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Methods of Application of Nitrogen Fertilizer for No-till Cropping

by

Thomas LeRoy Jensen

A THESIS

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ABSTRACT

A study was conducted to evaluate forms and methods of application of nitrogen fertilizers for no-till cropping. There were three sets of experiments conducted in Southern Alberta. In the first set, the recovery of N-15 enriched urea and ammonium nitrate, broadcast under continuous no-till and tilled cropping, was measured at three sites. In the second set, nitrogen fertilizers unenriched with N-15 were applied. The crop yields from banded and broadcast urea and ammonium nitrate, and anhydrous ammonia were determined for three site-years. In the last set, there was one experiment in which the recovery of N-15 enriched fertilizer in the crop and residual in the soil was measured for fall and spring applications of broadcast, banded, and broadcast-incorporated ammonium nitrate under no-till cropping.

There were significant differences among the forms and methods of application of nitrogen fertilizer for no-till cropping. If a granular form of nitrogen (urea or ammonium nitrate) was broadcast on the soil-plant residue surface and not incorporated, ammonium nitrate resulted in greater fertilizer recovery than urea.

Anhydrous ammonia (which is injected in bands) on

no-till was one of the highest yielding treatments. If urea or ammonium nitrate were banded instead of broadcast, the yields were similar to the anhydrous ammonia application.

Spring applications of nitrogen fertilizers tended to result in greater crop uptake of nitrogen than equivalent fall applications. Banded fertilizer led to greater uptake than did broadcast fertilizer for both fall and spring applications, and whether or not the broadcast fertilizer was incorporated into the soil.

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INTRODUCTION

The type and intensity of tillage used in dryland cropping systems in Southern Alberta has changed over time due to developments in equipment, weed control procedures, the need to overcome soil erosion, and the need to better conserve soil moisture. Initial cropping systems used when the area was first settled were generally intensive tillage practices involving soil inversion with an implement such as a plough. These tillage systems resulted in excessive wind erosion and poor soil moisture conservation. Systems have developed that help retain crop residues on the soil surface to reduce erosion and conserve soil moisture. The development of appropriate herbicides has made it possible to further reduce the need for tillage. The extreme in tillage reduction is a no-tillage cropping system.

Research into reduced tillage systems has concentrated in three main areas. Initially, there was a great need to develop seeding equipment that could properly place crop seeds into the soil in the presence of the plant residue thatch left from the previous crop. Another important aspect that has required, and still requires development, is effective weed control using herbicides. The third area of research, and the one which concerns this study, is fertilizer management.

This study was initiated to evaluate various aspects of nitrogen fertilizer management in a no-till cropping system. The management alternatives investigated were nitrogen fertilizer form (urea, ammonium nitrate, and anhydrous ammonia), fertilizer placement (broadcast and banding), and times of application (fall and spring).

2. LITERATURE REVIEW

This review is a summary of various aspects of past and present research regarding reduced or no-tillage. A summary of the meaning of terms used to describe various reduced tillage systems is presented. No-tillage and tillage are terms which will be used extensively in this review and their clear definitions are required for the purpose of discussion. The past history of no-tillage and present trends in tillage systems will be discussed. There are potential benefits and problems associated with a reduction in tillage. A change in tillage practices results in both physical and biological effects upon the soil. These effects will be reviewed. Changes in tillage practices have resulted in specific research needs. Nitrogen fertilizer management for no-tillage will be reviewed concerning fertilizer use, forms of nitrogen and methods of applications.

2.1 Definition of Terms

There are many terms used to describe reduced-tillage cropping systems. Similar terms are used in different geographical areas but the understanding of these terms is somewhat different.

In most studies there is usually a comparison between what the authors call no-tillage and conventional tillage. Conventional tillage describes what common tillage practices are in use in the specific geographical region. In many areas this refers to ploughing with a moldboard plough followed by a discing operation or two, and then harrowing before seeding. In other areas, conventional tillage may already be a form of reduced tillage in which tillage operations are restricted and not as intense as a ploughing system.

A common definition of no-tillage or no-till is a cropping system in which the crop is planted either entirely without tillage or with just enough tillage to allow placement and coverage of the seed with soil to allow it to germinate and emerge (Phillips and Young 1973, Phillips et al 1980). Another definition is that no-tillage or zero-tillage is a procedure whereby a crop is planted directly into a seedbed not tilled since the harvest of the previous crop (Schneider et al 1979, Sumner and Boswell 1981, Ramig and Ekin 1983). Yet another more descriptive definition is that no-till is placing the crop seed into the soil by a device that opens a trench or slot through the sod or previous crop residue only sufficiently wide or deep to receive the seed and provide seed coverage. No other soil manipulation is done. Weeds are controlled by herbicides, crop rotation and plant competition (Crosson 1982).

Conservation tillage is a general term used to describe any tillage system which retains some or all crop residues on the soil surface to reduce water and wind erosion (Crosson 1982). In the Great Plains region of North America it also refers to conservation of soil moisture. Conservation tillage can include no-tillage and varying degrees of minimum tillage.

For the context of this review and subsequent discussions, no-till will be used to describe a cropping system in which all weed control is done using herbicides, and the only soil disturbance is that which occurs when the crop seeds are planted. Tillage is defined as the common dryland cropping system in Southern Alberta in which a crop is planted into a seed bed which was prepared by only a few tillage operations done with a heavy duty cultivator or offset disc followed by the smoothing of the seedbed with a rod weeder and harrows.

2.2 History and Trends in Tillage

Developments in cropping go back as far as when man changed from hunting and gathering to an agricultural based system involving the planting and harvesting of crops.

Early cropping systems were a form of no-tillage or minimum tillage. The crop seed was scattered in the cropping area with no soil manipulation, or at most a minimum scratching of the surface to partially cover the seed. Crop and weeds plants were allowed to grow, and the desired crop plant parts were harvested when mature.

As agricultural cropping became more intense, the amount of soil manipulation increased. With advances in technology, the power to do the tillage evolved from hand labour to animal power, and then to machine power. Intensive tillage became the commonly accepted cropping system. Intensive tillage was not questioned until various experimental studies were done into soil cultivation during the eighteen and early nineteen hundreds. A controversy developed regarding the actual need for tillage. One opinion was that the main role for tillage was weed control. Another opinion was that tillage was necessary to develop soil tilth or structure (Kuipers 1970).

The advent of selective herbicides such as 2,4-D increased the feasibility of growing crops without tillage as weeds could now be controlled without tillage (Phillips et al 1980, Unger and McCalla 1980, Carter 1982). In the United Kingdom, the trend toward reduced tillage grew due to the scarcity and high cost of labour and the need for timeliness of seeding winter crops. In the United States, reduced tillage was attractive due to better erosion control, timeliness of double cropping, and water conservation (Carter 1982).

No-till cropping systems in North America were started initially in areas where corn was the main crop. No-till cropping practices are relatively recent in the Northern Great Plains of North America (Schneider et al 1978).

Estimates of the eventual amount of crop land that will be farmed using conservation tillage in the U.S. varies from 90%, with 50% of this no-till (Triplett and VanDoren Jr. 1977), down to 50-60% conservation tillage with no-till being a small proportion of this (Crosson 1982).

The increased use of no-tillage depends to a large extent on whether herbicide costs decline in proportion to tillage costs (Lindwall 1985), and if crop yields using no-tillage are similar or greater than those using a tilled cropping system. In an economic study of soil conservation practices in the Brown soil zone of Saskatchewan, the high cost of herbicides was mentioned as being a major obstacle to wide-spread producer adoption of minimum and no-till cropping practices (Zentner and Campbell 1985). No-till or direct drilling has been a commercial practice for some crops in many parts of the world for many years but the practice has gained little acceptance in the semi-arid regions of the prairies (Lindwall 1985).

2.3 The Benefits and Problems of No-till Cropping

When a previously tilled soil is converted to no-till cropping there are potential benefits and problems.

2.3.1 Benefits of No-till Cropping

There are many potential benefits resulting from a no-till cropping system. The major benefit which has encouraged the adoption of no-tillage is reduced soil erosion (Lal 1974; Triplett and VanDoren 1977; Phillips et al 1980; Sumner and Boswell 1981; Engle et al 1982; Crosson 1982; Warren 1983; Bandell 1984; Rice and Smith 1984). No-tillage, one of the forms of conservation tillage, not only drastically reduces soil erosion but it is one of the most effective and least expensive methods of controlling erosion (Papendick 1984).

Some other important benefits are reduced on-farm energy use (Rice and Smith 1984) and reduced labour costs. There is also potential to expand the arable land base because land which could not be farmed using intensive tillage due to excessive erosion can be farmed successfully using a form of conservation tillage (Phillips et al 1980).

By maintaining crop residues on the surface of a no-till soil there is more rapid moisture infiltration, enhanced snowtrapping and lower evaporation losses, all of which can result in overall increased moisture conservation (Cannell 1981). An additional benefit regarding moisture conservation is that the need of fallowing in a crop rotation can be eliminated or at least reduced (Engle et al 1982). By reducing the amount of summer fallow, moisture will be used more efficiently which helps reduce saline seepage problems that have been aggravated or created due to excess additions of soil moisture to ground water systems during fallow periods.

There is also the potential for higher yields under no-till due to the increased moisture conserved (Warren 1983), and more efficient use of nitrogen fertilizers if properly managed (Bandel 1984). Higher yields are also expected over the long-term due to the reduction of soil losses. One study compared projected wheat yields over a 20 year period with no-till losing 5 tonne of soil per hectare and conventional tillage losing 45 tonne on highly erodible land in the Palouse area of Eastern Washington State (Papendick 1984). The predicted total yield advantage for no-till over the 20 years was 6922 kg/ha.

Annual weeds have been shown to be less of a problem under no-till because of less incorporation of weed seeds (Stobbe 1979).

The organic matter level of a previously tilled soil has been observed to increase under no-till cropping (Cannell et al 1980; Cannell 1981; Engle et al 1982).

2.3.2 Problems of No-till Cropping

Changing from conventional tillage to no-till cropping resulted in many initial problems. Early attempts at no-till were limited because of the lack of appropriate seeding equipment that could properly place crop seeds in the soil when crop residues were left on the surface. Thus, low plant populations, resulting from poor germination was a problem (Bandel 1984, Papendick 1984). The development of seed drills that can operate efficiently under heavy crop residue conditions has largely overcome low plant populations.

Adequate weed control has been challenging in no-till cropping systems. In-crop spraying using selective herbicides is not much different from that in conventional tillage. The difference is the use of non-selective pre-plant herbicides such as paraquat or glyphosate. Annual weeds seem to be less of a problem when tillage is reduced, but in many areas perennial weeds have become more of a problem. Many of these weeds were previously controlled by tillage and are difficult to control using herbicides only (Stobbe 1979, Crosson 1982).

The crop residue thatch left on the surface of the soil has resulted in a greater potential for problems with insects, rodents, plant diseases and production of phytotoxins during decomposition (Unger and McCalla 1980, Phillips et al 1980).

Soil compaction and associated higher bulk densities, have been observed under no-tillage cropping. This is especially so on soils with medium to coarse textures (Cannell et al 1980, Cannell 1981).

Losses of fertilizer nitrogen due to leaching or denitrification and/or volatilization have been shown to be a greater problem under no-till compared to conventional tillage (McMahon 1976, Tyler and Thomas 1977, Phillips et al 1980, Mueller et al 1981, Randall 1983). Losses as a result of these processes vary considerably among studies, probably because of differences in weather.

Slower decomposition of plant residues has been thought to be a problem with no-till, especially when it limits the amount of plant available nitrogen (Cannell 1980).

The increased use of agricultural chemicals, especially herbicides, has been cited as a potential environmental concern (Crosson 1982). The greater amount of compounds being released into the environment might not be significant because, although more chemicals are used under no-till compared to conventional tillage, erosion losses of soil particles which have adsorbed these chemicals are greatly reduced and pollution of water bodies by chemicals may, in fact, be less.

Cooler soil temperatures restricting crop emergence and growth with no-till have been shown to be a problem on poorly drained soils and in moist and/or cold climates (Unger and McCalla 1980, Crosson 1982).

Fertilizer practices that have worked well for conventional tillage have been shown to be less efficient, and under some conditions poorly adapted to no-till production (Fredrickson et al 1982, Bandel 1984, Papendick 1984).

Although many of these problems are unique to no-till cropping systems, proper management and technological developments have often resulted in successful no-till farming.

2.4 The Effects of No-Tillage

To evaluate the effects of a reduction in tillage, it is important to understand both the physical and bio-environmental changes that occur. Both are a result of the lack of intensive soil manipulation and the collecting of plant residues on the soil surface instead of being mixed throughout the cultivated layer.

