more rapid rate compared to

surface placed residues. Overall, liquid manure application and oat crop residue burial were found to significantly increase the rate of residue decomposition.

3.2 Introduction

The fine textured soils found in the Red River Valley of southern Manitoba, Canada, present a unique residue management challenge to annual crop producers, compared to the soil types found in other regions of the province. A common residue management practice in cereal production systems is the burning of cereal crop residues, as producers feel that maintaining large quantities of cereal residues within the soil or on the soil surface can result in slow warming and drying of the spring seedbed, interference with seeding equipment and subsequent loss of seed placement accuracy, immobilization of applied nitrogen fertilizers and a harbor for crop disease inoculum.

Several residue management alternatives have been identified as having the potential to reduce producer reliance on straw burning. Incorporation of the residues through tillage may help to increase the rate of residue decomposition by placing the residues in intimate contact with soil microbial communities and inorganic nutrient sources to support the growth and metabolism of these communities as the residues are mineralized. However, the addition of large quantities of carbon to soils can result in the immobilization of a large proportion of the inorganic nitrogen already contained within the soil. The addition of abundant carbon can reduce the rate of microbial mineralization of crop residues, as sufficient nitrogen will not be available to support the metabolic requirements of the soil microbes. The addition of liquid hog manure, may help to sustain the rate of residue decomposition, acting as a source of carbon and/or nutrients for microbial populations, and at the same time, may provide an environmentally responsible method for use of the abundant quantities of liquid manure currently produced in southern Manitoba.

3.3 Objective of the Study

The objectives of the study were to determine the rate of oat residue mass loss when residues were either buried or place on the soil surface in mesh litter bags; and to determine the effect of amending the soil with liquid hog manure prior to residue bag placement.

3.4 Materials and Methods

3.4.1 Field Site Treatment Design and Layout

The study was conducted over a 9-week period in a growth cabinet maintained at 23°C and 55% relative humidity. Soil was collected from a field site in Fannystelle, MB during the fall of 2000 and stored at 0°C until the experiment was initiated. Soil was dried and ground to pass a 2-mm sieve and then brought to a moisture content of 70% moisture holding capacity and incubated for 10-days prior to treatment establishment to allow the soil microbial communities to become active after storage. Liquid manure was collected one week prior to the start of the experiment from GrayMac Farms in Fannystelle, MB and stored at 2°C until use.

The experimental treatments included:

1. Control soil with surface placed litter bags
2. Control soil with buried litter bags
3. Hog manure amended soil with surface placed litter bags
4. Hog manure amended soil with buried litter bags

Each of the four treatments was replicated three times and each replicated treatment was established in triplicate to allow destructive sampling at 3, 6 and 9 weeks

Litterbags were constructed of plastic fiber screen with 1-mm holes. Two 10-cm disks were cut from the screen material and sewn together using polyethylene thread to prevent it from disintegrating during the experiment. Mesh bags were weighed and 0.017 kg of whole oat residue, an application rate equal to approximately 6000 kg ha^{-1}, collected from a commercial production field at the same time as the soil used in the experiment, was placed inside the mesh bags, the small opening left in the bags were sewn closed, and the final mass of the litterbag and the residue was measured.

The treatments were replicated three times and applied by placing 2 kg of soil in 10-cm diameter pots, all at once for surface placed treatments or by placing 1 kg in the pot, placing the litter bags on the soil surface and then placing the final 1 kg of soil on top of the litter bag for the buried treatments. 200-ml of liquid hog manure was applied to the experimental soils, a field application rate equivalent to 98 kg ha^{-1}, in all manure amended treatments evenly on the soil surface of the for the surface placed residue treatments or on the surface of the first 1 kg of soil in the buried residue treatments.

Soil moisture content was maintained at 60-70% moisture holding capacity during the experiment by adding 300-ml of distilled water to each pot every 4 days.

Residue mass loss was determined by weighing each of the litter bags after being removed from the growth cabinet after incubation, 3, 6 and 9 weeks, and subtracting this mass from the original unaltered oat residues. The percent mass loss was determined as the amount of loss divided by the original mass.

3.4.2 Statistical Analysis

Data was analyzed using the GLM procedure of Statistical Analysis Software at the 5% (α=0.05) significance level. Least Significant Difference (LSD) factor means were used to separate factor mean significance groupings. The effect of residue placement, liquid manure application and incubation period were determined separately using the slice option in the SAS GLM.

3.5 Results and Discussion

3.5.1 Percent Residue Mass Loss

Table 3.1 Residue mass loss for placement and amendment factors for each incubation period

	% Mass Loss		
Placement			
Incubation Period	Surface	Buried	P-Value
3-Week	1.7b	14.8a	0.0002
6-Week	9.8b	21.6a	0.0007
9-Week	10.3b	44.8a	<.0001
Amendment			
Incubation Period	Control	Manure	P-Value
3-Week	7.4	9.0	0.5937
6-Week	14.9	16. 5	0.6189
9-Week	23.2b	31.9a	0.0084
CV (%)		30.64	

Values followed by different lower case letters and P-values indicate a significant difference between treatments within incubation period (P <0.05).

The statistical model determined that the data was highly significant in this experiment with a P-value of <.0001. The slice analysis used in the GLM also indicated that both experimental factors were highly significant with placement being significant at all sampling intervals, however, manure application was found to have a significant effect after the 9-week interval only. In all cases the buried residues had a greater rate of mass loss compared to the surface placed residues. A significant manure by placement interaction was also observed, with a P-value of 0.0284. Figure 3.1 shows the effects of residue placement and manure application on the rate of residue mass loss for all incubation periods.

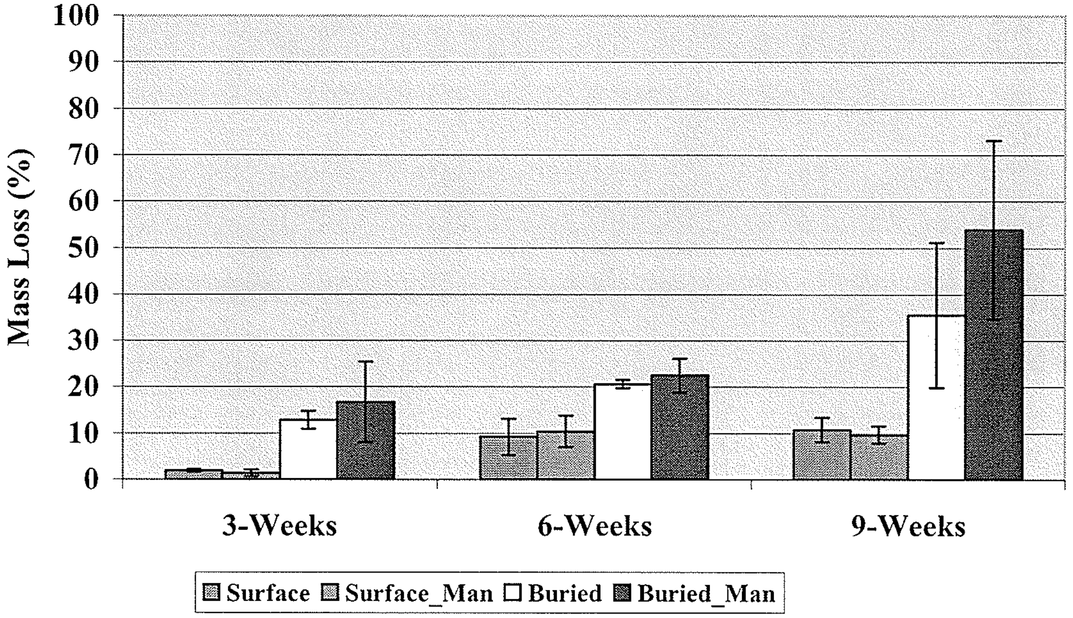

Figure 3.1 Residue placement and manure application effect on residue mass loss for each incubation period. Error bars are standard deviation about the mean for all treatments within incubation period.

3.5.2 Residue Placement Effects

Surface placed residues were more exposed to the atmosphere and were not placed in as conducive an environment for microbial decomposition as the buried residues, due to a less moist environment. The buried residues would have been more easily colonized by soil microbial populations as well which may have resulted in the observed increase in residue mass loss. Previous studies have shown that surface placed residues tend to be colonized by fungal species, while buried residues are colonized more by bacterial species (Adu and Oades 1987; Aulakh et al. 1991). This may have played a significant role in the increased rate of residue decomposition exhibited by the buried residues. Studies by Cogle et al. (1989), Christenson (1986), Schomberg et al. (1994) and Parker (1962) all reported that buried residues decomposed at a more rapid rate than surface placed residues and attributed this result to a host of factors including more favorable moisture conditions, more intimate contact with inoculum for soil microbial species, and increased availability of soil nitrogen for microbial metabolic use during residue decomposition.

The consistent effect of residue burial on the rate of residue mass loss, for each incubation period, indicates that buried residues will generally always exhibit a greater rate of decomposition compared to surface placed residues due to the same factors identified previously by other authors. The effects of residue placement and the associated LSD family groupings are found in Figure 3.2.

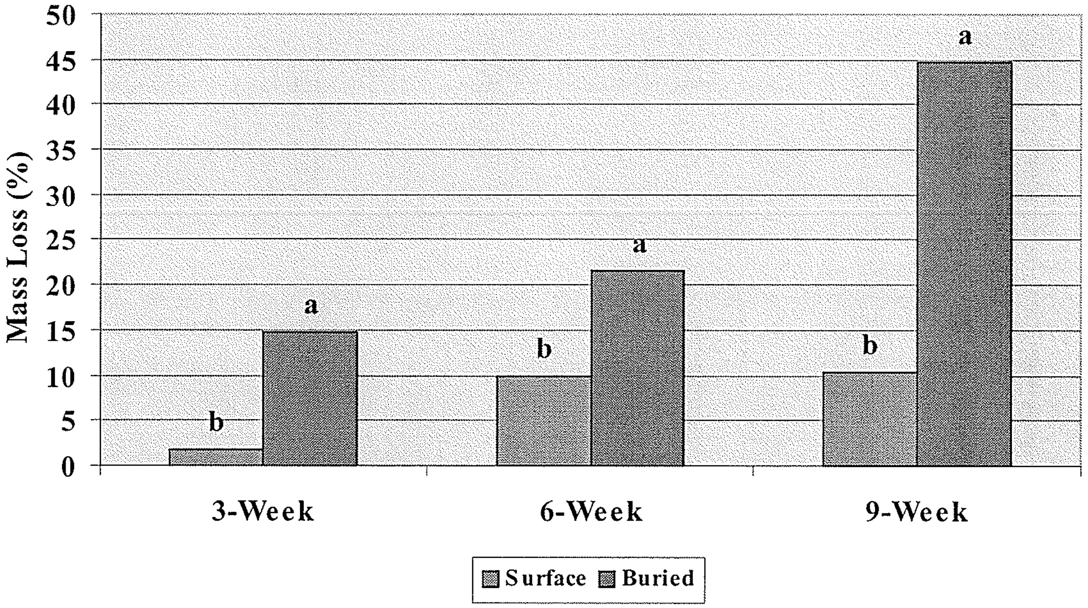

Figure 3.2 Residue placement effect on residue mass loss for each incubation period. Treatments followed by different lower case are statistically different for residue mass loss (P <0.05).

3.5.3 Manure Application Effects

Manure application had a significant positive effect on the rate of oat residue mass loss after the 9-week incubation period. This was also reported by Fraser et al. (1988) and Gregorich et al. (1998), these authors cited increases in crop residue decomposition when solid feedlot cattle and liquid hog manure, were applied to soil. This may have been due to both manure nitrogen and manure carbon additions. Studies which use soil respiration rates to determine the effects of manure application to soil may not be able to distinguish between the effects of carbon and nitrogen on the resulting rate of soil respiration. However, this study, which used mass loss to determine the effects of residue burial and manure application, in lieu of soil CO_2 respiration, offers a more succinct analysis of manure effects on actual residue decomposition and not solely soil microbial activity, an indicator of residue decomposition rate, as such, the increased rate of decomposition observed in this study cannot be pinpointed as the effect of manure nitrogen or carbon. These data do suggest, however, that the application of liquid hog manure to clay soils receiving high rates of oat residue does increase the rate at which the added residues are decomposed. This may be due to an increase in soil microbial activity in the presence of abundant nutrients, supplied through manure application, and that a 9-week period was required to stimulate the activity to significantly different and detectible levels. Alternatively, the lack of response to manure application until after the 9-week incubation period may indicate that it was not until the ninth week that the magnitude of the manure effect was greater than the variation between replicates. The effects of manure application and the associated LSD family groupings are found in Figure 3.3.

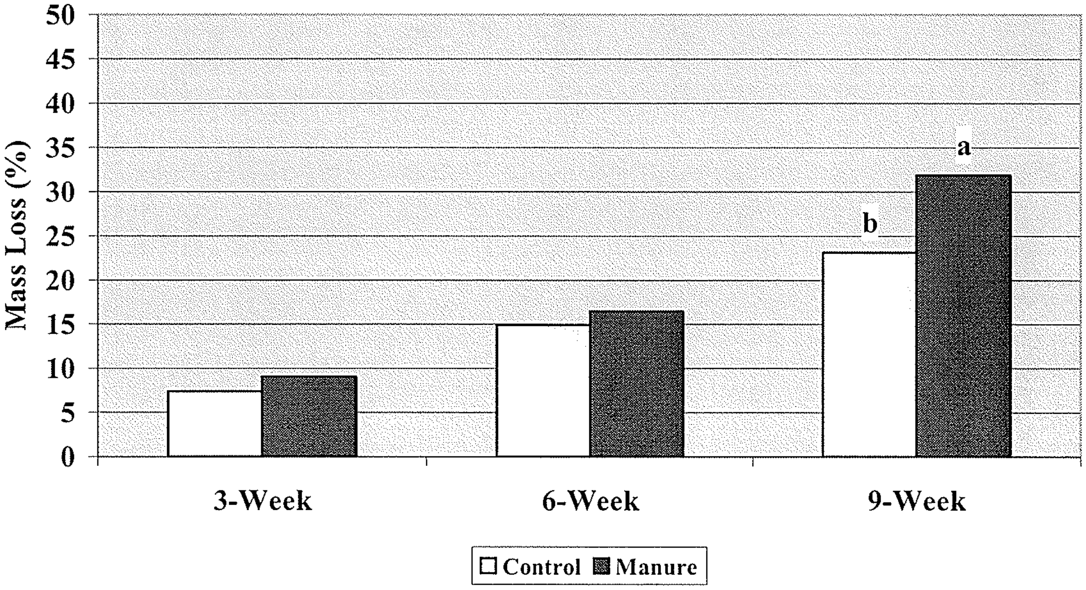

Figure 3.3 Manure application effect on residue mass loss for each incubation period. Treatments followed by different letters are statistically different for residue mass loss ($P < 0.05$).

3.6 Summary and Conclusions

The results presented in this study suggest that residue placement relative to the soil surface can play a major role in the rate at which soil placed oat crop residues are decomposed. Buried residues exhibited a consistently higher rate of residue mass loss over all incubation periods. This is likely the result of several factors including a greater ability for soil microbial species to colonize added residues, increased availability and reduced variability of soil moisture contents, and increased availability of soil nitrogen to be used by soil microbes during the decomposition of the residue.

Manure application was found to have a significant positive effect on the rate of oat residue mass loss after a 9-week incubation period, however, no effect was found after a 3 or 6-week incubation. Due to the design of the experiment, it was not possible to determine the exact cause of increased residue mass loss in the presence of liquid manure. The effects of individual manure constituents on the rate of residue decomposition will be explored more fully in subsequent chapters.

The overall effect of manure application to the clay soils in this study, regardless of the effect of either manure nitrogen or carbon, was a significant increase in the rate of oat crop residue mass loss after a 9-week incubation period. Based on these findings, oat crop residues will tend to decompose more rapidly when soil is amended with liquid hog manure and the residues are incorporated into the soil system. This experiment was carried out under sustained optimal conditions for microbial activity, high temperature and relative humidity and a constant soil moisture content of 70% holding capacity, therefore, these results may not be directly applicable to the crop production systems used in the Red River Valley as climatic conditions are often variable in the region. However, it can be expected that oat crop residues may decompose at a significantly higher rate when soils are amended with liquid hog manure and when incorporated through tillage. Thus, manure application to soils and incorporation of crop residues through tillage, may be viable alternatives to post-harvest stubble burning for the sustainable management of excessive quantities of oat crop residues.

4. EFFECT OF TILLAGE SYSTEM INTENSITY AND LIQUID HOG MANURE APPLICATION ON CEREAL CROP RESIDUE DECOMPOSITION IN FINE TEXTURED SOILS IN SOUTHERN MANITOBA

4.1 Abstract

Straw burning is a residue management tool often used in the fine textured soil regions of the Red River Valley in southern Manitoba, Canada. This is in response to prolific cereal biomass growth resulting from abundant rainfall received throughout the growing season and high soil moisture contents during the spring seeding season. If straw is not removed or burned, these factors are thought to result in delayed or impeded seedling emergence, uneven crop stands, immobilization of nitrogen fertilizers and high crop disease pressure. The objective of our research project was to examine possible residue management alternatives to straw burning. Carbon dioxide and nitrous oxide fluxes were presumed indicators of biological activity and, therefore, microbial decomposition. Data were collected on 43 sampling dates throughout the fall and spring, over two field seasons, to quantify the potential for liquid hog manure application to increase the rate of microbial decomposition of large quantities of cereal crop residues in these clay soils. Soil moisture content and soil temperature were monitored for the duration of the experiment. Three tillage systems: zero, chisel plow and V-disk primary tillage; were included in the study as factorial treatments in year-1 and as main plots in a

split plot design in year-2 of the study. Fall manure application was the second factorial treatment in year-1 and the split-plot factor in year-2.

The more intensive chisel plow and V-disk primary tillage systems exhibited greater CO_2 respiration compared to the zero tillage system. Fall manure application consistently increased the rates of CO_2 and N_2O respiration in all years and sampling periods. Soil moisture and temperature fluctuations were not significantly affected by tillage system or manure application. Results suggest the application of liquid hog manure, in conjunction with any of the three tillage systems evaluated, has the potential to increase the rate of cereal residue decomposition in the fine textured soils of the Red River Valley.

4.2 Introduction

The fine textured soils found in the Red River Valley of southern Manitoba, Canada, often present unique residue management challenges to annual crop producers. A common residue management practice in cereal production systems is to burn cereal crop residues. Maintaining large quantities of cereal residues within the soil or on the soil surface is thought to result in slow spring soil warming and drying, can result in a loss of seed placement accuracy during seeding operations, immobilization of applied nitrogen fertilizers and increased crop disease pressure.

Several residue management alternatives have been identified as having potential to reducing producer reliance on straw burning, increasing soil and residue contact and increasing the supply of soil inorganic nitrogen to increase the availability of nitrogen to soil microbial populations. Incorporation of crop residues through tillage may increase the rate of residue decomposition by placing the residues in intimate contact with soil microbial communities and inorganic nutrient sources to support the microbial population growth and function while residues are decomposed.

The addition of large quantities of carbon to soils has been shown to result in the immobilization of soil inorganic nitrogen pools. The addition of crop residue carbon, can, therefore, reduce the rate of crop residue decomposition, as sufficient soil nitrogen will not be available to support the metabolic requirements of the microbial communities responsible for residue decomposition. The addition of a nitrogen source, such as liquid hog manure, may help to sustain the rate of residue decomposition, acting as a source of both ammonium nitrogen and readily available carbon as volatile organic compounds for microbial populations. If residue decomposition can be stimulated by liquid hog manure application to soil, this practice may provide an environmentally responsible method for use of the abundant quantities of liquid manure currently produced in southern Manitoba and reduce the incidence of stubble burning as a crop residue management strategy in the Red River Valley.

4.3 Objective of the Study

This study had two objectives. The primary objective was to quantify the effect of liquid hog manure application to clay soils on the rate of microbial decomposition of cereal crop residues. The secondary objective was to evaluate the effect of three primary tillage systems on the rate of cereal crop residue decomposition with and without the addition of liquid hog manure. The three tillage systems considered were fall chisel plow, fall one-way disk and zero fall primary tillage.

4.4 Materials and Methods

4.4.1 Field Site Treatment Design and Layout

4.4.1.1 2000-2001 Experiment

The study was conducted at a 4.6 ha field site near Fannystelle, Manitoba, legal location SE-8-3-25. The average annual precipitation for the area is 513 mm water equivalent and the soils are classified as Rego Humic Gleysol and Gleyed Rego Black Chernozem for the Osborne and Red River soil series clays, respectively. The Osborne soils are naturally poorly drained but have been improved with surface drainage and dominate the lower slope areas of the landscape and the Red River series are found in the upslope, imperfectly drained areas. Soil texture is clay with a clay content >80%. Physical and chemical characteristics for the soil used in all the experiments reported in this thesis are found in table 4.1

Table 4.1 Field site soil physical and chemical characteristics

pH	
0-15 cm	7.1
15-60 cm	8.0
Electrical conductivity (dS m^{-1})	
0-15 cm	0.78
15-60 cm	1.30
Organic matter content (%)	8.6
Particle Size Analysis (%)	
Sand	3
Silt	16
Clay	81

The initially proposed design of the project included several manure application rates and a variety of manure application methods as well as several tillage systems. Due to resource constraints, the project was simplified in order to maintain the desired field-scale status and a statistically sound experimental design. Consequently, the design included only one manure application rate with two application methods, direct injection and surface application and incorporation, and three tillage systems, including chisel, disk and zero primary tillage based systems. The systems chosen for experimentation were thought to represent the majority of tillage and manure application systems typically employed in the Red River Valley. The chisel-based primary tillage system is the most widely used of the three, the disk-based primary tillage system was included in the design as it was hypothesized that the cutting action of the disks may decrease the overall particle size of the cereal straw, thus increasing the rate of residue decomposition. The zero primary tillage system was included as an example of a low intensity tillage system, but is currently not widely used in the region.

The field project was initiated in August 2000. The plot area was selected and a detailed topographic survey of the area was conducted in order to assess potential influences of landscape and drainage. Analysis of the topographic data revealed that the entire plot area was slightly south sloping. Plots were established parallel to the slope and the site was divided into two separate blocks, one corresponding to the upper slope area and the other on the lower slope portion, the slope was approximately 1 % across the entire plot area. The blocks were separated by a drainage ditch within the inter-block area; this area was used for maneuvering the commercial scale field equipment used in the study and also allowed for excess water to drain from the plot area. It was necessary to divide the plot area into two identical blocks for plot randomization, as the tillage equipment used was not available in identical widths. By placing two of the four replicates in each block, the blocks maintained the same overall dimensions and minimized the disruption of management in the surrounding field.

The experiment was set up as a randomized complete block design with eight treatments and four replications of each. Each plot was 161.2 m long and approximately 10.5 m wide, the width varying slightly with the tillage equipment used. Repeated sampling of soil respiration rates was utilized within each plot to assess the inherent variability within the field in terms of microbial activity. Figure 4.1 provides a diagrammatic representation of the plot layout. The treatments consisted of eight residue-manure management combinations:

1. Chisel plow fall primary tillage (Chisel)
2. Chisel plow fall primary tillage with injected hog manure (Chisel_Man)
3. V-disk fall primary tillage (Disk)
4. V-way disk fall primary tillage with surface applied hog manure (Disk_Man)
5. Zero fall primary tillage (Direct)
6. Zero fall primary tillage with injected hog manure (Direct_Man)
7. Straw removal (Stubble)
8. Swath burning (Burn)

The experiment was established on land that had been cropped to oats in the spring of 2000, the oats were swathed in early-September and the 2700 kg ha^{-1} crop was harvested on September 24th using a rotary combine operated by the co-operating producer. Straw and chaff were chopped and spread with the combine, and the plot area was immediately diamond harrowed to provide an even distribution of the crop residue.

Manure samples were collected from the earthen manure storage facility adjacent to the plot area in July 2000 to determine the nutrient content of the manure prior to application. Manure was applied and tillage operations were completed on October 4th and 5th.

Primary tillage treatments were applied using commercial-scale tillage equipment at a ground speed of 10 km h^{-1}. The chisel plow treatment was applied using a 10-m-wide chisel plow equipped with 25-cm sweeps on 25 cm spacing operated 10 cm below the soil surface. The one-way disk operation was completed using a 9.1-m-wide one-way V-disk with 50-cm disks that engaged the soil to approximately 5-10 cm. No primary tillage was included in the zero tillage treatment; however, as the manure injection equipment did provide some level of soil disturbance in the zero tillage with manure treatment, the injection equipment was operated in the zero tillage plots which did not receive hog manure as well, providing identical soil disturbance levels for all zero tillage plots with and without hog manure application. The chisel tillage operation was completed prior to manure application and the disk tillage operation was completed 30 minutes after liquid manure had been applied.

Manure injection was completed using a 8300-litre tanker injection unit leased from the Prairie Agricultural Machinery Institute (PAMI). The unit was a pull-type tanker with an integral toolbar on a hydraulically controlled three-point hitch. The toolbar was modified by replacing the original light-duty coil spring type shanks with heavy-duty spring trip reset chisel plow shanks fitted with 25-cm sweeps, as the original light duty shanks did not have sufficient down pressure to engage the clay soils which dominate the study area. Shank spacing was 55 cm with a total implement width of 4.2 m. Manure was applied at 93,329 L ha^{-1} corresponding to an NH_4^+-N application rate of 110 kg ha^{-1} and was injected to approximately 10 cm below the soil surface for the injected treatments. The surface broadcast manure treatment was applied using the same manure application unit with the shanks raised out of the soil, placing the liquid on the soil surface. Surface applied manure was incorporated using a one-way disk. Plots that did not receive fall-applied manure were amended with inorganic nitrogen fertilizer prior to spring planting to equalize nutrient concentrations between the two nutrient sources for final yield analysis.

Straw loading rates were determined prior to treatment application by collecting all crop residue remaining after oat harvest from 5 random 1 m^2 quadrants within each block, 10 samples in total. The collected biomass consisting of straw and chaff was air dried and weighed to establish a residue-loading rate of 6000 kg residue ha^{-1}.

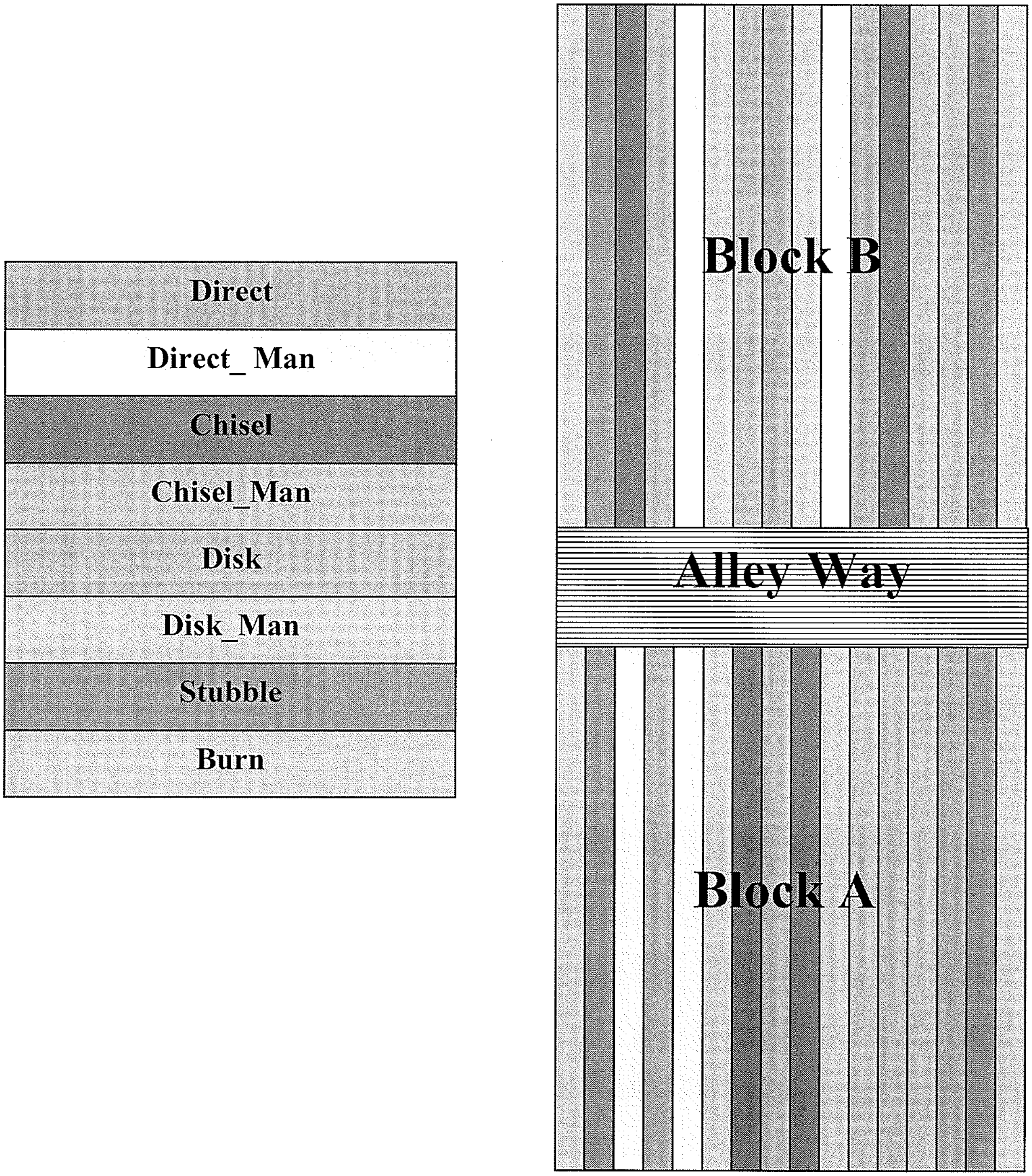

Figure 4.1 Fall 2000 plot layout diagram

4.4.1.2 2001-2002 Experiment

Several modifications were made to the experimental design and the sampling protocol for the second field season. The experimental design was modified to a randomized complete block (RCB) with a split-plot design instead of a simple RCB. The split-plot design allowed for a side-by-side comparison of fall manure and spring fertilizer amended treatments. Tillage systems were maintained as the main plot and were randomized within blocks, and the split plots were established as the fall manure and spring fertilizer nutrient sources. Main plots measured 13.6 m x 161.2 m, and contained the two split plots 6.8 m in width. Four replications of each main plot were established, two in Block A and two in Block B, to evaluate the effect of topographic variability. The total plot area was equal to 2.1 ha. Figure 4.2 provides a diagrammatic representation of the plot layout.

Due to the lack of an oat crop within the vicinity of the source of liquid hog manure, the second year field plots were established adjacent to the first year plots on wheat instead of oat straw. Since the chemical composition of oat and wheat straw is comparable, the change in residue type was viewed as a minor variation from the original project outline. Also, in the fall of 2001, field plots were located in a field area where fire would not be easily contained or controlled, therefore, the burning and standing stubble/no chaff treatments were not included in the second year of the study.

Wheat straw was chopped and spread during wheat harvest operations using a commercial rotary combine provided by the co-operating producer. Straw loading rates were determined by collecting 10 random 1 m^2 quadrat samples from throughout the plot area consisting of standing stubble, straw and chaff, prior to tillage treatment and manure application.

The following six treatments were applied on October 20th, 2001:

1. Chisel plow fall primary tillage (Chisel)
2. Chisel plow fall primary tillage with injected hog manure (Chisel_Man)
3. V-disk fall primary tillage (Disk)
4. V-way disk fall primary tillage with surface applied hog manure (Disk_Man)
5. Zero fall primary tillage (Direct)
6. Zero fall primary tillage with injected hog manure (Direct_Man)

Liquid hog manure application was completed on October 20th by a custom applicator using a dragline application system. The application rate was 65,916 L ha^{-1}, equivalent to 134 kg ha^{-1} NH_4^+-N. The tool bar application system was designed with 30 cm shank spacing and injected the manure to approximately 5 cm. Surface applied manure treatments were achieved by raising the injection toolbar above the soil and allowing the manure to be distributed directly onto the soil surface. Plots were one-way disked 30 minutes after surface manure application. Chisel plow treatments were tilled prior to manure injection. Zero primary tillage plots, not receiving manure, were subjected to a single pass with the injection toolbar to provide an accurate comparison of manure vs. non-manured treatments.

