THE EFFECTS OF CROP RESIDUE MANAGEMENT ON ZERO TILL CROP PRODUCTION IN MANITOBA

A Thesis

Submitted to the Faculty

of

Graduate Studies

The University of Manitoba

by

David Ronald Sparks Rourke

In Partial Fulfilment of the

Requirements for the Degree

of

Master of Science

May 1981

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ABSTRACT

Rourke, David Ronald Sparks, M.Sc., The University of Manitoba, May, 1981.
The Effects of Crop Residue Management on Zero Till Crop Production in Manitoba.
Major professor: Dr. E. H. Stobbe, Department of Plant Science.

The influence of three straw management practices on the emergence, vegetative growth and grain yield of spring wheat (*Triticum aestivum* L. cv. Sinton) and rapeseed (*Brassica napus* L. cv. Tower) grown under zero tillage and conventional tillage was studied over a two year period. The three straw management practices tested were burning, raking and spreading. The study was conducted on a well drained sandy loam soil as well as on a poorly drained clay soil.

The study indicated that emergence of wheat and to a lesser extent, rapeseed emergence could be reduced under zero tillage when straw was spread. The method of straw management had little effect on crop emergence on conventional tilled soils. Wheat yields were found to be similar under both zero tillage and conventional tillage. However, rapeseed yielded considerably higher when grown under zero tillage as compared to conventional tillage. The method of straw management was more important for zero tillage than for conventional tillage and was more important on clay soils than for sandy loam soils.

ACKNOWLEDGEMENTS

The author wishes to gratefully acknowledge the following individuals and organizations for their assistance in the preparation of this thesis.

Dr. E. H. Stobbe, my advisor, for his encouragement, support and guidance given throughout this study.

Dr. C. Shaykewich, Department of Soil Science and Professor G. M. Young, Department of Plant Science for reviewing this manuscript.

Elaine Gauer, for her cooperation in this study.

Herb Weidman, for providing land for the Sanford trials.

The summer students, Patricia Jedel, Robert Klinck, Diane Walmsley and Brent Wright, whose efforts were always appreciated and the technicians and friends in the Department who made the time more enjoyable.

The University of Manitoba and The National Science and Engineering Research Council for financial assistance.

My wife Diane, for her patience, love and understanding and for typing this manuscript.

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INTRODUCTION

Tillage has been considered a fundamental part of crop production for thousands of years. As scientific agriculture has developed, agriculturalists in their quest to increase understanding have examined the need for tillage. Kuiper (1970) suggested that there are two main schools of thought on the purposes of tillage. He proposed that the English school considered tillage primarily as a method of controlling weed growth, whereas the German school considered that tillage was absolutely necessary to develop and maintain the soil in a physical condition compatible with plant growth.

The introduction of herbicides in modern agriculture facilitated research on soil tillage. Since all weeds could be controlled without tillage, zero tillage crop production could be evaluated. Zero tillage has been defined as a system of crop production where the crop is seeded into undisturbed stubble with the least possible soil manipulation effectively possible and in combination with chemical weed control if necessary (Donaghy, 1978).

The replacement of tillage with chemicals and zero tillage cropping techniques have shown that tillage is not necessary for the growth and development of crops. Donaghy (1973) has shown that successful crop production is possible without the use of tillage in Manitoba.

Investigations examining the effects of straw management practices on crop production using conventional tillage methods have been extensively examined but there has been no research examining straw management practices in zero tillage cropping systems in Manitoba. In 1978, a joint project was initiated to examine the effects of straw management and tillage practices on crop growth and soil physical properties. Changes in soil physical properties were determined by Elaine Gauer of the Department of Soil Science, and the evaluation on the effect of crop growth is presented in this thesis.

The objective of the present study was to determine the impact of straw management on crop growth on zero till fields. The study involved the examination of three straw management practices on the growth of wheat and rapeseed on two different soil types.