2.4.1 Physical Effects

The surface plant residue layer that is present in no-till systems greatly affects the moisture collection, infiltration and retention. The stubble left from the crop harvested in the fall is able to trap and retain more snow than if fall tillage is done, incorporating a portion of this stubble into the soil. Melting snow and yearly rainfall is able to infiltrate faster into the soil because the soil surface is less prone to aggregate breakdown from raindrop impact or surface water flow (Gantzer and Blake 1978). The increased plant residue layer under no-tillage compared to tilled cropping conserves moisture by reducing surface evaporation losses from the soil (Gantzer 1978). A common misconception about leaving the plant residues on the surface instead of incorporating them throughout the tilled layer is that a plant residue layer will accumulate steadily the longer no-tillage is practised. It has been shown in a study of nitrogen cycling in no-tillage ecosystems that the amount of crop residues did not increase because surface decomposition, measured as weight loss in crop residue, was nearly complete over an annual cycle (House et al 1984).

The conservation of soil moisture due to both the surface plant residue and the lack of tillage has the effect of higher moisture content and can result in higher leaching losses of nitrate nitrogen, (Thomas 1973) and lower concentrations of oxygen in the soil atmosphere resulting in more anaerobic conditions (Doran 1980). It has been observed that although overall oxygen concentrations can be lower in a no-till soil compared to conventional tillage, there can be more oxygen to a greater depth in more continuous pores that exist in a soil when it is not tilled (Tyler and Thomas 1977, Gautzer 1978, Dowdell et al 1979, Douglas et al 1980). These pores can be the result of soil fauna (e.g. earthworms) or from the natural swelling and contraction of the soil due to wetting-drying cycles. Although oxygen may be higher in these more continuous pores, the overall oxygen content of the soil is lower due to a lower pore volume and more anaerobic conditions in the micropores (Ellis 1979).

It has been observed that the pH of the surface layer of soil is lower for no-till compared to conventional tillage. This has usually been attributed to the acidification caused by surface broadcast nitrogen fertilizers (Blevins 1977, Fox and Hoffman 1981, Fee 1982, Blevins 1983). If surface broadcasting of nitrogen fertilizers is the regular fertilizer practice it has been shown that lime applications may be required to neutralize the increased acidity (Phillips et al 1980).

It has been generally shown that no-tillage as compared to conventional tillage, is more successful on well drained soils and in warm climates (Triplett and VanDoren 1978). In areas of cool moist climates, lower yields have often resulted under no-till cropping compared to tilled cropping while in a warmer dry climate, the yields have been greater for no-tillage (Mueller et al 1981). The significant interaction of tillage, soil drainage and climate emphasize the need for area-specific research to assess the potential for reducing tillage (Deibert 1978, Christensen 1983, Doran 1983, Kitur et al 1984). No-tillage usually results in cooler, more moist soil than conventional tillage especially in the spring. In the fall and winter, soil temperatures may be higher under no-till. This results in dampened soil temperature fluctuations. Lower soil temperatures in the spring slow crop emergence and seedling growth. This is often compensated later in the growing season by more available soil moisture (Unger 1978).

2.4.2 Bio-Environmental Changes

The ceasing of intensive tillage in a cropping system helps to create a soil ecosystem that is more similar to a natural terrestrial ecosystem (Fleige and Baeumer 1974, Stinner et al 1983, House et al 1984).

The plant residues that are left on the soil surface and not incorporated into the soil have been observed to decompose slower and as a result, the mineralization of nitrogen is slower (Thomas et al 1973, Moschler and Martens 1975, Deibert 1978, Triplett et al 1979, Doran 1980, Frye et al 1980, Phillips et al 1980, Powlson 1980, Engle et al 1980, Randall 1983). When there is tillage, decomposition of both soil organic matter and recent plant residues is enhanced (Stinner et al 1983). This is a result of the physical disruption of soil humus particles and plant residues resulting in a larger surface area exposed for microbial decomposition (House et al 1984). Also, with increased aeration of the soil system there is increased decomposition of organic matter because these processes are largely oxidative (Carter 1982, Gevers 1984). Under no-till, potentially mineralizable nitrogen from organic matter may be greater, but the actual amount mineralized can be less because of more anaerobic conditions (Doran 1980). In the short-term (a few years), the amount of mineralization of organic matter is less for no-till compared to tillage. In the medium-term (about ten years), the amount of mineralization is almost equal (Peterson et al 1981). It is thought that in the long-term, the amount of mineralization will be greater for the no-till system (Carter 1982, Grevers 1984). The half-lives of plant residues in a no-till and tilled system were observed to be 48 and 24 months, respectively (Grevers 1984). If the tillage system used in an area is a reduced tillage system, only slight differences will be observed between it and a no-till system regarding mineralization and immobilization (Carter 1982).

A soil that is cropped using no-tillage practices has been shown to generally have a larger biomass than the same soil farmed using a tilled cropping system (Zerfus 1979, Lynch and Panting 1980). There are differences in the variety of microbes, with no-till having the greater variety (Doran 1983). Larger populations of denitrifying microbes have been found and apparently the cause is a less oxidative soil environment (Doran 1980, Linn and Doran 1981). Not all workers agree that there is a larger biomass for no-till soils compared to soils which are tilled. Some research studies in which the biomass was measured in both the 0 to 5 cm and 5 cm to 10 cm depths showed that although biomass carbon and nitrogen were significantly higher in the 0 to 5 cm layer for the no-till soil, the opposite was true for the 5 cm to 10 cm layer (Powlson and Jenkins 1981, Carter 1982). It was concluded that rather than an increase in biomass within the Ap horizon, a redistribution of biomass had occurred. Carter (1982) concluded that the nitrogen immobilized in the biomass was an important source of labile nitrogen during periods of net mineralization.

The greater biomass in the surface layer of no-till soils has been attributed with significantly immobilizing greater amounts of nitrogen for no-till as compared to conventional tillage (Doran 1980, Frye et al 1980, Randall 1983, Kitur et al 1984). This immobilization is thought to play a major role in the retention of nitrogen in a soil. The biomass can immobilize a significant amount of nitrogen fertilizer that is broadcast on the surface and not incorporated (House et al 1984).

Some studies comparing the organic matter levels of soils under no-till and conventional tillage have shown that organic matter content has increased under no-till cropping (Lal 1974, Fleige and Baeumer 1974, Bandel et al 1975, Moschler and Martens 1975, Lal 1976, Blevens et al 1977, Lal 1979, Legg 1979, Stinner et al 1983). A previously tilled soil, but no-till cropped for five years, had increased levels of organic matter in the 0 to 15 cm depth and similar levels in the 15 to 30 cm depth (Fleige and Baeumer 1974). In the same experiment, a long term grassland soil was also no-till cropped for the five year period. In this case, the organic matter level decreased compared to the same soil still in grassland. It was hypothesized that no-till cropping would eventually results in a soil organic matter content that would be intermediate between those established under conventional tillage and a grassland ecosystem. Other researchers have alluded to the eventual establishment of a new soil organic matter equilibrium content that will be greater than that under conventional tillage (Stinner et al 1983, Grevers 1984, Papendick 1984). A more stable productivity capacity is probably established when this new soil equilibrium is achieved (Papendick 1984). Even though tillage has been shown to cause definite declines in the levels of organic matter in soils (Tiessen et al 1982, Hagin and Tucker 1982), not all studies have concluded that there is an increase in total organic matter under no-tillage. Powlson and Jenkinson (1981) concluded from studies in England where cereals were grown that changing from conventional tillage to no-till had little effect on the amount of organic matter in the soil. The location of organic matter was shown to be concentrated near the soil surface, but the overall annual deposition and decomposition rate of plant residues was very similar even though short-term rates varied. Carter (1982) observed an accumulation of organic matter in the 0 to 5 cm layer, and a reduction of organic matter in the 5 to 10 cm layer for Brown and Dark Brown soils growing wheat in western Canada. There was a formation of vertical gradients of plant nutrients and organic matter due to the absence of soil mixing by tillage, but there was not a change in the total amount of organic matter.

Nitrogen is more susceptible to losses through denitrification under the lower oxidative environment for no-till compared to conventional tillage (Frye and Thomas 1979, Cannell et al 1981, Doran 1980, Engle et al 1980, Phillips et al 1980, Powlson 1980, Dowdell and Crees 1980, Broder 1981, Fee 1982, Rice and Smith 1982, Fredrickson et al 1982, Crosson 1982, Carter 1982, Randall 1983, Kitur et al 1984, Grevers 1984, Bandel 1984). Burford et al (1981) measured a higher nitrous oxide flux from no-till than from a tilled soil from research done in England.

Nitrogen cycling is thought to be more efficient under no-tillage than for tillage (Grevers 1984). House et al (1984) concluded from research in Georgia that no-tillage systems mimic natural ecosystems in the manner that plant residues are decomposed. Crop litter decomposes slower than soil-incorporated residue. The slower decomposition and lack of mixing results in a higher concentration of nitrogen and organic matter in the top soil layer.

2.5 Research Needs for Nitrogen Fertilization of No-Till

Since a reduction in tillage can greatly affect nitrogen transformations in the soil ecosystem, research into the methods of nitrogen fertilizer application has been suggested. Diebert (1978) suggested that there is a need for research into the immediate and long-term effects of reduced tillage on fertilizer practices. Research related to the source and rate of nitrogen, time of application and placement of nitrogen, was emphasized by Schneider et al (1978). Unger and McCalla (1980) discussed the need of coordinated research into the physical, chemical, and biological components of the plant-soil environment in no-till systems. Because of the increasing costs of nitrogen fertilizers, research is needed to develop fertilizer management that is more efficient (Fredrickson et al 1982). Moncrief (1984) stressed that fertilizer management in many instances can "make or break" an attempt at an alternative tillage system. Papendick (1984) stressed the need of research into the interaction of weed competition and fertilizer management.

2.6 Nitrogen Fertilizer Management for No-Till

Nitrogen fertilizer management for no-till cropping was not studied in detail for many of the early reduced tillage studies. In many cases it was thought that common methods of application were sufficient. Moschler et al (1972) compared surface broadcast applications of ammonium nitrate for no-till and conventional tillage corn production in Virginia. The broadcast fertilizer was incorporated by discing for the conventionally-tilled treatments. Higher yields were observed under no-till. It was concluded that surface applications of ammonium nitrate were sufficient to supply the nitrogen fertilizer requirements of crops grown using no-tillage. Lal (1979) reported that the appropriate method of fertilizer application for no-tillage systems is a controversial issue and that the response of no-till crops was variable and soil and site specific. He reported that there were two opposing schools of thought. The first was that there was more efficient fertilizer use by crop plants under no-tillage because of greater nutrient availability in the surface layer of the untilled soil. This greater availability was thought to be due to greater accumulations of nutrients in the surface layer of an untilled soil. The second opinion was that there was less fertilizer used by crop plants due to more weed competition, lower soil temperatures, more immobilization by the biomass and higher losses of nitrate through denitrification and leaching. The greater potential for denitrification was due to higher moisture contents in the untilled soil. The higher leaching losses were attributed to increased water infiltration and movement through the soil profile. Legg (1979) reported that when there was relatively low rainfall, no-till corn used nitrogen fertilizer more efficiently due to greater levels of available moisture. However, some researchers have thought that as a result of slower mineralization of nitrogen from crop residues and a greater potential for leaching and denitrification losses, no-till crops will require more nitrogen fertilizer than conventional tillage (Thomas 1973, Phillips and Young 1973, Crosson 1982). Other studies have shown that at low rates of nitrogen fertilizer, conventional tillage will out-yield no-till. At medium rates, the yields are similar, and at high rates, the no-till yields were the greatest (Moschler and Martens 1975, Heinenen 1978, Triplett et al 1979, Stobbe 1979, Blevins 1983, Phillips et al 1984, Bandel 1984, Kitur et al 1984).

In the first few years after changing to a no-till cropping system, higher rates of nitrogen fertilizer may be required (Deibert 1978, Doran 1983). After a few years, the organic matter will equilibriate at a higher level in the soil and nitrogen fertilizer requirements may be lower for no-till cropping (Lal 1979). Grevers (1984) postulated that during the initial three to five years of no-till, crops require more fertilizer nitrogen than conventional tillage. After ten years, the nitrogen requirement was similar, and beyond ten years, less fertilizer nitrogen may be required.

2.6.1 Forms of Nitrogen Fertilizer

It is necessary to evaluate how crop use of various forms of nitrogen fertilizer interact with a reduction in tillage. Some of the nitrogen forms that have been evaluated are ammonium nitrate, urea-ammonium nitrate solution, anhydrous ammonia, and urea.

Ammonium nitrate generally resulted in a greater yield than urea when surface broadcast for no-till cropping (Schneider et al 1979, Fox and Hoffman 1981). This was especially so when precipitation was not received soon after application. Dowdell and Crees (1980) measured more residual nitrogen in the soil from ammonium nitrate and ammonium sulphate than from calcium nitrate when winter wheat was grown in a clay textured soil in England. They attributed this to differences in ammonium adsorption onto clay colloids for the ammonium nitrogen forms and higher leaching losses of nitrates from the calcium nitrate. Although ammonium nitrate is superior to urea when surface broadcast with no incorporation, it is usually more expensive and becoming less available (Fee 1982).

Urea-ammonium nitrate solution has been tested for no-till. Fox and Hoffman (1981) found lower corn yields in Pennsylvania for this form than for ammonium sulphate or ammonium nitrate if no rain was received soon after application. Urea-ammonium nitrate solution is convenient to mix with herbicides but is subject to volatilization losses when surface broadcast (Fee 1982). The yield with this fertilizer was intermediate between the higher yield for ammonium nitrate and the lower yield for urea when all three forms were broadcast and not incorporated for no-till corn in Georgia (Touchton and Hargrove 1982).