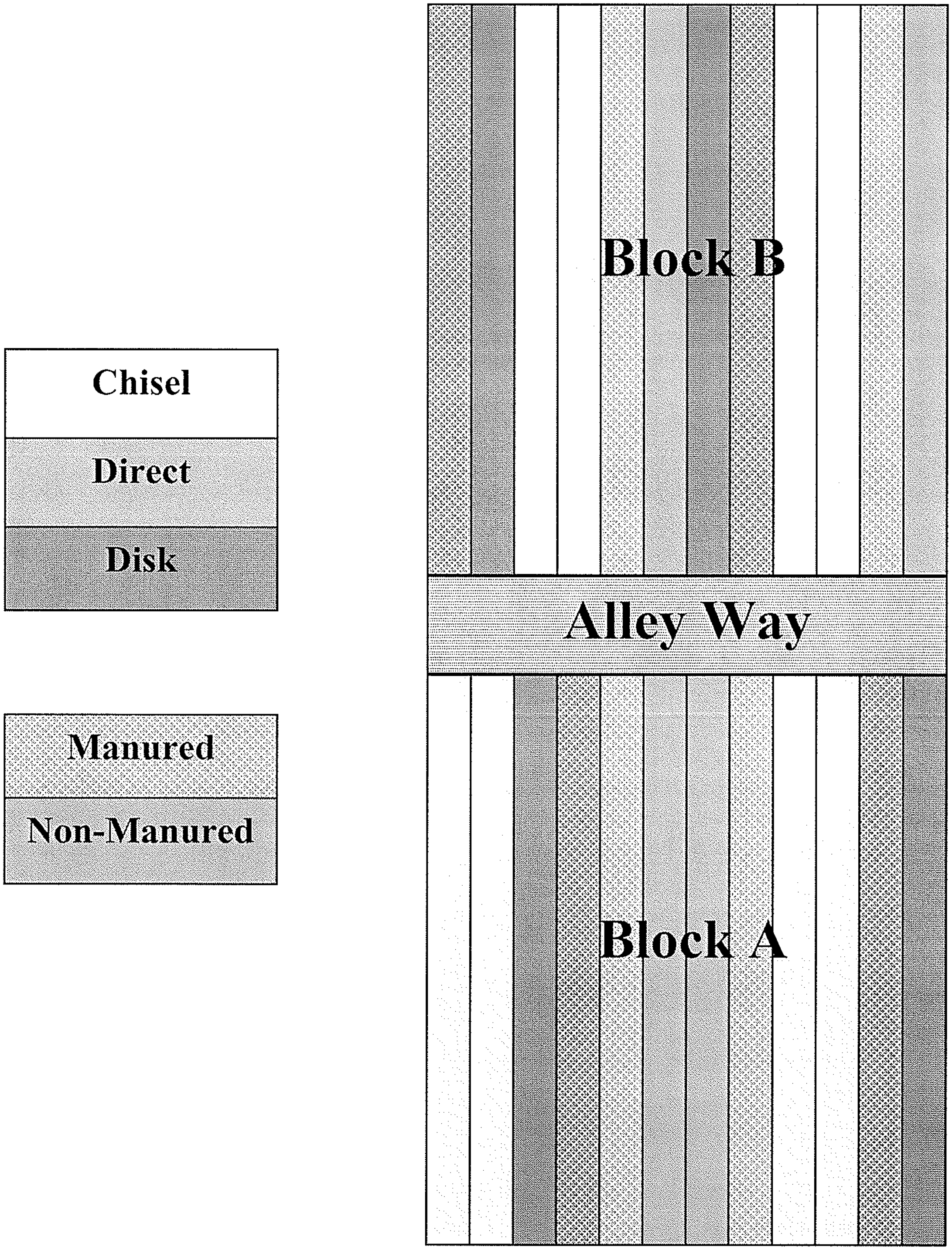

Figure 4.2 Fall 2001 plot layout diagram

4.4.2 Soil Respiration Measurements

4.4.2.1 2000-2001 Experiment

After the tillage and manure treatments had been applied, the in-field soil respiration of carbon dioxide and nitrous oxide was determined periodically. CO_2 and N_2O were considered an easily monitored indicator of soil microbial activity and therefore, the rate at which the soil microbial population is able to decompose applied residues. *In situ* PVC collars 10 cm high with a 20 cm inside diameter were installed by inserting the collars into the soil to approximately 5 cm, leaving 5 cm of the collars exposed. The bottom edge of the collars was tapered to facilitate their insertion into the soil while maintaining an airtight seal between the collar and the soil surrounding it. The collars were installed by placing a 0.1 m x 0.1 m x 0.4 m wood beam on top of the collars and striking the beam with a sledge hammer until the collars reached the appropriate depth. Two collection chambers were installed in each plot, one at the north end and one at the south end, both placed in the center and approximately 10 m from the end of the plot. Figures 4.3 and 4.4 provide diagrams of the collection chambers used in year-1 and year-2 of the study respectively. Chamber covers used to collect soil respiration rate samples were constructed with the same PVC material used for the *in situ* collars described previously. One end of each cover was closed using a circular piece of 0.07 m thick PVC sheet cut with the same outside diameter as the collection chamber cover and epoxyed to the chamber cover. Two holes were drilled in the top of the chamber cover to allow for air pressure equalization between the collection chamber and the surrounding atmosphere. A 0.13 m rubber septum was inserted into the chamber top to allow for the extraction of soil gas samples once the cover was installed. Rubber bands cut from truck tire inner tubes, 0.8 m wide, were placed around the bottom of the chamber covers and were pulled down over the *in situ* collection wells to provide the required airtight seal during sampling.

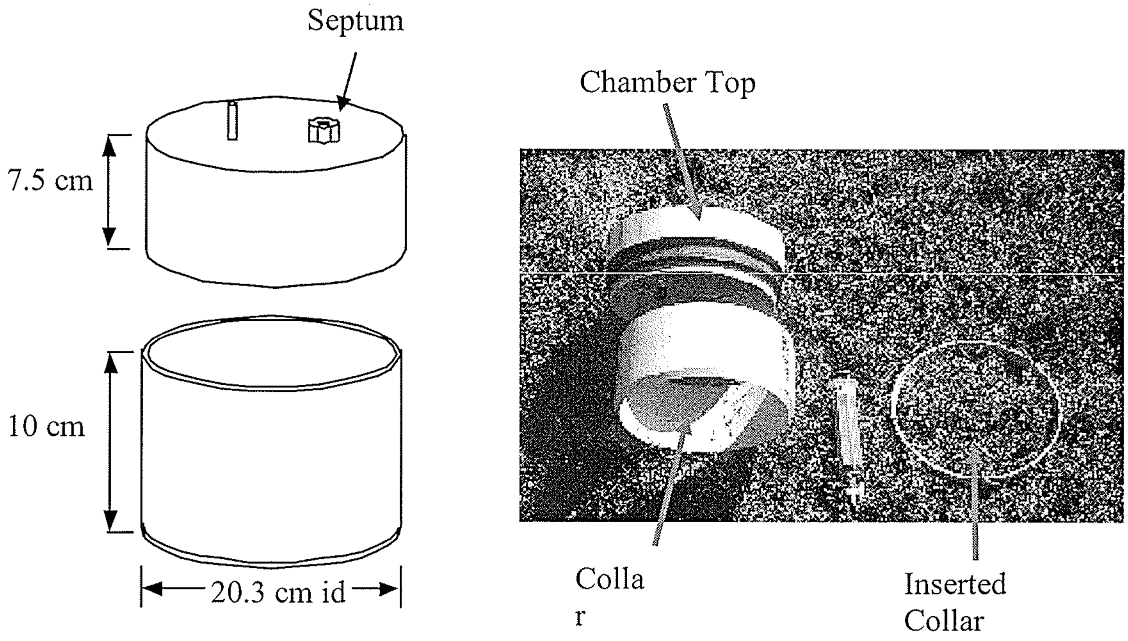

Figure 4.3 Year-1 soil respiration rate collection chamber design

The soil respiration rate sampling procedure for CO_2 and N_2O required the collection chamber covers to be placed on top of the collection collars, the rubber seal to be pulled down over the collars and allowing gas to accumulate in the chamber for 60 minutes. After the 60-minute accumulation period, a 20-ml syringe with an 18-gauge, 0.038-m needle was inserted into the septum in the top of the chamber cover and the atmosphere was mixed by retracting the syringe plunger to its maximum volume twice before extracting 20 ml of the atmosphere contained in the collection collar. The syringe was then removed from the septum, the volume reduced to 15 ml and injected into blood sample collection vials (Vacutainer, Beckton-Dickson) sealed with silicon that had previously been purged twice with helium gas and brought to a negative pressure of < 0.5 Torr. The entry point of the needle into the collection vial was re-sealed with silicon shortly after sampling to prevent the loss of the pressurized atmosphere samples. Gas samples were analyzed using a Varian 3800 Gas Chromatograph equipped with electron capture, thermal conductivity and flame ionization detectors for the measurement of N_2O, CO_2, and CH_4, respectively. Using peak areas derived from the GC and standard curve analysis, carbon dioxide and nitrous oxide concentrations within the collection chamber could be calculated. See Appendix A in the back of the thesis for calculations used to derive carbon dioxide and nitrous oxide flux values.

During the Fall 2000 sampling period, samples were collected between 1:00 P.M. and 6:00 P.M. on October 4th, 5th, 6th, 8th, 10th, 12th, 17th, 19th, 24th, 27th, 29th and 31st. and Spring 2001 soil respiration rate samples were collected on April 19th and 25th, May 2nd, 15th, 25th, 29th and June 1st. Soil respiration rate samples were taken a minimum of twice weekly and in the event of rainfall samples were taken more frequently to obtain data on the increased levels of soil respiration that typically follow the re-wetting of dry soils.

4.4.2.2 2001-2002 Experiment

Soil respiration rates were collected using the same methods employed in year-1 with a slightly modified collection chamber system and different collection chamber placements. Flat chamber covers were used in place of the cylindrical chamber covers used during the first field season. The flat chamber covers consisted only of the top portion of the original covers described and used in the first year. The flat covers were fitted with a rubber band around their edges, which were placed against a rubber ring installed on the topside of the *in situ* collection chamber collars. The contact of the two rubber seals effectively created an airtight seal to prevent ambient atmosphere from entering into the sample collection chamber during equilibration. Two elastic bands were pulled over the cover and fastened to small hooks mounted on the side of the collection chamber to ensure an airtight seal.

The placement of the respiration rate sampling wells was also modified from year-1 to facilitate a more detailed and less variable sampling protocol. After the fall primary tillage and liquid hog manure application operations had been completed, two sampling wells were installed side by side per split-plot for a total of four wells per main plot. One well was placed directly over the furrow created by the manure application equipment and the other was placed into the undisturbed soil immediately adjacent to the furrow. It was thought that respiration rate samples collected from the area disturbed by the injection equipment would exhibit elevated soil respiration rates compared to undisturbed soil and would therefore induce variability into the data collected. By sampling these two areas separately, this relationship could be further examined and variability more effectively accounted for.

The chamber atmosphere samples were collected and processed in the same manner used in year-1. Soil respiration rate samples were collected, during Fall 2001, on October 22nd, 24th, 26th, 30th, November 1st, 3rd, 5th, 8th, 16th and 23rd. Spring 2002 sampling dates were April 9th, 14th, 15th, 16th, 17th, 18th, 19th, 20th, 23rd, 26th, 29th, 30th, May 1st, 6th, 7th, 17th, and 24th. Soil respiration rate measurements were analyzed for carbon dioxide and nitrous oxide gas concentrations.

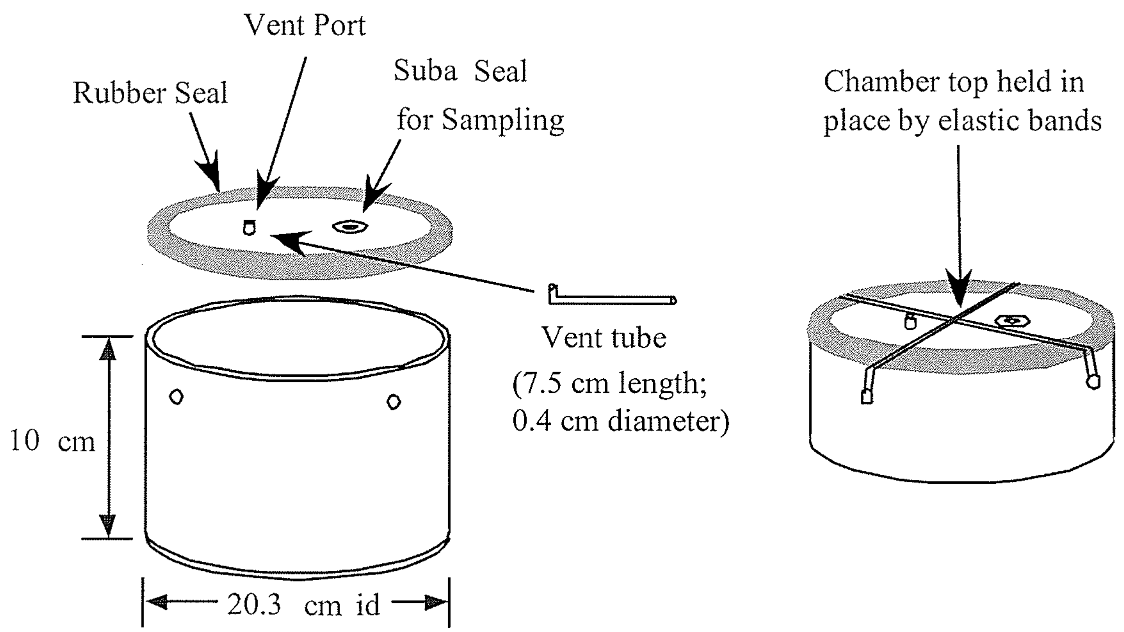

Figure 4.4 Year-2 soil respiration rate collection chamber design

4.4.3 Soil Moisture

Gravimetric soil moisture content was measured to quantify the differences in soil moisture between the three tillage systems, because soil moisture is known to influence the rate of soil microbial activity. During fall and spring sampling periods, in each year, for each treatment, the moisture content was determined by collecting approximately 200 cm^3 of field moist soil to a 7.5 cm soil depth in 250 cm^3 screw top, airtight sample containers. In the laboratory, the screw-top lids were removed from the containers, moist soil was weighed in the sample containers and oven dried at 105°C for 24 hours. Oven-dried samples were weighed and the gravimetric moisture content was determined using the equation:

$$\frac{\text{Mass Moist soil (g)} - \text{Mass Dry soil (g)}}{\text{Mass Dry soil (g)}} = \text{\% Gravimetric } H_2O \qquad \text{(Equation 4.1)}$$

4.4.4 Soil Temperature

Soil temperature is known to influence the rate of residue decomposition, by regulating the rate at which the soil microbial communities metabolize. Immediately following fall tillage treatment application in both study years, an *in situ* Tidbit^{TM} soil temperature data-logger, with a 1-hour sampling frequency, was installed 5 to 7.5 cm below the soil surface in each plot. Soil temperature was recorded throughout the fall period until spring seeding operations required them to be removed. Temperature loggers were not re-deployed after seeding operations were complete. Soil temperature information collected by the data loggers was processed optically using Onset Computer Corporation-Optic Base Station and Boxcar Pro 4.2 software.

4.4.5 Soil Nitrogen Sampling and Analysis

During the first growing season of the study soil samples were taken at two depths, 0-15 cm and 15-60 cm, twice during the 2001 growing season. Samples were taken prior to wheat seeding and after the wheat crop had been harvested. Each plot was sampled separately by taking five 2.5-cm diameter cores at approximately 30-m intervals to the 60-cm depth and separating the 0-15-cm and 15-60-cm samples for laboratory analysis. In the laboratory, soils were air-dried for two days, ground to pass a 2-mm sieve and stored in whirl pack bags until analysis.

In the second study year, soil samples were again taken at two depths, 0-15 cm and 15-60 cm. Soil samples were collected prior to canola seeding and following the canola harvest. Plots were sampled and soil samples were processed in the same manner as outlined for 2001.

Analysis of air-dry soil for ammonium and nitrate nitrogen contents, for both site years, was completed using a modified version of the method described by Maynard and Kalra (1993). The extraction procedure consisted of adding 5.0 g of air dry soil to 25 ml KCl extract solution and shaking for 30 minutes.

4.4.6 Rainfall

Each year, a tipping bucket rain gauge was installed on the site at the time of fall treatment application, removed at the time of winter freeze-up and re-deployed after the spring-thaw was nearly complete. The rain gauge remained in the field throughout the field season to collect growing season precipitation data.

4.4.7 Statistical Analysis

Data was analyzed using the GLM procedure of Statistical Analysis Software at the 5% (α=0.05) significance level. LSMEANS was used for data sets with missing values, otherwise Least Significant Difference (LSD) factor means were used to separate factor mean significance groupings.

The soil microbial activity data collected was highly variable with coefficients of variation of up to 60 % and 250 % for CO_2 and N_2O, respectively. Therefore, in order to fulfill the requirements for statistical analysis, being that treatment and error effects are additive and that error effects are random, independent, normally distributed and have similar treatment variances, the log transformation was required (Moore and McCabe 1993). Values presented for CO_2 and N_2O flux values are back-transformed to retain the induced homogeneity of variance achieved with the initial log transformation used for statistical analysis. Also, due to negative N_2O evolution data values, log (N_2O flux +10) was used for analysis to insure that all possible data points were included in the analysis.

4.5 Results and Discussion

4.5.1 Topsoil Nitrogen Concentration

Figure 4.5 shows the inorganic nitrogen concentrations for all treatments in the spring of 2001 and 2002. The soil nitrogen concentration is an important observation to consider for analysis of soil respiration rate data because abundant soil nitrogen may increase the rate of microbial decomposition of added crop residues. In both years the manure amended plots had the highest concentration of nitrate in the surface 15 cm of soil. Spring 2002 data suggest that the target fall manure nitrogen application rate was achieved, whereas the spring 2001 data suggest that manure nitrogen was possibly under-applied to reach the desired 110 kg ha^{-1} application rate or that the 2000-2001 over winter losses of nitrogen were greater than the losses resulting during the 2001-2002 winter period.

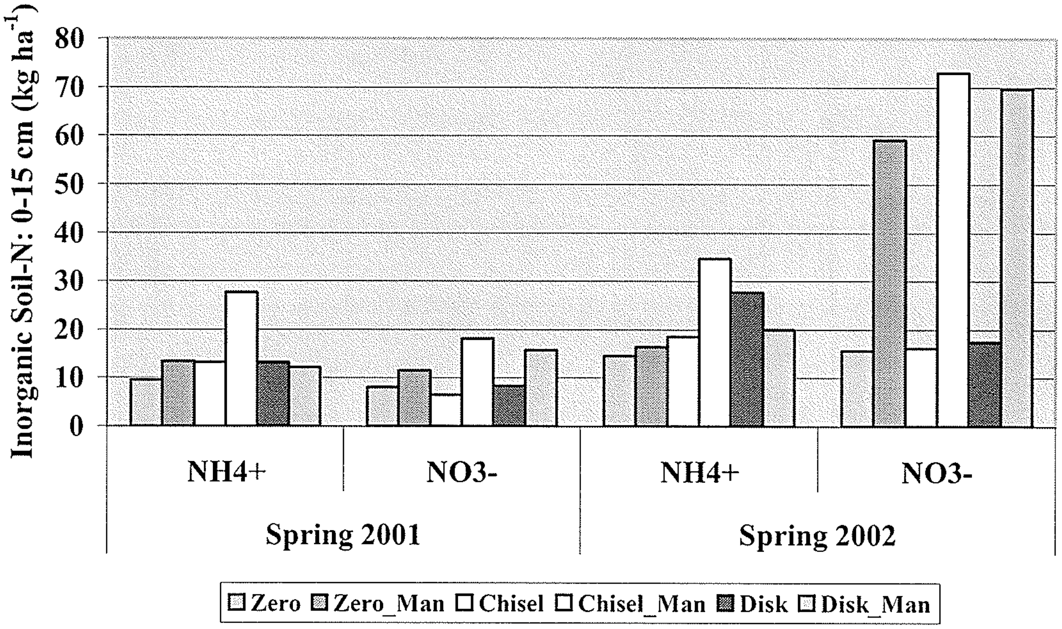

Figure 4.5 Spring 2001 and 2002 nitrate and ammonium concentrations (0-15 cm).

4.5.2 Soil Respiration

The soil respiration data collected was highly variable with coefficients of variation of up to 60 % and 250 % for CO_2 respiration and N_2O evolution, respectively. The data was, therefore, log transformed in induce homogeneity of variance for the CO_2 data and due to negative N_2O evolution data points the log of (x+10) was used for statistical analysis to insure that all possible data points were included in the analysis.

4.5.2.1 Fall Sampling Period

4.5.2.1.1 Carbon Dioxide

Table 4.2 Fall 2000 tillage and manure treatment mean CO_2 fluxes.

	5-Oct	6-Oct	8-Oct	10-Oct	12-Oct	17-Oct	19-Oct	24-Oct	26-Oct	31-Oct
					g CO_2-C ha^{-1} day^{-1}					
Fall Tillage System										
Zero	*405	1498	1231	5836	1958	1318	3272	1807	604	4673
Chisel	375	1021	1828	6156	2380	1848	1864	1442	516	5881
Disk	514	1496	2951	6532	3322	2539	2635	1522	928	6265
Nutrient										
Manure	538	1877a	2307	6896a	2836	2191	3765a	1926	1000a	6105
No Manure	324	800b	1699	5453b	2271	1612	1415b	1255	365b	5108
CV (%)	17	14	8	2	7	14	8	14	20	5
					ANOVA P-values					
Tillage	0.84	0.56	0.42	0.26	0.22	0.53	0.52	0.89	0.46	0.34
Nutrient	0.27	0.013	0.61	0.0071	0.38	0.59	0.016	0.19	0.030	0.31
T*N	0.75	0.12	0.76	0.24	0.11	0.85	0.08	0.47	0.57	0.88

*Back-transformed values: Means followed by different letters are significantly different ($P<0.05$).

During the fall 2000 sampling period, significant CO_2 respiration rate differences were found between the manured and non-manured treatments on four of the ten sampling dates, with the manured treatments having a higher rate of CO_2 respiration. There were no significant differences observed on any of the sampling dates between any of the three tillage systems. The interaction between nutrient and tillage was found to be non-significant on each sampling date during the fall 2000 sampling period. Figure 4.6 shows the relative differences in CO_2 respiration from the manured and non-manured treatments on the four dates that significant difference was observed due to manure application.

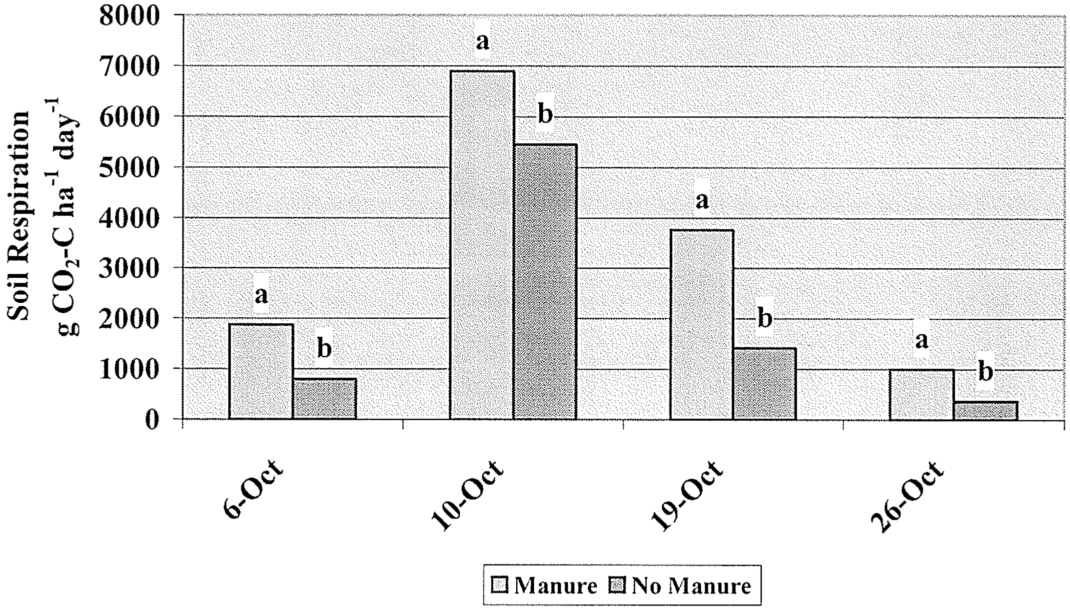

Figure 4.6 Nutrient factor CO_2 respiration: Fall 2000. Nutrient treatments with different lower case letters are significantly different ($P< 0.05$).

Table 4.3 Fall 2001 tillage and manure treatment mean CO_2 fluxes.

	22-Oct	24-Oct	26-Oct	30-Oct	1-Nov	3-Nov	5-Nov	8-Nov	16-Nov
					g CO_2-C ha^{-1} day^{-1}				
Fall Tillage System									
Zero	2518	1829	814	706	2160	893	4280	1060	816
Chisel	2019	1465	556	836	2192	1071	4029	1041	961
Disk	1264	987	799	958	2826	1058	3902	1118	702
Nutrient									
Manure	2830a	1927a	947a	860	2683	1299a	4334a	1343	1059
No Manure	1037b	927b	500b	806	2102	716b	3807b	803	593
CV (%)	11	12	13	12	10	8	2	10	9
					ANOVA P-Values				
Tillage	0.58	0.35	0.35	0.42	0.85	0.88	0.23	0.91	0.60
Nutrient	0.0035	0.039	0.0060	0.44	0.064	0.0006	0.035	0.088	0.055
T*N	0.16	0.23	0.33	0.16	0.31	0.12	0.32	0.88	0.53

*Back-transformed values: Means followed by different letters are significantly different ($P<0.05$).

During the fall 2001 sampling period, significant differences in the rate of CO_2 respiration were observed on five of the nine sampling dates between the manured and non-manured treatments, with the manured treatments exhibiting a higher respiration rate than the non-manured treatments. There were no significant differences observed between the three tillage systems tested and there was no significant interaction between tillage and manure application, as was the case during the fall of 2000. Figure 4.7 shows the differences in CO_2 respiration from the manured and non-manured treatments for the five sampling dates on which significant differences were observed between nutrient treatments.

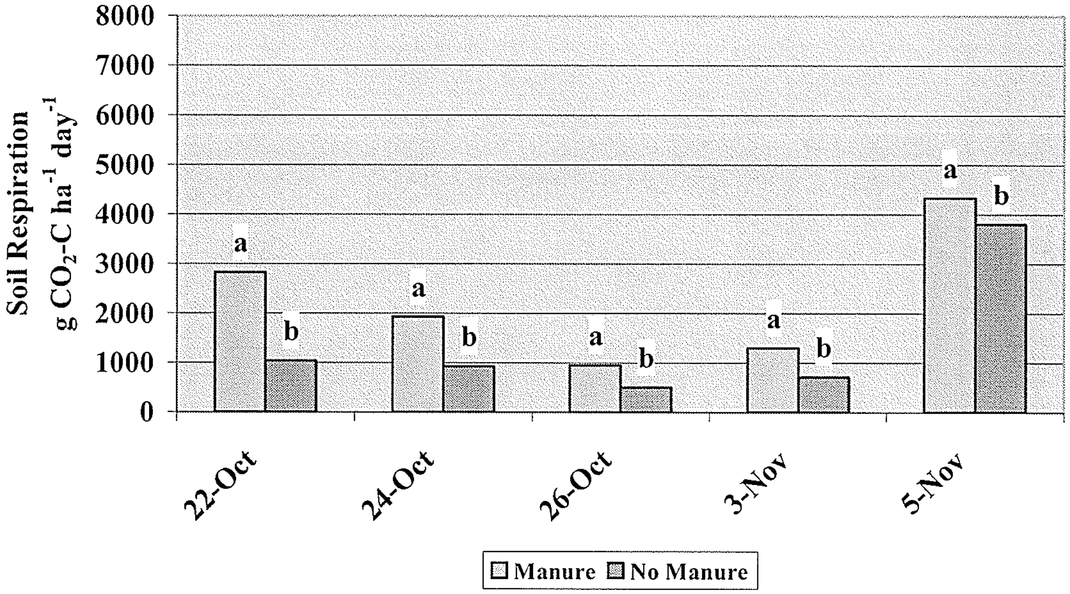

Figure 4.7 Nutrient factor CO_2 respiration: Fall 2001. Nutrient treatments with different lower case letters are significantly different ($P < 0.05$).

4.5.2.1.2 Nitrous Oxide

Table 4.4 Fall 2000 tillage and manure treatment mean N_2O fluxes.

	5-Oct	6-Oct	8-Oct	10-Oct	12-Oct	17-Oct	19-Oct	24-Oct	26-Oct	31-Oct
					$g\ N_2O\text{-}N\ ha^{-1}\ day^{-1}$					
Fall Tillage										
Zero	19.65	17.45	15.55	27.87	16.68	19.47	26.15	15.45	16.32	29.40
Chisel	18.85	19.11	16.70	32.82	14.00	20.88	21.39	18.38	14.97	28.87
Disk	15.23	18.59	21.71	30.38	27.90	14.18	16.80	12.20	11.57	25.96
Nutrient										
Manure	20.12	23.44a	23.84a	36.21a	24.04	23.67a	32.07a	20.58a	18.01a	42.92a
No Manure	15.70	13.33b	12.13b	24.50b	15.01	12.69b	10.83b	10.10b	10.56b	13.24b
CV (%)	21	19	20	14	24	19	23	16	14	25
					ANOVA P-values					
Tillage	0.28	0.90	0.42	0.41	0.23	0.057	0.53	0.077	0.18	0.75
Nutrient	0.072	0.018	0.024	0.016	0.18	0.0014	0.0028	0.0005	0.0056	0.0015
T*N	0.13	0.65	0.90	0.45	0.47	0.19	0.43	0.083	0.27	0.60

*Back-transformed values: Means followed by different letters are significantly different ($P<0.05$).

Nitrous oxide evolution rates for the fall 2000 sampling period were significantly greater for the manured than for non-manured treatments on all but two of the ten sampling dates. The effect of tillage system was not found to be significant at any time during the sampling period and no significant tillage by nutrient interaction was observed on any date. On the October 5th sampling date, the manured treatment was also nearly significant greater than the non-manured treatment with a P-value of 0.07. On all dates regardless of significance, the manured treatments tended to evolve greater quantities of nitrous oxide than the non-manured treatments. Figure 4.8 shows differences between manure and non-manured treatments for N_2O evolution for the sampling dates on which significant differences were observed.

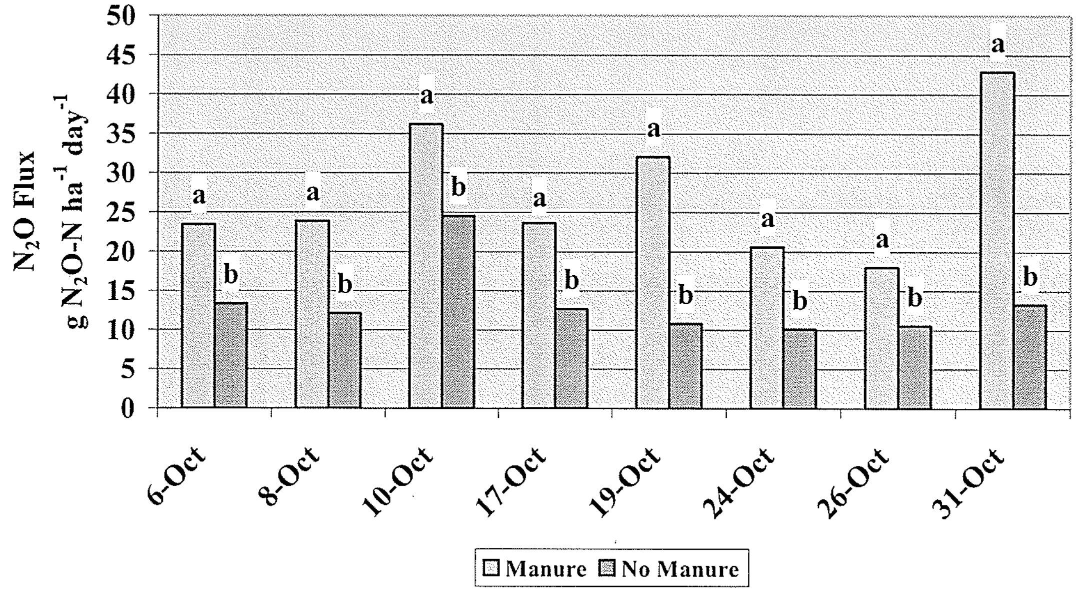

Figure 4.8 Nutrient factor N_2O flux: Fall 2000. Nutrient treatments with different lower case letters are significantly different ($P < 0.05$).