LITERATURE REVIEW

Research in Zero Tillage Crop Production

Small Grain Cereals

Production of small grain cereals using zero tillage techniques has been studied over a large number of years and in a number of countries.

In the Netherlands, Bakerman and de Wit (1970) reported that small grains, corn and green manure crops offered no risk when sown by zero tillage and yields could be expected to be equal or superior to those obtained from conventional tillage. Baeumer and Bakerman (1973) while noting yields of cereals were satisfactory from zero tilled plots, stated germination and early plant growth was sometimes found to be reduced. Germination could be expected to be reduced with zero tillage if the soil was excessively wet and cold due to the presence of heavy mulches or if toxic plant residues inhibited germination. Germination rates were found to be increased with zero tillage on light to medium soils with a friable surface.

Hodgson *et al*. (1977) working in Leeds, United Kingdom found no significant difference in spring barley yields when zero tillage techniques were implemented in a trial lasting 4 years. They noted that while emergence and tillering were similar to that under conventional tillage, seedling loss was greater with zero tillage, resulting in a lower plant stand on zero till plots. They also noted that higher nitrogen applications were necessary to maintain comparable yields with zero tillage, probably due to lower rates of mineralization of soil nitrogen on zero till soils.

Finney and Knight (1973) working at Jealott's Hill, United Kingdom with winter wheat on a well drained sandy loam found marked differences in the development of the seminal root system in winter wheat on zero till plots. Slower extension of the seminal root and earlier lateral branching resulted in the production of a shallower seminal root system which persisted throughout the season. They attributed this to zero tilled soils having fewer large pores. Differences in adventitious root development, shoot growth and grain yield, however, were not observed.

Cannell et al. (1977) studied the development of cereals on heavy naturally imperfectly drained soils in southern England. These soils did, however, have tile and secondary drainage to facilitate removal of excess water. Contrary to the work of Finney and Knight (1973), they found that zero till plots had at the end of tillering, more roots below 40 cm and in the top 5 cm. As a result, in a dry year, more water was extracted from zero till soils at all depths below 40 cm. They recommended that zero tillage was suitable for the heavy soils in the United Kingdom, as zero tillage yields were always at least equal and in dry years gave higher yields of winter wheat and spring barley.

Cannell and Finney (1973) in earlier work, however, did find yield depressions of small grain cereals with zero tillage in the first years after the establishment of zero till plots. The reasons given included: inadequate drilling equipment, large numbers of perennial grassy weeds and imperfect drainage. Yields were found to improve after about 3 years. This was attributed to increased earthworm activity allowing for better internal drainage and soil tilth. Problems with drilling equipment were overcome in latter trials (Cannell et al., 1977) by burning of the surface residues to facilitate drill penetration and soil-seed contact.

Elliot et al. (1977) following recommendations by Cannell and Finney (1973) conducted their zero tillage trials on a well drained sandy loam which was free of grassy weeds and had residues removed by burning. Emergence, early plant growth and final straw yield was found to be lower on zero till plots than with conventional tillage. Grain yields while slightly lower in the first year were higher under zero tillage in the fourth year and over all four years no significant difference was found.

Examples of small grains production using zero tillage can also be found in the United States. Davidson and Santelman (1973) found zero till to produce lower yields than plowings in a four year study in Oklahoma. They, however, attributed the lower yields to problems in seeding and weed control. Wicks (1973) from North Platte, Nebraska, worked with a winter wheat-sorghum-fallow rotation. Winter wheat yields were equal or superior to conventionally tilled treatments. Zero till treatments were planted into chemically treated fallow, so no soil disturbance was involved. Wicks and Smika (1973) also studied the effect of zero tillage in a winter wheat-fallow rotation. Wheat yields obtained from no-till fallow yielded 7 bushels per acre more than wheat from conventional fallow. Fenster (1977) in a similar trial found the same trend, but yield differences were lower.

Schneider et al. (1978) working in North Dakota, obtained 35% more wheat when the wheat was sown directly into 14 inch stubble as compared to the situation where it was sown into flat stubble.