Anhydrous ammonia use for no-till cropping has been limited. Phillips and Young (1973) suggested that this form of nitrogen can be used in a preplant, seeding, or side-dress operation. It has been thought that anhydrous ammonia is less adaptable for use in no-till cropping due to the problem of residue clearance and the extra soil disturbance caused by injection into the soil (Deibert 1978). It was suggested that anhydrous ammonia will be used more in reduced tillage in the future (Fee 1982). Such use would require equipment that can clear the greater amounts of crop residues present under no-tillage compared to a tilled cropping system.

Research studies evaluating the effectiveness of urea have shown that there can be considerable losses due to volatilization when the fertilizer is broadcast on the surface and not incorporated (Power 1973, Terman 1979). Lower yields for broadcast urea, compared to nitrate and/or ammonium forms of nitrogen have been observed for no-till cropping (Deibert 1978, Schneider 1979, Engle et al 1982, Warren 1983, Randall 1983). Bandel (1984) reported ammonia volatilization losses of 30 to 50% for surface broadcast urea under no-till corn production in Maryland.

Various factors affect the losses by ammonia volatilization. If adequate rainfall is received within a day or so of application, the urea is dissolved and moved into the soil (Bandel, 1980, Tomar and Soper 1981, Fox and Hoffman 1981, Fenn and Miyamoto 1981, Fee 1982). Urea is soon hydrolyzed into ammonia and carbon dioxide by the biomass and soil humus urease activity. Generally, the ammonia is dissolved in the soil solution forming ammonium ions unless the soil reaction is quite alkaline. As long as the soil is supplied with oxygen, nitrification by nitrifying organisms proceeds. Touchton and Hargrove (1982) suggested that there is a large potential for ammonia volatilization losses from unincorporated broadcast urea applications under no-till cropping due to the urease activity of the biomass present in the organic residues at the soil surface. Carter (1982) reported a greater potential for volatilization of ammonia from both urea and ammonium nitrogen fertilizers for untilled soils compared to tilled soils. Ammonia losses from urea can occur when the soil reaction is acidic, neutral or alkaline, as it is largely controlled by the amount of urease activity. Losses from ammonium nitrogen fertilizers will generally only occur when the soil reaction is alkaline because the equilibrium between ammonium and ammonia tends towards the ammonia ion.

Some studies have shown that it is not always valid to attribute lower yield responses from urea compared to other nitrogen forms due to higher ammonia volatilization losses only. Some of these losses may, in fact, be preferential immobilization of urea by the soil biomass (Hargrove and Kissel 1979, Hargrove and Kissel 1980).

2.6.2 Methods of Application

Early studies regarding no-till cropping assumed that surface broadcast fertilizers were the most practical method of application. This assumption was due to the lack of research into band placement for no-tillage and the lack of appropriate equipment that could band or inject fertilizers while clearing the plant residues at the soil surface (Bandel 1980). Triplett et al (1972) showed from research in Ohio that placement of low rates of fertilizer in the seed row resulted in greater yields than equivalent rates of surface broadcast nitrogen for corn in an untilled soil. Phillips and Young (1973) recognized that it was an over-simplification to suggest that there was no need for fertilizer changes when changing from tillage to no-tillage.

Placement studies under tilled conditions have shown that various sources of nitrogen are equally effective when placed in bands in the soil (Harapiak 1980). Research studies to evaluate band placement of nitrogen under no-till cropping have shown yield increases in favour of banding (Koehler et al 1977, Schneider et al 1978, Heinemann 1978, Schulte 1979, Tomar and Soper 1981, Mengel et al 1982, Ramig and Ekin 1983, Bandel 1984). There may be more fertilizer nitrogen immobilization and ammonia volatilization under no-till compared to tilled cropping, and if so, fertilizer placement could result in greater benefits under no-till (Fee 1982, Warren 1983). Placing nitrogen fertilizers in a band decreases the amount of immobilization by the biomass near the soil surface in no-till soils (Tomar and Soper 1981, Fee 1982, Rasmussen 1983, Doran 1983, Rice and Smith 1984). Some other advantages to band placement are separation of fertilizer from the seed and better weed control (Engle et al 1982). The better weed control is a result of weeds being less competitive for fertilizer nitrogen with crop plants if the fertilizer is in bands.

Band placement can result in greater use of fertilizer nitrogen by the crops grown using no-tillage than if the fertilizers were broadcast on the soil surface (Fredrickson et al 1982, Carter 1982). Doran (1983) reported up to 20% yield increases due to band placement compared to surface broadcasting for no-till corn in Maryland.

There is question of the optimum location of the nitrogen fertilizer band in relation to the seed row. Heinonen and Huhtapalo (1978) reported research results from Sweden that showed that banding resulted in greater yields when the bands were about 3 to 6 cm to the side and 3 to 4 cm deeper than the seed row under tilled cropping. In addition, alternate placement of bands every two seed rows was as effective as a band placed between every two rows. Papendick (1984) reported promising results from a placement of nitrogen in a band between a "paired row" of wheat grown in Washington State. The seeds were planted in pairs of rows spaced 10 to 18 cm apart with a space of 33 to 40 cm between the next pair. The fertilizer was deeply banded between the two closely spaced rows at approximately 10 to 13 cm depth below the soil surface.

If a urea-ammonium nitrate solution fertilizer is used for no-till cropping, banding results in greater yields than does a surface broadcast spray application (Touchton and Hargrave 1982). Bandell(1984) reported that another alternate method of applying this fertilizer solution is to dribble it in bands on the soil surface. Results from no-till corn in Maryland showed that lowest to highest yields were obtained from broadcast surface sprayed, surface banded, and then subsurface banded, respectively.

Frye et al (1980) reported results from Kentucky showing that greater yields were obtained from use of urea and ammonium nitrate fertilizers that were treated with a nitrification inhibitor (N-Serve 24) compared to the same fertilizers not treated with the inhibitor. The inhibition of nitrification can decrease losses by reducing denitrification and leaching of nitrates.

The optimum timing of nitrogen fertilizer applications varies with the geographic location and the type of tillage system. No-till systems can change the placement and time of application options for fertilizers (Deibert 1978).

Heinemann (1978) conducted studies which showed that delay and side-dressing of nitrogen fertilizer for no-till corn was more efficient than surface broadcasting as a preplant operation. A delay or split of fertilizer applications maintained yields for no-till corn compared to yields of tilled corn that received nitrogen fertilizer early in the spring (Thomas et al 1980). Spring applications can result in greater crop yields and greater plant uptake of fertilizer nitrogen than fall applications (Olson and Swallow 1984). Band placement of fertilizer has the effect of making the time of application less critical (Bandel 1984).

In summary, no-tillage is a cropping system in which all weed control is done using herbicides and the only soil disturbance is that which occurs when the crop seeds are planted. The increased use of no-tillage depends to a large extent on whether herbicide costs decline in proportion to tillage costs. The benefits that can result from converting to no-tillage cropping from tilled cropping are reduced soil erosion, reduced on-farm energy use, reduced labour costs, increased moisture conservation, higher yields, less problems with annual weeds, and increased organic matter contents of soils. Problems that occur using no-tillage are residue clearance difficulties when seeding, inadequate weed control, a greater potential for insects, rodents and plant diseases, soil compaction, increased losses of fertilizer nitrogen, and poor crop emergence due to cooler soil temperatures. The surface plant residue layer present in no-till systems increases moisture collection, infiltration and retention. Plant residues that are left on the soil surface and not incorporated, decompose slower and mineralization of nitrogen is slower. Nitrogen is thought to be more efficiently conserved under no-tillage compared to tilled cropping. Ammonium nitrate generally results in greater yields than urea when surface broadcast for no-till cropping. Research studies to evaluate band placement of nitrogen under no-till cropping have shown yield increases in favour of banding compared to surface broadcasting.

3. MATERIALS AND METHODS

Three experiments were conducted comparing methods of nitrogen fertilization for a no-tillage cropping system. Two of the experiments contained tillage treatments. The first experiment compared broadcast urea and ammonium nitrate under no-till and tilled cropping. The second experiment compared broadcast and banded urea and ammonium nitrate, and anhydrous ammonia, again for no-till and tilled cropping. The third experiment was a comparison of the interaction between fall and spring applications by broadcasting, with or without incorporation, and banding. Only ammonium nitrate was used in the last experiment. In the first and third experiments, N-15 enriched fertilizers were utilized, while the second experiment used standard commercial fertilizers.

3.1 Comparison of Broadcast Urea and Ammonium Nitrate

An experiment was conducted at three sites in Southern Alberta during 1980 to compare the amount of fertilizer nitrogen uptake by grain with broadcast urea and ammonium nitrate fertilizers under both no-till and tilled cropping. The experiment was placed on existing research fields which compared conventional tillage and no-tillage.

The first site was about 12 km north of Foremost in the Brown soil zone. The second site was 11 km northwest of Raymond and the third site was at the Lethbridge Research Station. The last two sites were located in the Dark Brown soil zone (See Appendix A for a site description).

A randomized block design with four replications containing five fertilizer treatments and a zero-nitrogen treatment was placed on both a tilled field and a no-till field at each site. The two fields were adjacent to each other. The fertilizer treatments were ammonium nitrate (AN) 40, AN 80, Urea (U) 40, and U 80 kg/ha of nitrogen. The fertilizers had a 2% atom percentage of N-15. In the case of the ammonium nitrate, the N-15 was equally divided between the ammonium and nitrate ions.

The fertilizers were broadcast on the soil surface the first week in May, approximately one week before seeding. The plots were one square metre plots that were adjacent to each other. The urea and ammonium nitrate were surface broadcast on the plots by hand. The urea was in a granular form with the granules about 1.5 mm in diameter. The ammonium nitrate was in a powder form with the individual particles about 0.1-0.2 mm in diameter.

In the tilled field, the fertilizers were incorporated to a 10 cm depth, using a garden rake, while in the no-till field the fertilizers were left on the soil-plant residue surface. The tilled plots had been cultivated twice using a field cultivator before the fertilizers were applied. The only incorporation that occurred under no-till was that which resulted from the seeding operation.

The seeding operation was done using a hoe drill with narrow seed openers (1.6 cm width) at a 20.3 cm spacing. The crop seeds were placed at a 4 cm depth. An in-row application of 10 kg/ha of P was used on all plots.

At the Foremost and Raymond sites, spring wheat (variety Chester), and at Lethbridge, barley (variety Galt) was seeded. The plants were grown to maturity and harvested in the first week of September. Harvest of the plants was done by hand. A 0.7 m by 0.7 m area was sampled in the center of the 1 m by 1 m plot. This area was sampled to avoid any border effects from adjacent plots. The samples were threshed and the grain was retained from each plot. The grain was weighed for yield determination and then ground to pass a 2 mm sieve. The ground samples were analyzed for total nitrogen content by a macro-Kjeldahl technique (Kirk 1950). An aliquot containing approximately 1 mg of nitrogen from the Kjeldahl analysis was acidified to a pH of 4 and was dried at 70 degrees C in an oven. The dried sample was used to determine the atom percentage

N-15 using a Micromass 602D mass spectrometer.

The results from the analyses were used to determine the nitrogen derived from the fertilizer (NDFF), nitrogen derived from the soil (NDFS) and the fertilizer use efficiency (see plant material calculations in Appendix C).

The fertilizer use efficiency data were analyzed statistically using analysis of variance. Each experiment and tillage type was analyzed as a separate experiment for each site. The results from the three sites were grouped together for a three site average. The data from the three sites were analyzed using analysis of variance with the sites being the replicates and the pooled error being used for determination of the least significant difference.

3.2 Comparison of Banded and Broadcast Urea and Ammonium Nitrate, and Anyhydrous Ammonia

Experiments were conducted for two years (1981,1982) at one site 22 km southeast of Carmangay and for one year at another site, 8 km north of Glenwood. The sites were in the Dark Brown and Black soil zones, respectively (See Appendix B for site descriptions). There were two separate experiments for each tillage type at the sites in each year. Each experiment included banded and broadcast urea, and ammonium nitrate, along with injected anhydrous ammonia, all at two rates (N at 30 and 60 kg/ha). The two different tillage experiments were continuous tilled and continuous no-till. The plots were organized in a randomized block design with 4 replicates of 11 fertilizer treatments for each separate tillage experiment. The individual plots were 1.8 m wide and 6 m long. An individual experiment covered an area 20 m by 54 m which allowed 6 m pathways between replicate blocks. The broadcast urea and ammonium nitrate, and banded anhydrous ammonia were applied one day before seeding at each site. Banding of urea and ammonium nitrate was done in the same pass as the seeding operation. The hoe drill previously described was used. The seed drill was adapted to band urea or ammonium nitrate. A blanket application of P at 10 kg/ha was applied in the seed row.