Table 4.5 Fall 2001 tillage and manure treatment mean N_2O fluxes.

	22-Oct	24-Oct	26-Oct	30-Oct	1-Nov	3-Nov	5-Nov	8-Nov	16-Nov
				g N_2O-N ha^{-1} day^{-1}					
Fall Tillage									
Zero	17.65	15.82	14.67	11.28	29.68	12.08	19.21	11.98	11.46
Chisel	15.27	14.08	12.95	12.34	22.94	16.49	23.95	13.27	11.91
Disk	11.96	16.08	13.19	11.47	25.67	12.24	22.52	11.05	10.79
Nutrient									
Manure	18.77a	19.74a	15.89a	12.92a	30.96a	16.80a	22.72	14.72a	12.76a
No Manure	11.14b	10.92b	11.32b	10.48b	21.24b	10.41b	21.08	9.48b	10.02b
CV (%)	15	11	12	5	25	10	26	8	7
				ANOVA P-values					
Tillage	0.23	0.86	0.77	0.59	0.88	0.14	0.55	0.34	0.36
Nutrient	0.0086	0.0010	0.012	0.011	0.13	0.0039	0.69	0.0008	0.0006
T*N	0.47	0.76	0.61	0.59	0.48	0.61	0.58	0.47	0.32

*Back-transformed values: Means followed by different letters are significantly different ($P<0.05$).

Similar to the results reported for the fall of 2000, the fall 2001 sampling period resulted in significant manure treatment differences on seven of the nine dates with the manured treatments resulting in higher rates of N_2O production than the non-manured treatments. Similar to all previously reported sampling dates there was no significant effect of tillage or tillage by nutrient treatment interactions. Figure 4.9 shows the differences in N_2O evolution between manured and non-manured treatments on dates when significant differences were observed.

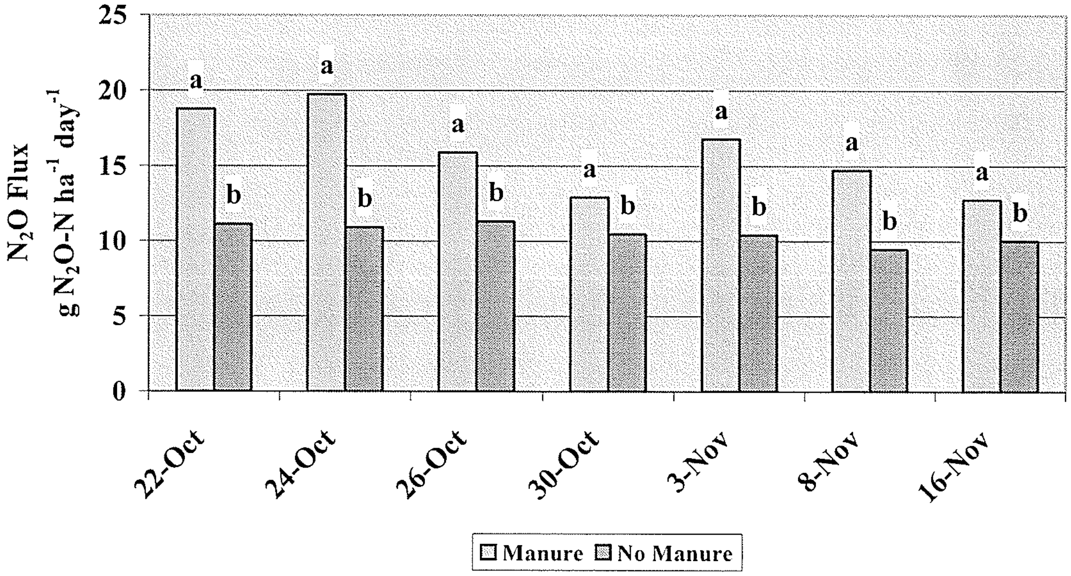

Figure 4.9 Nutrient factor N_2O flux: Fall 2001. Nutrient treatments with different lower case letters are significantly different ($P< 0.05$).

4.5.2.2 Spring Sampling Period

4.5.2.2.3 Carbon Dioxide

Table 4.6 Spring 2001 tillage and manure treatment mean CO_2 fluxes.

	19-Apr	25-Apr	2-May	25-May	29-May	1-Jun
			g CO_2-C ha^{-1} day^{-1}			
Fall Tillage						
Zero	2181	1508	2208	4236	3939b	3901
Chisel	2540	2825	2292	4435	5906a	4078
Disk	2358	2081	4179	4606	3935b	4606
Nutrient						
Manure	2293	2518	2655	4945	4813	3444
No Manure	2426	1758	3130	3907	4374	4946
CV	10	14	17	8	8	8
			ANOVA P-values			
Tillage	0.81	0.41	0.19	0.90	0.010	0.78
Nutrient	0.56	0.47	0.57	0.089	0.41	0.12
T*N	0.22	0.67	0.24	0.34	0.21	0.83

*Back-transformed values: Means followed by different letters are significantly different ($P<0.05$).

Tillage system was found to have a significant effect on the rate of CO_2 respiration on May 29th during the 2001 spring sampling period, with the chisel tillage system exhibiting a greater rate of CO_2 respiration than the zero and disk systems which did not vary significantly. Figure 4.10 shows the CO_2 respiration effect of the three tillage systems. Manure application did not cause a significant increase in soil CO_2 respiration during the spring 2001 sampling period and no significant manure by tillage interaction was observed.

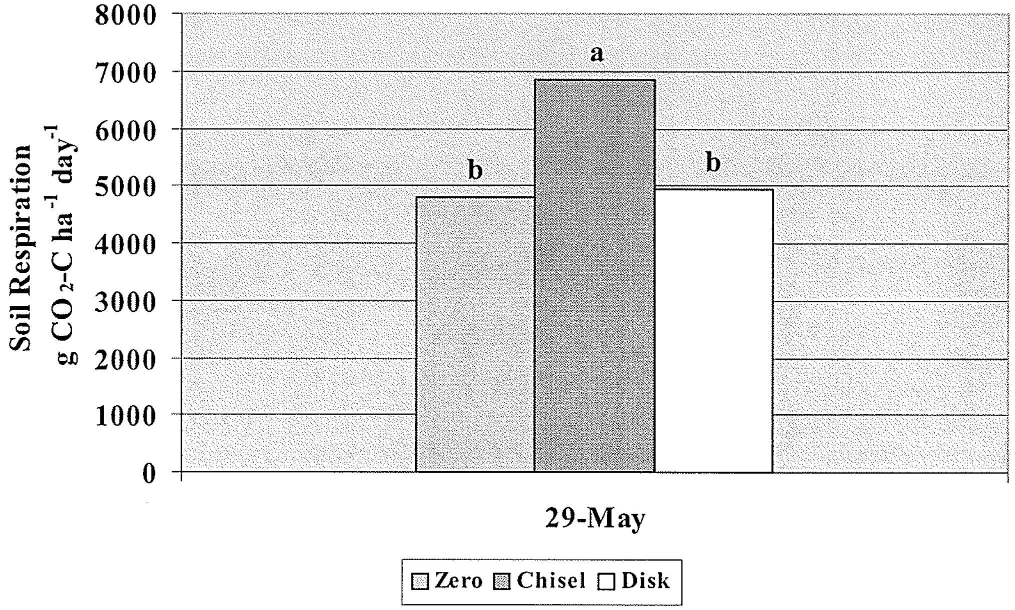

Figure 4.10 Fall tillage factor CO_2 respiration: Spring 2001. Nutrient treatments with different lower case letters are significantly different ($P < 0.05$).

Table 4.7a Spring 2002 tillage and manure treatment mean CO_2 flux: April 9-April 20.

	9-Apr	13-Apr	14-Apr	15-Apr	16-Apr	17-Apr	18-Apr	19-Apr	20-Apr
					g CO_2-C ha^{-1} day^{-1}				
Fall Tillage									
Zero	1771	3579	4807	6475	2661	1027b	496b	609	1600
Chisel	1129	3045	6673	7788	2990	1623a	836a	1173	2136
Disk	1026	3264	6789	8314	3265	1985a	1186a	797	1722
Nutrient									
Manure	1290	3875	7544a	9697a	3627a	1682	985	1013	2376a
No Manure	1328	2716	4636b	5355b	2317b	1408	693	706	1263b
CV (%)	8	8	5	4	6	8	14	8	4
					ANOVA P-values				
Tillage	0.23	0.84	0.50	0.37	0.32	0.0036	0.011	0.12	0.28
Nutrient	0.72	0.16	0.012	0.0001	0.037	0.63	0.29	0.18	0.0003
T*N	0.15	0.72	0.63	0.36	0.97	0.33	0.18	0.59	0.31

*Back-transformed values: Means followed by different letters are significantly different ($P<0.05$).

Table 4.7b Spring 2002 tillage and manure treatment mean CO_2 flux: April 23-May 24.

	23-Apr	26-Apr	29-Apr	30-Apr	1-May	6-May	7-May	17-May	24-May
	g CO_2-C ha^{-1} day^{-1}								
Fall Tillage									
Zero	607b	773	590	1468b	408	883	1511	879	1524
Chisel	1340a	1035	928	2230a	618	1163	2048	1076	1540
Disk	971a	815	957	1748b	633	960	1582	827	1962
Nutrient									
Manure	1088	1227a	977a	2256a	683	1314	2236a	1139	1849
No Manure	857	522b	672b	1374b	423	690	1191b	716	1502
CV (%)	8	8	6	4	7	10	5	7	5
	ANOVA P-values								
Tillage	0.012	0.11	0.055	0.020	0.13	0.37	0.16	0.42	0.86
Nutrient	0.33	0.0014	0.038	0.0011	0.063	0.051	0.0026	0.14	0.32
T*N	0.19	0.92	0.72	0.49	0.42	0.74	0.45	0.87	0.54

*Back-transformed values: Means followed by different letters are significantly different ($P<0.05$).

During the spring 2002 sampling period, significant tillage system effects were observed on three of the eighteen sampling dates. On all three dates the zero tillage system had the statistically lowest rate of CO_2 respiration. On April 17th and 18th the chisel and disk systems were not found to vary statistically, however, on April 30th the chisel system was found to have respired significantly greater amounts of CO_2 than both the zero and disk tillage treatments which were not found to vary significantly on the April 30th sampling date.

On eight of the eighteen sampling dates the manured treatments were found to have released significantly greater amounts of CO_2 than the non-manured treatments. On the May 1st and 6th sampling dates, the manured treatments were found to be nearly significant with P-values of 0.063 and 0.051 for manure effects, respectively.

The effect of tillage was significant for CO_2 respiration rate only during the spring sampling periods; there were no significant tillage effects observed on any of the sampling dates during the fall sampling periods in either experimental year. The observance of significant manure application effects on CO_2 respiration were evenly spread throughout the duration of the experiment, however, with significant manure effects being observed on nine dates during the fall and eight during the spring sampling periods. In all cases, were significance was observed, the manured treatments had a higher rate of CO_2 respiration regardless of tillage system or sampling period. Figures 4.11 and 4.12 show the effects of tillage and manure application, respectively, on the rate of soil CO_2 respiration for the sampling dates on which factor significance was observed.

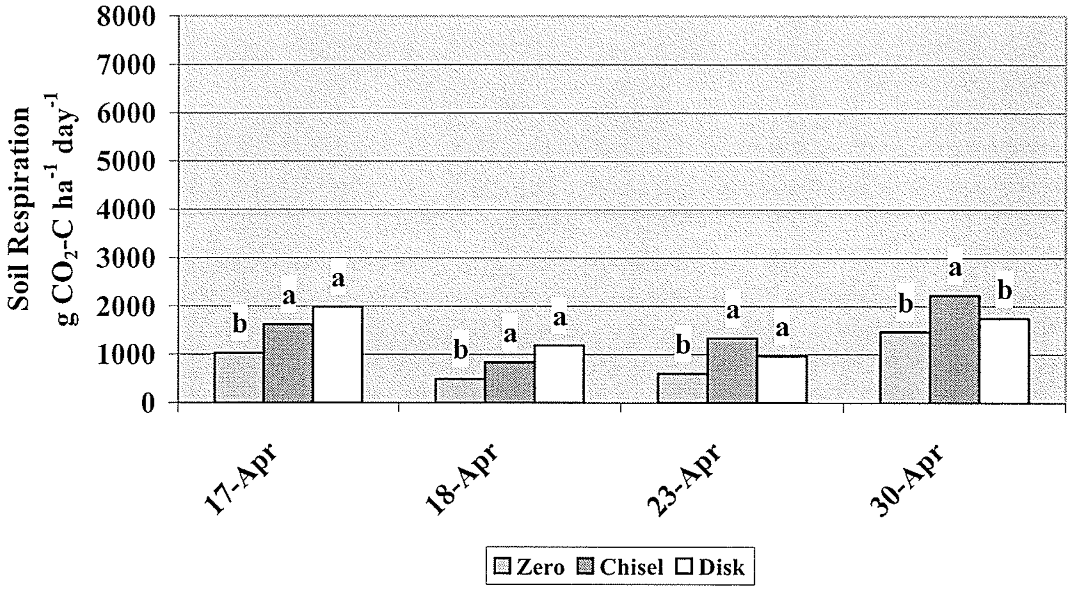

Figure 4.11 Fall tillage factor CO_2 respiration: Spring 2002. Nutrient treatments with different lower case letters are significantly different ($P < 0.05$).

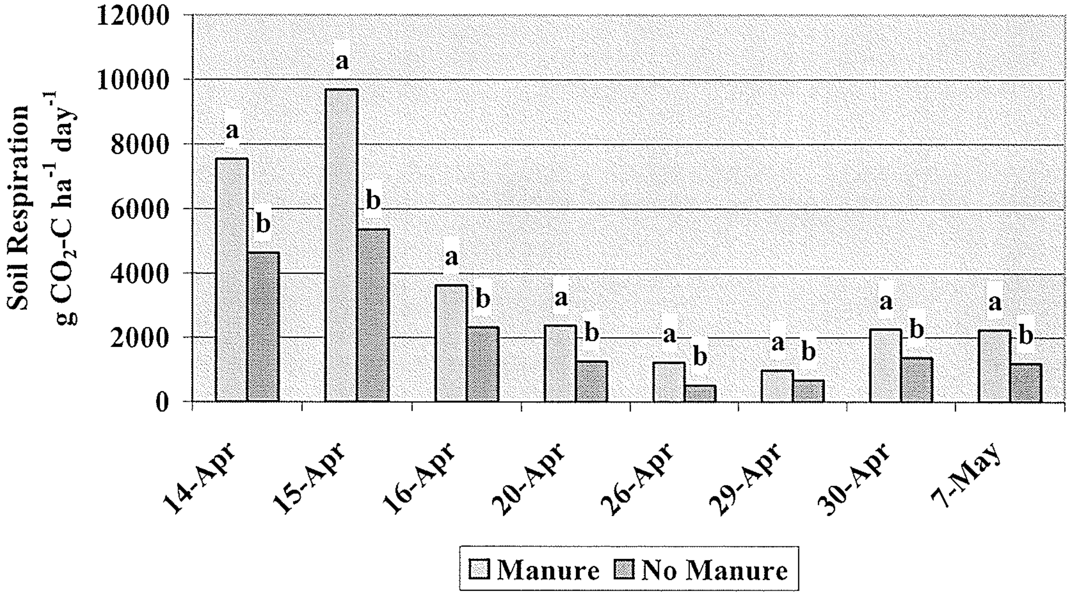

Figure 4.12 Nutrient factor CO_2 respiration: Spring 2002. Nutrient treatments with different lower case letters are significantly different ($P < 0.05$).

4.5.2.2.4 Nitrous Oxide

Table 4.8 Spring 2001 tillage and manure treatment mean N_2O flux.

	19-Apr	25-Apr	2-May	25-May	29-May	1-Jun
			g N_2O-N ha^{-1} day^{-1}			
Fall Tillage						
Zero	10.66	12.51	13.20	16.21	15.14	12.56
Chisel	10.33	11.16	13.48	13.42	13.07	11.36
Disk	13.42	11.50	15.59	12.55	11.92	11.24
Nutrient						
Manure	12.41	12.68	16.06	15.94a	15.46a	12.94a
No Manure	10.53	10.77	12.12	12.18b	11.30b	10.50b
11	9	17	20	10.85	8	8
			ANOVA P-values			
Tillage	0.26	0.77	0.74	0.20	0.38	0.52
Nutrient	0.27	0.23	0.27	0.039	0.045	0.036
T*N	0.24	0.53	0.45	0.38	0.49	0.32

*Back-transformed values: Means followed by different letters are significantly different ($P<0.05$).

During the Spring 2001 sampling period three of the six sampling dates showed significant differences between the manured and non-manured treatment for N_2O evolution rate. Significance was not observed for tillage or tillage by nutrient interaction on any of the sampling dates during the spring 2001 sampling period. Figure 4.13 shows the effect of manure application on N_2O evolution on the three sampling dates where significant manure effects were observed.

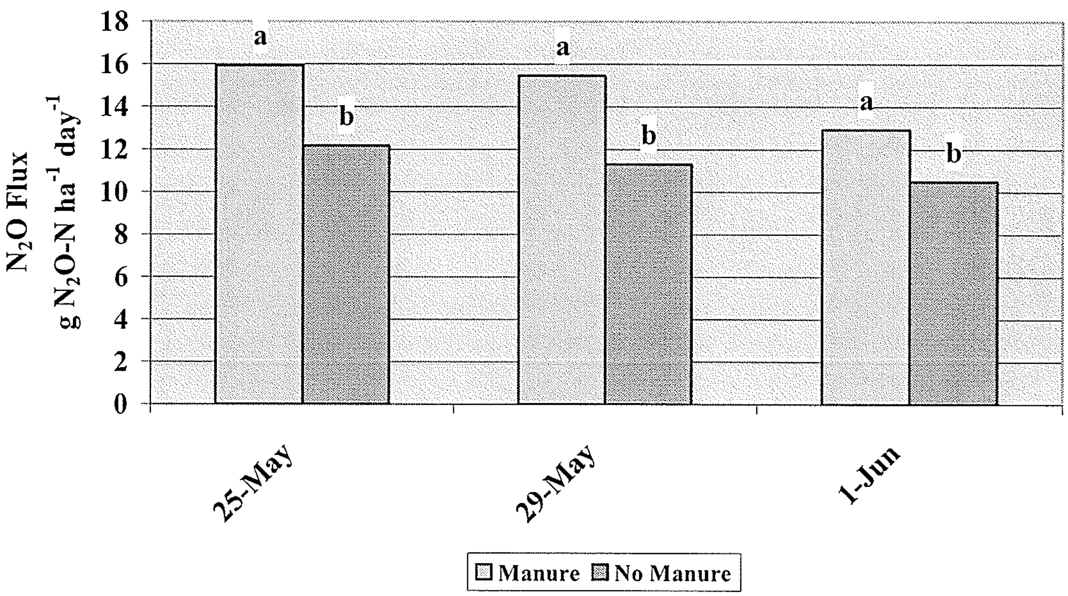

Figure 4.13 Nutrient factor N_2O flux: Spring 2001. Nutrient treatments with different lower case letters are significantly different ($P < 0.05$).

Table 4.9a Spring 2002 tillage and manure treatment mean N_2O flux: April 9-April 20.

	9-Apr	13-Apr	14-Apr	15-Apr	16-Apr	17-Apr	18-Apr	19-Apr	20-Apr
					$g\ N_2O\text{-}N\ ha^{-1}\ day^{-1}$				
Fall Tillage									
Zero	114.60	148.83	98.46	126.65	44.28	15.91	17.58	15.01	29.06
Chisel	172.56	101.96	150.48	182.47	53.82	21.86	23.19	27.36	37.06
Disk	150.90	235.91	352.32	352.57	96.36	20.55	42.32	28.36	39.47
Nutrient									
Manure	186.75	247.60a	329.49a	376.98a	96.05a	22.76	37.30a	30.50a	47.24a
No Manure	105.28	76.87b	71.34b	64.14b	33.60b	16.12	18.09b	16.65b	23.61b
CV (%)	14	18	12	8	15	10	13	12	9
					ANOVA P-values				
Tillage	0.80	0.72	0.32	0.40	0.15	0.11	0.067	0.15	0.31
Nutrient	0.12	0.023	0.0006	<.0001	0.0038	0.097	0.0009	0.0006	0.0003
T*N	0.27	0.24	0.58	0.13	0.73	0.28	0.075	0.11	0.70

*Back-transformed values: Means followed by different letters are significantly different ($P<0.05$).

Table 4.9b Spring 2002 tillage and manure treatment mean N_2O flux: April 23-May 24.

	23-Apr	26-Apr	29-Apr	30-Apr	1-May	6-May	7-May	17-May	24-May
					$g\ N_2O\text{-}N\ ha^{-1}\ day^{-1}$				
Fall Tillage									
Zero	16.80b	24.88	16.74b	16.54b	12.95	16.20	15.18	14.53	11.82
Chisel	26.28a	29.67	25.51a	23.32a	16.51	19.11	19.63	16.00	11.70
Disk	21.90ab	32.77	27.00a	20.47ab	16.90	20.74	15.88	13.42	13.58
Nutrient									
Manure	24.79	35.66a	24.47	26.08a	17.17a	20.62	21.35a	16.83a	12.38
No Manure	18.53	22.55b	21.69	14.14b	13.73b	16.75	12.45b	12.47b	12.35
CV (%)	14	16	18	8	6	15	8	13	6
					ANOVA P-values				
Tillage	0.044	0.35	0.017	0.026	0.13	0.19	0.18	0.36	0.59
Nutrient	0.13	0.0018	0.46	<.0001	0.023	0.19	<.0001	0.0095	0.74
T*N	0.95	0.57	0.54	0.58	0.42	0.98	0.57	0.81	0.78

*Back-transformed values: Means followed by different letters are significantly different ($P<0.05$).

On three of the eighteen sampling dates during the 2002 spring sampling period, significant tillage system effects were observed and on twelve of the eighteen dates significant manure effects were observed on the rate of N_2O evolution. No significant effect of an interaction between the two factors was observed on any of the sampling dates. Figures 4.14 and 4.15 show the effects of tillage and manure application, respectively, on the rate of N_2O evolution for the sampling dates on which factor significance was observed.

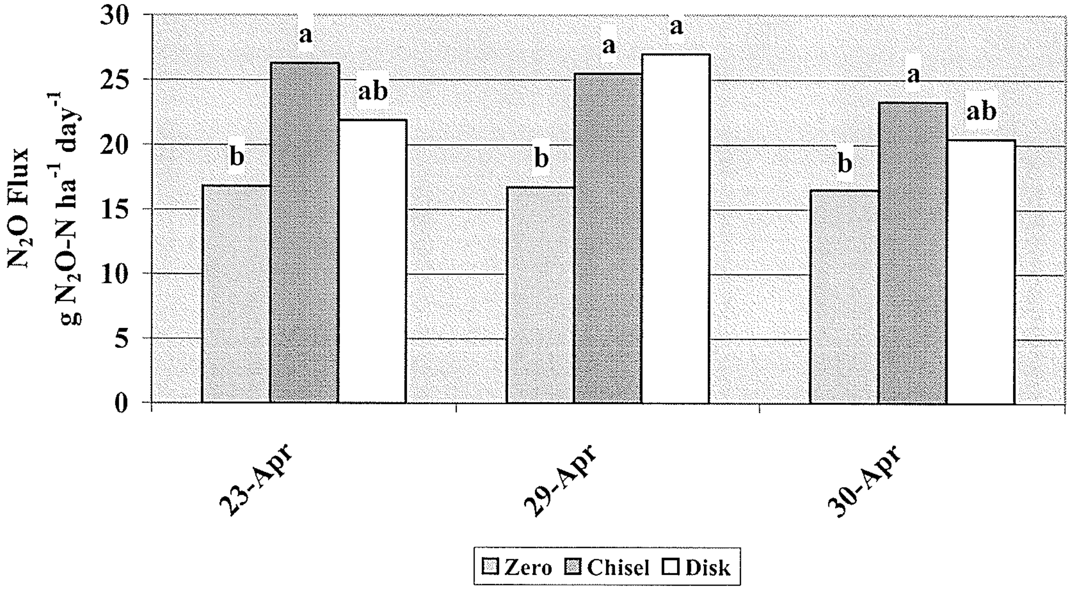

Figure 4.14 Fall tillage factor N_2O flux: Spring 2002. Nutrient treatments with different lower case letters are significantly different ($P< 0.05$).

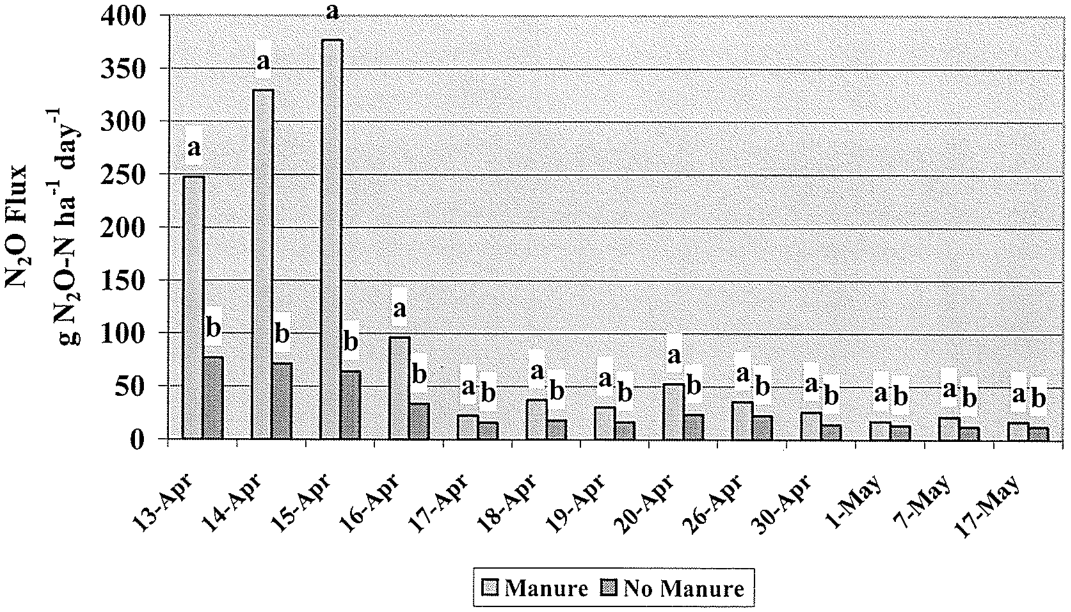

Figure 4.15 Nutrient factor N_2O flux: Spring 2002. Nutrient treatments with different lower case letters are significantly different ($P< 0.05$).

Measures of soil carbon dioxide and nitrous oxide respiration were used to quantify differences in soil microbial activity resulting from the application of hog manure and primary tillage operation treatment factors in order to evaluate the effects of these factors on the overall rate of cereal crop residue decomposition. Each of the sampling dates was analyzed separately to reduce the variability observed within the data set due to environmental inconsistencies throughout the sampling period, such as rainfall events and atmospheric temperature. Generally the effect of tillage operations was not as influential on the rate of soil CO_2 and N_2O respiration as the effect of fall applied liquid hog manure.

4.5.3 Soil Temperature

4.5.3.1 Daily Soil Temperature

Soil temperature can have a profound effect on the rate of microbial activity in soil ecosystems and can also affect the germination and development of annual crop seedlings, soil temperature was therefore monitored throughout the duration of the study. Figures 4.16 and 4.18 depict the daily soil temperature fluctuation measured for each treatment from the outset of the fall sampling period, which was specific to each year, until freeze up in the same year. Figures 4.17 and 4.19 depict soil temperature variation from the point where all treatments achieved a daily average soil temperature greater than zero until spring seeding operations.

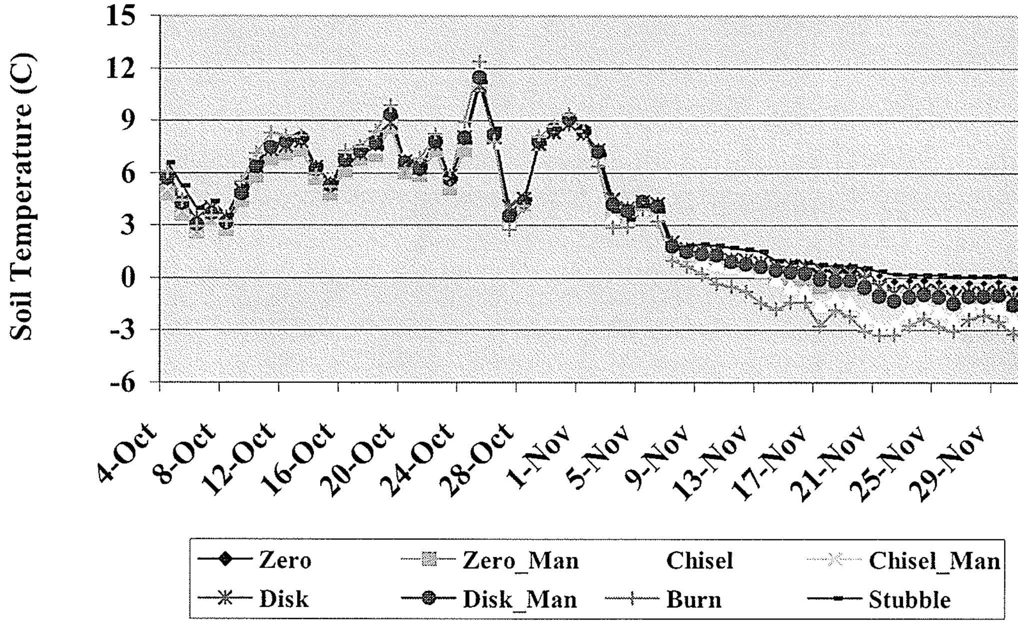

Figure 4.16 Daily average soil temperature: October 4-December 1, 2000

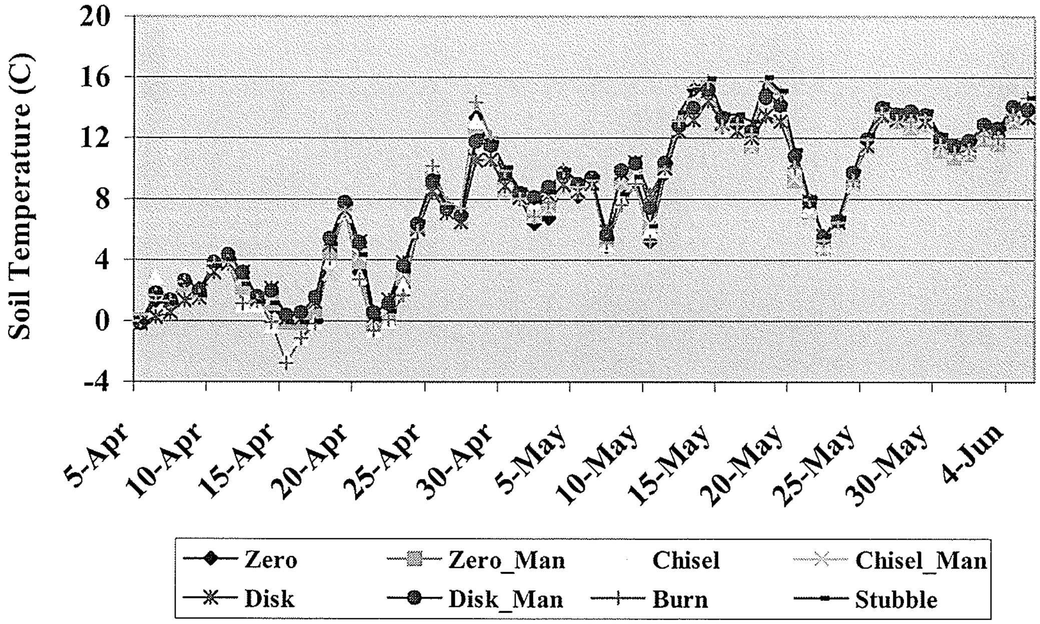

Figure 4.17 Daily average soil temperature: April 5-June 5, 2001.