Canadian researchers have also examined the effects of zero tillage on small grain cereal production. Lindwall (1973) reports that yields of spring sown wheat on zero-tilled fallow were greater by 4 bu/ac in 2 year rotations and 7 bu/ac in 3 year rotations than yields on bladed fallow at Lethbridge. Bentley et al. (1978) working with barley at Edmonton, on three soil types, found no consistent differences in yield as a result of different tillage treatments over a 6 year period. They did observe, however, that at one location in one year the zero till plots became waterlogged and poor aeration resulted, causing nitrogen deficiencies and lower yields. Austenson et al. (1978) studied the effects of various drills on production of wheat without tillage. The results of the study shows that yields reflected initial stand establishment obtained with various drills and that better stands were obtained when amounts of residue on the soil surface were minimal.

Donaghy (1973) reported the results of three years work involving zero tilled wheat and barley on 3 soil types in Manitoba. Zero tillage was shown to result in improved crop stands. However, yields did not differ significantly from the conventionally tilled treatments.

Survival and yields of winter wheat in Manitoba has been greatly enhanced when sown directly into standing stubble using zero tillage cropping techniques (Stobbe, 1978). Direct seeding of winter wheat into standing stubble gives the benefit of being able to effectively capture snow in the stubble to provide an insulating layer to protect the winter wheat. This technique also allows for a greater amount of stored water in the soil to be used by the crop during the summer. Stobbe (1978) measured approximately a 20% yield advantage with zero till winter wheat as compared to conventionally sown winter wheat.

Small Grain Oilseed Crops

Only a limited amount of work has been conducted which involves zero till production of small grain oilseeds. Vez and Viellioud (1971) reported equal or higher oilseed rape yields using zero tillage in three out of four experiments on a heavy soil in Switzerland. Bakerman and de Wit (1970), however, obtained mainly decreased yields with zero tillage in six experiments conducted in the Netherlands. Zero tillage resulted in approximately 400 kg/ha less seed than conventional tillage. Experiments conducted by Donaghy (1973) in Manitoba showed that zero tilled rape and flax always yielded at least equal to conventional tillage. It was observed that on the heavier soils tested, yields from zero tillage plots could in some years be significantly higher. Final yields of rape and flax were found to be highly correlated to the emergence obtained in these trials.

Other Crops

Perhaps the crop receiving the most attention in regards to zero tillage crop production is corn. Sorghum and soybeans have also been tested quite extensively. More limited amounts of research have been conducted on practically every type of crop grown.

Triplett *et al*. (1970) tested 3 corn rotations on 6 soil types over a period of 6 years in Ohio. They found that on well drained medium textured soils the highest yielding treatments corresponded to the treatment leaving the most residue on the surface. The highest corn yields were, therefore, obtained from direct seeding corn onto a killed sod. This treatment was the most effective in reducing evaporation and runoff and increasing infiltration. On sandy soils, Triplett *et al*. (1970) found similar yields on zero till and ploughed treatments. At one site, however, zero till resulted in an average advantage of 13 bu/acre over 5 years. This was attributed to the mulch decreasing soil movement and increasing moisture availability. On the medium and light textured soils, zero tillage produced the highest yields regardless of rotation used. On clays, however, it was found that zero till continuous corn resulted in lower yields than continuous corn produced with conventional tillage. Corn produced under zero till conditions on the heavy clays was found to be equal to conventionally tilled corn when either a corn-oat-meadow or a corn-soybean rotation was implemented. Van Doren et al. (1976) reports the long term effects of the work initially reported by Triplett et al. (1970). After 11 years, corn yields were found to be remarkably insensitive to tillage, over a wide range of soil types, cropping systems, climates and duration of use, so long as equal plant density and weed control were achieved. They also stated that zero tillage could suffer significant yield losses on some poorly drained soils, but, apparently only when in continuous corn. Zero tillage was shown to have yield advantages on some well drained sloping soils due to conservation of water by mulch on the soil surface and stabilization of a desirable soil structure. Blevins et al. (1971) and Hill and Blevins (1973) working in Kentucky, established zero till corn on a killed sod mulch. The results of these experiments showed that zero tillage enhanced corn yields by making water more available for plant growth. Yields obtained by Hill and Blevins (1973) show that zero tillage increased corn yields by about 625 kg/ha.