The broadcast fertilizer treatments were incorporated to a 10 cm depth under tillage and were left on the soil-plant residue surface under no-tillage. The banded treatments consisted of alternate inter-row bands at a 41 cm spacing and a 10 cm depth. The anhydrous ammonia was applied using a small 1.8 m wide applicator. The bands of ammonia were 15 cm deep and spaced 30 cm apart (see Figure 1).

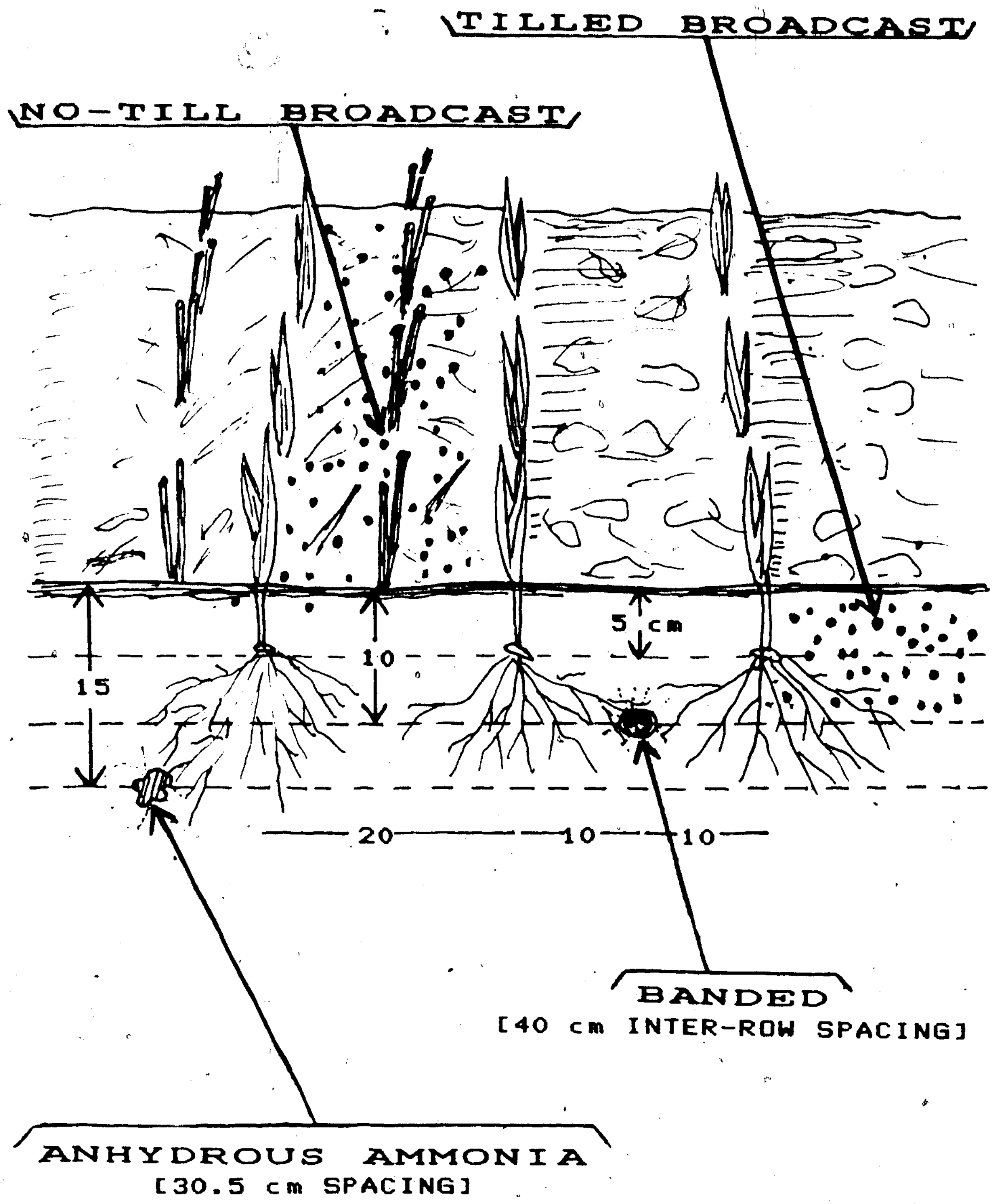

Figure 1 Fertilizer Placement

Yield samples were taken at plant maturity with a small plot combine which took a sample 1.2 m wide and 6 m long down the center of the plots. The yield data from each separate experiment were analyzed statistically using analysis of variance. The data from each of the six experiments (three on tillage and three on no-till) were analyzed statistically for differences between the forms of nitrogen, placement, timing of application, and some of the interactions between the main factors. Each experiment was analyzed separately. Portions of the data from each experiment were analyzed as separate factorial experiments to determine if certain factors or interactions were statistically significant. The comparisons made were: overall response to nitrogen fertilizer, urea compared to ammonium nitrate (combined broadcast and banded, and broadcast only), all three forms when they were banded, the application methods for ammonium nitrate, and the application methods for urea.

3.3 Comparison of Broadcast Versus Banded, and Fall Versus Spring Applications of Ammonium Nitrate Fertilizer

The experiment was conducted at the Carmangay site used in the previous experiment. The fertilizer plots were placed on a field that had been continuously cropped using no-tillage for four years. The experimental design was randomized block with 4 replicates and 8 treatments. The ammonium nitrate fertilizer was applied to plots 1 m by 1 m in dimension which were located 2.1 m apart (center to center). Thus, there was a 1.1 m border separation between the plots. Seeding of the plots was done with the same seed drill used in the previous experiments. Because of the separation of the plots, there was no contamination of one plot from adjacent plots.

The fertilizer treatments were no-till fall broadcast, no-till spring broadcast, no-till fall banded, no-till spring banded, fall broadcast and incorporated, and spring broadcast and incorporated. Nitrogen was applied at 40 kg/ha. Ammonium nitrate containing 2% N-15 was used for all the fertilized treatments. The nitrogen fertilizer was applied by hand. The broadcast treatments were spread evenly over the square metre area. For the incorporated treatments, the fertilizer was mixed into the top 10cm of soil using a hoe and a garden rake. There was no additional tillage in the incorporated treatments. One of the two zero-nitrogen treatments in each replicate was tilled in the same manner as the incorporated fertilizer treatments. The other was not tilled and corresponded to the no-till treatments.

The banded fertilizer was applied in two bands on each square metre plot. The two bands were 33 and 66 cm from the edge of each plot. The bands were positioned in the same direction as seeding. Plant residues were cleared from two 6 cm wide strips. A small trench was excavated that was 10 cm deep and 2 cm wide. The fertilizer was split equally between the two bands and spread evenly along the bottom of each trench. The excavated soil was replaced in the trenches, smoothed and the plant residues were spread back over the band area.

The fall applied fertilizer treatments were applied in mid-October 1981. The spring applied fertilizer treatments were applied the first week in May 1982, one day before seeding.

In addition to the main portion of the experiment, there were other plots included to determine the amount of recovery in the soil in the spring of the fall-applied fertilizer nitrogen. The plots were 0.7 m by 0.7 m in size, and there were three replicates of fall broadcast, fall broadcast and incorporated, and fall banded placements. Ammonium nitrate fertilizer was applied at 40 kg of nitrogen per hectare. The fertilizer nitrogen contained 5.3% N-15. The sub-plots soils were sampled the first week in May 1982. The banded treatment consisted of a 0.7 m long, single band, 10 cm deep down the center of the plot. The broadcast treatments were as explained above.

The main plots were seeded to barley (variety Galt) the first week in May, and were grown to maturity with harvest the first week in September. Phosphate fertilizer was placed in the seed row at a rate of 10 kg/ha of phosphorus. All the above ground plant parts were included in the sample. The weights of grain and straw (plus chaff) were taken. The grain and straw were ground to pass a 2 mm sieve and were analyzed for total N and for the atom percentage N-15 as previously described. The soil in the plots was sampled three days after the harvesting of the barley.

Soil sampling depths of both the 1 m by 1 m plots and 0.7 m by 0.7 m plots were: 0-15, 15-30, 30-60, 60-90, and 90-120 cm. The top two depths were taken as 15 cm wide slices across the plot. The remaining depths were sampled with a hydraulic core sampler which removed a single 5 cm diameter core. The soil samples were analyzed for total N (Bremner 1965) with a pre-treatment so that nitrate and nitrite were included. The yields and laboratory results were used to determine the nitrogen derived from fertilizer, nitrogen derived from the soil, fertilizer use efficiency, the amount of fertilizer nitrogen recovered in the above ground plant parts and soil, and the total amount of fertilizer nitrogen recovered (See Appendix C for soil and plant calculations and baseline data).

The data from the spring soil samples were analyzed using the Students-t test.

The results from the 1 m by 1 m plots were analyzed using analysis of variance. The various parameters studied were percent fertilizer nitrogen in the above ground portion of the plant, percent fertilizer nitrogen in the soil within the depth sampled, total percent fertilizer recovered (plant plus soil fertilizer nitrogen), yield of grain, yield of straw, total plant yield (grain plus straw), and the assumed loss of fertilizer nitrogen (100 minus the total percent recovered).

4. RESULTS AND DISCUSSION

4.1 Broadcast Urea and Ammonium Nitrate

The general trend of fertilizer use efficiencies related to fertilizer form was similar for each of the three sites, regarding the no-till experiments, but varied somewhat in the tilled experiments.

At the Foremost site the lowest fertilizer use efficiencies were observed for broadcast urea fertilizer under no-tillage (Table 4.1). The highest fertilizer use efficiencies were ammonium nitrate under no-tillage. This was the only site where the greatest fertilizer use efficiencies were observed for no-till rather than tilled. The urea fertilizer was not used as efficiently as the ammonium nitrate under no-tillage. Under tilled conditions when both forms of nitrogen were incorporated, the two forms of nitrogen were not significantly different (Table 4.1).

At the Lethbridge site, the lowest fertilizer use efficiencies were again the urea fertilizer that was broadcast on a no-till soil and not incorporated (Table 4.2). The highest efficiencies observed were with ammonium nitrate, but in this instance were under tilled rather than no-till cropping. The differences between the fertilizer

Table 4.1 Fertilizer use efficiencies, Foremost site 1980

EXPERIMENT	Treatment Form	N Rate (kg/ha)	FERTILIZER USE EFFICIENCY % (grain only)
No-till	U	40	31
	U	80	23
	AN	40	52
	AN	80	47
Tilled	U	40	39
	U	80	35
	AN	40	44
	AN	80	33

U = Urea; AN = Ammonium Nitrate

L.S.D. at 95% confidence, No-till = 10, Tilled = 14

use efficiencies of urea and ammonium nitrate were not as marked as at the Foremost site for the no-till experiment. At the nitrogen rate of 40 kg/ha, the urea was less efficiently used than the ammonium nitrate. At the nitrogen rate of 80 kg/ha, even though the urea had a tendency to be less efficiently used, there was no significant difference. The interaction of fertilizer form and tillage was also somewhat different at the Lethbridge site. As at the Foremost site, there was no difference between urea and ammonium nitrate at the 40 kg of nitrogen per hectare rate. However, at the 80 kg of nitrogen per hectare rate, there was a significant difference with the ammonium nitrate being used more efficiently than urea (Table 4.2).

Results at the Raymond Site were similar to the results found at the Lethbridge site. The lowest fertilizer use efficiencies were again observed for urea under no-till conditions and the highest efficiencies were ammonium nitrate under tillage. At this site, however, there was a significant difference between urea and ammonium nitrate for both the tilled and no-till experiments (Table 4.3). The urea was less efficiently used than the ammonium nitrate.

When the data from the three sites were combined, the urea fertilizer was not as efficiently used as the ammonium

Table 4.2 Fertilizer use efficiencies, Lethbridge site 1980

EXPERIMENT	Treatment Form	N Rate (kg/ha)	FERTILIZER USE EFFICIENCY % (grain only)
No-till	U	40	11
	U	80	9
	AN	40	23
	AN	80	15
Tilled	U	40	22
	U	80	17
	AN	40	29
	AN	80	33

U = Urea, AN = Ammonium Nitrate

L.S.D. at 95% confidence, No-till = 10, Tilled = 10

nitrate (Table 4.4). Under no-tillage, the urea had fertilizer use efficiencies of 17 and 14% for the nitrogen levels of 40 and 80 kg/ha respectively compared to efficiencies of 32 and 26% for ammonium nitrate. The same comparisons for tillage were 25 and 23% compared to 34 and 31%. Averaging the results for the two levels of nitrogen fertilizer (40 and 80 kg/ha) the ammonium nitrate compared to urea resulted in an increase in fertilizer use efficiency of 20 and 13% for no-tillage and tillage respectively.

There are two explanations for the lower efficiency of urea compared to ammonium nitrate. They are greater volatilization losses of ammonia as urea is hydrolyzed (Schneider et al 1979, Touchton and Hargrove 1982), and greater immobilization of urea by the soil biomass (Hargrove and Kissel 1979).