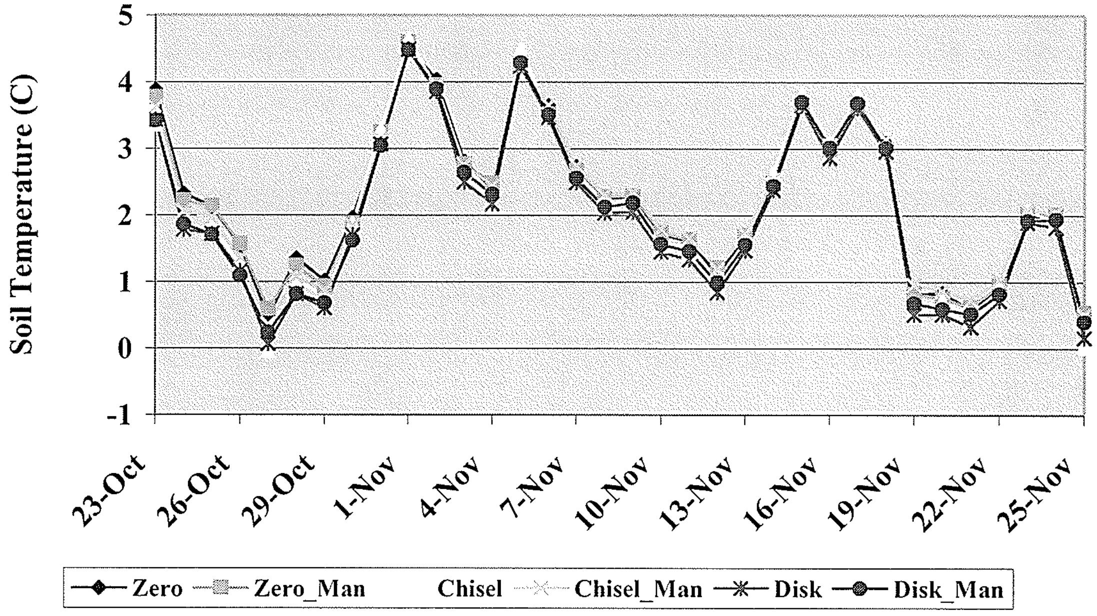

Figure 4.18 Daily average soil temperature: October 23-November 25, 2001

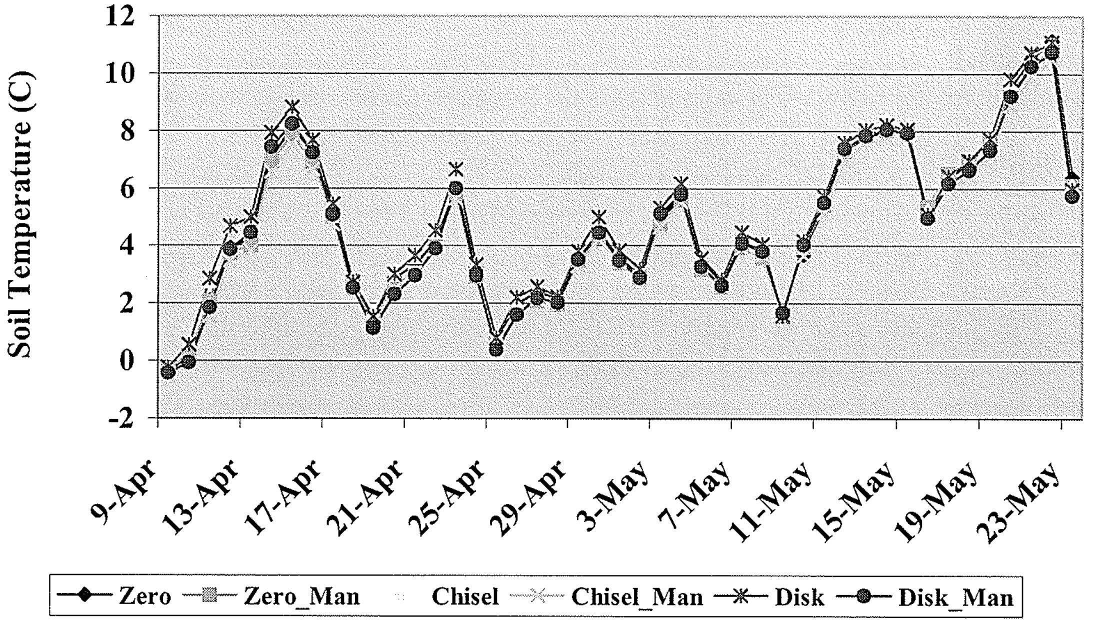

Figure 4.19 Daily average soil temperature: April 9-May 24, 2002.

4.5.3.2 Average Soil Temperature

One of the major limitations to retaining excessive levels of crop residues within the seedbed area, according to agricultural producers, is that soils are thought to remain cool and wet throughout the spring seeding season resulting in late emerging or thin crop stands. Average soil temperatures were therefore calculated for each tillage system, with and without the addition of liquid manure, to explore the relationship between retaining and managing crop residues on the average soil temperature until freeze up and seeding for the fall and spring periods, respectively. Average soil temperatures for all treatments within all years can be found in Figure 4.20. Statistical analysis (not reported) determined there to be no significant difference in soil temperature between any of the tillage systems or nutrient management systems included in the study. Generally, the manured treatments were slightly cooler than the non-manured treatments, likely as a result of the greater moisture content of these soils, as will be described in subsequent sections. Soil temperature data loggers were placed at a soil depth of 5-7 cm due to their size and the amount of soil required to provide complete coverage of the units. Soil temperature variation between treatments may have varied more at the soil surface due to the influence of solar radiation, however, these data are unknown.

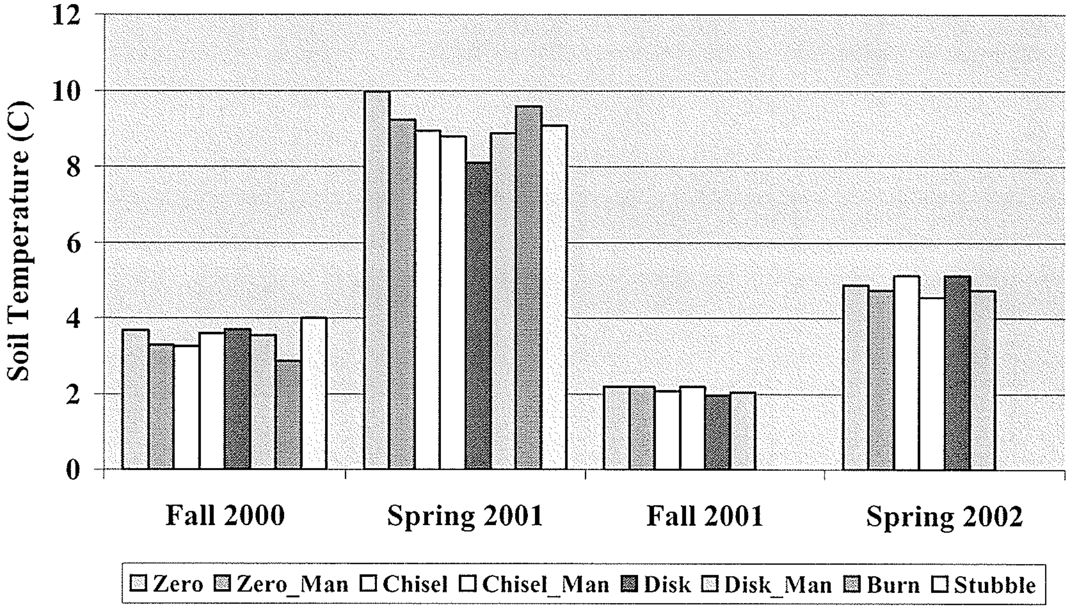

Figure 4.20 Average soil temperature.

4.5.4 Soil Moisture

Soil moisture is often a regulating/controlling factor for the rate of soil microbial activity. There were no tillage system effects on the soil moisture content in either year for the spring or fall sampling periods. The was a significant nutrient source effect in the fall of 2001, where the manured plots were found to be more moist than the non-manured treatments with P-value of 0.02, the same effect was found in the fall of 2000 as well, but was non-significant with P-value 0.07. This result is logical as large quantities of water were added to these treatment plots in the form of liquid manure. Graphical representation of gravimetric soil moisture for all treatments can be seen in Figure 4.21. Generally, there was little difference between any of the treatments, however, the spring sampling periods did tend to be more moist than the fall, which was likely a contributing factor the greater N_2O evolution rates observed in the spring compared to the fall sampling periods.

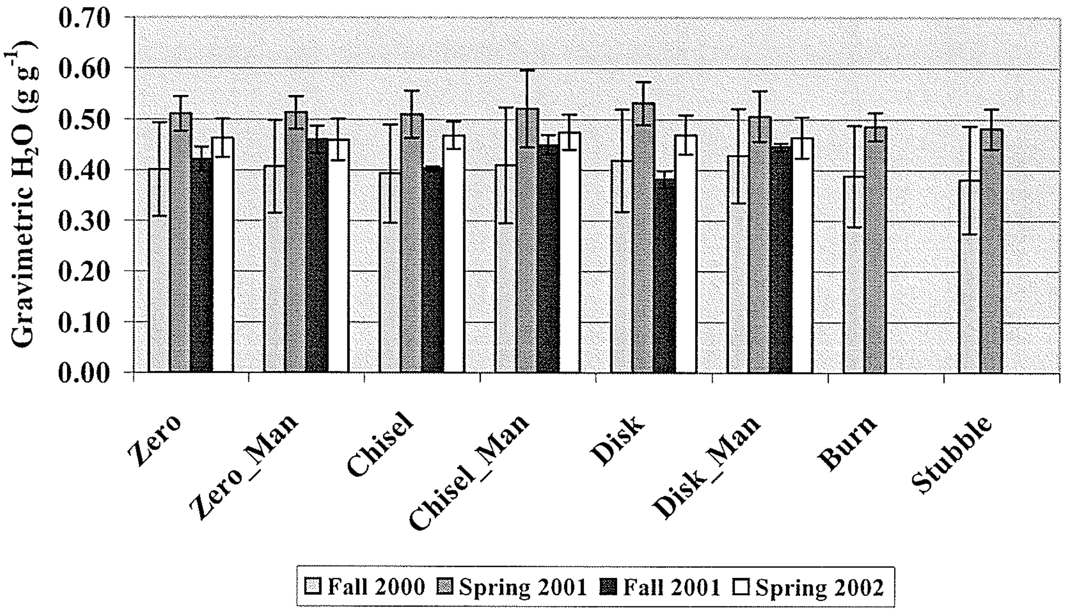

Figure 4.21 Gravimetric moisture content for all sampling periods. Error bars are standard deviation about the treatment mean.

4.5.5 Effect of Tillage System, Manure Application, Soil Moisture and Temperature on Soil Respiration

A total of 10, 6, 9 and 18 sampling dates were included in the CO_2 and N_2O respiration analysis for fall 2000, spring 2001, fall 2001 and spring 2002 sampling periods, respectively. CO_2 respiration rate analysis revealed that out of the 43 sampling dates 4 showed significant effects of tillage, one during the spring 2001 and 3 during the spring 2002 sampling periods. The tillage effect on CO_2 respiration from the least to the greatest was generally zero < chisel = disk. The zero tillage system should, theoretically, have provided the least amount of mixing of the cereal crop residues with the soil, which would act as a source of microbial inoculum for colonization of the residues. Furthermore, residues remaining on the soil surface will be exposed to a less favorable, less moist environment than residues mixed into the soil using the chisel or disk tillage implements. Soil temperature may have had an effect on which sampling dates significant tillage or manure effects were observed for CO_2 respiration, as high soil temperatures have been shown to increase the rate of soil microbial activity (Stott et al. 1986). The relationship between soil temperature and soil respiration was, however, uncertain in this experiment. However, rainfall, by providing a flush of CO_2 or N_2O release following a soil rewetting event, may have affected microbial respiration more so than soil temperature, which has been reported by (Adu and Aodes 1978).

The effect of tillage system on CO_2 respiration from the soil was not as important as the effect of manure application, as manure effects were significant on 17 of the 34 sampling dates. Tillage systems are thought to have influenced the rate of decomposition by either placing the residues in intimate contact with the soil or retaining them on the soil surface. The data presented here, on the few dates that did show a significant effect of tillage, are consistent with this hypothesis as the more intensive chisel and disk tillage systems generally resulted in greater CO_2 respiration than the zero tillage system. Tillage systems were thought to have more of a direct effect than manure application on seedbed quality and the resulting crop emergence and final yields, which were characterized during each growing season and reported in Chapter 5.

The effect of liquid hog manure application on CO_2 was thought to be important in this study, as one of the limiting factors to microbial decomposition of cereal residues is often the availability of nutrient sources for microbial decomposers. On forty percent of the sampling dates, a positive effect of manure application on daily soil CO_2 respiration was observed. This may suggest that on these dates, soil moisture and temperature conditions were favorable for microbial activity and therefore required more soluble carbon or inorganic nitrogen than could be provided by the non-manure amended treatment soils, whereas in the manure amended treatments, microbial activity was not limited by substrate availability and the available carbon provided by the cereal crop residues was readily decomposed.

The effects of manure nitrogen cannot be concluded to have caused the increase in soil respiration solely, as the effects of manure nitrogen and manure carbon on the rate of soil respiration could not be evaluated separately. Results from the growth cabinet study described previously indicate that manure application does in fact increase the rate of oat residue mass loss. This may be the result of increased soil nitrogen availability but may also be due to an overall increase in soil microbial activity induced by the addition of manure carbon.

Nitrous oxide production in soil is a result of anaerobic microbial activity when soils become saturated and oxygen is not available for microbial respiration. Microorganisms use nitrate instead of oxygen as their terminal electron acceptor and the incomplete reduction of nitrate to N_2 results in the production of N_2O. Three criteria must be met in order for denitrification to occur and N_2O gas to be produced. The soil or a particular microsite within the soil matrix must be anaerobic; there must be a source of nitrate and, lastly, a carbon source must be present. Fine clay soils are prone to denitrification as the pore spaces that dominate the structure of clays are easily filled with water providing anaerobic microsites for denitrification. The addition of hog manure and cereal crop residues to clay soils in this study provided all the criteria necessary to induce denitrification reactions, by providing carbon and nitrogen. As the process requires a carbon source, the rate of denitrification was an appropriate indication of whether or not the carbon sources being added to the soil matrix was being decomposed more readily under manure amended conditions. Other studies have reported that manure carbon can induce N_2O production in the early stages of microbial activity following manure application (Paul and Beauchamp 1989; Tenuta et al. 2000). Again, the preferential use of manure and crop residue carbon by soil microbial communities cannot be quantified in this experiment, but the potential effects of manure carbon addition to soil on the rate of soil microbial activity cannot be discounted.

As was the case for CO_2 respiration results, only 3 of the 43 sampling dates showed a significant N_2O flux response to the tillage systems employed, however, 30 of the 43 dates showed an N_2O response to manure application, evenly distributed between the fall and spring sampling periods.

The N_2O flux response to the application of liquid manure, compared to the non-manured treatments, was likely due to the abundance of nitrate nitrogen available for denitrification to occur but may have also been stimulated by the addition of soluble manure carbon. Furthermore, the quantity of water applied to the soil, in the form of liquid manure, may have been sufficient to induce widespread microsite anaerobicity throughout the manured plot area and the retained cereal straw would have provided an abundant carbon source for microbial metabolism. The increase in N_2O evolution from the manured plots indicates an increased rate of microbial activity within these treatments regardless of the tillage system treatments imposed.

4.6 Summary and Conclusions

A total of 4 and 17 of the 43 possible sampling dates showed a significant effect of tillage system and manure application, respectively, on the rate of soil CO_2 respiration. The N_2O evolution rates were significantly affected by tillage system and manure application on 3 and 30 of the sampling dates, respectively. Based on this data, it can be concluded that the tillage system used on these clay soils may not have as great an impact on the rate of microbial decomposition of crop residues as manure application. On the dates where tillage treatment caused significant differences in CO_2 respiration, the disk and chisel tillage systems resulted in a greater CO_2 flux than the less intensive zero primary tillage treatment. Significant effects of manure application on soil CO_2 respiration where observed on considerably more sampling dates than tillage effects, suggesting that the soil ecosystems may be limited by the availability of nutrients contained in the manure for microbial metabolism when environmental conditions were conducive to activity.

The fall application of liquid manure increased the rate of soil CO_2 respiration which is an indication of an increased use of carbon contained in the system. However, it is not possible to pinpoint which soil carbon source, residue or manure, is being utilized by the microbial community to provide this increased rate of CO_2 respiration. Liquid manure does contain carbon in various forms and has been reported to provide short-term increases in CO_2 and N_2O respiration from soil that may last for 2-3 days (Tenuta et al. 2000). However, in this study, manure application caused a longer-term increase in CO_2 respiration as significant effects of manure application were observed throughout the fall and subsequent spring sampling periods alike.

Tillage system effects on N_2O evolution rate where significant on only 3 dates only, all during the Spring 2002 sampling period, with the chisel plow being greater than or equal to the disk system which was greater than the zero tillage system. This is likely a result of the increased availability of a carbon source to drive the denitrification process, provided as cereal straw. Statistically, manure application had the most pronounced effect on the rate of N_2O production with 30 of the 43 dates having greater N_2O evolution rates from the manure amended versus the non-amended treatments. The effect of nitrate nitrogen availability within the manured plots may have caused the increase in N_2O evolution and was not necessarily an effect of increased residue decomposition. However, carbon is required for the denitrification process to occur, therefore, an increase in N_2O production may indicate that fall applied manure can increase the overall rate of cereal crop residue decomposition.

Based on the data presented here, when clay soils in the Red River Valley are simultaneously amended with cereal crop residues and liquid hog manure, as opposed to having cereal residues added to the system without manure application, the rate of soil microbial activity will be increased, which may result in an increased rate of microbial decomposition of the added residues. The effect of tillage systems that incorporate crop residues into the soil had a positive yet inconsistent influence on the rate of CO_2 and N_2O respiration from these clay soils. Data presented in Chapter 3 indicated that the application of manure did result in a significant increase in the actual rate of crop residue mass loss under ideal climatic conditions, and support the data presented here in terms of increased soil microbial activity and a subsequent increase in residue decomposition upon the addition of liquid manure to the soil system.

The experimental design and commercial scale of this field experiment did not allow for a more detailed examination of the effect of manure carbon addition to this soil system. Additional research is required to determine what quantity of increased soil respiration can be attributed to manure carbon and/or crop residue carbon mineralization, when clay soils are amended with liquid hog manure and cereal crop residues.

5. EFFECT OF TILLAGE SYSTEM INTENSITY AND LIQUID HOG MANURE APPLICATION ON WHEAT AND CANOLA CROP PERFORMANCE IN CLAY SOILS IN SOUTHERN MANITOBA

5.1 Abstract

A field scale research project was initiated to evaluate the effects of using three tillage systems, in lieu of straw burning, as the primary method of cereal crop residue management in clay soils. Chisel, disk and zero tillage systems were evaluated for their effects on final yield and quality of wheat and canola in 2001 and 2002 of the study, respectively. Additional data were collected, including seedling emergence, soil nitrogen concentration, soil moisture and temperature, annual rainfall and soil surface residue cover, to characterize crop responses to the various tillage systems employed.

The study also included an evaluation of the use of liquid hog manure as a source of nitrogen for crop production as compared to commercial nitrogen fertilizer. Each of the three tillage systems was established with fall applied hog manure or spring applied commercial nitrogen fertilizer and the factors described above were used to evaluate crop performance for each nitrogen amendment. There were no significant differences observed for surface residue cover, seedling emergence, soil moisture, soil temperature or final yields of wheat or canola between any of the tillage systems included in the study. Nitrogen source was found to have no significant effect on the yield or quality of wheat in 2001 but manure nitrogen was found to have a significant positive effect on the yield of

canola in 2002 compared to urea nitrogen fertilizer. Based on the crop yield and quality data collected during this two year field scale study, it is concluded that producers within the fine textured soil regions of the Red River Valley have the potential to adopt low intensity tillage systems and continue producing high yielding, high quality wheat and canola crops without using straw burning as a means of primary residue management. The problems commonly associated with managing cereal residues in this region, being cool, wet soils, uneven crop emergence, and high crop disease pressure, were not found to have any significant effect on crops grown on commercial scale research plots during the 2001 and 2002 growing season.

5.2 Introduction

The clay texture of the soils found in the Red River Valley of southern Manitoba presents a unique challenge to small grain and oilseed producers in the region; in managing excessive amounts of cereal crop residue. The presence of large quantities of cereal straw is thought to result in prolonged periods of cool and wet spring soil conditions that are not conducive for rapid crop seedling emergence and performance and the achieving maximum yield potential. Straw burning following the cereal crop harvest is a residue management tool often used by producers to dispose of crop residues to eliminate their effect on subsequent crops. Burning has been cited to reduce crop disease pressure, to increase the rate of soil warming and drying during the spring and to allow for efficient and timely spring seedbed preparation.

The use of fall primary tillage operations to incorporate crop residues and induce the decomposition of these residues may be an acceptable alternative to straw burning as a primary residue management practice. There may be a synergistic effect of fall primary tillage operations and fall liquid hog manure application to clay soils on the rate of residue decomposition, which may serve to provide an good seedbed condition for annual crop establishment on these soils without relying on straw burning for residue management. Incorporating crop residues via tillage operations instead of burning the residues may help to reduce the rate of soil organic matter depletion, which has been linked to poor soil aggregation, increased soil bulk density and compaction and reductions in the inherent natural fertility of Black Chernozem soils.

Liquid hog manure application to clay soils may prove to stimulate soil microbial activity and induce residue mineralization but may also be an effective source of macro and micro-nutrients for crop production. The use of manures in lieu of commercial nitrogen and phosphorus fertilizers may improve the profitability of annual crop production, maintain soil quality and microbial activity and reduce the reliance of producers on off-farm inputs to maintain crop productivity.

5.3 Objective of the Study

The first objective of the study was to evaluate the performance of hard red spring wheat and canola under three tillage systems, fall chisel plow, fall one-way disk and zero primary tillage, in clay soils which have received high loading rates of cereal straw. The performance of these crops was also compared to that of crops grown on soils where the preceding crop residues had been disposed of through straw burning. The second objective of this study was to evaluate the performance of crops grown using fall applied liquid hog manure as the sole nitrogen source to that of a crop grown using spring applied commercial nitrogen fertilizer.

5.4 Materials and Methods

5.4.1 Field Site Treatment Design and Layout

The experiment was designed as a field-scale project to evaluate the effects of tillage systems and manure application on the performance of Spring wheat and argentine canola in 2001 and 2002, respectively. Refer to Sections 3.4.1.1 and 3.4.1.2 for detailed information on the design and layout of the experiment in year-1 and year-2, respectively.

5.4.1.1 2001 Crop Year

Hard red spring wheat was seeded on June 6, 2001, using a 12.7-m commercial air seeder. Monoammonium phosphate was applied, in furrow, at 40 kg ha^{-1}, and the plots were diamond harrowed to facilitate soil packing, a smooth field surface and even crop emergence. All treatments that did not receive fall-applied hog manure received an equivalent application of 110 kg ha^{-1}, actual nitrogen, by surface broadcasting 323 kg ha^{-1} ammonium nitrate (34-0-0), post-seeding, using air delivery fertilizer application equipment.

5.4.1.2 2002 Crop Year

On May 24, 2002, fertilizer split-plots received 260 kg ha^{-1} broadcast urea fertilizer (46-0-0) and 74 kg ha^{-1} monoammonium phosphate fertilizer (11-52-0) immediately prior to canola seeding. This was equivalent to a nitrogen and phosphate application rate of

127 kg N ha^{-1} and 38 kg P ha^{-1}, respectively. It was assumed that the availability of fall manure applied phosphate would be 50 %, however, 50 % efficiency is based on the assumption of broadcast application of manure vs. banded placement of fertilizer P, therefore spring fertilizer phosphate was broadcast applied at half the rate applied as liquid manure during the previous fall.

Canola was seeded on May 24th at 5.6 kg ha^{-1} using a 12.7-m air-seeder perpendicular to the direction of tillage treatment application to reduce the incidence of soil compaction observed in year-1 of the study from repeated field trafficking. Seed was placed between 1.5 cm and 2.5 cm deep and the seedbed was diamond harrowed after the seeding operation to ensure adequate seed to soil contact.

Crop care and management, including fungicide and herbicide application, was the responsibility of the co-operating producer in both study years.

5.4.2 Surface Residue Cover Measurements

Surface residue measurements were made in order to quantify the soil surface residue cover that would result from using the various tillage systems studied. The method used was developed specifically for this study using existing digital image analysis software and hardware. An 8-mm digital video camera was used to capture video streams of the soil surface the entire length of the experimental plots, prior to Spring seeding operations in both years and post spring seeding operations in 2002 only.

In order to maintain a consistent image surface area, the camera was fastened, at a fixed height, to a custom built tripod frame fitted with pneumatic tires which allowed for soil surface images to be easily recorded by pulling the cart the length of each plot while recording. A VMS 200^{TM} Video Mapping System unit specially designed to work in conjunction with video equipment was also fitted to the cart frame. The VMS unit was equipped with a GPS antenna, and once initialized, recorded the geographical location of the camera in an audio format on the 8-mm tape used to capture video streams of the soil surface. MediaMapper^{TM} software was used to download the coordinate information recorded on the 8-mm tape by the VMS 200^{TM} unit and developed a surface map of the path that had been followed by the camera. The map developed by the software allowed the tape to be moved forward or rewound to any specific point on the map, allowing video streams of each individual plot to be isolated and the video images to be analyzed individually.

Once the videos streams of each individual plot had been isolated, 10 snapshot still images from each plot were isolated from each plot stream. Using ASSESS^{TM} Image Analysis Software for Plant Disease Quantification, each still image was analyzed for surface residue coverage by contrasting the difference in surface area covered by the light colored crop residue and the darker soil surface. An average residue surface cover value was determined for each plot by averaging the values obtained from each individual still image. Figures 5.1 and 5.2 show the side and top view construction schematic of the tripod camera frame and the profile of the video image collected, respectively.

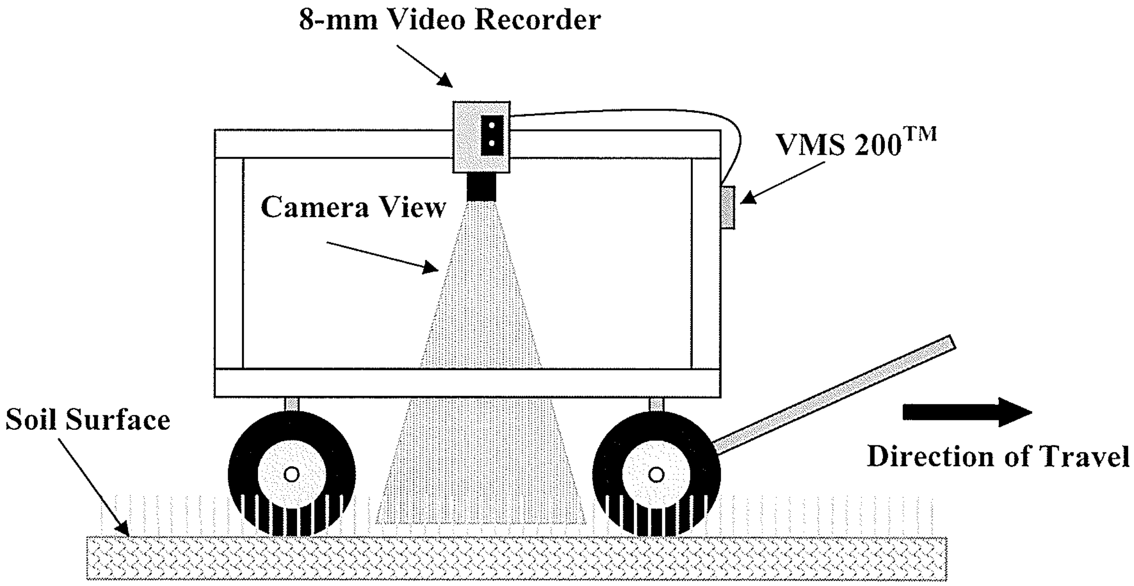

Figure 5.1 Soil surface video capture tripod frame: side view schematic.

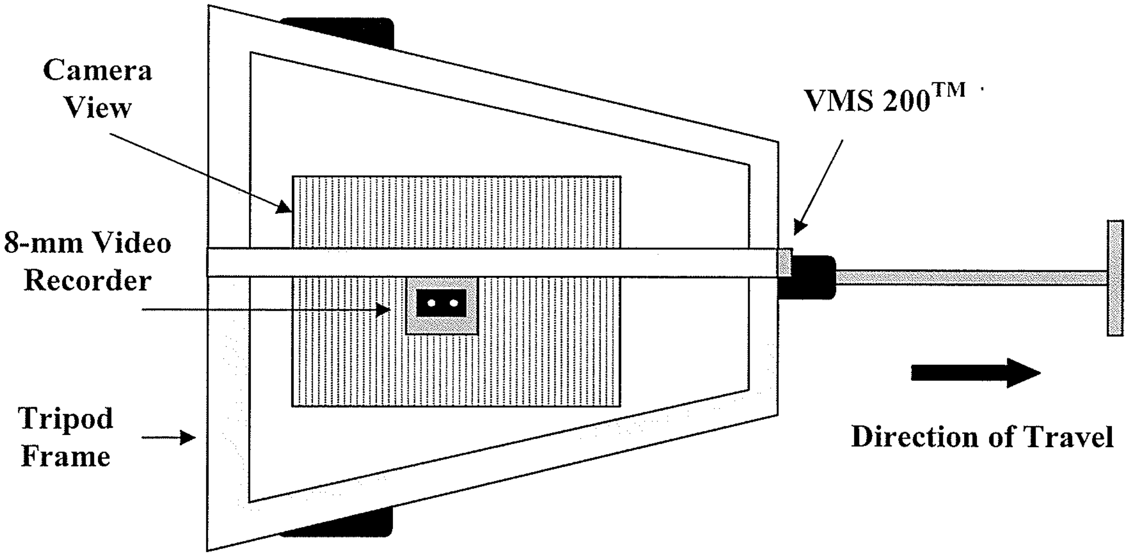

Figure 5.2 Soil surface video capture tripod frame: top view schematic.

5.4.3 Emergence Counts

Emergence counts were collected 16 and 24 days after seeding had been completed in 2001 and 2002, respectively. Counts were taken in 2001 by collecting five replicate counts per plot, one approximately every 30 m, of the wheat plants which had emerged in a 100 cm length of seed row. Canola plant emergence counts in 2002 were collected using 800 cm^2 quadrats measuring 10 cm x 80 cm. Ten replicate counts were taken per plot, one approximately every 15 m, by placing the quadrat on a discernable seed row and counting the number of plants inside the quadrat.

5.4.4 Soil Nitrogen Sampling and Analysis

Refer to section 4.4.5 for the protocols followed for soil nitrogen sampling and analysis.