Allen et al. (1977) and Unger (1978 a) at Bushland, Texas, found higher sorghum yields with zero tillage as a result of increased moisture conservation. Grain yields were also found to increase with increasing rates of mulch cover. Allen et al. (1977) reported that zero tillage resulted in approximately 500 kg/ha more grain sorghum during the 6 year study, as compared to conventionally tilled plots.

Working at Blacksburg, Virginia, Moody et al. (1963) observed that corn plants were spindly with narrow leaves and chloratic for approximately 2 months, when grown using zero tillage with a heavy mulch. This was attributed to long exposure to the cooler temperatures, associated with zero tillage. However, after 2 months the zero till plants grew faster and by silking were 64 cm taller than conventionally tilled plants. Zero till plots with high mulch and high rates of nitrogen averaged 42 bu/acre more corn than did the conventional treatment over 3 years. Shanholtz and Lillard (1969) and Moschler et al. (1972) also working at Blacksburg, Virginia, noted that zero till corn production resulted in both higher forage and grain yields. The higher yields observed in the 11 years of testing were attributed to the more favourable moisture conditions associated with zero tillage.

Sanford et al. (1973) double cropped sorghum and soybeans onto wheat stubble in Mississippi. Yields for both zero till soybeans and sorghum were lower than conventionally tilled plots in the first two years of the trials. In the third year, weeds were controlled and soybeans in this year yielded the same as conventionally tilled soybeans. The zero till sorghum, however, outyielded the conventionally tilled sorghum. McGregor et al. (1975) also working in Mississippi, found similar results with zero till soybeans where weeds were controlled.

Poor seed coverage resulted in a 16 percent lower corn stand on zero till plots in New Hampshire (Estes, 1972). Despite the significantly lower stand, silage yields were recorded to be 22.5 percent greater on zero till plots than conventional till plots. This was attributed to the greater amount of water available on zero till plots.

Siemens and Oschwald (1978) found emergence and early growth of corn, grown on zero till plots at Ames, Iowa, to be slower than on conventional tilled plots. It was also found, that treatments with the least amount of tillage tended to yield less. Other work in Iowa, by Mock and Erbach (1977) gave similar results. It was noted here, that when planting was delayed and the soil allowed to warm before planting, tillage systems had very similar effects on plant growth and no difference in yields was observed. It was suggested that cold tolerant corn hybrids were needed to take advantage of earlier planting sometimes possible with zero tillage.

Griffith et al. (1973) studied the effects of a number of tillage systems on corn production at 5 locations in Indiana. They found as tillage decreased and percent ground cover, increased plant growth was slowed and maturity delayed. This effect was most pronounced in Northern Indiana and either non-existent or opposite in Southern Indiana. It seems as though the hybrid used was extremely sensitive to soil temperatures. The cooler soil temperature of Northern Indiana reduced growth, whereas, the warmer soil temperatures of Southern Indiana enhanced production.

Lal (1976) working in Nigeria, suggested that zero tillage effects on soil temperature could be beneficial. Lal found corn always to have higher yields on zero till plots. Soybeans and cowpeas in rotation with corn, also yielded higher on zero till plots. Higher yields were attributed to retention of soil organic matter, maintenance of higher levels of total nitrogen and exchangeable bases, more favourable moisture and temperature conditions and to increased infiltration and decreased runoff. These conditions were associated with zero till plots with adequate amounts of residue.