The results from these experiments agree well with the results that Schneider et al (1979) obtained at two sites in North Dakota with wheat fertilized by broadcast urea and ammonium nitrate under no-till. Yields were lower with urea compared to ammonium nitrate. Bandel (1984) mentioned that volatilization losses may be as high as between 30 to 50% from spring broadcast urea under no-till corn production. Fox and Hoffman(1981) reported greater yields from broadcast ammonium nitrate than from broadcast urea in no-till corn cropping.

This initial 1980 study with broadcast nitrogen fertilizers on no-till or broadcast-incorporation on tillage suggested that other methods of application should be investigated. Bandel et al (1980) stressed the need for research comparing the efficiencies of broadcast and banded urea fertilizer under no-till cropping.

4.2 Comparison of Banded and Broadcast Urea and Ammonium Nitrate, and Anhydrous Ammonia

In all the three no-till and the three tilled experiments, the top yielding treatments were nitrogen fertilizers that had been placed in bands in the soil, while generally the lower yielding fertilizer treatments were surface broadcast (Tables 4.5 and 4.6). In all except one of the experiments, there was a highly significant response to added fertilizer (Tables 4.7 and 4.8). The exception was the tilled experiment at the Glenwood site in 1982 (Tables 4.6 and 4.8). The zero-nitrogen plots had a four replicate average yield of 1629 kg/ha. This was not significantly different from all except one of the fertilized treatments. The only fertilized treatment significantly different from the check treatment was the anhydrous ammonia at the 60 kg/ha rate of nitrogen that had a yield of 2076 kg/ha. This

Table 4.3 Fertilizer use efficiencies, Raymond site 1980

EXPERIMENT	Treatment Form	N Rate (kg/ha)	FERTILIZER USE EFFICIENCY % (grain only)
No-till	U	40	8
	U	80	11
	AN	40	22
	AN	80	17
Tilled	U	40	14
	U	80	17
	AN	40	30
	AN	80	25

U = Urea, AN = Ammonium Nitrate

L.S.D. at 95% confidence, No-till = 5, Tilled = 6

Table 4.4 Fertilizer use efficiencies, three site average

EXPERIMENTS	Treatment Form	N Rate (kg/ha)	FERTILIZER USE EFFICIENCY % (grain only)
No-till	U	40	17
	U	80	14
	AN	40	32
	AN	80	26
Tilled	U	40	25
	U	80	23
	AN	40	34
	AN	80	31

U = Urea, AN = Ammonium Nitrate

L.S.D. at 95% confidence, No-till = 8, Tilled = 8

is difficult to explain because the tilled field had lower plant available nitrogen than the no-till field according to the previous fall soil test results (Table B.2 in Appendix B). Under no-tillage, there was a significant response to added fertilizer nitrogen. Also, the highest yielding treatment for both the tillage and no-tillage experiments at the Glenwood site in 1982 had similar yields (Tables 4.5 and 4.6). The yields were 2040 for banded urea at a nitrogen rate of 60 kg/ha under no-tillage and 2076 for banded anhydrous ammonia at a nitrogen rate of 60 kg/ha under tillage.

When the average yields from urea and ammonium nitrate are compared without separating banded or broadcast treatments, there was no statistically significant difference between the two forms (Tables 4.7 and 4.8). If only the broadcast treatments are compared for the two forms in question, there was no statistical difference observed in the tilled experiments (Table 4.8). Under no-tillage however, one of the experiments, the Carmangay site in 1981, showed a significantly greater yield with ammonium nitrate compared to urea (Table 4.7). The average yields for broadcast ammonium nitrate and urea were 1973 and 1721 kg/ha respectively at the Carmangay site in 1981). The other two no-till experiments in 1982 showed no difference between the two granular forms of nitrogen when they were broadcast. Fox and Hoffman (1981) reported lower yields and lower nitrogen uptake with urea compared to ammonium nitrate in two of four years for no-till corn in Pennsylvania. They attributed the variability of response to unincorporated urea fertilizer to the timing of rainfall after nitrogen application. From their observations, they made the following general conclusions regarding ammonia volatilization from the urea fertilizer under no-till: (1) loss was insignificant if there was 10 mm rain within 48 hours of application of urea; (2) if the 10 mm rain was 3 days after application, losses could be moderate (<10%); (3) if 3 to 5 mm of rain fell within 5 days, or 7 to 9 mm within 9 days, losses could be moderate (10 to 30%); and (4) if no rain fell within 6 days, the loss could be substantial (>30%). Although no accurate rainfall data are available from the Carmangay and Glenwood sites, it was noted that the Carmangay site in 1981 received no significant precipitation for about two weeks after seeding. In 1982 at both the Carmangay and Glenwood sites, there was some rain observed within two weeks of the fertilizer application. The rain gauges at the sites were read every two to three weeks after seeding. Despite the scant rainfall data, the author

Table 4.5 Yields of treatments comparing three forms of nitrogen, placement, and rate of N for no-tillage

Form	Placement	N Rate (kg/ha)	EXPERIMENT Carmangay 1981	Carmangay 1982	Glenwood 1982
			- kg grain/ha		
Check	none	0	1029	810	1134
AN	Broadcast	30	1744	989	1548
AN	Broadcast	60	2203	1716	1842
AN	Banded	30	1973	1278	1593
AN	Banded	60	2183	1900	1761
U	Broadcast	30	1640	1167	1660
U	Broadcast	60	1802	1433	1786
U	Banded	30	2253	1334	1694
U	Banded	60	2690	1992	2040
AA	Banded	30	2264	1141	1898
AA	Banded	60	2883	1572	1976
L.S.D. at 95% confidence =			524	526	474

AN = Ammonium Nitrate, AA = Anhydrous Ammonia, U = Urea

Table 4.6 Yields of treatments comparing three forms of nitrogen, placement and rate of N for tillage

Form	Placement	N Rate (kg/ha)	EXPERIMENT Carmangay 1981	Carmangay 1982	Glenwood 1982
			kg grain/ha		
Check	none	0	1101	884	1629
AN	Broadcast	30	1109	1457	1817
AN	Broadcast	60	1620	1744	1666
AN	Banded	30	1229	1481	1398
AN	Banded	60	2012	1808	1986
U	Broadcast	30	1120	1386	1624
U	Broadcast	60	1479	1696	1597
U	Banded	30	1384	1517	1788
U	Banded	60	1665	2024	1971
AA	Banded	30	1698	1953	1723
AA	Banded	60	1944	1814	2076
L.S.D. at 95% confidence =			336	453	409

AN = Ammonium Nitrate, AA = Anhydrous Ammonia, U = Urea speculates that the relatively greater yield response to urea in relation to ammonium nitrate for the no-till experiments in 1982 compared to 1981 may have been due to rainfall soon after the fertilizer application.

There were no significant differences in yields from banded urea and ammonium nitrate on the tilled experiments, but in two of the three no-till experiments, the urea yielded more than the ammonium nitrate (Table 4.7). These two experiments were at Carmangay 1981 and at Glenwood 1982. The average differences of yield in favour of urea were 393 and 190 kg/ha, respectively (Table 4.5). These results do not agree with the results of other researchers. Harapiak (1980) mentioned that all forms of nitrogen fertilizer should be equally effective for no-tillage when placed in bands. The results from this study tend to show that the urea was more efficiently used than ammonium nitrate when the two forms were banded under no-tillage. It is the author's opinion that this tendency should be further investigated. One possible explanation for the difference is lower denitrification losses from the urea than ammonium nitrate under more moist surface soils for no-till compared to tillage.

If broadcast ammonium nitrate was compared to banded ammonium nitrate, no difference was observed for any of the

Table 4.7 Summary of comparisons from the experiments under no-tillage

COMPARISON	NO-TILL		
	Carmangay		Glenwood
	1981	1982	1982
Response to N	**	**	**
Forms (U and AN)	ns	ns	ns
Forms (broadcast)	AN>U*	ns	ns
Forms (banded)	AA>U>AN*	ns	AA=U>AN*
Methods (AN)	ns	ns	ns
Methods (U)	Ba>Br*	Ba>Br*	Ba>Br*

ns = not significant, N = nitrogen, U = Urea,
AN = Ammonium Nitrate, AA = Anhydrous Ammonia,
Ba = Banded, Br = Broadcast
* = significant difference at 95% confidence,
** = significant difference at 99% confidence

Table 4.8 Summary of comparisons from the experiments under tillage

COMPARISON	TILLED		
	Carmangay		Glenwood
	1981	1982	1982
Response to N	**	**	ns
Forms (U and AN)	ns	ns	ns
Forms (broadcast)	ns	ns	ns
Forms (banded)	AA>U=AN*	ns	ns
Methods (AN)	Ba>Br*	ns	Ba>Br*
Methods (U)	Ba>Br*	Ba>Br*	Ba>Br*

ns = not significant, N = Nitrogen, U = Urea,
AN = Ammonium Nitrate, AA = Anhydrous Ammonia,
Ba = Banded, Br = Broadcast
* = significance at 95% confidence,
** = significance at 99% confidence

three no-till experiments (Table 4.7). However, for the tilled experiments, banding resulted in 388 and 120 kg/ha greater yields than broadcasting for the Carmangay 1981 and Glenwood 1982 sites respectively. These results indicate that broadcasting and banding ammonium nitrate are equal under no-till. These results are not in agreement with many reports favouring band placement under no-till cropping regardless of the nitrogen fertilizer form (urea or ammonium nitrate), (Shulte 1979, Doran 1983). Engle et al (1980) indicated that banding will result in greater yields than broadcasting because of less immobilization by the soil biomass and because of less weed competition. Also, results reported in the following section (4.3) using N-15 enriched ammonium nitrate show both yield increases and higher plant uptake of fertilizer nitrogen when banding is compared to broadcasting.

The anhydrous ammonia treatments tended to be high yielding in all six of the experiments (Tables 4.5 and 4.6). In the two experiments in 1981 at Carmangay, there were greater average yields of 299 and 248 kg/ha for the no-till and tilled experiments, respectively, when anhydrous ammonia was compared to banded urea and ammonium nitrate (Tables 4.7 and 4.8). The other four experiments in 1982 showed that anhydrous ammonia was not significantly different from banded urea and ammonium nitrate, but anhydrous ammonia was always one of the high yielding treatments. Yields from anhydrous ammonia under no-tillage have not been reported in the literature. It has been suggested that using anhydrous ammonia would give satisfactory results. For example, Phillips and Young (1973) mentioned that anhydrous ammonia could be used as a pre-plant or side-dressing application. Deiber et al (1978) suggested that the injection of anhydrous ammonia would cause unwanted soil disturbance and that the crop residues would cause clearance difficulties. However, Fee (1982) suggested that any problems with anhydrous ammonia on no-till could be overcome. The results reported in this section indicate anhydrous ammonia is a suitable nitrogen fertilizer for no-till cropping.

A final important result from each of the six experiments was that banded urea yielded significantly more than broadcast urea (Tables 4.7 and 4.8). The average yield increase due to banding urea rather than broadcasting under no-tillage was 419 kg/ha. The corresponding average yield increase for urea under tillage was 240 kg/ha. Banding urea was superior for both tillage and no-tillage cropping although the effect was greatest with no-tillage. The probable reason for this result is that surface broadcasting of urea can result in lower crop yields than banding because of higher ammonia volatilization losses after urea hydrolysis (Touchton and Hargrove 1982). Warren (1983) mentioned the difficulty to design a urea fertilizer program for no-till unless the urea could be incorporated into the soil. Bandell et al (1980), and Bandel (1984) also emphasized the importance of banding urea for no-tillage cropping.

4.3 Broadcast versus banded and fall versus spring applications of ammonium nitrate fertilizer

The data from spring soil sampling from the N-15 experiment at Carmangay showed no significant difference between the fall treatments regarding the total fertilizer nitrogen recovery to a 120 cm depth (Table 4.9). However, with sampling to only the 30 cm depth, there were significant differences (Table 4.9). The method of sampling may have been a factor in the high degree of variability. The top two layers were each sampled by taking a 15 cm wide and 15 cm deep slice across the plot. Sampling below this depth was done using a single 5 cm diameter core from the center of the plot. The 30-120 cm depth was more variable in nitrogen recovery among the three replicates, compared to the 0-30 cm depth sampled by slicing.

The percent recovery to a 120 cm depth for the fall treatments were 95% for the broadcast and incorporated treatment, 96% for the banded treatment and 77% for the broadcast treatment (Table 4.9). There was a tendency for more fertilizer loss in the treatment that was surface broadcast and not incorporated as compared to the treatments with incorporation or banding. Considering only the 0-30 cm depth, the fall broadcast treatment had markedly less fertilizer nitrogen recovery than the incorporated treatment (Table 4.9). The probable reason why there was a significant difference for results from samples down to the 30 cm depth and not for the total depth sampled was due to differences in sampling techniques. The 0-15 and 15-30 cm depths were sampled by taking a slice of soil across the plot, mixing the whole volume of soil from which a sub-sample was removed and analyzed for the total nitrogen content. The sub-samples from depths below 30 cm were taken from a single core from the centre of the plot. The core sampling technique gave more variable results than the soil slice technique. One possible way to decrease the variability among the samples taken from the soil cores would be to take considerably more cores (perhaps six), bulk them together and remove a sub-sample after mixing to be analyzed for total nitrogen.