5.4.5 Cereal and Oilseed Crop Harvest

5.4.5.1 2001 Crop Year

Spring wheat was harvested from each plot to quantify yield differences between tillage treatments and the two nutrient sources. During the growing season factors other than tillage system and/or nutrient source treatments introduced variability into crop yield. Part of this variability was due to repeated field trafficking that caused soil compaction within the plots, especially under excessively moist fall and spring soil conditions. In addition, high levels of precipitation during the growing season resulted in temporary flooding of isolated, low-lying areas of the plot area causing considerable crop damage. In an attempt to minimize the effects of soil compaction and extreme moisture conditions on yield expression, a total of 10 1-m^2 whole plant sub-plots, referred to as micro-plots in subsequent sections, were harvested from each plot at 13 m intervals. Samples were collected from areas that were not visibly affected by factors other than those that were accounted for in the experimental design, i.e. areas of recognizable compaction and or extreme moisture conditions were avoided in sampling. Samples collected from the micro-plot areas were weighed and threshed to obtain total biomass yield, grain yield and harvest index. Micro-plot sample weight values were averaged for each plot and yield values in kg ha^{-1} were calculated based on the area harvested.

After micro-plot sampling had been completed, plots were individually swathed and the crop was allowed to cure for approximately 1 week. Each plot was threshed individually using a commercial scale combine harvester, and the mass of wheat harvested was determined in kg $plot^{-1}$ using a grain cart weigh wagon equipped with load sensors. Grain sub-samples were collected and analyzed for protein concentrations and wheat grade.

5.4.5.2 2002 Crop Year

Canola was swathed on August 22nd, 2002, and swaths were harvested on September 18th, using a commercial combine. The crop was uniform the plot area so micro-plot sampling was not deemed necessary in the second study year. Each plot was harvested and weighed separately using a grain cart weigh wagon. Sub-samples were collected from each plot for grain quality analysis.

5.4.6 Cereal and Oilseed Crop Quality Analysis

Wheat protein analysis and canola grading services were provided by Cargill Ag Horizons, Elm Creek, MB.

5.4.7 Statistical Analysis

Statistical analysis was completed using the GLM option of ANOVA in Statistical Analysis Software (SAS). The data collected was normally distributed and did not require transformation. Data was analyzed using a 5 % significance level ($\alpha = 0.05$) Least significant differences (LSD) between treatment means were used to determine and delineate significant treatment effects.

5.5 Results and Discussion

Tables 5.1 and 5.2 contain the factor means, LSD significance groups and P-values for soil surface residue cover, seedling emergence and final yield and protein content of wheat in 2001 and final canola yield in 2002.

Table 5.1 2001 crop performance parameters.

	Res. Cover (%)	Emergence (plants m row^{-1})	Yield (kg ha^{-1})	Protein (%)
Fall Tillage				
Zero	22.8	38.9	957	14.8
Chisel	22.2	41.9	991	15.0
Disk	22.2	41.1	866.2	14.8
Nutrient				
Manure	22.8	39.4	849	14.7
Fertilizer	21.9	41.9	1027	15.0
CV (%)	10	8	20	2
		P-Values		
Tillage	0.76	0.32	0.77	0.40
Nutrient	0.31	0.16	0.26	0.12
T*N	0.71	0.21	0.28	0.87

Table 5.2 2002 crop performance parameters.

	Residue Cover (%)			
	Pre-Seed	**Post-Seed**	**Emergence (Plants m^{-2})**	**Yield (kg ha^{-1})**
Fall Tillage				
Zero	31.6	36.4	24.8	1598
Chisel	34.0	37.9	29.6	1593
Disk	33.0	38.0	29.9	1278
Nutrient				
Manure	33.1	37.7	28.1	1569a
Fertilizer	32.6	37.1	28.1	1411b
LSD				136
CV (%)	7	7	19	18
		P-Values		
Tillage	0.31	0.48	0.33	0.22
Nutrient	0.81	0.63	0.96	0.038
T*N	0.092	0.37	0.75	0.92

5.5.1 Surface Residue Cover

No significant effect of tillage system or manure application was observed for the percentage of remaining oat residue soil surface coverage after the spring 2001 seeding operations had been completed. Figure 5.3 shows the relative residue coverage for each of the three tillage systems with and without manure application after the 2001 seeding operations had been completed. The effect of manure application was not thought to have a significant impact on the level of surface residue retention. However, the impact of tillage system, each having a different mode of residue incorporation as well as varied levels of intensity of action, was expected to have a more pronounced effect.

Two measurements were completed during the Spring of 2002, one prior to and one after the seeding operation. Figures 5.4 and 5.5 show the resulting soil surface residue coverage for each treatment factor combination for pre-plant and post-plant measurements, respectively. The relative residue loading rates between the two spring measurement periods was different with the oat residue in 2001 being added at approximately 6000 kg ha^{-1} and the wheat residue in 2002 at approximately 4000 kg ha^{-1}. The pre-seeding measurement in 2002 resulted in a higher level of soil surface residue cover compared to the post-seeding measurement completed in 2001, despite a lighter straw-loading rate. The effects of tillage system and manure application were again found to be insignificant for both the pre-seeding and post-seeding residue cover measurements with numerical values for all treatment factor combinations being quite similar. The lack of variation between the treatments may have been due to the relatively shallow tillage depth for the implements used in the experiment and the lack of ability of these implements to effectively bury the applied crop residues.

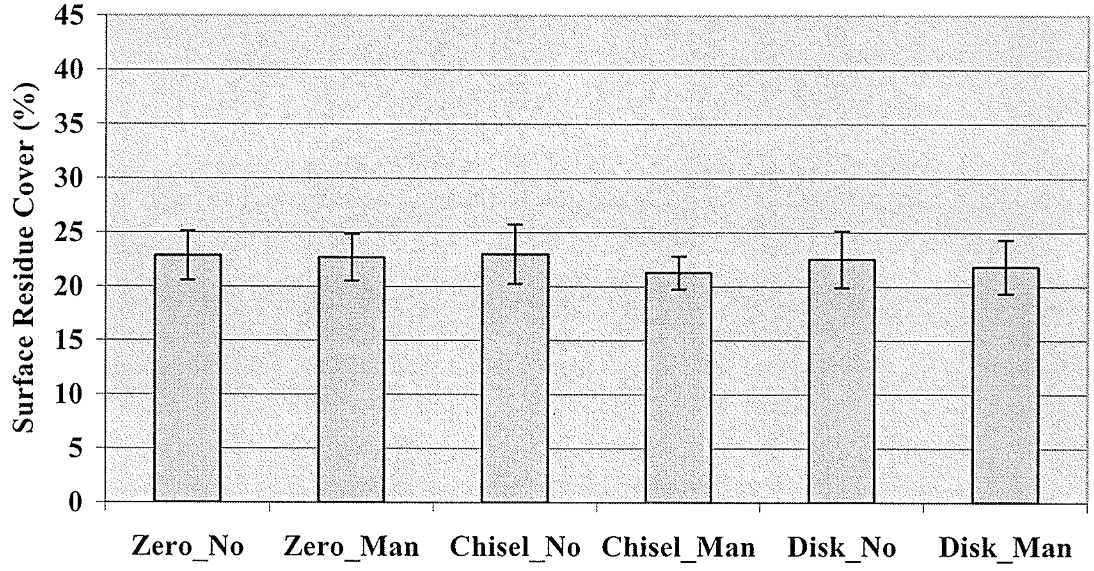

Figure 5.3 Spring 2001 post-seeding surface residue cover. Error bars are standard deviation about the treatment mean.

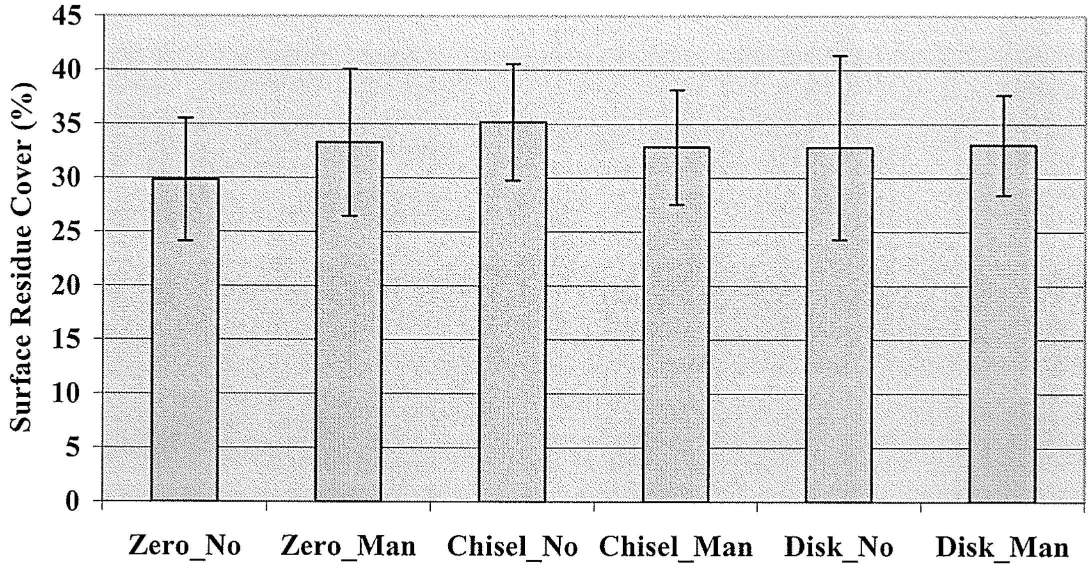

Figure 5.4 Spring 2002 pre-seeding surface residue cover. Error bars are standard deviation about the treatment mean.

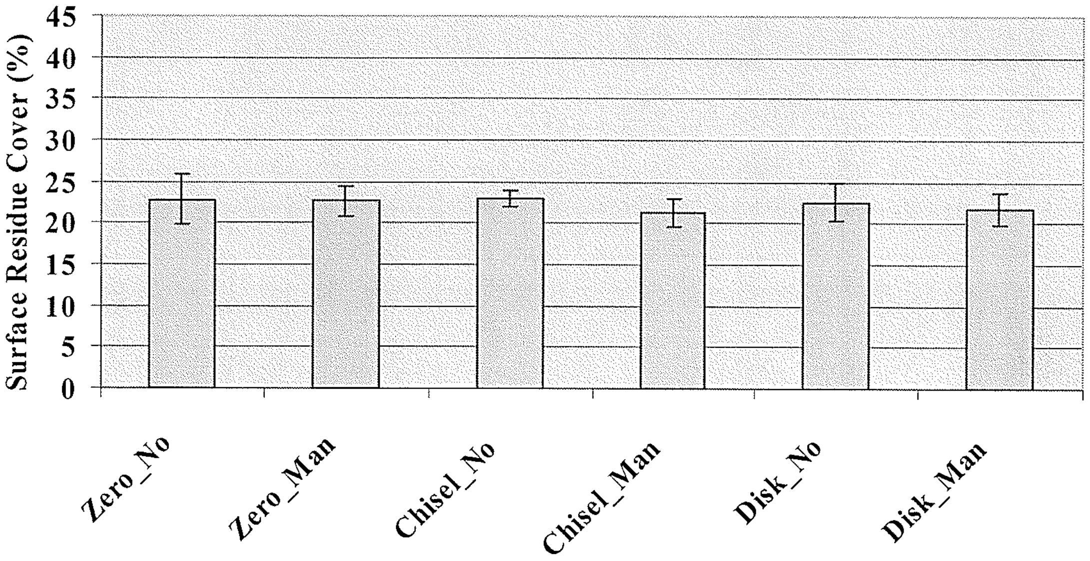

Figure 5.5 Spring 2002 pre-seeding surface residue cover. Error bars are standard deviation about the treatment mean.

5.5.2 Emergence Counts

Analysis of the wheat and canola seedling emergence count data collected in 2001 and 2002, respectively, showed no significant differences between the tillage or nutrient management systems. The lack of significantly large numerical differences between the treatments in terms of soil surface residue cover may indicate that the conditions for seedling emergence between the treatments did not vary, resulting in a uniform crop stand across all treatments. Plant counts per meter row of wheat in 2001 and per square meter for canola in 2002 are graphically displayed in Figures 5.6 and 5.7, respectively.

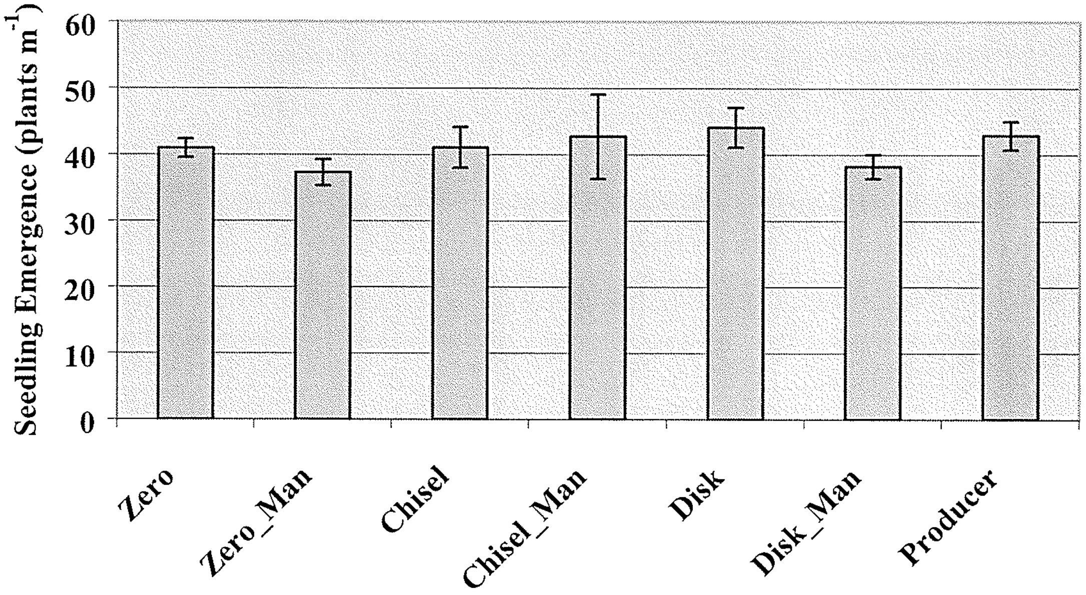

Figure 5.6 Spring 2001, wheat seedling emergence counts. Error bars are standard deviation about the treatment mean.

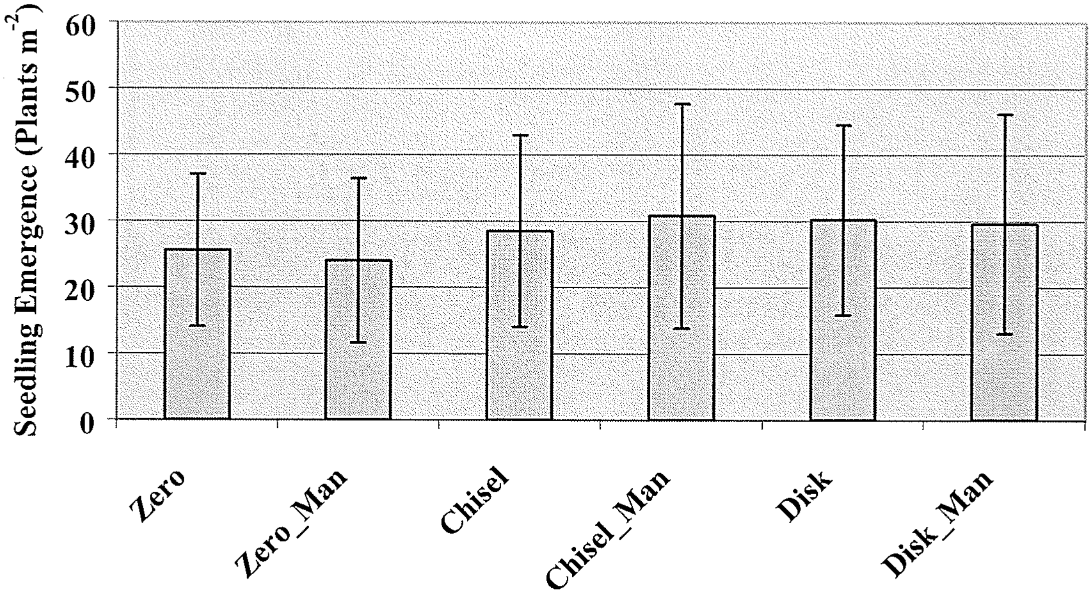

Figure 5.7 Spring 2002 Canola seedling emergence counts. Error bars are standard deviation about the treatment mean.

5.5.3 Soil Nitrogen

Statistical analysis were not carried out for nitrate and ammonium concentration values shown in Figures 5.8 and 5.9 for 2001 and Figures 5.10 and 5.11 for 2002, but were included to provide information on the potential nitrogen availability levels within all treatments. Concentrations in kg ha^{-1} were calculated using bulk density values of 1.24 kg m^{-3} and 1.33 kg m^{-3} for the 0-15-cm and 15-60-cm depths, respectively. As can be seen in the figures, the pre-seeding nitrate levels for the manured treatments were greater than the non-manured treatments in both years. A greater amount of inorganic nitrogen was present in the spring of 2002 compared to 2001, and in both years the manured chisel plow treatment had a numerically greater amount of ammonium nitrogen present in the 0-15-cm depth. In all cases generally, the post-harvest residual nitrogen concentrations were lower than the pre-seed sample concentrations.

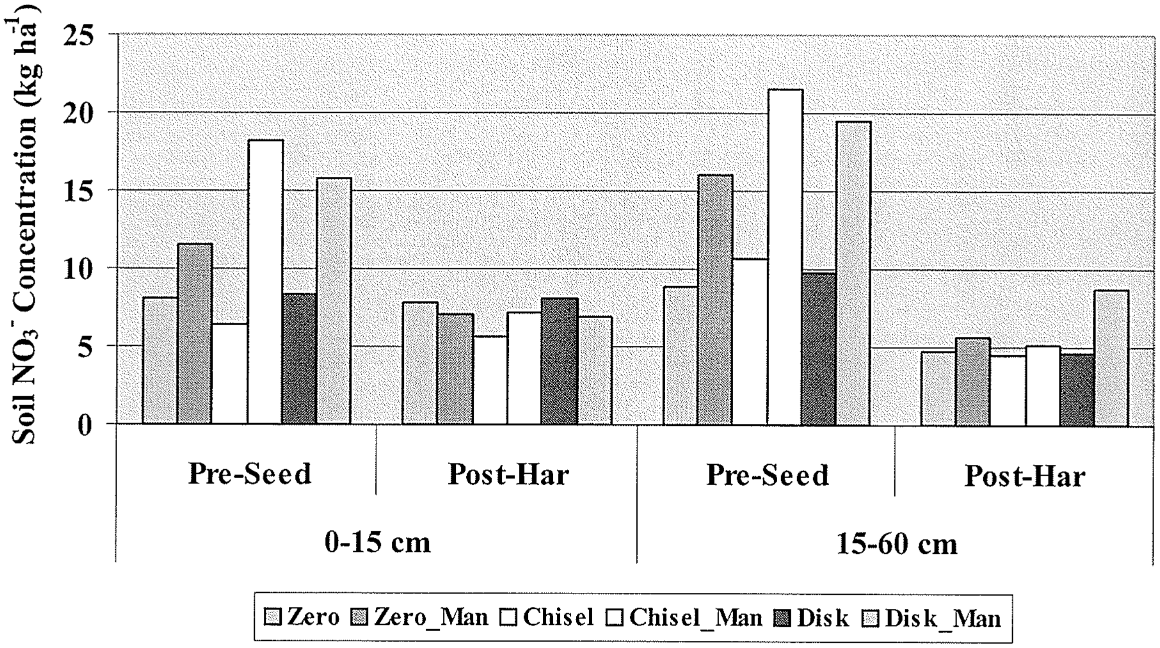

Figure 5.8 2001 Nitrate nitrogen concentration.

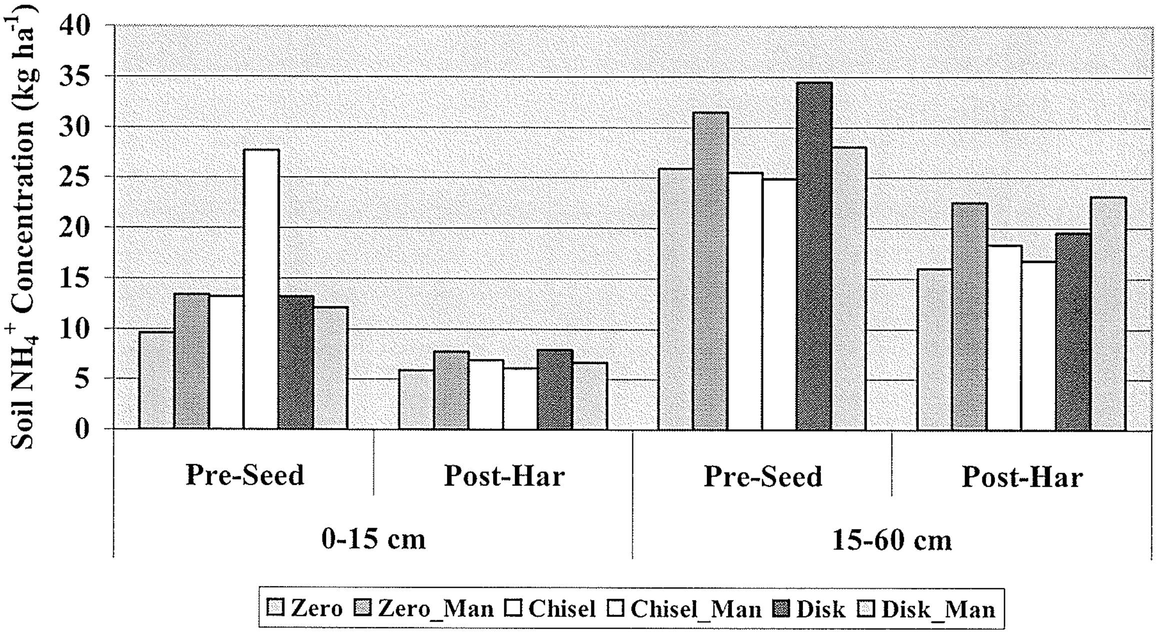

Figure 5.9 2001 Ammonium nitrogen concentration.

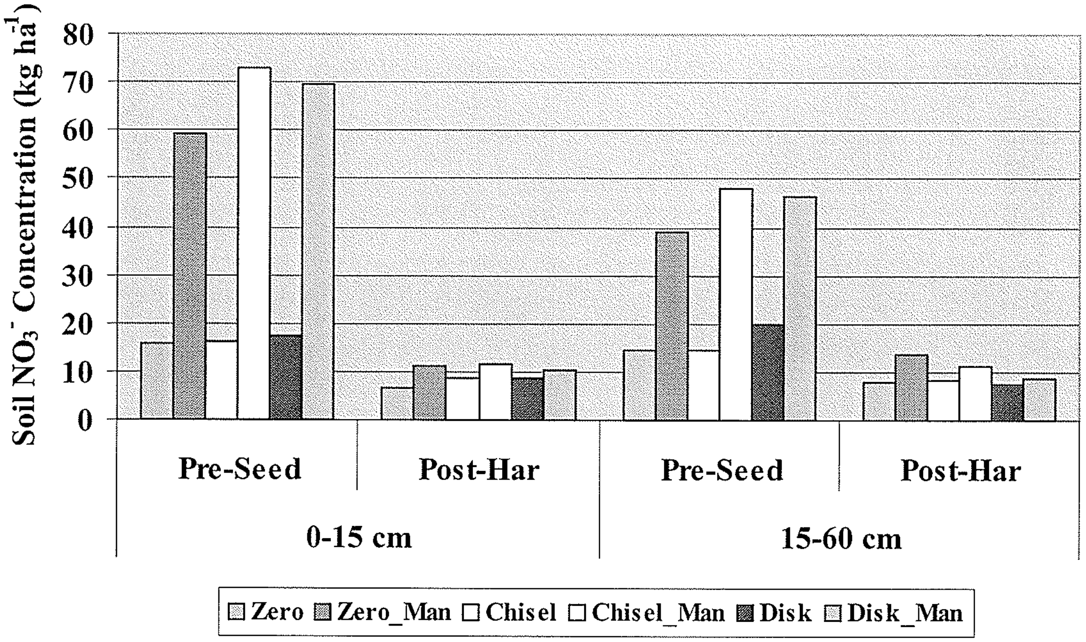

Figure 5.10 2002 Nitrate nitrogen concentration.

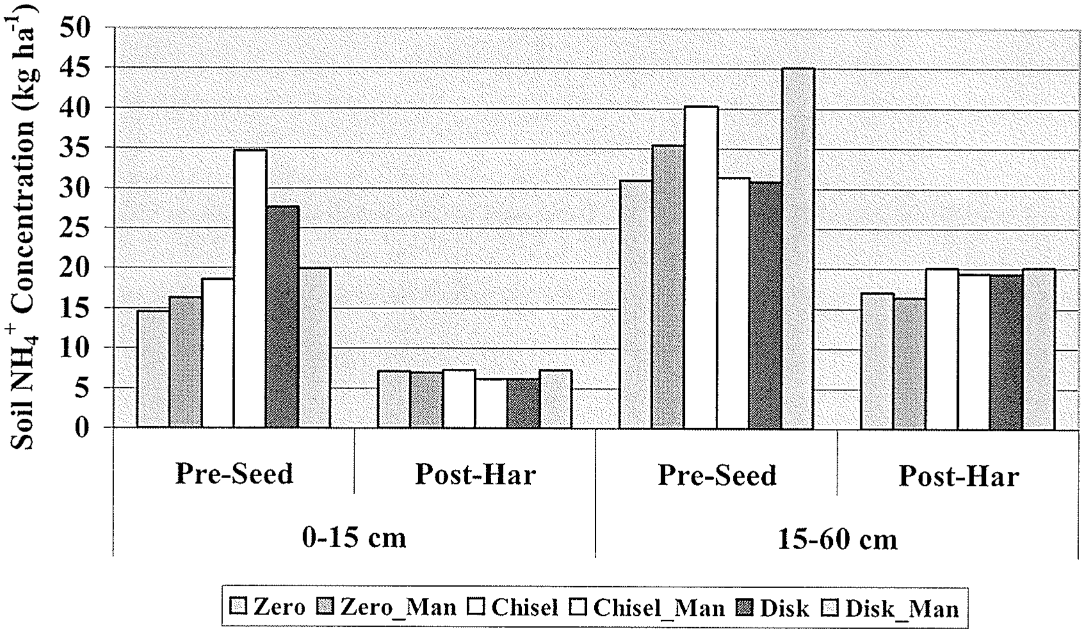

Figure 5.11 2002 Ammonium nitrogen concentration.

5.5.4 Final Crop Yield and Quality

5.5.4.1 2001 Wheat Crop

The yield of spring wheat was not found to be significantly affected by the primary tillage systems or sources of nitrogen used in this experiment. Wheat yield was, however, found to be highly variable within treatments, a factor likely contributing to the lack of significance observed.

Figure 5.12 includes a reference yield treatment that was established and maintained by the project cooperating producer. Final yield data from the reference treatment was obtained by harvesting several strips of crop, identical in size to the harvested areas within the plots, directly adjacent to the plot area, during the fall of 2001. These values were not included in the statistical analysis as they were not properly included in the experimental design, but are included as a reference to the yields expected by producers who regularly dispose of cereal oat residues through straw burning. In this case, the area surrounding the plot area was burned during the fall of 2000 and the control plots were harvested from this area.

The chisel plow primary tillage treatment using nitrogen fertilizer had the greatest final yield; however, the chisel plow with manure treatments had the lowest. The disk tillage with manure treatments had a lower yield relative to the nitrogen fertilizer treatment; while the zero primary tillage system had a greater yield with manure compared to nitrogen fertilizer. The hog manure amended zero primary tillage system yielded roughly the same as the reference treatment, the chisel plow with nitrogen fertilizer treatment yielded greater, and all others yielded lower than the control. The increase over the more intensive tillage systems, chisel and disk-based, is attributed to a decreased incidence of manure nitrogen immobilization in the presence of the incorporated oat crop residue.

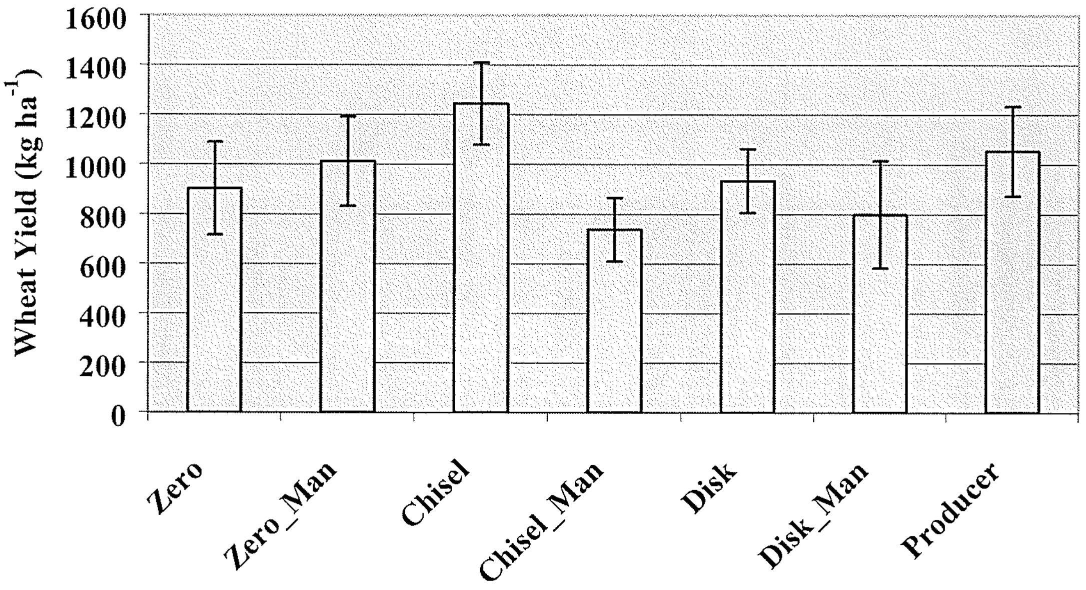

Figure 5.12 Final wheat yields for all treatments. Error bars are standard deviation about the treatment mean.

Wheat protein content values are found in Figure 5.13, and were not significantly affected by tillage or manure application. This was attributed to the relatively low wheat yields recorded, and the lack of compensation of the wheat plants for nitrogen to be used for yield or protein development.

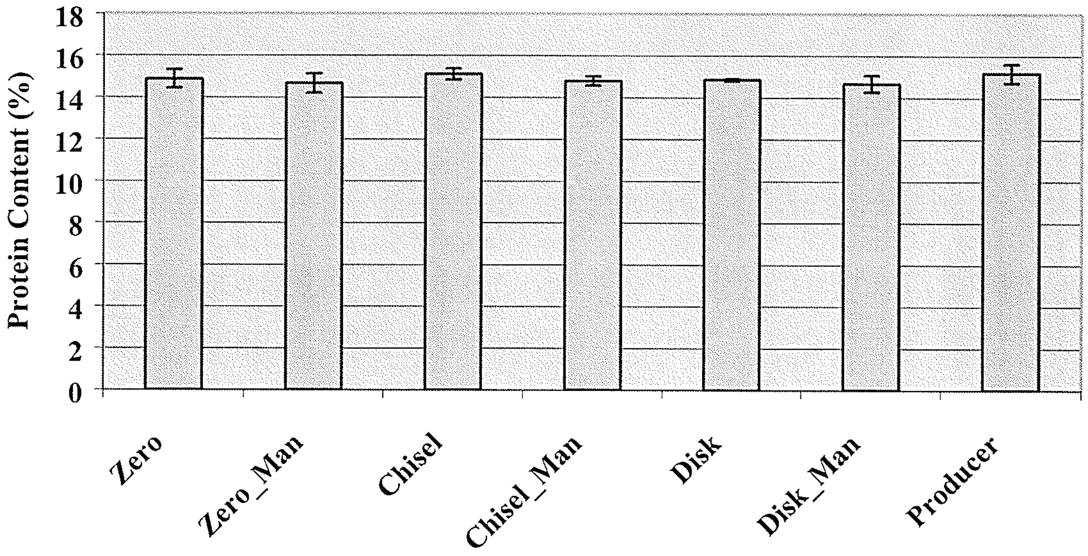

Figure 5.13 Wheat protein content for all treatments. Error bars are standard deviation about the treatment mean.