Stibbe and Ariel (1970) working in Israel, found sorghum yielded less on zero till plots in all but the driest years. The zero till plots had been established on previously tilled soils and the previous years traffic and tillage pans were a problem on zero till plots. Plants on zero till plots were characterized by shallow rooting. The shallow rooting and lack of a mulch (residues burned) restricted the amount of soil moisture available to plants, causing earlier maturity and dying off of the zero till plants. When vetch was sown in the sorghum stubble, zero till plots also yielded less.

Low yields were attributed to higher weed infestations and less favourable soil conditions on the zero till plots.

Effect of Zero Tillage on Soil Properties

Soil Fertility and Plant Nutrition

Changes in rooting habits and lack of soil mixing are the two main reasons why we might expect to find differences in the nutrient status of zero tilled plants and changes in the fertility of zero till soils.

Bakerman and de Wit (1970), Donaghy (1973), Hodgson *et al*. (1976), Cannell and Finney (1973) and Pidgeon and Soane (1977) have all suggested that zero till crops require more nitrogen than do conventionally tilled crops. The most common reason for this finding appears to involve the immobilization of soil nitrogen during the decomposition of organic matter. Dowdell and Cannell (1974) have also suggested reduced mineralization and nitrification of soil nitrogen in zero tilled soils due to cooler soil temperature as another reason for higher nitrogen requirements. Other reasons for higher nitrogen application include presence of weeds and compensation for thin stands or poorly developed root systems. Cannell and Finney (1973) suggested that on heavy clay soils, aeration on zero till plots has been shown to be restricted and denitrofication may also be important. Loss of nitrogen by leaching has also been demonstrated to be higher on zero till plots in some circumstances.

Tyler and Thomas (1977) working with zero till corn on a silt loam soil in Kentucky, which was previously in bluegrass sod for 50 years, measured the loss of nitrate from the plot. They observed large losses of nitrate from zero till plots, particularly in May and June. They attributed the losses to the movement of surface applied nitrate into natural soil cracks and channels, which extended far into the soil. They therefore, recommended that large nitrogen applications on corn be delayed from 4 to 6 weeks after planting, when rains are less frequent and soil cracks have swollen closed.

Although cereals have been shown to need a greater amount of nitrogen under zero tillage, Bakerman and de Wit (1970) and Donaghy (1973) have shown that at high nitrogen rates, small grains grown under zero tillage are more efficient nitrogen users. Donaghy (1973) indicated, that when greater than 67 kg. of nitrogen per hectare was used, zero till wheat outyielded conventionally tilled wheat, but below this level conventionally tilled wheat was superior. Zero till small grains, peas and sugar beets grown in the Netherlands had higher yields when high rates of nitrogen were applied, but lower yields as compared to conventional tillage when low or intermediate rates of nitrogen were applied (Bakerman and de Wit, 1970). Moschler et al. (1972) found that zero till corn used nutrients more efficiently than conventionally tilled corn. Both conventionally tilled corn and zero till corn received the same nutrient input and yields were equal, but higher amounts of nutrients were found after harvest in the zero till corn plots.

Many researchers have measured the formation of nutrient gradients within a zero till soil. Bakerman and de Wit (1970), Moschler et al. (1972) Cannell and Finney (1973), Hodgson et al. (1977), Ellis et al. (1977) and Drew and Saker (1978) have all noted that N, P, K and organic matter were found in higher concentration in the surface horizons of zero till soils as compared to conventionally tilled soils. These same nutrients were found to be lower on zero till soils at intermediate horizons and the same as conventionally tilled soils in the deeper horizons. The reason for the formation of these gradients is the lack of soil mixing associated with zero tillage. Hodgson et al. (1977) noted that P and K contents in barley shoots were not affected despite the distinct gradients found.