Malhi and Nyborg (1983) recovered only 71% of N-15 enriched urea fertilizer in the spring that was incorporated into a Black soil at Ellerslie, Alberta, on October 24th. Recoveries of incorporated KNO3 and banded (NH4)2SO4 were 60% and 84%, respectively. Aulakh and Rennie (1984) obtained spring soil sampling recoveries of 73% and 89%, respectively, from N-15 enriched potassium nitrate and urea that was incorporated in September in a Black Soil at Blaine Lake, Saskatchewan. The average of recoveries for the three methods of application in the spring at Carmangay using ammonium nitrate were in general agreement with the results reported in the Malhi and Nyborg (1983) and Aulakh and Rennie (1984) studies.

Yield results obtained from the main plots in the fall showed that soil disturbances on the one zero-nitrogen treatment resulted in a yield increase over the undisturbed treatment (Table D.2). The average yield of the incorporated zero-nitrogen treatment was 1050 kg/ha compared to 680 kg/ha for the undisturbed zero-nitrogen treatment. Apparently, more nitrogen was mineralized from plant residues and soil organic matter as a result of the soil disturbance. However, this increase in available nitrogen from the soil cultivation did not significantly affect the amount of fertilizer nitrogen that was taken up by the barley (Table 4.10). The fall broadcast-incorporated and fall broadcast treatments had fertilizer use efficiencies of 10 and 14% respectively. There appears to have been a tendency to reduce plant uptake of fertilizer nitrogen by disturbing the soil in the fall. House et al (1984) reported that tillage increases the rate of crop residue mineralization. Other researchers mentioned that nitrogen mineralized at a slower rate under no-tillage compared to tillage (Moschler and Martens 1975, Deibert et al 1978, Triplett et al 1979, Frye et al 1980, Phillips et al 1981, Powlson 1980, Engle et al 1980, Peterson et al 1981, Carter 1982, Randall 1983, Stinner et al 1983 and Grevers 1984).

at was recovered in the plants, i.e., fertilizer use efficiencies for the six fertilizer treatments ranged from a low of 10% to a high of 43% (Table 4.10). The lowest fertilizer use efficiencies were 10 and 14% for the fall broadcast incorporated and fall unincorporated treatments, respectively. The spring broadcast incorporated and unincorporated spring treatments had identical efficiencies of 23%. The banded treatments had efficiencies of 34 and 43% for the fall and spring applications respectively. These results show that the least efficient manner to supply nitrogen fertilizer to the crop plants was to broadcast

TABLE 4.9 Fertilizer nitrogen present in the soil at spring sampling, Carmangay, Fall 1981 to Spring 1982

TREATMENT	FERTILIZER N RECOVERED (%)	
	0-30 cm	0-120 cm
Fall Broadcast	49a	77a
Fall Broadcast and incorporated	79b	96a
Fall Banded	65ab	95a

For each column, different letters denote significance at 95% confidence.

fertilizer in the fall whether it was incorporated or not. Broadcasting in the spring resulted in higher levels of uptake of fertilizer compared to fall broadcasting. All four broadcast fertilizer treatments were less efficiently used than banding whether the banding was done in the fall or spring. The spring banded treatment was more efficiently used by the barley than was the fall banded treatment.

There are few significant differences among the treatments with respect to the amount of residual fertilizer nitrogen in the soil after harvest (Table 4.11). The two treatments with the lowest soil recoveries (spring band and fall band) as shown in Table 4.11, had the highest fertilizer use efficiencies (Table 4.10).

The distribution of residual fertilizer nitrogen in the soil profile was influenced by the timing of the fertilizer application and the method of placement (Table 4.12). Banding has the effect of physically placing the fertilizer nitrogen deeper in the soil profile compared to broadcasting. Fall applications resulted in deeper distribution as compared to spring applications. Apparently fall-applied fertilizer nitrogen was partly leached down the soil profile by late fall, winter and early spring precipitation.

The total amount of fertilizer nitrogen remaining in the soil-plant system is the sum of the portion remaining in the soil and the portion which was taken into the above ground portion of the barley plants. The plant uptake portion, soil remaining portion, and the total amount remaining are shown in Figure 2. All fertilizer nitrogen not accounted for in the soil to a 120 cm depth and the above ground portion of the plants is assumed to be lost through denitrificati n, ammonia volatilization or leaching. This assumption is consistent with previously reported studies

Table 4.10 The effect of tillage, time of application, and methods of application on use of N-15 enriched NH_4NO_3 fertilizer, Carmangay 1982

TREATMENT	FERTILIZER USE EFFICIENCY (%)
Incorporated Fall	10
No-till Fall Broadcast	14
Incorporated Spring	23
No-till Spring Broadcast	23
No-till Fall Banded	34
No-till Spring Banded	43

L.S.D. at 95% confidence = 9

regarding no-tillage in England and Kentucky, respectively, (Dowdell and Crees 1980, Kitur et al 1984) and tilled cropping in Central Alberta (Malhi and Nyborg 1983).

The no-till fall broadcast treatment had one of the lowest plant uptake amounts and one of the lowest soil residual amounts of fertilizer nitrogen (Figure 2). This treatment had a loss of 37% of applied fertilizer. By incorporating the fertilizer into the top 10 cm of soil, the plant uptake amount was not significantly different, but the loss of fertilizer nitrogen from the soil-plant system was reduced to 23%. The spring broadcast-incorporated and no-till spring broadcast treatments were similar in regards to plant uptake, soil storage and loss of fertilizer nitrogen. However, this experiment was conducted with ammonium nitrate, and if urea fertilizer had been used, there might have been differences between spring broadcast-incorporated and no-till spring broadcast as was shown in results from the 1980 experiments in this study. The potential for volatilization losses after urea hydrolysis by urease activity can be greater for a broadcast treatment without incorporation than if it is incorporated (Fenn and Miyamoto 1981).

The losses from the fall band and spring band treatments did not differ significantly. The loss of applied nitrogen was 17 and 9, respectively. Although not significantly different in this experiment, the fall band treatment had more possibility for leaching and/or denitrification losses than the spring banded application.

The data from this experiment, which showed that the spring fertilizer applications resulted in greater plant uptake of fertilizer nitrogen than equivalent fall

Table 4.11 The effect of tillage, time of application and methods of application on recovery of N-15 enriched NH_4NO_3 fertilizer in the soil, Carmangay, 1982

TREATMENT	RECOVERY OF FERTILIZER N (%)
No-till Spring Banded	48
No-till Fall Banded	49
No-till Fall Broadcast	50
Spring Incorporated	62
No-till Spring Broadcast	65
Fall Incorporated	66

L.S.D. at 95% confidence = 16

applications, agrees with work under no-tillage in Kansas by Olson and Swallow (1984). They reported that spring applications of fertilizer resulted in more efficient fertilizer use than fall applications in four of five years of a study which measured the fate of N-15 enriched nitrogen fertilizer applied to winter wheat.

Table 4.12 Distribution of fertilizer nitrogen remaining in the soil by sampling depths after harvest (% of total applied)

SAMPLING DEPTH (cm)	TREATMENT Inc Fall Br	No-till Fall Br	Inc Spring Br	No-till Spring Br	No-till Fall Band	No-till Spring Band
0-15	41	27	46	46	21	32
15-30	13	7	14	18	10	11
30-60	9	7	2	1	11	4
60-90	2	5	0	0	5	1
90-120	1	4	0	0	2	0
Total	66	50	62	65	49	48

Inc = Incorporated, Band = Banded, Br = Broadcast

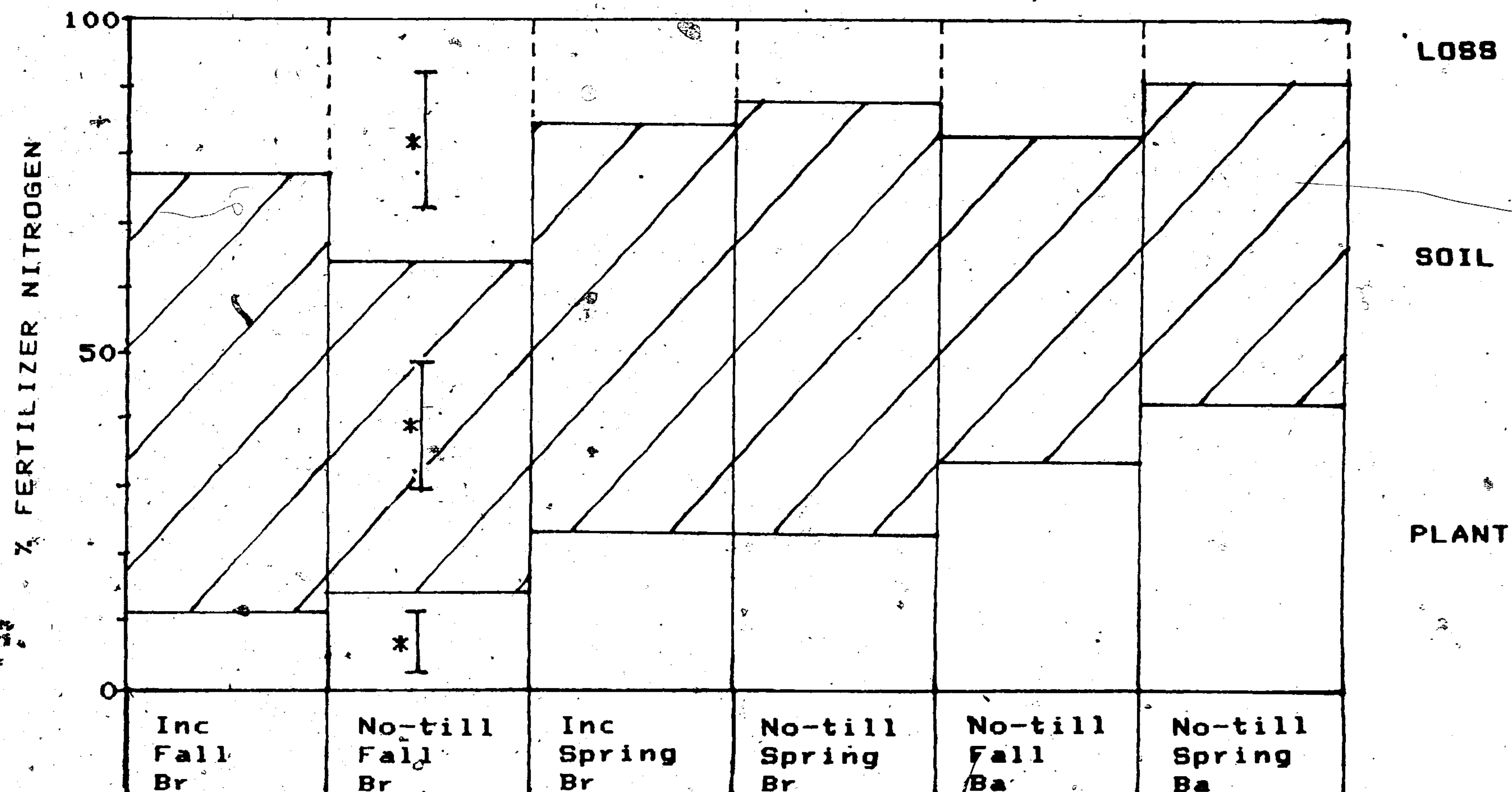

Figure 2 Fertilizer nitrogen recovery

(Inc = incorporated, Br = Broadcast, Ba = Band, * = L.S.D. at 95% confidence)

Banding of the ammonium nitrate had the effect of making the timing of fertilizer application less critical. Bandel (1984) concluded that injecting urea-ammonium nitrate fertilizer solution early in the spring reduced the effect of timing by lowering fertilizer losses compared to the same fertilizer surface broadcast at the same time.

Another effect of banding was that the fertilizer was used more efficiently by the crop plants (Figure 2). Doran (1983) reported a 20% increase in yields from banded fertilizer nitrogen compared to broadcasting. He attributed the greater yields to increased nitrogen use efficiency because banding placed the fertilizer out of the highly biologically-active surface layer so there was less immobilization by the soil biomass. Other researchers have mentioned that placement in bands results in less immobilization of fertilizer nitrogen (Engle et al 1980 and 1982, Fee 1982, Rasmussen 1983, Tomar and Soper 1981, Fredrickson et al 1982, and Rice and Smith 1984). The statistical analyses for the various factors studied in this experiment are summarized in Table D.1 in Appendix D.

5. CONCLUSIONS AND RECOMMENDATIONS

The following are conclusions stemming from the results of the three experiments reported in this study:

1. Broadcasting ammonium nitrate resulted in greater uptake of nitrogen by the crop compared to the same treatment for urea.

2. When a granular form of nitrogen (urea or ammonium nitrate) was used for no-tillage and tilled cropping, placing the fertilizer in bands rather than surface broadcasting resulted in higher yields. This was especially so for urea.

3. The anhydrous ammonia applications were some of the higher yielding treatments compared to broadcast or banded urea and ammonium nitrate.

4. If urea or ammonium nitrate were placed in bands in the soil, the resulting crop yields more nearly approached the yields resulting from anhydrous ammonia.