5.5.4.2 2002 Canola Crop

No significant tillage treatment effects were found for the final yield of canola in 2002, however, nutrient source was significant, with a P-value of 0.04, where the hog manure amended treatments had greater yields compared to those receiving inorganic nitrogen and phosphorus sources in the form of urea and monoammonium phosphate, respectively. Manured split plots had slightly greater yields than the fertilizer split plots for all three tillage systems. The zero and chisel plow primary tillage systems resulted in nearly identical yields that were greater than the disk tillage treatments in the case of both hog manure and fertilizer nitrogen sources.

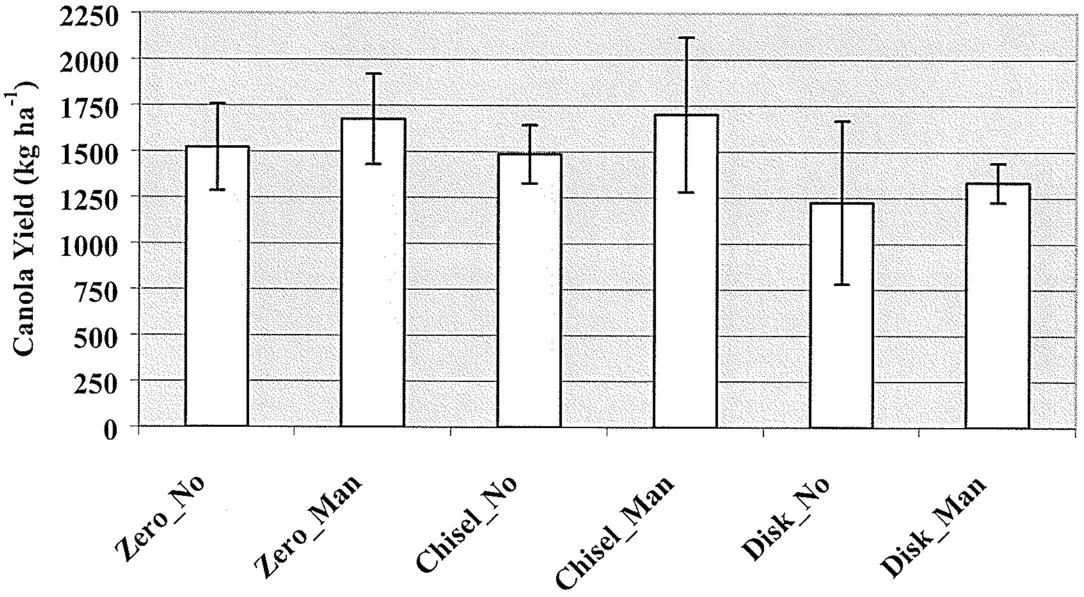

Figure 5.14 Final canola yield for all treatments. Error bars are standard deviation about the treatment mean.

5.6 Tillage System and Manure Application Effects on Crop Performance

5.6.1 Surface Residue Cover

There were few significant findings in this study in terms of spring wheat and canola crop responses to tillage system or manure application treatment factor effects. The only significant difference between the treatments was the higher grain yield of the manured canola treatments in 2002 compared to the fertilizer nitrogen treatments.

The effect of manure application was hypothesized not to have an effect on the amount of residual crop residue remaining on the soil surface after spring seeding operations had been completed due to the low amount of soil disturbance provided by the manure injection tools. This proved to be true for both the manure application and tillage treatments, which was unexpected. We expected that the chisel and disk tillage systems, being more aggressive soil engaging tools compared to the zero primary tillage system, would result in less soil surface residue cover than the zero tillage treatment. In 2001, the lack of a significant difference after the seeding operation may have been due to the aggressive nature of the seeding system employed in the study, a commercial air-seeder equipped with 25-cm sweeps, which may have buried a sufficient amount of crop residue to negate any surface residue variation that may have existed after the primary tillage operations. This type of seeding implement is widely used throughout the Red River Valley region to achieve effective weed kill prior to spring seeded crop emergence, and is considerably more aggressive than spoon, knife and/or disk seed furrow openers used on a comparable air-seeder frame. This reasoning for the lack of significant differences between the tillage systems is not applicable to the second year, however, due to the fact that there were no significant differences found for surface residue cover even before the seeding operations had been applied to the plot area.

The design of this particular study did not allow an in depth study of the effect of tillage system on surface residue cover retention as the treatments were applied for a one year period only and on different plots of land for year-1 and year-2 observations. Had the treatments been applied to the same plot area in both years of the study, the effects of zero primary tillage management on surface residue cover may have been more pronounced, and a more prolonged study would likely result in more significant differences over time as the amount of surface residues continued to accumulate over time. Surface residue cover for the more intensive disk and chisel plow based systems would likely remain constant over time, where the zero primary tillage system would increase to an equilibrium level where input of crop residues was equal to the potential rate of residue mineralization.

5.6.2 Seedling Emergence

No significant effect of either treatment factor, tillage or manure, were observed for wheat or canola seedling emergence in 2001 and 2002 of the study, respectively. The disk and chisel plow primary tillage systems tended to be slightly, but not significantly, greater than the zero tillage system in both study years. Data collected in 2002 from the canola crop was much more variable than the spring wheat data collected in 2001. This variability with canola emergence is not uncommon, as canola is a small seeded crop which and is seeded shallow and at a low seeding rate. The non-significant trends observed for plant emergence counts in the various treatments did not translate into similar trends for final harvest yields.

As previously discussed, the single year nature of the experiments, carried out over two years on different plots of land, does not lend itself to a true examination of the effects of alternative residue management strategies on seedling emergence grown in the fine clays found in the southern Red River Valley. Subsequent years of zero primary tillage management may prove to have a significant positive or negative effect on crop seedling emergence. However, in this project, there was no significant difference in crop seedling emergence between any of the three tillage systems used for spring seeded hard red spring wheat or argentine canola.

5.6.3 Final Seed Grain Yields

Spring wheat final yields showed no significant response to primary tillage system or nutrient management system, in year-1 of the study. The target yield of spring wheat in the area is generally 2700-3400 kg ha^{-1}, the average plot yield in year-1 of the study was 1000 kg ha^{-1}, representing a greater than 50 % yield reduction relative to the target.

The 2001 growing season was characterized by heavily saturated spring soil conditions resulting in the crop being planted considerably later than normal. The crop was seeded in generally optimal conditions on June 6th, 2001, and emerged promptly and evenly. Heavy rainfall events in mid-July, however, followed by a prolonged period of flooding resulted in moderate to high crop yield reductions. The fall application of liquid hog manure to the plots, under moist soil conditions, resulted in a noticeable level of soil compaction throughout the plots which was also thought to have contributed to reduced wheat yields. The plots that received liquid hog manure treatments, during the fall of 2000, showed signs of nitrogen deficiency throughout the 2001-growing season. Soil nitrogen concentration analysis revealed that there were 25, 45, 28 kg ha^{-1} of inorganic nitrogen in the 0-15-cm soil depth and 48, 46, 48 kg ha^{-1} inorganic nitrogen in the 15-60-cm soil depth in the zero, chisel and disk tillage systems receiving fall applied liquid manure, respectively. These topsoil nitrogen concentrations were likely not sufficient to support vigorous plant growth initially, but once the subsoil nitrogen reserves were reached by the developing crop root systems, the nitrogen deficiency was overcome. The fertilizer amended plots did not show signs of nitrogen deficiency throughout the growing season as they were amended instead by a post-seeding broadcast ammonium nitrate application of 110 kg ha^{-1} actual nitrogen. Had the growing season been more favorable for crop growth with the absence of multiple crop stresses, the fertilizer plots would likely have had slightly higher yields. On average, 25 kg ha^{-1} more inorganic nitrogen was present in the manured plots compared to the fertilizer amended plots prior to spring seeding operations. It may be assumed that the fate of at least a portion of the fall applied manure nitrogen would have been lost through denitrification, post application and during the spring period, and that a portion would have been immobilized microbially during the decomposition of the Fall applied oat straw residues.

The canola crop observed in the second year of the study was not subjected to the level of excess water stress as the wheat crop grown in 2001 and, as a result, provided yields more typically achieved by local producers. Fertilizer recommendations were targeted at a yield of 2500 kg ha^{-1}, but a more realistic goal for the area would be 1700-1800 kg ha^{-1}.

Average yields in 2002 were 1500 kg ha^{-1}, suggesting the crop was relatively healthy and provided an accurate representation of what a producer might expect from using the crop residue management systems studied commercially.

The zero and chisel plow primary tillage systems yielded similarly and reported slightly greater yields than the disk tillage system. The crop response to manure application compared to canola grown using commercial nitrogen and phosphorus fertilizer was observed throughout the growing season. Manured plots appeared more dark green with slightly more vigorous growth, the split-plot design of the experiment in year-2 reduced the variability from year-1 and allowed a side-by-side visual comparison of crop development and performance. One possible cause for significant manure application effects could be a difference in potential availability of phosphorus to the canola crop during the growing season. Manitoba Agriculture and Food guidelines recommend assuming 50 % availability of manure-applied phosphorus during the growing season. The majority of phosphorus contained in liquid hog manure is found in the solid organic portion and requires microbial mineralization to release forms of phosphorus readily available for plant root uptake. As such, the spring applied phosphate fertilizer was applied at one half the rate of phosphorus applied during the previous Fall as liquid hog manure. Neither of the phosphorus sources were seed placed which would reduce the availability of the applied phosphorus to the developing crop, also more than 50 % of the applied phosphorus may have become available on the manure-amended plots resulting in non-equivalent levels of available phosphorus and increased yields from the manure amended plots.

5.6.4 Crop Quality

5.6.4.1 Year-1 Wheat Crop

Wheat crop protein content was not significantly affected by the tillage or nutrient management systems observed in this study. This may have been due to the fact that the yield potential of the wheat crop was decreased significantly over the course of the growing season. A late seeding date coupled with prolonged soil inundation from untimely and intense rainfall events and lastly, high fusarium head blight disease pressure throughout the plots and surrounding fields likely contributed to the low yield potential of the crop. These factors, together with the soil compaction that was observed throughout plot area, were the likely cause of the low yields produced throughout the plot area regardless of tillage or nutrient management system. Had optimal conditions existed during the growing season, nitrogen availability may have had a more significant effect on wheat protein yields.

5.6.4.2 Year-2 Canola Crop

The general trend in canola crop quality was that manured treatments produced Canada #2 canola and the fertilizer amended treatments produced Canada #1 grade canola. This was attributed to the differences observed in maturity at the time of swathing between the two nutrient sources. The manured treatments, which were observed to have more vigorous growth throughout the growing season, contained more green seed in the quality sub-samples collected during plot harvesting operations; indicating that the swathing operation was completed earlier than optimal for the manured treatments. It was, however, necessary to swath the entire plot area at once regardless of non-uniform maturity to simplify the subsequent harvest operations. As the growth of the manured canola plots was found to be more vigorous during the growing season and the yield was found to be greater than the fertilizer amended plots, the lower grade assigned to the manured canola is thought to be due to the premature harvest conditions and not to fundamental differences between the two nutrient sources.

5.7 Summary and Conclusions

Straw burning in the Red River Valley is often cited as a required residue management system to maintain efficient crop production in the fine textured soils dominating the area. Decreased rate of soil drying and prolonged cool soil conditions during the spring prior to seeding are thought to be two consequences of not removing fall post-harvest crop residues, especially from high biomass yielding crops such as oats. Data reported in Chapter 4 suggested that there was no difference in mean soil temperature or gravimetric moisture between soils in which residues had been retained and those in which the residues were removed through burning. Data presented in this chapter showed that there was no yield penalty for using low intensity residue management systems in fine textured soils. Yields collected from wheat plots in 2001 resulted in slightly greater yields from the chisel plow treatment compared to the reference treatment plots in which the oat straw was burned, and the zero primary tillage treatment yielded equal to the reference treatment. There were also no tillage system induced differences in the amount of surface residue cover remaining after spring seeding operations, which may have resulted in the same lack of treatment difference for crop seedling emergence counts for both wheat and canola. This was likely due to the short term nature of the experiment, where crop residues from multiple cropping years was not allowed to accumulate and cause potential reductions in crop seedling emergence. Wheat protein concentration was not found to be affected by tillage system or manure application.

In conclusion, this research has shown little effect of retaining, rather than burning, cereal crop residues within the soil system on the performance of spring wheat and canola in the Red River Valley. Crop emergence in plots receiving several types of fall primary tillage intensities did not vary significantly. Even with zero primary tillage, crop performance was equal to the crop grown on residue burned plots. This data suggests that there is potential to reduce the use of residue management systems that include straw burning and also the intensity of the tillage systems used to produce spring wheat and canola in the fine textured soils of the Red River Valley without sustaining an appreciable loss in crop yield.

6. A MICROCOSM STUDY TO EVALUATE THE EFFECT OF LIQUID NITROGEN, GLUCOSE AND HOG MANURE APPLICATION ON OAT RESIDUE DECOMPSITION IN CLAY SOIL

6.1 Abstract

Data collected from field studies designed to evaluate the rate of soil respiration associated with liquid hog manure and cereal residue application to heavy clay soils was highly variable. This microcosm study was initiated to study the effects of these amendments under controlled laboratory conditions.

The study was designed as a 3x2 factorial with nutrient source and incubation medium as the experiment factors. Nutrient and energy amendments consisted of liquid manure, ammonium sulphate, calcium nitrate as nutrient sources and glucose as the sole experimental energy source; amendments were applied to a medium consisting of soil and soil amended with oat residues at a rate of 6000 kg ha^{-1} equivalent. Manure and nitrogen sources were added at 110 kg ha^{-1} equivalent and glucose was added at a rate equivalent to the total carbon added in the form of liquid manure. A control treatment was included with and without oat residue additions to quantify background soil respiration. Five replications of each factor combination were included in the experimental design.

Statistical analysis of the cumulative rate of CO_2 respiration from each treatment revealed that the application of oat residue resulted in higher CO_2 respiration rates than the associated non-residue amended treatments. CO_2 respiration was significantly

affected by nutrient amendment as followed the pattern glucose>manure>NH_4^+-N>Control>NO_3^--N.

Manure application to soils resulted in a greater rate of soil CO_2 respiration than ammonium or nitrate nitrogen amendments. Manure application did not induce CO_2 respiration to the same extent as the glucose amendment. Results from this study suggest that the microbial populations in these clay soils were limited by soluble carbon availability. The CO_2 respiration response to manure was likely influenced by an increase in soluble carbon, supplied by the manure, to be used for microbial metabolic processes.

6.2 Introduction

Data analysis for measurements of soil respiration rates in the field are often highly variable and difficult to interpret, consequently making conclusions concerning appropriate courses of action for agricultural producers equally difficult. Microcosm studies are a valuable alternative to field scale studies for acquiring detailed and less variable information on soil processes. The reduction in variability is due to the ability of researchers to control factors such as soil and atmosphere moisture and temperature, as well as using homogeneous soil samples to reduce the probability of including non-representative micro-site samples to represent a large land area.

Since the data collected in the field studies described in previous chapters was highly variable, a microcosm study was designed to provide more detailed data under controlled soil and atmosphere conditions on the effects of liquid manure application on the rate of oat residue decomposition.

Our hypothesis is that the nitrogen contained in the liquid manure amendment in this study would increase the rate of residue decomposition. However, the soluble carbon sources contained in liquid manure may also increase the rate of soil CO_2 evolution as well. Therefore the experiment was designed to include a glucose treatment applied at a concentration equal to that of the total carbon added as liquid hog manure. Inorganic sources of nitrate and ammonium nitrogen were also evaluated for their ability to induce residue mineralization, compared to the effect of manure nitrogen application.

6.3 Objective of the Study

The objective of the study was to evaluate the effect of liquid hog manure, nitrate and ammonium nitrogen and glucose application on the rate of oat residue decomposition in fine clay soils using a closed chamber microcosm where the environmental conditions could be controlled and held constant. The controlled environment and small-scale nature of the experiment also allowed for more detailed study of the effects of individual constituents contained in the manure on the soil respiration rates observed.

6.4 Materials and Methods

6.4.1 Experimental Design

The study was conducted using soil, liquid hog manure and oat residues collected the field study site near Fannystelle, Manitoba. For detailed soil characteristic information refer to section 4.4.1.

The study was designed as a 5x2 factorial experiment with liquid nutrient amendment and the oat crop residue amendment constituting the factorial experimental unit. Four nutrient amendments were applied with and without oat straw and a control soil with and without straw was included totaling ten treatments. Five water blanks were also included to determine background atmospheric CO_2 levels. The treatments applied were:

Soil Control (S)

Soil + Liquid Hog Manure (M)

Soil + Glucose (G)

Soil + Ammonium Sulphate (NH4)

Soil + Calcium Nitrate (NO3)

Soil + Oat Straw (R)

Soil + Oat Straw + Liquid Hog Manure (M_R)

Soil + Oat Straw + Glucose (M_R)

Soil + Oat Straw + Ammonium Sulphate (NH4_R)

Soil + Oat Straw + Calcium Nitrate (NO3_R)

6.4.2 Straw and Manure Sampling

Oat residues included the total aboveground biomass including standing stubble, threshed straw and chaff, collected from several $1m^2$ quadrats within a three hectare area. Straw collected from the quadrats was air-dried and massed to determine an average straw loading rate of 6000 kg ha^{-1} at the field site.

Manure samples were collected one week prior to use, and refrigerated until treatment application. A manure sub-sample was delivered to Norwest Labs, Winnipeg, for nitrogen and organic carbon content analysis.

6.4.3 Soil Processing and Analysis

Soil was dried and ground to pass a 2-mm sieve. Prior to the beginning of the study, soils were moistened to field capacity and incubated for 10 days at 23 °C and 55 %

relative humidity. Soil moisture was monitored and treatment application was conducted once the soil moisture content had decreased to 70 % field capacity. The incubation process was necessary to stimulate microbial activity prior to treatment application, as microbial community activity would have become stagnant during the soil drying and processing procedures.

6.4.4 Microcosm Apparatus

Microcosm apparatus consisted of 15 ml 1.0-M sodium hydroxide (NaOH) and 15 ml acidified water contained in 20-ml disposable scintillation vials and 30 grams of oven-dry equivalent soil in 125-ml glass jars in a 1.5-L mason jar. NaOH has a high affinity for CO_2 and will therefore trap CO_2 respired from the soils within the sealed microcosm atmosphere. Acidified water was included in the microcosm apparatus to maintain a humid atmosphere; the water was acidified to prevent bacterial growth. Five water microcosms were included in addition to the treatment microcosms, where NaOH traps were placed in microcosms containing only 20-ml scintillation vials containing 15-ml acidified water. These blank microcosms were used to determine the background atmospheric CO_2 concentration for each sampling date, which was subtracted from the CO_2 concentration in the treatment microcosms for each date.

6.4.5 Manure Application

Amendments were incorporated into 30 g of oven-dried equivalent soil and incubated in 125-ml jars. Nutrient amendments were applied in aqueous form in appropriate dilutions to assure that each soil mixture received the same volume of water at the time of treatment application. The total volume of nutrient amendment added was 3.03 ml for each treatment as this was the required volume of liquid manure required to achieve an application rate equivalent to 110 kg N ha^{-1}. This value was based on a sub-sample analysis from Norwest Labs, Winnipeg, to determine a manure ammonium nitrogen and total carbon content of 1.3 kg 1000 L^{-1} and 4.7 kg 1000 L^{-1}, respectively, in fresh manure collected on May 22, 2001.

6.4.6 Nitrogen, Glucose and Oat Straw Application

The inorganic nitrogen amendments, ammonium sulphate and calcium nitrate, consisted of 0.0188 g and 0.0328 g $(NH_4)_2 SO_4$ and $Ca(NO_3)_2$ in 3.03 ml deionized H_2O, respectively. The glucose amendment treatment was applied at the same rate as the total soluble carbon concentration in the liquid hog manure, therefore, the glucose amendment consisted of 0.0355 g $C_6H_{12}O_6$ added to 3.03 ml deionized H_2O. Control soils, both with and without oat straw additions, were amended with 3.03 ml deionized water to maintain uniform moisture content for all treatments.

Straw was air-dried and ground to 2 mm using a Wiley mill to facilitate residue amendment to the microcosm soil. Using a bulk density value of 1140 kg m^{-3} and a 0.75-m soil depth per hectare to determine the total soil mass to which 6000 kg of residue would be added in the field, a straw application rate of 0.211 g per 30 g oven-dry soil was used.

6.4.7 NaOH Trap Sampling Protocol

NaOH traps were changed at appropriate intervals to ensure that the atmosphere within the microcosms did not become oxygen limited. Initially, traps were changed daily and after one week of intensive sampling traps were sampled weekly. A total of 23 samples (trap changes) were collected over a 100-day period.

6.4.8 NaOH Sample Analysis

Total inorganic carbon contained in the NaOH traps was determined by colorimetric analysis after back titration with H_2SO_4, using a modified Technicon AutoAnalyzer II, Industrial Method No. 455-76W/A (1978). The average background atmospheric CO_2 concentration was determined from water blank microcosm NaOH traps for each sampling date and was subtracted from each treatment microcosm CO_2 yield value.

6.4.9 Soil Nitrogen Extraction and Analysis

For details on the soil nitrogen extraction procedure used refer to section 4.4.5.

6.4.10 Statistical Analysis

Analysis of variance was performed using the GLM procedure of the Statistical Analysis Software system (SAS Institute Inc. 2002) with residue application and amendment type analyzed as separate factors. Means of each factor were compared using Fisher's Least Significant Difference (LSD) when the F-value in ANOVA was significant ($P<0.05$). The slice option was used in the GLM to test the significance of amendment addition with and without oat residues. Contrast analysis in the GLM procedure was used to further evaluate the effects of amendment addition on cumulative CO_2 evolution and post-incubation soil nitrate and ammonium nitrogen concentrations.

6.5 Results and Discussion

Treatment factor mean values for cumulative carbon dioxide evolution, soil ammonium and nitrate nitrogen concentrations remaining after the incubation term was complete, and the results of statistical analysis are found in Table 6.1.

Table 6.1 Total release of CO_2 and inorganic soil nitrogen concentration.

	CO_2 (mg)	**NO_3^--N (mg kg soil^{-1})**	**NH_4^+-N (mg kg soil^{-1})**
Residue			
Soil	29.67a	35.06a	8.30
Soil +Residue	65.56b	26.24b	8.04
LSD	2.54	1.52	0.51
Amendment			
Control	42.87cd	16.57c	7.75b
Nitrate	40.26d	39.26b	7.71b
Ammonium	44.31c	39.15b	8.05b
Manure	51.86b	46.13a	8.30ab
Glucose	58.79a	12.15d	9.06a
LSD	4.02	2.41	0.80
CV (%)	9	9	11
		P-values	
Residue	<.0001	<.0001	0.3087
Amendment	<.0001	<.0001	0.0092

Table 6.2 Total release of CO_2 with and without residue addition.

	CO_2 Evolution (mg)		Slice Contrast P-value
Amendment	**Soil Only**	**Soil + Residue**	**Soil Only vs Soil + Residue**
Control	25.34c	60.40cd	<.0001
Nitrate	22.55c	57.96d	<.0001
Ammonium	23.64c	64.97bc	<.0001
Manure	34.62b	69.10ab	<.0001
Glucose	42.22a	75.36a	<.0001
LSD	4.70	6.99	
CV (%)	11.96	8.05	
P-value	<.0001	0.0004	

Table 6.3 Residue amended treatment contrasts for cumulative release of CO_2.

Contrast	P-value
Control vs Amendment	0.0226
Nitrogen vs Manure	0.0148
Manure vs Glucose	0.0727
Carbon sources vs Nitrogen sources	0.0002
Control vs Inorganic Nitrogen	0.7127
Control vs Nitrate	0.4703
Control vs Ammonium	0.1819
Control vs Manure	0.0159
Control vs Glucose	0.0002

6.5.1 Cumulative Carbon Dioxide Respiration

The decomposition curves for all treatments and the cumulative CO_2 evolution from each amendment treatment with and without residue addition are shown in Figures 6.1 and 6.2, respectively. Both the residue addition and amendment factors were found to have a significant effect on the total amount of CO_2 released during the incubation. P-values for various treatment contrasts are shown in Figure 6.3.

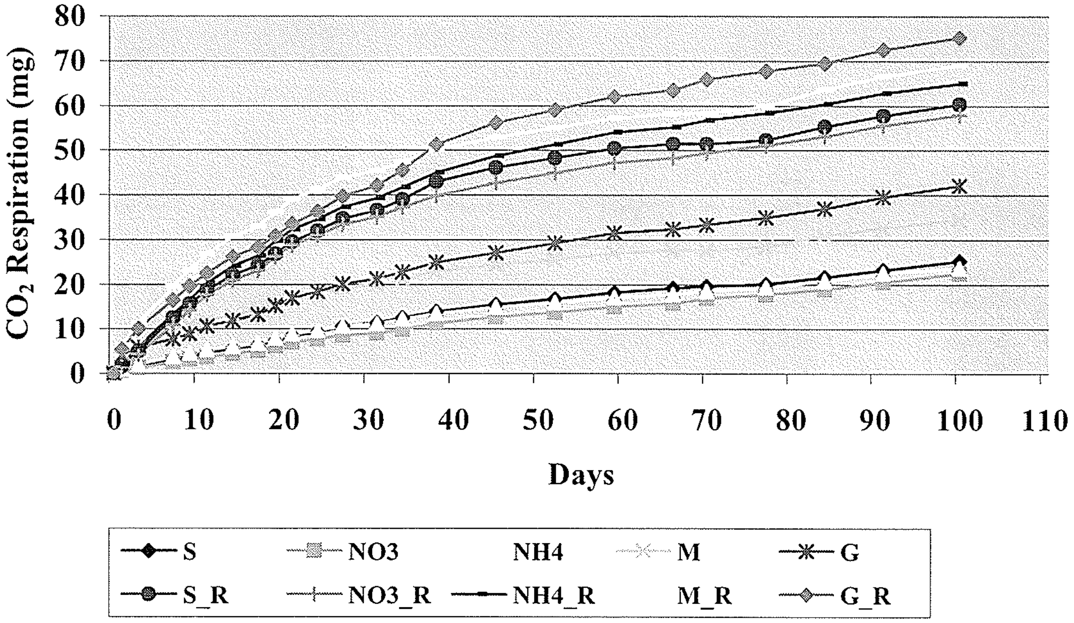

Figure 6.1 Carbon dioxide evolution curves.

The effect of amendment addition on CO$_2$ evolution was significant with and without residue addition, P-values 0.0004 and <.0001, respectively. Each amendment was tested individually for residue addition effects using the slice option in the GLM of SAS (Table 6.2). The increase in CO$_2$ evolution with residue addition reflects the metabolism of the added carbon source as an energy source for the soil microbial population.

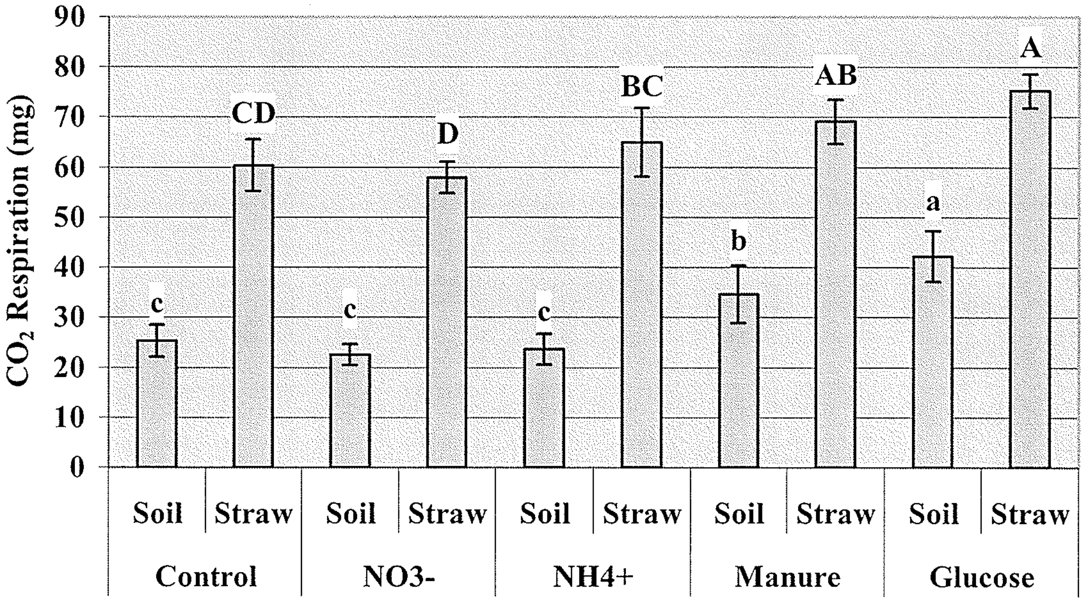

Figure 6.2 Amendment effect on CO_2 evolution with and without residue addition. Error bars are standard deviation about the treatment mean. Amendment treatments followed by different letters are statistically different ($P < 0.05$).

6.5.1.1 Nitrogen Amendment Effect

There was no significant difference in CO_2 evolution between the inorganic nitrogen treatments and the control soil in the non-residue amendment treatments indicating that microbial metabolism in the unammended soil was not nitrogen limited. Table 6.4 shows the carbon balance for each amendment minus the control treatment with and without added residue. In the residue amendment treatments the ammonium treatment resulted in a significant increase in CO_2 evolution over the nitrate treatment but was not different from the control while the nitrate treatment resulted in lower CO_2 evolution than the control. The slight net increase in CO_2 evolution from the ammonium treatment indicates that the microbial community may have been nitrogen limited (Table 6.4).

Table 6.4 Amendment effect minus control on total CO_2 respiration.

	CO_2 Increase (mg)	
Amendment	**Soil Only**	**Soil + Residue**
Nitrate	-2.75	-2.41
Ammonium	-1.63	4.59
Manure	9.35	8.73
Glucose	16.95	14.89

6.5.1.2 Manure and Glucose Amendment Effect

The glucose amended treatment exhibited the greatest rate of CO_2 evolution with and without residue addition and was significantly higher than all other treatments without residue but was statistically the same as the manure treatment and remained greater than all other treatments when residue was added. Manure application to non-residue amended soils resulted in a significant CO_2 evolution increase over the inorganic nitrogen and control treatments but was greater than the control and nitrate treatments, only, when residue was added.

To examine the effect of manure carbon addition on the rate of soil CO_2 evolution, a net carbon balance was calculated using a carbon input value of 14.24 mg total manure and glucose carbon. The resultant CO_2 release from the unammended and residue amended treatments were similar for the manure and glucose addition (Table 6.4). The amount of carbon released from the glucose treatment was equal to the glucose carbon added while the manure treatment released 66 % and 61 % of the manure carbon added, without and with oat residue addition, respectively. The glucose likely exhibited the greatest rate of CO_2 respiration due to mineralization of the readily available carbon contained in the amendment. The residue and non-residue amended manure treatments released similar amounts of CO_2 indicating a lesser availability of the manure carbon compared to the glucose carbon. Based on these results, approximately 60-65 % of the manure carbon from the manure used in this study was readily available for microbial metabolism. Manure carbon may not be expected to evolve the same amount of CO_2 as the glucose amendment because at least a portion of the carbon in manure would be tied up in complex and less bioavailable organic molecules.

The smaller release of CO_2 from the manure treatment compared to the glucose treatment suggests that inorganic nitrogen availability was not limiting the growth and metabolism of the soil microbial community, as manure is a source of both carbon and nitrogen. These results concur with those of Knapp et al. (1983), who suggested that the decomposition of crop residues added to soils is often more limiting in available, high quality carbon than in available nitrogen. Contrast analysis of the residue-amended treatments supported this observation where the carbon containing treatments, manure and glucose, released a significantly greater amount of CO_2 than the nitrogen only treatments, nitrate and ammonium (Table 6.3).