Lower pH and Mg have also been found in the surface horizons of zero till plots (Blevins et al., 1978). Since Mg was not added to the soil in zero till corn trials and is subject to leaching, there was a net downward movement of Mg from the surface horizon. The decline of pH is attributed to the acidic nature of nitrogen fertilizers. Blevins et al. (1978) applied lime to the surface of zero till soils in an effort to overcome the decline in pH and the associated yield decreases. It was found that surface liming without incorporation was an efficient way to overcome soil acidity caused by nitrogen fertilization of zero till corn.

Estes (1972) has indicated that zero till, if practiced over a long period may lead to deficiencies of micro-nutrients in the plant material. Estes (1972) working in New Hampshire on a relatively infertile soil noted that concentrations of Ca, Mg, Zn, Mo, Bo and Al in corn leaf tissue were significantly reduced on zero till plots. Silage yields, however, were 16 percent higher on zero till plots as compared to conventional tillage in the same trials.

Soil Erosion

Soil erosion both by wind and water has threatened agricultural production in many areas. Soil erosion occurs basically, because soils are frequently left without protection of a mulch cover. Overworking of soils has lead to reductions in organic matter and soil aggregate stability.

Bakerman and de Wit (1970), Moschler et al. (1972) and Buhtz et al. (1970) have reported increased soil organic matter, particularly in the surface horizon, under zero till crop production. Baeumer and Bakerman (1973) have stated that increased organic matter may increase stability of soil aggregates. Tomlinson (1974) showed that zero tillage maintains aggregate stability much better than conventional tillage when trials were initiated on a sod. Blevins et al. (1971) have shown that when trials are initiated on a killed sod, zero till is able to maintain soil structure and organic matter in its original state for a much longer period of time than does conventional tillage.

Mulch on the soil surface has been shown by Matthews (1972) to absorb the energy of falling raindrops, thereby preventing soil splash erosion and maintaining high rates of water infiltration and reduced runoff. Laflen et al. (1978) found that not only was runoff reduced by the presence of a mulch but the sediment concentration in runoff water was also reduced. Siemens and Oschwald (1978) noted that besides decreased soil loss, loss of agricultural chemicals were also significantly reduced from zero till plots.

To illustrate the importance of tillage in controlling soil erosion, Harrold et al. (1967) over a 7 year period measured soil losses from a corn field with a 9 percent slope. The conventional tilled plots lost 20.5 tonnes per hectare while zero till plots lost only 2 tonnes per hectare. McGregor et al. (1975) showed similar losses from continuous soybean plots in Mississippi. Approximately 7 times more soil was lost with conventional tillage as compared with zero tillage.

Soil losses due to wind erosion have been even greater. Schmidt and Triplett (1967) measured soil loss due to one severe wind storm from a corn field. Losses from the conventionally tilled plots measured 321 tonnes per hectare whereas only 5 tonnes per hectare were lost from zero till plots. Baeumer and Bakerman (1975) suggest that for dry land farming, 3500 kg of straw per hectare at harvest will provide adequate soil protection from erosion without presenting problems with seeding, weed control or soil fertility.

Soil Temperature

The temperature of the soil is an important factor, which affects germination and vegetative and reproductive growth of crop plants. Unger (1978 b) working with sorghum on a clay loam soil in Bushland, Texas, found that by adding progressively higher rates of mulch to the soil surface, there was a respective decrease in average soil temperature means, maximums, minimums and standard deviations. This was found to be true throughout the growing season, however, during the winter period when soil temperatures approached or fell below 0°C, the mulch had the opposite effect. The insulating value of the mulch caused higher average soil temperatures. It was noted, that although all mulch levels decreased soil temperatures during the growing season, emergence and growth of sorghum was not affected, except at the two highest mulch levels (8 and 12 tonnes/ha). Even at these extremely high rates, the effects of the cooler soil temperature were relatively minor and were more than offset in later season growth when soil moisture became limiting. Soil moisture availability was found to increase with increasing rates of mulch. Philip and Young (1973) on experimental plots at Lexington, Kentucky, found daytime maximum temperatures averaged between 1° and 4°F cooler, whereas night-time minimum temperatures averaged about 1°F warmer under killed sods, as compared to normally cultivated ground. The lower net temperature reported here did not adversely affect germination or crop growth.