5. Spring applications of nitrogen fertilizer were more efficiently used by crop plants than equivalent fall applications.

6. Banding of nitrogen fertilizers during the fall was more efficiently used by the crop plants than a spring surface broadcast application.

The following are recommendations for further research into forms and methods of application of nitrogen fertilizer for no-till cropping:

1. When [illegible] 15 enriched nitrogen fertilizers on small plots as done in two of the three sets of experiments in this study, higher levels of enrichment should be used. This is advised so that the amount of fertilizer nitrogen remaining in the soil can be more accurately determined (for example 5 to 10% abundance rather than 2% used in this study).

2. It would be useful to repeat the last experiment using both urea and ammonium nitrate forms of nitrogen. This would allow comparisons between these two forms as affected by the method and timing of application.

3. Experiments of a longer duration (at least 5 years) in which the various fertilizer treatments would be applied to the same soil plot each year are recommended. This would allow monitoring of soil organic matter levels and soil biomass size to see if these two characteristics are greatly affected by the fertilizer treatment.

4. Experiments should be conducted having a wider spectrum of fertilizer levels to determine the yield response curves for crops grown using no-tillage cropping practices.

6. REFERENCES

Aulakh, M.S., and Rennie, D.A., 1984. Transformations of fall-applied nitrogen-15 labelled fertilizers. Soil Sci. Soc. Am. J. 48:1184-1189.

Bandel, V.A., Ozienia, S., Stanford, G., Legg, J.O. 1975. Nitrogen behavior under no-till vs. conventional corn culture. First-year results using unlabelled nitrogen fertilizer. Agron. J. 67:782-786.

Bandel, V.A., Ozienia, S. and Stanford, G. 1980. Comparison of nitrogen fertilizers for no-till corn. Agron. J. 72:337-341.

Bandel, V.A. 1984. Maximizing N efficiency in no-till corn. Solutions. March/April:36-42

Blevins, R.L., Thomas, G.W. and Cornelius, P.L. 1977. Influence of no-tillage and nitrogen fertilization on certain soil properties after five years of continuous corn. Agron. J. 69:383-386.

Blevins, R.L., Thomas, G.W., Smith, M.S., Frye, W.W. and Cornelius, P.L., 1983. Changes in soil properties after 10 years continuous non-tilled and conventionally tilled corn. Soil Tillage Res. 3:135-146.

Bremner, J.M., 1965. Macro-Kjeldahl method to include nitrate and nitrite. In C.A. Black, ed. Methods of soil analysis, part 2, chemical and microbiological properties. American Society of Agronomy, Madison, Wis.

Broder, M., 1981. No-till systems may require more nitrogen. Crops and Soils May-June:23.

Burford, J.R., Dowdell, R.J. and Crees, R. 1981. Emission of nitrous oxide to the atmosphere from direct-drilled and ploughed clay soils. J. Sci. Food Agric. 32:219-223.

Cannell, R.Q., Ellis, F.B., Christian, D.D., Graham, J.P. and Douglas, J.T., 1980. The growth and yield of winter cereals after direct drilling, shallow cultivation and ploughing on non-calcareous clay soils, 1974-8. J. Agri. Sci. Camb. 94:345-359.

Cannell, R.Q., 1981. Potentials and problems of simplified cultivation and conservation tillage. Outlook Agr. 10:379-384.

Carter, R.M., 1982. Nitrogen cycling in zero tillage farming systems. Ph.D. Thesis, Department of Soil Science, University of Saskatchewan, Saskatoon.

Christensen, L. and Magleby, R., 1983. Planting without plowing. Farmline. April:12-13.

Crosson, P., 1982. Conservation tillage and conventional tillage: A comparative assessment. PB82-249160, Resources for the Future., Inc. Washington, D.C.

Deibert, E.J., French, E., Hoag, B., and Nowatzki, R., 1978. No-till: North Dakota research emphasis. N.D. Farm Res. 35:3-7.

Doran, J.W., 1980. Soil microbial and biochemical changes associated with reduced tillage. Soil Sci. Soc. Am. J. 44:765-771.

Doran, J.W., 1983. Tailoring fertilizer placement. Agr. Res. May:12.

Douglas, J.T., Goss, M.J., and Hill, D., 1980. Measurements of pore characteristics in a clay soil under ploughing and direct drilling, including use of radioactive tracer (Ce-144) technique. Soil & Tillage Res. 1:11-18.

Dowdell, R.J., Crees, R., Burford, J.R., and Cannell, R.Q., 1979. Oxygen concentrations in a clay soil after ploughing or direct drilling. J. Soil Sci. 30:239-245.

Dowdell, R.J., and Crees, [illegible]., 1980. The uptake of N-15 labelled fertiliser by winter wheat and its immobilisation in a clay soil after direct drilling or ploughing. J. Sci. Food Agric. 31:992-996.

Ellis, F.[illegible]lliot, J.G., Pollard, F., Cannell, R.Q., and Barnes, B.[illegible]979. Comparison of direct drilling, reduced cultivation and ploughing on the growth of cereals. J. Agri. Sci. Camb. 93:391-401.

Engle, C.F., Halvorson, A.R. Koehler, F.E., and Meyer, R., 1980. Fertilizing conservation and no-tillage grain production systems. Wash. State U. Cooperative Extension Service. EM4547.

Engle, C.F., Entenmann, F., Hermanson, R., Hinman, H., Meyer, R., and Hyde, G., 1982. No-tillage grain production in the intermediate rainfall area of Eastern Washington. Wash. State U. Cooperative Extension Service. EB1038.

Fee, R., 1982. How to fertilize for conservation tillage. Crops and Soils Oct.:16-19.

Fenn, L.B., and Miyamoto, S., 1981. Ammonia loss and associated reactions of urea in calcareous soils. Soil Sci. Soc. Am. J. 45:537-540.

Fleige, H., and Baeumer, K., 1974. Effect of zero-tillage on organic C and total N content and their distribution in different N-fractions in loessial soils. Agro-Ecosystems 1:19-29.

Fox, R.H., and Hoffman, L.D., 1981. The effect of N fertilizer source on grain yield, N uptake, soil pH, and lime requirement in no-till corn. Agron. J. 73-891-894.

Fredrickson, J.K., Koehler, F.E., and Cheng, H.H., 1982. Availability of N-15 labelled nitrogen in fertilizer and in wheat straw to wheat in tilled and no-till soil. Soil Sci. Soc. Am. J. 46:1218-1222.

Frye, W.W., and Thomas, G.W., 1979. The soil fertility environment in reduced tillage systems. Agron. Abstracts Annual Meeting:171.

Frye, W.W., Blevins, R.L., M[illegible]ck, L.W., Well, K.L., and Ellis, J.H., 1980. Surface application of urea and ammonium nitrate treated with N-SERVE 24 nitrogen stabilizer for no-tillage corn. Down to Earth 36:26-28.

Gantzer, C.J., and Blake, G.R., 1978. Physical characteristics of Le Sueur clay loam soil following no-till and conventional tillage. Agon. J. 70:853-857.

Grevers, M.C., 1984. Tillage and nitrogen cycling. The Optimum Tillage Challenge. Proceedings of the Sask. Inst. of Agrologists Update Series.

Hagen, J., and Tucker, B., 1982. Fertilization of Dryland and Irrigated Soils. Springer-Verlag, Berlin Heidelberg, New York.

Harapiak, J.T., 1980. Fertilization under zero and minimum tillage conditions. Presented at Managing Agricultural Technology for Profit Seminar, Banff, Alberta.

Hargrave, W.L., and Kissel, D.E., 1979. Ammonia volatilization from surface applications of urea in the field and laboratory. Soil Sci. Soc. Am. J. 43:359-36 .

Heinemann, H.G., 1978. Conserving nitrogen for corn. Ag. Research, U.S.D.A. Aug.

Heinonen, R., and Huhtapalo, A., 1978. Fertilizer placement for small grains. Seminar paper Department of Agr. Eng., U. of Alberta.

House, G.J., Stinner, B.R., Crossley, D.A. Jr., Odum, E.P., and Langdale, G.W., 1984. Nitrogen cycling in conventional and no-tillage agroecosystems in Southern Piedmont. J. Soil and Water Conservation, May-June:194-200.

Kirk, P.L., 1950. Kjeldahl method for total nitrogen. Anal. Chem. 22:354-358.

Kitur, B.K., Smith, M.S., Blevins, R.L., and Frye, W.W.,

1984. Fate of N-15 depleted ammonium nitrate applied to no-tillage and conventional tillage corn. Agron. J. 76:240:242.

Koehler, F.E., Fischer, M.E., and Meyer, R.W. Fertilization practices for no-till wheat in the Pacific Northwest. Agron. Abstracts p. 161.

Kuipers, H., 1970. Introduction: historical notes on the zero-tillage concept. Neth. J. Agric. Sci. 18:219-224.

Lal, R., 1974. No-tillage effect on soil properties and maize production in Western Nigeria. Plant and Soil 40:321-331.

Lal, R., 1976. No-tillage effects on soil properties under different crops in Western Nigeria. Soil Sci. Soc. Am. Proc. 40:762-768.

Lal, R., 1979. Influence of six years of no-tillage and conventional plowing on fertilizer response of maize (Zea maize) on an Alfisol in the tropics. Soil Sci. Soc. Am. J. 43:399-407.

Legg, J.O., 1979. Nitrogen behavior in reduced tillage systems. Agron. Abstracts, Am. Soc. Agron. p. 175.

Lindwall, C.W., 1985. Minimum tillage for conservation. Proceedings of Soil Conservation "The Ultimate Challenge". P.F.R.A., Weyburn, Saskatchewan.

Linn, D.M., and Doran, J.W., 1981. Soil microbial and dehydrogenase activities with reduce tillage as related to the degree of soil aerobiosis. Agron. Abstracts, Am. Soc. Agron. p. 165.

Lynch, J.M., and Panting, L.M., 1980. Cultivation and the soil biomass. Soil Biol. Biochem. 12:29-33.

Malhi, S.S., and Nyborg, M. 1983. Field study of the fate of fall applied N-15 labelled fertilizers in three Alberta soils. Agron. J. 75:71-74.

McMahon, M.A., and Thomas, G.W., 1976. Anion leaching in two Kentucky soils under conventional tillage and a killed sod mulch. Agron. J. 68:437-442.

Mengel, D.B., Nelson, D.W., and Huber, D.M., 1982.

Placement of nitrogen fertilizers for no-till and conventional till corn. Agron. J. 74:515-518.

Moncrief, J., 1984. Where we're headed with conservation tillage. Solutions March/April:17.

Moschler, W.W., Shear, G.M., Martens, D.C., Jones, G.D., and Wilmouth, R.R., 1972. Comparative yield and fertilizer efficiency of no-tillage and conventionally tilled corn. Agron. J. 64:229-231.

Moschler, W.W., Martens, D.C., and Shear, G.M., 1975. Residual fertility in soil continuously field cropped to corn by conventional and no-tillage methods. Agron. J. 67:45-48.

Moschler, W.W., and Martens, D.C., 1975. Nitrogen, phosphorus and potassium requrements in no-tillage and conventionally tilled corn. Proc. Soil. Sci. Soc. Am. 39:886-891.

Mueller, D.H., Daniel, T.C., and Wendt, R.C., 1981. Conservation tillage: best management practice for nonpoint runoff. Environ. Management 5:33-53.

Olson, R.V., and Swallow, C.W., 1984. Fate of labelled nitrogen fertilizer applied to winter wheat for five years. Soil Sci. Soc. Am. J. 48:583-586.

Papendick, R.I., 1984. Changing tillage and cropping systems: impacts, recent developments, and emerging research needs. U.S.D.A., W.A. 99164-6421.

Peterson, G.A., Fenster, C.R., and Lamb, J., 1981. Nitrate-N accumulation during fallow as affected by time under a no-till system. Agron. Abstracts, A.S.A. p. 187.

Phillips, S.H., Young, H.M., 1973. No Tillage Farming. Reiman Associates, Milwaukee, Wis.

Phillips, R.E., Blevins, R.L., Thomas, G.W., Frye, W.W., and Phillips, S.H., 1980. No-tillage agiculture. Sci. 208:1108-1113.

Power, J.F., Alessi, J., Reichman, G.A., and Grunes, D.L., 1973. Recovery, residual effects and fate of nitrogen fertilizer sources in a semiarid region. Agron. J. 65:765-768.

Powlson. D.S., 1980. Effect of cultivation on the mineralization of nitrogen in soil. Plant and Soil 57:151-153.

Powlson, D.S., and Jenkinson, D.S., 1981. A comparison of the organic matter, biomass, adenosine triphosphate and mineralizable nitrogen contents of ploughed and direct-drilled soils. J. Agr. Sci. Camb. 97:713-721.

Ramig, R.E., and Ekin, L., 1983. No-till annual cropping. Columbia Basin Ag. Res. Special Report 680.

Randall, G.W., 1983. Conservation tillage a plan for winning the profit game. Crops and Soils June-July, p. 18-20.

Rasmussen, P.E., 1983. Winter wheat response to nitrogen fertilizer in no-till annual cropping and conventional tillage wheat-fallow rotation. Columbia Basin Agr. Res. Special Report 680.