The lack of a positive CO_2 evolution response to inorganic nitrogen addition and the increase in CO_2 release from carbon amended treatments (manure and glucose) agrees with results reported by Knapp et a. (1983). If the system had been nitrogen limited, the response to nitrogen only treatments would have been greater. Therefore, the respiration increase in the manure and glucose treatments can be attributed to carbon additions to the soil system, indicating a carbon as opposed to a nitrogen limiting environment within the microcosm soils.

6.5.2 Soil Nitrogen Status

The soil nitrogen status of the microcosm soils was determined after the termination of the experiment to quantify the differences in inorganic nitrogen supply to the microbial communities in each amendment treatment. The residue and amendment additions had a significant effect on nitrate nitrogen concentration and amendment was significant for ammonium nitrogen, only (Table 6.1).

The addition of oat residue lowered the concentration of nitrate nitrogen probably due to immobilization. The soil-only treatments, with no residue added, retained a higher fraction of the added nitrogen in the inorganic form but exhibited a slower CO_2 respiration rate compared to the residue-amended treatments.

The application of the various amendments resulted in significantly higher concentrations of nitrate and ammonium nitrogen. The manure treatment resulted in a significantly greater concentration of nitrate than all other treatments. The two inorganic nitrogen treatments were not different from each other but had significantly greater concentrations of nitrate than the control and glucose treatments. The lower nitrate concentration in the glucose treatment compared to the control soil indicates that the microbial population was effective in immobilizing the soil nitrogen that was already present or that was mineralized over the course of the experiment.

Ammonium concentrations did not vary significantly in any of the treatments. However, the glucose amendment had a significantly greater concentration of ammonium than the two inorganic nitrogen and the control treatments.

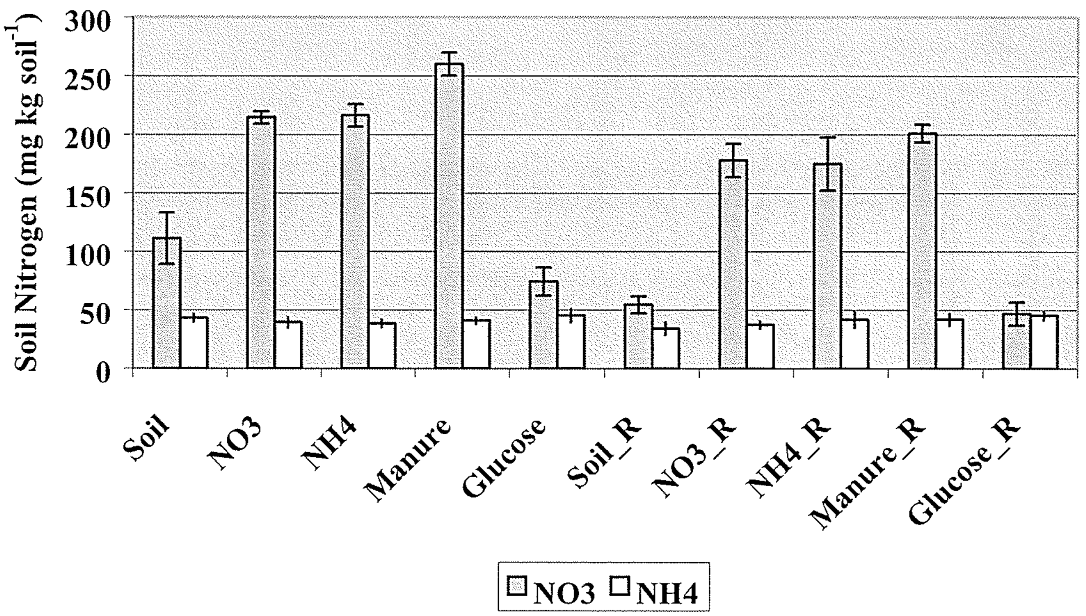

Figure 6.3 Inorganic soil nitrogen remaining post-incubation. Error bars are standard deviation about the treatment mean.

The lack of CO_2 respiration response to added inorganic nitrogen is not uncommon and has been reported by others. Knapp et al. (1983) found an initial CO_2 respiration response to added nitrogen in the first 60 hours of experimentation but found a lack of response to added nitrogen 240 hours into the experiment, suggesting that a significant proportion of the soluble carbon had already been utilized within the initial ten days of incubation. The initial nitrogen addition in this experiment was sufficient to lower the C:N ratio of the soil and wheat straw mixture to 48:1.

One of the factors contributing to the lack of response to added nitrogen in this study may have been the relatively low C:N ratio of 48 to 1 for the oat residue added; cereal residues are typically reported to have a C:N ratio of 80-90. A C:N ratio of 20-30 is generally reported to be the point where the products of mineralization and immobilization reactions are balanced, below this C:N ratio, mineralization reactions dominate, and above this value, immobilization dominates until the quantity of CO_2 released is sufficient to reduce the C:N ratio to where mineralization is favored. The low residue C:N ratio means that less additional nitrogen, beyond that supplied by the residue, would be required to stimulate decomposition compared to higher C:N ratio residues. There was a slight increase in CO_2 release when ammonium nitrogen alone was added to the residue amended soil but the increase was not significant, overall, the soil microbial population was found not to be limited by nitrogen availability.

6.6 Summary and Conclusions

This study was designed to evaluate the effectiveness of liquid hog manure to accelerate oat residue decomposition in clay soils under controlled environmental conditions. The findings of this study suggest that the decomposition of crop residues produced in the clay dominated soil regions of Southern Manitoba may not be limited by soil nitrogen availability. Rather it is the quality of the residues, or the proportion of soluble carbon material present, which limit the rate at which oat crop residues can be metabolized by soil microbes.

Results of this experiment showed that the addition of a glucose carbon source to oat residue amended soils resulted in a greater increase in CO_2 evolution rate than the addition of liquid hog manure or nitrate or ammonium as inorganic nitrogen sources. The manure amendment provided a greater rate of CO_2 respiration than the two inorganic nitrogen amended treatments, suggesting that increased respiration of manure treated soil was due to factors other than the addition of manure nitrogen. The carbon added in the manure may have provided the respiration increase by supplying a readily metabolizable energy source for soil microbes. This conclusion is supported by the increase in respiration observed from the glucose amended treatments to which no additional nitrogen was added beyond that supplied by the soil itself. A net carbon balance for the glucose and manure treatments showed that the increase in CO_2 released compared to the residue amended control treatment was equal to 100 % and 61 % of the glucose and manure carbon added, respectively.

In conclusion, the addition of liquid hog manure increased the rate of CO_2 respiration from microcosm soils. However, the application of a soluble carbon source without additional nitrogen addition increased soil respiration relative to manure application, suggesting that the increase in soil respiration is attributable to the addition of manure carbon, not manure nitrogen. Based on these data, the application of liquid hog manure to clay soils may stimulate the rate of soil respiration by supplying a source of carbon to the microbial community, but has a limited ability to increase the rate of oat residue decomposition under optimally controlled soil moisture and temperature laboratory conditions. Data reported in chapter 3 suggest that this is not that case however, as a significant increase in the rate of residue mass loss was observed when soils were amended with liquid manure.

Based on the results of these two studies, an increase in the rate of oat residue decomposition may be expected when soil is amended with liquid hog manure, due to an overall increase in the rate of soil microbial activity induced by liquid manure carbon application.

7. A MICROCOSM STUDY TO EVALUATE THE EFFECT OF LIQUID HOG MANURE APPLICATION RATE, OAT RESIDUE PARTICLE SIZE AND RESIDUE PLACEMENT IN CLAY SOIL ON OAT RESIDUE DECOMPOSITION

7.1 Abstract

It was thought that the application of liquid hog manure to clay soils might increase the rate of oat residue decomposition, which is typically added in large quantities, as the growing conditions in southern Manitoba are conducive to cereal biomass production. A microcosm study was designed to evaluate the effect of manure application rates greater than 110 kg manure N ha^{-1}, oat residue particle size and placement relative to the soil surface on the rate of oat residue decomposition.

The experiment included four application rate treatments of 0, 1x, 2x and 3x a typical application rate of 100 kg manure nitrogen ha^{-1}, two oat residue particle sizes, ground and whole, and surface placed and buried residues arranged in a 4x2x2 factorial design. Each factor was analyzed for the effect on soil respiration measured as total CO_2 released during the incubation period.

Manure application rate and residue particle size had a significant effect on soil CO_2 respiration. Manure application rates produced the following pattern of cumulative CO_2 respiration: 2x > 3x > 1x > 0x. Whole residue treatments exhibited a greater CO_2 respiration rate than ground residues.

In this study, increasing manure application rates increased soil respiration up to the 2x rate. Total CO_2 respiration from the 3x rate treatment was slightly lower than the 2x rate, possibly due to the microbial population reaching maximum growth and specific activity at the 2x application rate. Surface placed residues had greater cumulative CO_2 respiration rate than buried residues and was attributed to soil surface fungal colonies releasing more CO_2 than the microbial communities colonizing buried oat residues. CO_2 respiration was not significantly affected by oat residue particle size.

7.2 Introduction

This microcosm experiment was designed to investigate the effects of manure application rate, oat residue particle size and residue placement relative to the soil surface on the rate of oat residue decomposition

In the previous microcosm study a significant, positive effect of manure application to a mixture of clay soil and oat residues on the CO_2 respiration rate was observed and was attributed to increased microbial activity responding to manure carbon additions to the system. Due to the heavy application rate of oat straw employed in the study (6000 kg ha^{-1}), it was thought that increasing manure application rates may result in a concurrent increase in the rate of residue decomposition. The potential immobilization of much of the applied manure nitrogen in the presence of the abundant crop residues may reduce the ability of soil microbes to decompose added residues.

Studies that have evaluated the effect of residue placement on the decomposition rate of the residues generally report an increase in the decomposition rate of buried as opposed to surface placed residues. Similarly, ground residues are often, reported to be decomposed more quickly than whole residues. Both factors can be paralleled to the field study described in Chapter 4. The surface and buried residue placement treatments can be compared to the use of low-intensity zero tillage and medium intensity chisel based tillage systems in clay soils, respectively.

Harvest management can affect oat residue particle size and thus residue decomposition in several ways. First, rotary combine harvesters tend to produce a more finely ground straw than harvesters using conventional separation technology; and second, straw which is first chopped in lieu of simply being spread tends to consist of a smaller particle size.

This study was completed to further examine several questions that could not be addressed in the field study. To avoid the over-application of manure nitrogen and conserve the environmental integrity of the field site, the field scale study was confined to one application rate of 100 kg ha^{-1} manure nitrogen and only one particle size was used in the field study due to limitations in residue management equipment options. Also, the effect of grinding residues in the microcosm study described in Chapter 6 was thought to be potentially overestimating the rate of residue decomposition that might be observed under field conditions. These factors required additional attention and the microcosm study provided an opportunity to evaluate them in controlled and less variable soil moisture and temperature conditions than would be expected under field conditions.

7.3 Objective of the Study

The objective of this study was to evaluate the effect of manure application rate, oat residue placement and residue particle size on the rate of oat residue decomposition. Residues were buried or surface placed at each manure application rate; residues were also ground or left intact at each application rate and placement combination.

7.4 Materials and Methods

7.4.1 Experimental Design

The study was conducted using soil, liquid hog manure and oat residues collected the field study site near Fannystelle, Manitoba. For detailed soil characteristic information refer to section 4.4.

The study was designed as a 4x2x2 factorial experiment with manure application rate, oat straw particle size and oat residue placement as main factors. The experimental design consisted of 16 treatments with five replications of each. Each of the four rates of liquid hog manure was applied to soils that received residue either incorporated into or placed on the soil surface and each placement factor was applied with whole or ground residues as separate treatments.

7.4.2 Straw and Manure Sampling

Procedures for straw and manure sampling can be found in section 6.4.2.

7.4.3 Soil Processing and Analysis

Procedures for soil processing and analysis can be found in section 6.4.3.

7.4.4 Microcosm Apparatus

Details on the microcosm apparatus used can be found in section 6.4.4.

7.4.5 Oat Residue and Liquid Hog Manure Amendments

Four rates of liquid manure were applied to the incubated soils to represent a field application rate of 0, 100, 200 and 300 kg N ha^{-1} as NH_4^+-N. These treatments were chosen to simulate a typical manure nitrogen application rate of 100 kg N ha^{-1}, as well as a 2x and 3x rate and a control treatment receiving no manure. Deionized water was added where required to equalize the amount of water added to all treatments.

Oat straw was added immediately after the liquid manure amendments, at 0.211 g per 125-ml jar, equivalent to a field application rate of 6000 kg ha^{-1}. The residue particle size factor was applied using residue that was either ground through a 2-mm screen using a Wiley mill or hand cut into 2 cm lengths for the ground and whole residue treatments, respectively. The residue placement factor was applied by placing oat residues on the surface of pre-mixed, manure amended soil or incorporating residues into manure amended soil, for the surface and buried treatments, respectively.

7.4.6 NaOH Trap Sampling Protocol

All treatment amendments were made within a 90-min period and NaOH CO_2 traps were placed in the microcosms immediately following treatment application. Thereafter, traps were changed each day for two days, every two days for 6 sampling periods, and approximately every four days for seven samples, weekly for 7 samples and biweekly for 6 samples for a total of 29 sampling events.

7.4.7 NaOH Sample Analysis

Procedures for NaOH sample analysis can be found in section 6.4.8.

7.4.8 Statistical Analysis

Analysis of variance was performed using the GLM procedure of the Statistical Analysis Software system (SAS Institute Inc. 2002) with application rate, residue placement and particle size analyzed as separate factors. Means of each factor were compared using Fisher's Least Significant Difference (LSD) when the F-value in ANOVA was significant ($P<0.05$). The slice option was used in the GLM to test residue placement and particle size factors for each manure application rate.

7.5 Results and Discussion

Table 7.1 Total release of CO_2 and inorganic soil nitrogen concentration.

	CO_2 (mg)	**NO_3^- (mg kg soil^{-1})**	**NH_4^+ (mg kg soil^{-1})**
Manure Application Rate			
0x	39.78c	76.92d	93.91c
1x	48.20b	189.83c	89.71c
2x	56.13a	285.00b	108.38b
3x	54.16a	383.77a	119.14a
LSD	4.80	14.28	5.81
Residue Placement			
Surface	48.65	241.15a	101.41
Buried	50.50	226.62b	104.16
LSD		10.10	
Residue Particle Size			
Whole	52.87a	239.13a	100.78
Ground	46.27b	228.63b	104.79
LSD	3.13	9.93	
CV (%)	9.89	9.33	7.87
	P-values		
Application Rate	<.0001	<.0001	<.0001
Residue Placement	0.11	0.0056	0.19
Residue Particle Size	0.0002	0.042	0.056

7.5.1 Cumulative Carbon Dioxide Respiration

Figure 7.1 shows the total cumulative CO_2 respiration values for all factorial treatment combinations.

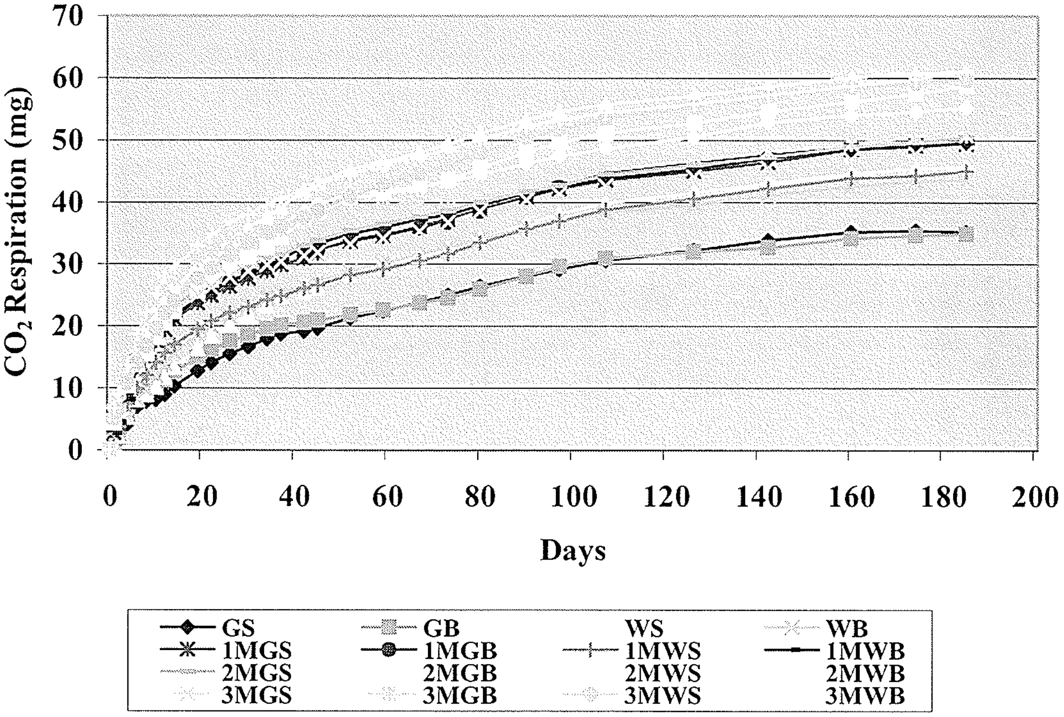

Figure 7.1 CO_2 Respiration curves for all treatments.

7.5.1.1 Manure Effects

The effects of manure application on cumulative CO_2 respiration can be seen in Figure 7.2. There was a highly significant effect of the rate of manure application on CO_2 respiration (P-value <0.0001). The average of all residue treatments for each manure application rate are used. The zero manure treatment yielded the lowest cumulative CO_2 respiration followed by the 1x rate, which was significantly different from the zero treatment. The 2x and 3x rate treatments did not differ significantly but evolved a significantly greater amount of CO_2 than the control and 1x rate treatments.

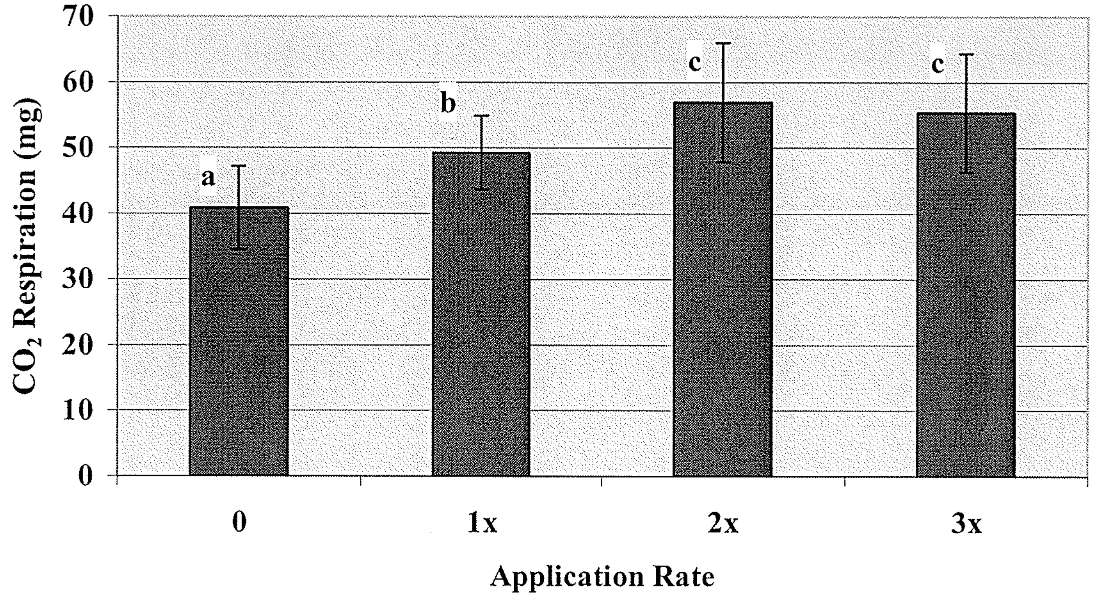

Figure 7.2 Manure application rate and cumulative CO_2 respiration. Error bars are standard deviation about the mean for application rate. Application rates followed by different letters are statistically different ($P < 0.05$).

The rate of soil microbial respiration observed in the zero manure treatment was significantly less than the three manure-amended treatments. The 1x application rate provided a 19 % increase in respiration over the control soil and the 2x and 3x rate treatments provided a 29 % and 26 % increase, respectively. The total manure carbon added was 5.91, 11.83 and 17.74 mg for the 1x, 2x and 3x rate treatments, respectively, therefore, assuming that all of the manure carbon was metabolized during the incubation period, manure carbon accounted for 62, 72 and 123% of the increase in CO_2 from the 1x, 2x and 3x manure application rate treatments, respectively. The net manure carbon balance in the 1x and 2x application rates treatments are similar to the values reported in Chapter 6 for the manure-amended treatment. These results suggest that 60-70% of the manure carbon added to the soil is readily available for microbial metabolism.

The increase in soil respiration with increasing manure application was consistent up to the 3x rate. The similar manure carbon input:output values for the 1x and 2x rates of 62 and 72 %, respectively, suggest that the effect of manure carbon was similar between the two treatments. The additional 38 and 28 % increase in CO_2 evolution over the zero manure treatment may have been due to an increased availability of substrate to the soil microbial community. The influence of additional manure application above the 1x rate was slightly less than the effect of the 1x rate of manure.

The reason for the convergence of the cumulative CO_2 values for the 2x and 3x treatments is unknown but may have indicated the point at which the maximum rate of soil microbial activity in the microcosm soil was reached. The carbon balance value, 124 % of respiration being attributed to manure carbon, suggests that the soil microbial community was unable to metabolize additional manure carbon beyond what was added in the 2x application rate treatment.

If is assumed that additional increases in CO_2 evolution, beyond that induced by manure carbon addition, is due to manure nitrogen, then the effect of an application rate greater than the 1x will provide less of an increase in carbon metabolism than the 1x rate. The high soil nitrate concentrations that resulted from 2x and 3x application rates are undesirable due to the potential for nitrate leaching and losses of nitrogen due to denitrification under field conditions. Therefore, the application of liquid manure beyond the recommended 1x rate should be avoided, as little additional affect on residue decomposition is likely and the potential for environmental nitrogen contamination and decreased nitrogen use efficiency is increased.

7.5.1.2 Residue Placement Effects

There was no significant difference in CO_2 respiration from the surface and buried cereal residue treatments for any of the manure application rates. P-values for sliced placement analysis for each application rate are found in Figure 7.5. The mean cumulative CO_2 evolution from each residue placement treatment is shown in Table 7.1.

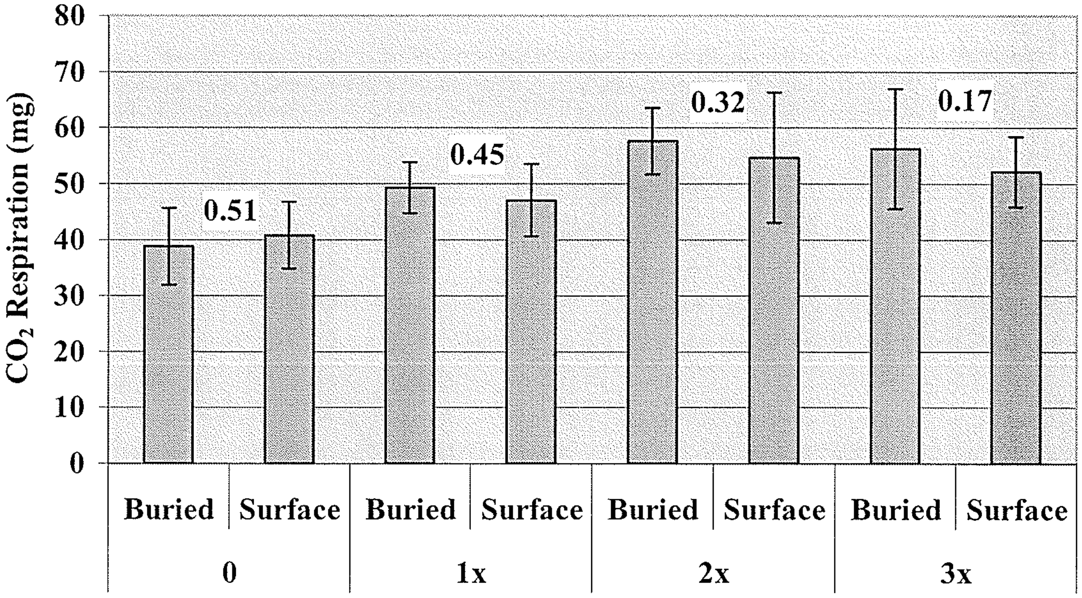

Figure 7.3 Residue placement effect on CO_2 respiration. Error bars are standard deviation about the factor mean within manure application rate. Displayed P-values are comparisons between placements at each application rate.

Numerous studies have been conducted to examine the relationship between crop residue placement relative to the soil surface and the resultant rate of decomposition that ensues. Cogle et al. (1989) found that incorporating wheat straw resulted in a greater CO_2 evolution rate compared to surface applied residues only up to 25 days of incubation, at which time the CO_2 respiration rates converged for the remainder of the 35-day experiment. Christenson (1986) found the barley straw decomposed more quickly than surface applied straw. Schomberg et al. (1994) found the same result for a host of different crop residues and Parker (1962) the same result for corn stalk residues.

Holland and Coleman (1987) reported differences in CO_2 respiration, biomass accumulation and biomass composition for surface placed and buried wheat residue treatments under zero tillage and moldboard plow tillage systems. The authors reported that crop residue incorporation resulted in increased CO_2 evolution, a lower proportion of fungal biomass in lieu of bacterial biomass and increased concentrations of inorganic nitrogen. These results were attributed to the lower resource carbon assimilation efficiency of bacteria compared to fungi, a more favorable environment for bacterial growth within the soil and an increase in mineralization of residue nitrogen. Adu and Oades (1987) suggest that surface residues will tend to be colonized more efficiently by fungi as they are able to adapt more readily to changes in climate compared to bacteria, which would be characteristic of the soil surface environment. Fungal hyphae are also better able to access soil nitrogen through hyphal extension onto the soil surface when colonizing surface residues whereas bacterial colonies have a limited ability to scavenge for inorganic nitrogen which is not in the general vicinity of growth.

Throughout the incubation study period, we observed that the surface placed residue treatments had abundant fungal hyphae growth on the residues compared to the incorporated residues. Aulakh et al. (1991) reported an increase in cumulative CO_2 respiration from surface placed wheat residues, due to the colonization of the residues by epiphytic fungi.

The lack of CO_2 evolution rate response to residue placement was probably a result of the micro-scale nature of the experiment. In most studies designed to evaluate this relationship larger quantities of soil, and subsequently residues, are used, allowing for a more realistic application of treatment variables than was achieved here. In this study, where 211 mg of residue was added to 30 g of soil, which tended to be composed of mostly clods with a few small aggregates, it was difficult to simulate surface and buried residue treatments that could be considered realistic for field conditions. The soil was difficult to manage and the large amount of residue added to simulate a field scale loading rate of 6000 kg ha^{-1} resulted in a somewhat non-uniform substrate mixture.

7.5.1.3 Residue Particle Size Effects

Whole residues released a significantly greater amount of CO_2 than ground residues for the 0, 2x and 3x manure application rate treatments. Residue placement was not significant in the 1x manure application rate treatments. P-values for the sliced analysis of residue particle size at each manure application rate are shown in Figure 7.6.

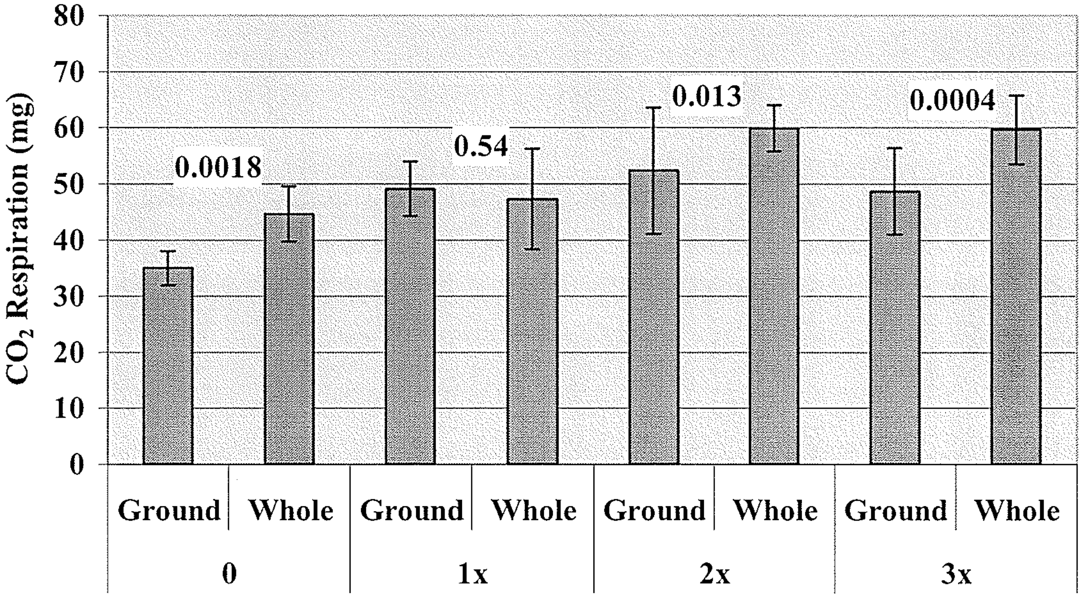

Figure 7.4 Residue particle size effect on CO_2 respiration. Error bars are standard deviation about the mean for particle sizes within application rate. P-values are presented for comparisons between particle sizes at each application rate.

Jensen (1994) also reported greater CO_2 evolution from whole compared to ground residues and stated that residue size could have affected CO_2 respiration in several ways. Smaller sized particles may be more susceptible to microbial attack due to the larger surface area exposed to microbial inoculum compared to whole residues. However, the larger surface area also makes ground residues more prone to a rapid reduction in residue quality and increases the potential for residue to become adsorbed to the surface of soil particles, rendering them less available for microbial metabolic processes. Whole residues may also provide a more aerobic environment for microbial activity and thus result in a greater rate of decomposition.

Broder and Wagner (1988) reported that populations of decomposing organisms that degrade more complex organic materials increase slowly and contribute to overall CO_2

respiration later in an incubation term, compared to species capable of rapid proliferation that rapidly metabolize highly soluble portions of the added material. We observed the same dynamic as the curves for the ground and whole residues were similar until around day-20 of the incubation, at which time the whole residue treatments began to evolve CO_2 at a faster rate than the ground treatments suggesting that carbon availability to the rapidly multiplying bacterial population was diminished after day-20 of the incubation period.

7.5.2 Soil Nitrogen Status

Nitrate concentrations were significantly lower for buried residue treatments than for surface placed treatments, while ammonium concentrations were not affected. The greater use of soil nitrogen by buried residues was not accompanied with an increase in CO_2 respiration, but may have resulted in an increase in organic nitrogen contained in the microbial biomass. This in not in agreement with results from a study by Holland and Coleman (1987) who demonstrated increased immobilization of soil nitrogen with surface applied wheat residues, compared to incorporated residues, and an increase in microbial nitrogen cycling efficiency with surface placed residues as well.

Nitrate concentrations were not affected by oat residue particle size but ammonium concentration was found to be greater for ground residues compared to whole residues. This suggests an increased rate of nitrogen use by fungal communities that likely colonized whole residues while ground residues would have been metabolized mainly by bacterial species. Fungal hyphae may have been better at exploring microcosm soils to obtain inorganic nitrogen for metabolic purposes, resulting in a net decrease in the ammonium nitrogen concentration after the incubation period.