Rice, C.W., and Smith, M.S., 1984. Short-term immobilization of fertilizer nitrogen at the surface of no-till and plowed soils. Soil Sci. Soc. Am. J. 48:295-297.

Schneider, R.P., Sobolik, F., and Riveland, N., 1978. No-till: promise and problems. N. Dak. Farm Res. 35:12-14.

Schneider, R.P., Johnson, B.E., and Sobolik, F., 1979. Nitrogen fertilization requirements for no-tillage and minimum tillage wheat. N. Dak. Farm Res. 37:22-24.

Schulte, E.E., 1979. Buildup soil K levels before shifting to minimum tillage. Better Crops with Plant Food 63:25-27.

Stinner, B.R., Hoyt, G.D., and Todd, R.L., 1983. Changes in soil chemical properties following a 12-year fallow: a 1-year comparison of conventional tillage and no-tillage agroecosystems. Soil & Tillage Res. 3:277-290.

Stobbe, E.H., 1979. Tillage practices on the Canadian prairie. Outlook on Agr. 10:21-26.

Sumner, M.E., and Boswell, F.C., 1981. Alleviating nutrient stress. In G.F. Akin and H.M. Taylor, eds. Modifying the Root Environment to Reduce Crop Stress. A.S.A.E. Monograph No. 4.

Terman, G.L., 1979. Volatilization losses of nitrogen as ammonia from surface-applied fertilizers, organic ammendments, and crop residues. Advances in Agron. 31:189-223.

Thomas, G.W., Blevins, R.L., Phillips, R.E., and McMahon, M.A., 1973. Effect of killed sod mulch on nitrate movement and corn yield. Agron. J. 65:736-739.

Thomas, G.W., Wells, K.L., and Murdock, L. W., 1980. Fertilization and liming. In No-tillage research, research reports and reviews. U. Ken., Lexington.

Tiessen, H., Stewart, J.W.B., and Bettany, J.R., 1982. Cultivation effects on the amounts and concentration of carbon, nitrogen and phosphorus in grassland soils. Agron. J. 74:831-835.

Tomar, J.S., and Soper, R.J., 1981. Fate of tagged urea N in the field with different methods of N and organic matter placement. Agon. J. 73:991-995.

Touchton, J.T., and Hargrove, W.L., 1982. Nitrogen sources and methods of application for no-tillage corn production. Agron. J. 74:823-826.

Triplett, G.B., Osmond, C.A., and Sutton, P., 1972. Fertilizer application methods for no-till corn. Ohio Report on Research and Development Agriculture, Home Economics and Natural Resources 57:39-41.

Triplett, G.B., and Van Doren, D.M.,Jr., 1977. Agriculture without tillage. Sci. Am. 236-28-33.

Triplett, G.B., Haghiri, F., and Van Doren, D.M., Jr., 1979. Legumes supply nitrogen for no-tillage corn. Ohio Report on Research and Development Agriculture, Home Economics and Natural Resources 64:83-85.

Tyler, D.D., and Thomas, G.W., 1977. Lysimeter measurements of nitrate and chloride losses from sod under conventional and no-tillage corn. J. Envir. Quality 6:63-66.

Unger, P.W., 1978. Straw mulch effects on soil temperatures and sorghum germination and growth. Agron. J. 70:858-864.

Unger, P.W., and McCalla, T.M., 1980. Conservation tillage systems. Advances in Agron. 33:1-58.

Warren, D., 1983. No-till cropping doesn't harm soil microbes. Crops and Soils; April-May:24-25.

Zentner, R.P., and Campbell, C.A., 1985. Economics of soil conservation in the Brown soil zone of Saskatchewan. Proceedings of Soil Conservation "The Ultimate Challenge". P.F.R.A., Weyburn, Saskatchewan.

Zerfus, V.M., 1979. Development of the microflora and biological activity of a leached chernozem with the reduction of its tillage. Sov Soil Sci. 11:677-681.

7. APPENDICES

APPENDIX A

Site Descriptions for Broadcast Urea and Ammonium Nitrate Experiment

The three sites are described for soil subgroup, legal location, cropping history and soil texture in Table A.1. Soil test results in the fall prior to spring seeding are available for the Foremost site (See Table A.2), but were not available for the Raymond or Lethbridge sites.

Table A.1 Experimental Site Information

	FOREMOST	LETHBRIDGE	RAYMOND
Soil Subgroup	Orthic Brown	Orthic Dark Brown	Orthic Dark Brown
Texture Ap Horizon	SL	SiL	C
Legal Location	NE21-7-11-W4	SW3-9-21-W4	NW8-7-20-W4

Cropping History - Foremost: 3rd year continuously cropped previously crop - fallow rotation

Cropping History - Lethbridge: 2nd year continuously cropped, previously crop-fallow rotation

Cropping History - Raymond: 3rd year continuously cropped, previously crop-fallow rotation

Table A.2 Soil test results, Foremost site, fall 1979

		Tilled				No-till			
Depth		0-15	15-30	30-60	60-120	0-15	15-30	30-60	60-120
	N	35	6	11	n.a.	23	6	9	n.a.
Kg/ha	P	24	7	1	n.a.	37	4	1	n.a.
**	K	791	454	484	n.a.	574	354	205	n.a.
Texture		SL	SL	SL	SL	SL	SL	SL	SL
pH		7.4	7.8	8.2	n.a.	7.6	8.1	8.6	n.a.
Db		1.1	1.25	1.4	1.4	1.1	1.25	1.4	1.4
Total N%		--0.13*--		0.09	0.06	--0.13*--		0.09	0.06

n.a. = not available, * = average 0-30cm

** = plant available, Db = bulk density

APPENDIX B

Site Description for Carmangay and Gle[illegible]es

1. Carmangay site

(a) Soil Subgroup: Orthic Dark Brown

(b) Profile description

--Ap horizon: 10 YR 3/2 moist, SiCL, medium subangular blocky macro structure, moderate fine granular meso structure, friable, wavy boundary, 18 to 20 cm

--Bm horizon: 10 YR 4/4 moist, SiCL, moderate medium subangular blocky, wavy boundary, 20 to 30 cm

--Cca horizon: 10 YR 5/4 dry, SiCL, weak fine prismatic macro structure and moderate medium subangular meso structure

--Ck horizon: 10 YR 5/4 dry, SiCL, massive

(c) Slope 0.5 - 2%

(d) Parent Material: Lacustrine

(e) Fall 1980 and 1981 Soil Test Results

The soil test results for available nitrogen, phosphorus and potassium, soil pH and electrical conductivity are shown in the following table (Table B.1).

Table B.1 Soil test results, Carmangay site

YEAR	TILLAGE TYPE	DEPTH cm	---Kg/ha--- N	P	K	pH	E.C. mS/cm
1980	tilled	0-15	22	21	1023	7.7	0.4
		15-30	9	3	484	8.0	0.3
		30-60	10	1	340	8.3	0.3
1980	no-till	0-15	20	23	920	7.6	0.4
		15-30	8	3	490	7.9	0.3
		30-60	8	1	355	8.3	0.3
1981	tilled	0-15	5	18	866	7.0	0.4
		15-30	6	2	454	7.4	0.3
		30-60	5	0	268	7.8	0.3
1981	no-till	0-15	5	30	802	7.2	0.4
		15-30	6	5	368	7.6	0.3
		30-60	5	0.5	241	8.0	0.3

(f) Cropping History

-1977 Tilled fallow (previous crop-fallow rotation)

-1978 Crop (spring wheat)

-1979 Continuous cropping (spring wheat)

-1980 Continuous cropping (spring wheat)

-1981 Continuous cropping (spring wheat)

-1982 Continuous cropping (spring wheat)

2. Glenwood site

(a) Soil Subgroup: Orthic Black

(b) Profile description

--Ap horizon: 10 YR 3/1 moist, C, fine subangular blocky (granular within the top 5 cm), diffuse boundary, 25 to 30 cm

--Bm horizon: 10 YR 3/2 moist, C, weak subangular blocky, diffuse boundary, 15 to 29 cm

--Cca horizon: 10 YR 4/2, C, massive

(c) Slope 0.5 - 2%

(d) Parent Material - Till

(e) Fall Soil Test Results (ie: samples taken in October of 1980 and 1981)

The soil test results for available nitrogen, phosphorus and potassium, soil pH and electrical conductivity are shown in the following table (Table B.2)

Table B.2 Soil test results, Glenwood site

YEAR	TILLAGE TYPE	DEPTH (cm)	N (kg/ha)	P (kg/ha)	K (kg/ha)	pH	E.C. mS/cm
1980	Tilled	0-15	15	9	1391	6.9	0.4
		15-30	17	2	864	7.5	0.3
		30-60	9	1	592	7.9	0.3
1980	No-till	0-15	15	20	1567	6.5	0.4
		15-30	9	9	1019	6.5	0.3
		30-60	4	2	897	7.5	0.3
1981	Tilled	0-15	9	23	1204	6.4	0.3
		15-30	3	2	790	6.9	0.5
		30-60	5	0	464	7.4	0.4
1981	No-till	0-15	13	25	1346	6.2	0.3
		15-30	6	5	902	6.5	0.5
		30-60	4	0	608	7.2	0.4

(f) Cropping History

-1977 Tilled fallow (previous crop-fallow rotation)

-1978 Crop (spring wheat)

-1979 Continuous crop (spring wheat)

-1980 Continuous crop (barley)

-1981 Continuous crop (barley)

-1982 Continuous crop (barley)

APPENDIX C

Soil and Plant Data, Carmangay Site, N-15 Experiment

1. Soil texture: SiCL

2. Soil bulk density (g/cubic cm): 0-15 cm = 0.95, 15-30 cm = 1.04, 30-120 cm = 1.30

3. Total soil nitrogen: 0-15 cm = 0.150, 15-30 cm = 0.110, 30-60 cm = 0.076, 60-90 cm = 0.050, 90-120 cm = 0.045

4. % N-15 in soil nitrogen. The overall average of the soil nitrogen prior to the N-15 experiment was 0.36971% N-15 and the delta N-15 was calculated to be 9.3

5. N-15 Soil and plant calculations

(a) Plant material

(i) delta N-15 = % N-15 plant sample minus 0.3663 divided by 0.3663 times 1000

(ii) % N-15 excess = % N-15 plant sample minus the four replicate average of zero-N plot samples

(iii) % nitrogen derived from the fertilizer (NDFF) = % N-15 excess plant divided by % N-15 excess fertilizer times 100

(iv) % nitrogen derived from the soil = 100 minus NDFF

(v) % fertilizer use efficiency = NDFF times N yield (plant) divided by rate of N applied and times 100

(b) Soil sample

(i) delta N-15 = % N-15 soil sample minus 0.3663 divided by 0.3663 times 1000

(ii) % N-15 excess = % N-15 soil sample minus the average of zero-N plot samples

(iii) NDFF = % N-15 excess in soil sample divided by % N-15 excess in the fertilizer times 100

(iv) fertilizer N in the soil sample = average bulk density times the average % N in the soil layer times % NDFF

(v) total fertilizer N in the soil layer = fertilizer N g/cubic cm times the volume of the sampling area in cubic cm

APPENDIX D

Results of the Statistical Analyses, Carmangay N-15 Experiment, 1982

A summary of the statistical analyses from the experiment at Carmangay in 1982 using N-15 enriched ammonium nitrate is presented in Table D.1 below. The various results summarized are the fertilizer use efficiencies of the crop parts above the ground, percent fertilizer nitrogen recovered in the soil, total percent nitrogen recovered, yield of grain (g/plot), yield of straw plus chaff (g/plot), total plant yield (g/plot), and the assumed percent loss of fertilizer nitrogen.

A separate summary of the yield results reported in kg/ha for the various fertilizer treatments and the two control treatments are presented in Table D.2 below.

Table D.1 Summary of the results of the statistical analyses, Carmangay site N-15 experiment, 1982

OBSERVATION	TREATMENT						L.S.D.
	ISBr	IFBr	NTSBr	NTFBr	NTSBa	NTFBa	(95%)
Fertilizer Use Efficiency %	23	11	23	14	43	34	9
Fertilizer Recovery Soil %	61	66	65	50	48	49	19
Total Recovery %	84	77	88	64	91	83	23
Grain Yield g/plot	152	139	166	153	218	204	51
Straw Yield g	178	167	207	176	265	233	68
Total Plant Yield g	330	306	373	329	484	436	112
Fertilizer Loss %	16	23	12	36	9	17	20

I= Incorporated, NT = No-tillage, S = Spring, F = Fall,

Br = Broadcast, Ba = Banded

Table D.2 Yield results of the fertilizer treatments and control treatments, Carmangay site N-15 experiment, 1982

TREATMENT	YIELD OF GRAIN kg/ha
ISBr	1520
IFBr	1390
NTSBr	1660
NTFBr	1530
NTSBa	2180
NTFBa	2040
I Control	1050
NT Control	680

I = Incorporated, NT = No-tillage, S = Spring, F = Fall
Br = Broadcast. Ba = Banded
L.S.D. at 95% confidence = 510 kg/ha