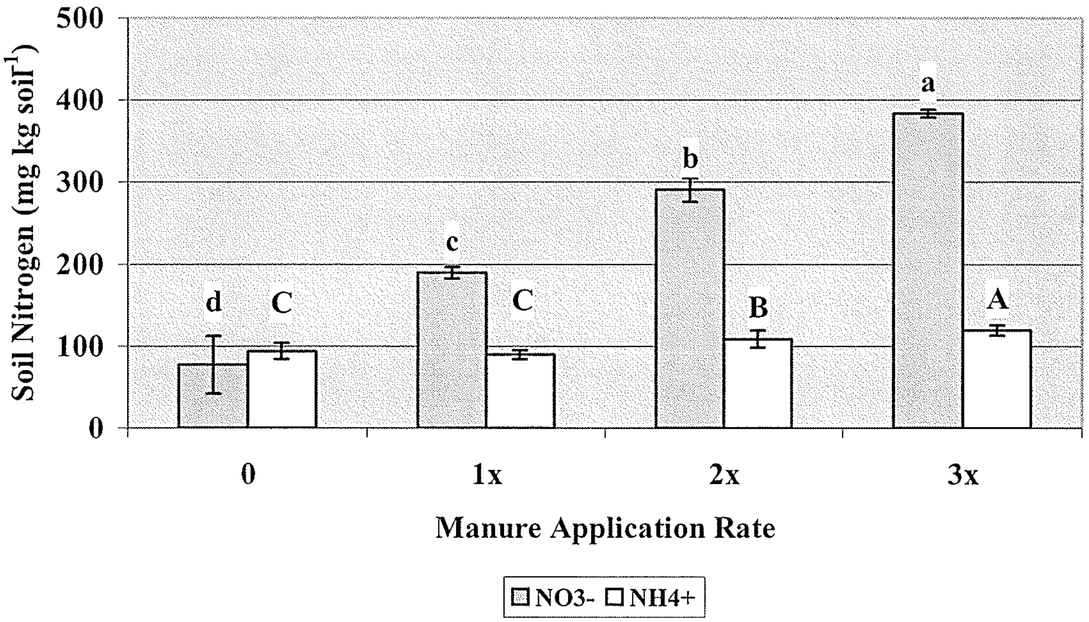

Figure 7.5 Inorganic soil nitrogen remaining post experiment termination. Error bars are standard deviation about the mean for all treatments within application rate. Application rates followed by different lower case and upper case letters are statistically different for soil nitrate and ammonium concentrations, respectively ($P < 0.05$).

7.6 Summary and Conclusions

The maximum rate of CO_2 evolution was achieved at the 2x manure application rate. This was a significant increase over the 1x rate, however the 3x rate provided no significant increase compared to the 2x rate and had a slight, yet non-significant negative effect on cumulative CO_2 respiration. From this data it may be concluded that a 100 kg ha^{-1} manure nitrogen equivalent application rate is not sufficient to maximize the rate of residue decomposition in this clay soil when amended with excessive quantities of oat crop residues.

The effect of the addition of increasing amounts of soluble carbon with the hog manure, as naturally occurring organic molecules, with increasing rates of manure application was not evaluated in this study. However, the effect of rapid mineralization of this carbon source should not be discounted and although it was not quantified, results from the microcosm study reported in Chapter 6 indicate that manure carbon addition may have induced the greater rate of CO_2 respiration observed in this study.

The nitrogen contained in anaerobically stored liquid animal manures is comprised mostly of ammonium ions with small concentrations of nitrate and organic-N contained in the organic portion, therefore, roughly 300 kg ha^{-1} ammonium nitrogen was applied with the highest manure rate treatment. This heavily nitrogen enriched environment may have been less than optimum for microbial growth and metabolism, resulting in a decreased rate of CO_2 respiration in the 3x application rate treatment. Ammonia nitrogen is known be toxic to crop plants and many soil fauna species at high concentrations (Olson and Kurtz 1982). A short communication study reported that the application of calcium nitrate as a nitrate source to microcosms resulted in decreased production of volatile fatty acid and phenolic compounds which are produced during the early stages of crop residue decomposition suggesting that high nitrate concentrations may lead to decreased microbial activity (Farquharson et al. 1990).

Most studies that report on the effect of residue placement relative to the soil surface have determined that incorporated crop residues exhibit a more rapid rate of decomposition compared to surface placed residues. The effect of residue placement was not significant in this study although buried residue treatments did have a slightly higher rate of CO_2 evolution compared to the surface placed residues. There was a significantly greater reduction in soil nitrate concentration for the buried residues as well suggesting a greater use of carbon for which greater amounts of inorganic nitrogen would be required to maintain microbial metabolism and community growth.

The high level of carbon assimilation efficiency exhibited by fungi, 40-70 %, Harley (1971) relative to bacteria, 30-40 %, Elliott et al. (1983), may have resulted in more of the added oat residues being metabolized in the surface placed treatments. Decomposition of crop residues by fungal species may therefore, increase the organic matter storage capabilities of agricultural soils and result in greater nutrient cycling efficiency, but likely will not increase the rate of oat residue decomposition.

Although it was hypothesized that a smaller residue particle size would exhibit a greater decomposition rate, the whole residue treatments yielded a significantly greater amount of total CO_2 evolution. This may have been due in part to the ability of these soils to bind and hold organic matter, thus providing physical protection from microbial attack. The surface area of the ground residues susceptible to microbial attack is greater for ground than for whole residues, but also provides more area for adhesion to clay particles and subsequent protection from soil microbes. In addition to the physical protection of the ground residues, there was likely a difference in the community structure associated with the two residue placements similar to the buried and surface placed residues. Whole residues were likely colonized predominately by fungal species more capable of exploring the soil matrix and extracting inorganic soil nitrogen for metabolic use than the bacterial populations, which likely were the species mainly responsible for metabolism of the ground residues. There was a significant difference in the amount of ammonium nitrogen remaining in the microcosm soils at the end of the incubation period. The whole residue treatments showed a lower ammonium concentration relative to the ground residues, indicating the there was either a greater use of soil nitrogen associated with the increase in CO_2 respiration from the whole residue treatments, or a greater rate of gaseous nitrogen loss.

In conclusion, of the three factors examined in this microcosm study, manure application rate, oat residue placement and residue particle size, manure rate and particle size had a significant effect the total amount of soil CO_2 evolved during the incubation period. As the rate of liquid hog manure application increased in three equal increments from 0 to 3x the recommended rate (100 kg N NH_4^+-N ha^{-1}), so did the rate of CO_2 respiration up to the 2x rate. No significant difference was found between the 2x and 3x application rates, and the 3x rate had a slight inhibitory effect on CO_2 evolution. A manure carbon input:output balance was calculated for each manure application rate. Assuming 100 % utilization, manure carbon addition accounted for 62, 72 and 124 % of the total carbon respired for the 1x, 2x and 3x application rates, respectively. The CO_2 evolution response to the 2x and 3x rates were less than the 1x rate. 38 and 28 % of the increase in evolved CO_2 from the 1x and 2x rate treatments could be attributed to factors other than manure carbon addition and may have indicated a response to manure nitrogen application. Based on these results, the recommended manure nitrogen application rate of 100 kg manure N ha^{-1} should not be exceeded in an attempt to increase the rate of crop residue decomposition, due to the high concentrations of soil nitrate which may result and the increased potential for environmental nitrogen contamination.

Buried crop residues were metabolized slightly more rapidly than surface placed residues although this observation was not great enough to be statistically significant. Oat residue particle size had a significant effect on the rate of decomposition in this study, where whole residues exhibited a greater rate of CO_2 respiration compared to the ground residue treatment. This was likely due to the large surface area of the ground residues allowing for rapid adsorption to soil aggregates rendering them unavailable for microbial colonization. The decomposition species colonizing the whole residues likely consisted mostly of fungi as opposed to bacteria in the ground residues. Fungi are better able to scavenge for soil nitrogen sources which may be inaccessible to soil bacteria, resulting in a greater rate of decomposition for the whole residues colonized by fungal communities.

8. GENERAL DISCUSSION

8.1 Liquid hog manure and cereal residue decomposition

A suite of studies was designed to evaluate the effects of liquid hog manure application to clay soil on the rate of cereal crop residue decomposition. Crop residues left on the soil surface are desirable to reduce the incidence wind and water erosion. However, the conditions that exist in the Red River Valley of Manitoba necessitate the use of specific crop residue management practices as the high moisture holding capacity of the soil and the abundant rainfall received in the area (approximately 500 mm annual precipitation) can result in excessively moist soil conditions throughout much of the spring seeding period. The growing conditions are also conducive to the production of large quantities of cereal crop biomass. Due to the moist soil conditions, which are exacerbated by the presence of these crop residues, post-harvest straw burning is commonly used for crop residue management. The predominance of this practice has prompted a detailed analysis of manure application effects on cereal decomposition rates.

Previous studies conducted on the rate of CO_2 evolution from soil after manure application have focused primarily on the rate of manure carbon and nitrogen mineralization, and the subsequent effects on soil microbial biomass, specific activity, soil nitrogen immobilization and soil CO_2 respiration induced by the application of manure carbon.

The fall application of liquid hog manure was shown, overall, in this study to increase the rate of soil CO_2 evolution compared to the non-amended treatments. This was not only the case during the fall sampling period following application but also during the following spring. Similar studies have shown such increases in CO_2 respiration, but have concluded that the increase was due to the mineralization of manure-applied carbon sources using hog slurry (Rochette et al. 2000), solid feedlot manure (Fraser et al. 1988), solid dairy manure (Rochette and Gregorich 1998) and, anaerobically stored hog slurry (Bernal and Kirchmann 1992), among others. Studies that have observed CO_2 respiration increases from hog manure application generally report a high initial rate of respiration attributed to the mineralization of highly soluble carbon sources in the manure such as volatile fatty acids, followed by a less rapid mineralization of other soluble manure carbon. Paul and Beauchamp (1989) reported that soil CO_2 respiration rates, during the first 24-48 hours of incubation, reflected the amount of volatile fatty acids and water soluble carbon contained in the manure.

Results from this study show that the increase in respiration induced by manure application was sustained throughout the fall post-application period and also throughout the following spring sampling period, suggesting that the increase was, at least in part, due to the mineralization of sources of carbon other than that added with the manure, which, according to other authors would have been mineralized within the first couple of weeks. This was reported by Saviozzi et al. (1997) who evaluated the CO_2 respiration rate of soils receiving both manure and wheat straw, together and separately. The greatest amount of cumulative CO_2 respiration was observed when the manure and straw were added simultaneously, as opposed to manure or straw alone, suggesting an additive effect when manure and straw are added together. Results from the initial microcosm study described in Chapter 6 did not support these findings, however, as the increases in CO_2 evolution due to manure application, with and without straw addition, were similar. The same result was observed with glucose application with and without residue addition, suggesting that the systems were not nitrogen limited and the increase in CO_2 evolution was due to the application of manure and glucose carbon only.

Results from the initial growth cabinet litterbag study indicated that the application of liquid manure to soils and the incorporation of crop residues into the soil system will increase the rate at which oat crop residues are decomposed. The suite of other experiments reported were not able to fully distinguish between the effects of manure carbon and nitrogen addition, and used soil CO_2 respiration as an indicator of residue decomposition, but did not measure decomposition directly. Results from the litterbag, which did measure residue mass loss directly, suggest that manure application to clay soils will in fact increase the rate at which oat crop residues are decomposed.

Results from the second microcosm experiment of this study show that total CO_2 evolution was increased with the 2x manure application rate over that observed for the 1x rate equal to 100 kg NH_4^+-N ha^{-1}, but was not increased with the 3x application rate. The increase from 0 to the 1x rate was greater than the increase from the 1x to the 2x rate. Rochette at al. (2000) reported a linear increase in CO_2 respiration from 0, 1x and 2x rates of hog manure application to soils.

Gregorich et al. (1998) reported that under field conditions, factors other than the soluble organic carbon content of the amendment were affecting the soil respiration rate. The smaller increase in CO_2 evolution from the 2x as opposed to the 1x application rate in the second microcosm study may indicate that there was an effect of manure nitrogen application. The lack of a further increase in total CO_2 evolution from the 3x application rate could be attributed to a maximum microbial population being reached and an inability to metabolize addition carbon beyond that added in the 2x application rate treatments.

The field study revealed significantly greater amounts of N_2O production from the manured compared to the non-amended treatments for a large proportion of the sampling dates, regardless of the sampling period (fall or spring). N_2O flux from soils requires both nitrate and a source of soluble carbon for anaerobic microbial respiration. Lessard et al. (1996) reported that N_2O flux events in their study were sporadic and closely followed the application of dairy manure slurry and were influenced by subsequent rainfall events. Paul and Beauchamp (1989) reported that denitrification losses of nitrogen were well represented by the concentrations of volatile fatty acids and water soluble carbon sources in the manures evaluated, (r=0.96), suggesting that the activity of denitrifying bacteria may be influenced by the presence of these carbon sources when applied to soil.

In this study, N_2O production events were measured both during the fall period following manure application and during the spring period prior to seeding. In both cases, the soil would have contained many anaerobic microsites arising from the banding application of water with the manure in the fall and saturated soils following snow melt in the spring. To satisfy the conditions for denitrification processes to proceed, nitrate nitrogen applied as manure was plentiful; however, much of the soluble carbon source added with the manure would have been mineralized during the fall period following manure application. This may indicate that during the spring denitrifying bacteria were utilizing straw carbon added the previous fall as opposed to manure carbon which may have undergone preferential use during the fall field season. However, it may also indicate the use of biomass carbon assimilated during the previous fall.

The results of this study indicate that there is in fact an increase in soil CO_2 and N_2O respiration rates when hog manure and cereal residues are added simultaneously to clay soils, as opposed to being added separately. The addition of these two amendments provides both a source of soluble carbon and readily available nitrogen to soil microbial communities. An increase in carbon metabolism from manure and crop residue application to soil will result in increased microbial population numbers more capable of residue decomposition compared to soils in which residues have been burned (Opperman et al. 1989). Straw burning has been shown to cause a reduction in bacterial population numbers of up to 50 % (Biederbeck et al. 1980). Emmond (1971) also reported that fields where residues had been returned had a greater soil aggregate formation potential compared to fields where residues were burned. Fields to which manure had been added had better soil structure than those to which crop residues alone had been added.

The increase in soil respiration and the associated increase in microbial population numbers in manure amended soils, compared to straw burned soils, coupled with an increase in stable soil aggregate formation and the associated benefits of improved soil structure, may result in the formation of a microbial population more able to mineralize excessive quantities of cereal residues. Both the field and laboratory components of this study have indeed shown an increase in soil CO_2 evolution, in response to the application of liquid hog manure with large quantities of cereal residues. However, the microcosm studies revealed that the application of a nitrogen source alone had little effect on CO_2 evolution. The carbon added in the manure was found to have more of an effect on the overall rate of CO_2 evolution, suggesting that the soil biological community was limited more by available carbon than inorganic nitrogen availability. The addition of manure and crop residues likely increased soil microbial population numbers and increased the ability of the soil to metabolize added residues. However, this increase in decomposition rate may not be sufficient to provide the level of decomposition required to significantly reduce the amount of cereal residues present during spring seeding. Therefore, the effects of the proposed residue management systems on crop performance require consideration before recommending any alternative system for widespread producer adoption.

8.2 Tillage systems and cereal residue decomposition

The effects of tillage systems on soil organic carbon concentrations, soil microbial biomass and the ensuing rate of residue decomposition and CO_2 respiration can be sizeable and have been widely documented. The increased adoption of conservation tillage systems which retain larger quantities of crop residues in their original, whole plant state, as well as retaining more residue on the soil surface for soil erosion control, have been shown to increase the rate at which soils store carbon (Doran 1980; Carter 1991; Ocio et al. 1991a; Dick et al. 1991; Angers et al. 1993).

Several of the research projects cited have dealt with the effect of no-till management of corn and soybean rotations in throughout the US Midwest and central Canada; these studies may not be directly comparable to the conditions present in the Red River Valley, but provide applicable information concerning the potential impacts of reduced tillage on factors such as seedling emergence, nitrogen immobilization and crop disease pressure. Terminology usage is sometimes confusing when trying to distinguish between 'no-till' row-crop production systems used in the US Midwest and central Canada and the direct seeding or 'zero tillage' production systems used in western Canada. Throughout this paper, the terms no-till and zero tillage will be used to identify row-crop and small grains production systems, respectively.

Comparisons of reduced tillage systems with more intensive systems, i.e. moldboard plowing, have generally shown an increase in microbial biomass and carbon sequestration after several years of tillage intensity reduction. However, negative implications of no-till management were reported by Dick et al. (1991) in a long-term study of continuous corn or a corn-soybean cropping sequence compared to a moldboard plow system. The negative impact of no-till system adoption was only realized on fine textured, poorly drained soils, whereas a significant increase in corn and soybean yields was observed when no-till management was adopted on more coarse, loamy, well drained soils. However, the yield penalty for no-till yield on the fine textured soils was reduced after a sustained period of no-till; in fact, after 20 years of zero tillage management, these plots outyielded the moldboard plow treatments. This study illustrates the need for using long-term studies when attempting to quantify a soils ability to be managed using conservation or reduced tillage systems.

Over the course of this two-year study, a total of four and three of the forty-three possible sampling dates showed significant tillage treatment effects on CO_2 and N_2O respiration rate, respectively. All dates on which significant treatment differences were found were during the spring sampling period, one day for CO_2 during the spring of 2001, and the remainder of the dates falling within the spring 2002 sampling period. In all cases the zero primary tillage treatment had the lowest rate of soil respiration. The chisel plow and disk tillage systems were generally found to be equal in CO_2 respiration rate. Similar relationships between the rate of soil respiration and tillage intensity have be reported by Dao (1998) and Angers et al. (1999) who compared no-till and moldboard plow systems and Buchanan and King (1993) comparing no-till and chisel plow tillage systems; all three of these studies found increases in CO_2 respiration from the more intensive moldboard and chisel plow treatments compared to the no-till systems. The increased rate of CO_2 respiration from the intensive tillage systems is attributed to an increased availability of crop residue to be used metabolically by the soil microbial community. Incorporated residues have generally been shown to decompose at a more rapid rate than soil surface placed residues, due to their proximity to microbial populations, soil nitrogen sources and more moist and less variable atmospheric conditions (Parker 1962; Holland and Coleman 1987; Aulakh et al. 1991). Results from the second microcosm experiment of this study showed a greater CO_2 respiration response, upon the addition of liquid manure, to surface placed than incorporated residue treatments, reinforcing the importance of differences in nutrient availability for residue decomposition between zero and intensive tillage managed soils. Generally, although not significant, the chisel and disk based tillage systems yielded higher CO_2 flux values than the zero tillage treatment. N_2O flux data did not show as distinguishable a trend as CO_2 for tillage systems effects.

8.3 Manure and tillage system effects on wheat and canola production

This research has shown that there is a positive effect of manure application and tillage incorporation of cereal residues on the rate of soil microbial activity. The associated increases in microbial populations, carbon and nitrogen mineralization potential and soil organic carbon storage with reduced tillage adoption and manure application, can have positive implications for soil health and the sustainability of soil resources. Therefore, it is important to consider the effects of alternatives to straw burning residue management, such as tillage and manure application, on the potential crop yield and quality that can be expected by producers should they chose to adopt these residue management systems.

There are limitations to making cropping system conclusions based on a relatively short time frame, in this case, two years of field data. A recently published article by Tanaka et al. (2002) suggested that longer-term, more in-depth, systems-based research is required in the Great Plains region in order to provide producers with appropriate cropping systems management information. Research previously cited (Dick et al. 1991) exemplifies this need as more than 16 years of depressed corn yields were recorded before no-till management was found to have the potential to increase yields compared to a moldboard-based tillage system.

Maintaining cereal residues in large quantities, in the fine textured soils of the Red River Valley has been cited by producers to have detrimental effects on crop production. Negative effects include slow soil warming and drying prior to Spring seeding operations, decreased operating efficiency of seeding equipment with inaccurate seeding depth resulting in uneven crop emergence and increased potential for residue plugging of the implement, increased crop disease pressure and the potential for immobilization of applied nitrogen fertilizer. In this study, however, seedling emergence counts collected for both spring wheat and canola revealed no significant effect of tillage systems or manure application on crop seedling establishment. The application of manure was not expected to influence emergence, but tillage systems and the resulting variation in surface residue cover was expected to have an effect. However, no significant differences in residue cover were observed between any of the tillage systems. This is likely the result of the short duration of the experiment; residue levels on the less intensive tillage treatments may not have accumulated to the point where seedling emergence was compromised.

No significant effect of tillage systems was observed for the final yields of wheat or canola in 2001 and 2002, respectively. Chisel tillage produced the greatest yields, greater than the producer stubble burn management checks. Zero tillage with manure nitrogen application was equal to the producer check; all other treatments were found to yield less than the check for wheat yields in 2001. Wheat protein content was not affected by tillage or nutrient source.

Manure application provided a significant canola yield increase across all tillage system treatments during the 2002 growing season. Zero and chisel tillage systems yields were identical both with and without manure and were greater than the disk primary tillage system in both cases.

The adoption of conservation tillage by producers, which may or may not include stubble burning, is reported to be affected by several factors. Zantinge et al. (1986)

suggested that the (un)availability of labor, capital investment for machinery and land area can prompt a producer to use either conventional or conservation tillage management systems. Where resources are limiting, a slight yield decrease in corn yields with no-till, with an associated decrease in input costs per hectare, could be considered acceptable. However, when resources are abundant, a producer may opt to use a more intensive tillage regime to capitalize on inputs and maximize the return per hectare. This relationship may hold true for row-crop producers who may see the slight yield benefit of intensive tillage; however, producers in arid regions of western Canada generally experience the opposite effect, as zero tillage systems often out yield conventional systems due to improved soil moisture conservation (Grevers et al. 1986). The cost of intensive tillage on the generally large land base holdings by western producers can decrease profitability; potential small yield increases associated with conventional tillage in more temperature regions of the prairies often do not justify the increased use of fuel and labor required to complete primary and secondary tillage operations.

In terms of relative cereal crop yields, Christian and Miller (1986) and Grevers et al. (1986) both reported decreases associated with reduced tillage compared to intensive tillage operations on poorly drained soils. However, yields were enhanced by reduced tillage practices when used on well to imperfectly drained soils for corn and wheat in the two studies, respectively. Research conducted on dryland Queensland Vertisolic clay soils in Australia, determined that there was a yield advantage to zero tillage seeding practices compared to more intensive systems. Similar to results reported by Dick et al. (1991), Kladivko et al. (1986) suggested that zero tillage monoculture corn yields, which are generally less than those produced using moldboard plow systems, on poorly drained, poorly structured, low organic matter soils, may improve over time in response to improvements in soil structure. Further, the authors suggest that corn produced in rotation with soybeans on poorly drained soils using zero tillage management, may in fact over time produce higher yields than moldboard plow systems. These studies, and others, have reported a general increase in soil moisture and an associated decrease in average soil temperature for no-till managed soils compared to more intensive tillage systems. In this study, no significant differences in soil moisture or temperature were observed between any of the treatments, suggesting that several of the reasons cited by producers in the Red River Valley as to why straw burning is necessary may not apply in all circumstances.

Crop yield data collected in this study have determined there to be no yield penalty associated with alternative residue management strategies compared to straw burnings. The importance of cropping systems management was highlighted by Ortega et al. (2002) who suggested that an intensive, continuous-cropped, diversified-rotation, managed using zero tillage practices, would result in increased soil organic carbon and nitrogen contents, improving the residue mineralization potential of these soils, compared to an intensively managed wheat-fallow cropping system.

Based on the yield data reported in this study, it may not be necessary to utilize straw burning as a residue management technique in the fine textured clay soils which dominate the Red River Valley. The use of chisel plow Fall primary tillage operations to incorporate post-harvest crop residues or leaving residues unaltered without primary tillage (zero tillage), and a direct Spring seeding operation using wide sweep furrow openers, should allow Valley producers to consistently achieve the same high yields without having to manage cereal straw using straw burning management techniques. In fact, the adoption of long-term zero tillage production practices may provide yield increases over intensive tillage systems due to increased soil structure and improved internal drainage in these fine textured soils.

9. SUMMARY AND CONCLUSIONS

The suite of field and laboratory studies conducted through 2000-2002 revealed that liquid manure application to these soils does increase the rate of soil microbial activity, which, was associated in all cases with an increased rate of soil CO_2 respiration, and under field conditions, the rate of N_2O evolution as well. The effect of tillage systems on CO_2 evolution from the soil was insignificant in most cases. However, the more intensive tillage systems included in the study, chisel plow and V-disk based systems, were found to induce slightly greater, rates of soil CO_2 respiration, compared to the zero primary tillage system. Similar studies have reported findings that indicate an effect of both manure carbon and nitrogen additions to soil on the subsequent rate of microbial activity. Prolonged CO_2 and N_2O respiration from field study soils throughout the fall and spring sampling periods, resulting from the simultaneous mineralization of crop residue and manure carbon, supports this relationship observed by others, and in microcosm studies reported here as well.

In the initial microcosm experiment, the application of liquid glucose to soil significantly increased the rate of soil CO_2 respiration compared to liquid manure and to inorganic nitrogen amendments. However, there was also a positive CO_2 evolution response to manure application. The lack of response to the nitrogen only treatments, suggest that the soil system was not limited by nitrogen availability. A manure carbon input:output balance suggested that manure carbon was responsible for approximately 60

% of the increase in microbial activity. Therefore, approximately 40 % of total CO_2 evolution can be attributed to the metabolism of carbon other than that added as manure.

Data were collected from the field study to determine the effects of manure application and tillage system intensity on the growth, performance and final yield and quality of spring wheat and canola during the 2001 and 2002 growing seasons, respectively. The final yields of wheat and canola were not found to be significantly affected by the tillage systems tested, however, chisel plow primary tillage was found to provide the a slight increase in wheat yield compared to the V-disk and zero tillage systems tested as well as a reference control where oat residues were burned the previous fall. The greatest canola crop yield was achieved with zero and chisel primary tillage systems, which were nearly identical to one another but out yielded the V-disk treatment. The form of nitrogen application, as inorganic fertilizer or liquid manure, was not found to have a significant effect on wheat yield, but a significant yield increase was observed when canola was amended with manure as opposed to nitrogen and phosphorus fertilizers.

Soil moisture, soil temperature and the rate of crop emergence was not significantly affected by tillage or nutrient management factors in either field season.

Overall, the rate of soil respiration, and therefore, potentially, the rate at which residues are decomposed in these clay soils, was increased with the addition of fall applied liquid hog manure. Increasing tillage intensity also stimulated soil microbial activity in the short-term. However, other studies have found that long-term adoption of zero tillage seeding and crop management systems can result in increased soil microbial activity. The absence of straw burning residue management practices was found to have no significant negative effect on the yield and quality of the spring wheat and canola crops grown using commercial-scale equipment in this large-plot research trial. In fact, the least intensive tillage system included in the study, zero primary tillage, was found to produce yields equal to the more intensive and costly chisel plow primary tillage system.

All of the individual experiments included in this study have indicated that the use of straw burning as a primary residue management practice may not be necessary to produce high yielding, high quality spring wheat and canola crops in the clay soil region of the Red River Valley.

Additional, large-scale, long-term, cropping-systems based research is required to continue to explore the effects of reduced or zero tillage systems adoption, crop rotations, residue management strategies, and manure application to these clay soils on the resulting yield and quality of the annual crop species produced in the region. Additional research on tillage systems management will provide producers with pertinent information on the most profitable and environmentally responsible means of sustained, and high-yielding crop production in the Red River Valley.

10. CONTRIBUTION TO KNOWLEDGE

The suite of experiments included in this study have provided information concerning the validity of the claims of agricultural producers in the Red River Valley of Manitoba that stubble burning is a required residue management practice in maintaining the high productivity of annual crops in the region. Research data presented here do not support this claim. Soil moisture and temperature values were not found to vary between stubble burning experimental treatment soils and the various tillage systems treatments evaluated. As such, the rate of wheat and canola seedling emergence was also not significantly affected by tillage system employed. Liquid manure application to the clay soils was found to increase the rate of soil microbial activity, presumably increasing the rate at which cereal crop residues would be decomposed in these soils.

Further research is required in the region to evaluate the long-term effects of producer adoption of reduced or zero tillage production systems, which exclude stubble burning as a residue management practice. This will require a more comprehensive evaluation of the residue management practices currently used by producers, including residue chopping and spreading during combine harvester operation, and post-harvest harrowing operations to provide an even distribution of crop residues. Further research must evaluate the use of alternative residue management and tillage systems using a systems-based approach, where the study is designed with long-term goals and incorporates an evaluation of the effect of crop rotations and manure application on long term yield trends.

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12. APPENDICES

I 2000-2001 N_2O Flux Calculations

$$\frac{1uLN_2O}{L \bullet h} x \frac{3.24L}{0.0324m^2} x \frac{1umoleN_2O}{22.4uLN_2O} x \frac{44ugN_2O}{1umoleN_2O} = 196.4\frac{ugN_2O}{m^2 \bullet h}$$

$$196.4\frac{ugN_2O}{m^2 \bullet h} x \frac{10^3 ngN_2O}{1ugN_2O} x \frac{1h}{60\text{min}} x \frac{1\text{min}}{60\text{sec}} = 54.56\frac{ngN_2O}{m^2 \bullet \text{sec}}$$

$$196.4\frac{ugN_2O}{m^2 \bullet h} x \frac{1gN_2O}{10^6 ugN_2O} x \frac{28gN}{44gN_2O} x \frac{10^4 m^2}{1ha} x \frac{24h}{1d} = 30.0\frac{gN_2O-N}{ha \bullet d}$$

II 2000-2001 CO_2 Flux Calculations

$$\frac{1\%CO_2}{L \bullet h} = \frac{10mLCO_2}{L \bullet h} x \frac{3.24L}{0.0324m^2} x \frac{1mmoleCO_2}{22.4mLCO_2} x \frac{44mgCO_2}{1mmoleCO_2} = 1964\frac{mgCO_2}{m^2 \bullet h}$$

$$1964\frac{mgCO_2}{m^2 \bullet h} x \frac{10^3 ugCO_2}{1mgCO_2} x \frac{1h}{60\text{min}} x \frac{1\text{min}}{60\text{sec}} = 545.6\frac{ugCO_2}{m^2 \bullet \text{sec}}$$

$$1964\frac{mgCO_2}{m^2 \bullet h} x \frac{1kgCO_2}{10^6 mgCO_2} x \frac{12kgC}{44kgCO_2} x \frac{10^4 m^2}{1ha} x \frac{24h}{1d} = 128.6\frac{kgCO_2-C}{ha \bullet d}$$

III 2001-2002 N_2O Flux Calculations

$$\frac{1uLN_2O}{L \bullet h} x \frac{1.62L}{0.0324m^2} x \frac{1umoleN_2O}{22.4uLN_2O} x \frac{44ugN_2O}{1umoleN_2O} = 98.21\frac{ugN_2O}{m^2 \bullet h}$$

$$98.21\frac{ugN_2O}{m^2 \bullet h} x \frac{10^3 ngN_2O}{1ugN_2O} x \frac{1h}{60\min} x \frac{1\min}{60\sec} = 27.28\frac{ngN_2O}{m^2 \bullet \sec}$$

$$98.21\frac{ugN_2O}{m^2 \bullet h} x \frac{1gN_2O}{10^6 ugN_2O} x \frac{28gN}{44gN_2O} x \frac{10^4 m^2}{1ha} x \frac{24h}{1d} = 15.0\frac{gN_2O - N}{ha \bullet d}$$

IV 2001-2002 CO_2 Flux Calculations

$$\frac{1\%CO_2}{L \bullet h} = \frac{10mLCO_2}{L \bullet h} x \frac{1.62L}{0.0324m^2} x \frac{1mmoleCO_2}{22.4mLCO_2} x \frac{44mgCO_2}{1mmoleCO_2} = 982\frac{mgCO_2}{m^2 \bullet h}$$

$$982\frac{mgCO_2}{m^2 \bullet h} x \frac{10^3 ugCO_2}{1mgCO_2} x \frac{1h}{60\min} x \frac{1\min}{60\sec} = 272.8\frac{ugCO_2}{m^2 \bullet \sec}$$

$$982\frac{mgCO_2}{m^2 \bullet h} x \frac{1kgCO_2}{10^6 mgCO_2} x \frac{12kgC}{44kgCO_2} x \frac{10^4 m^2}{1ha} x \frac{24h}{1d} = 64.3\frac{kgCO_2 - C}{ha \bullet d}$$