Anderson and Russell(1964), however, have shown soil temperature reductions under surface residues to be one of the causative factors for wheat yield decreases. Wilkinson (1966) in North Dakota has stated that for most of the growing season, warm season crops such as corn are growing at suboptimum soil temperatures. Practices which further reduce soil temperature could, therefore, have a large effect on growth of warm season crops in the northern areas.

Unger and Stewart (1976) working with double cropping in Texas, found lower soil temperatures with zero tillage. The lower soil temperatures were favourable for summer sowing when soil temperatures may otherwise be too warm. Siemens and Oschwald (1978), Mock and Erbach (1977) and Shanholtz and Lillard (1967) also reported cooler soil temperatures with zero till corn. Plant growth was not seriously affected in these trials.

The moderating effects of zero till on winter soil temperatures has been proposed by Stobbe (1978) as a mechanism of ensuring winter wheat survival in the more extreme environments. Hay (1977) from Edinburgh, suggests that moderated winter soil temperatures on zero till plots may enhance the survival and activity of earthworms and micro-organisms. Baeumer and Bakerman (1973) foresee moderation of winter soil temperature fluctuations with zero till as being undesirable as the frequency of freezing and thawing may be reduced. As a consequence, maintenance of soil tilth and porosity may be seriously impaired.

Soil Moisture

Zero till soils characteristically have higher moisture contents, particularly in the surface horizons than do conventionally tilled plots. Increased moisture contents associated with zero tillage are attributed to reduced evaporation and runoff, increased infiltration and reduced surface area. Baier and Robertson (1967) studied the effects of soil moisture availability on wheat grown in Ottawa. They found moisture stress in the top soil zones early in the season inhibits plant growth, tiller development and crown-root growth, all having serious consequences in later growth stages. Hills and Blevins (1973) found that the presence of a killed sod mulch in the zero till plots almost eliminated the loss of moisture by direct evaporation from the soil surface during the early growing period, but after full crop canopy had developed, losses from both systems were about equal.

Later season moisture availability has also been found to be more favourable with zero till systems. Cannell et al. (1977) in a dry year, found that by flowering, more water was extracted from zero till soils at all depths below 40 cm. In dry years zero till winter wheat and spring barley were able to outyield conventional till treatments largely due to moisture availability.

Shanholtz and Lillard (1967), Blevins et al. (1971), Allen et al. (1977) and Unger (1978 a) have all demonstrated high water use efficiency with zero tillage. Shanholtz and

Lillard (1967) grew corn on a grass sod in Blacksburg, Virginia. Zero tillage reduced surface runoff and evaporation, resulting in a greater amount of soil water under zero till in the 0 - 30 cm layer in the early season. This increase in available water associated with zero till plots was able to counter drought for 1 to 2 weeks longer than conventionally tilled plots. As a result, Shanholtz and Lillard measured water use efficiency in this experiment to be 81 percent for zero till and only 57 percent for conventionally tilled plots. Unger (1978 a) demonstrated how water use efficiency of sorghum could be influenced by mulch rate. Average water use efficiency was found to increase from 55 kg/ha per cm of water with no mulch to 115 kg/ha per cm of water with 12 tonnes of wheat straw per hectare.

Schneider et al. (1978) reported that zero tillage could be used to increase moisture availability in the Northern Great Plains. They reported a 3 - fold increase in available water where a 35 cm residue remained standing during the winter as compared to where the stubble was knocked down. The increase in moisture was directly attributed to increased snow capture. The additional stored water derived from the 35 cm standing stubble resulted in a 35 percent increase in the yield of spring wheat.

Other works to report higher soil moisture with zero tillage as compared to conventional tillage include: Hay (1977), Lindwall and Anderson (1977), Bentley et al. (1978), Cannell and Finney (1973) and Matthews (1972). Lal (1976) reported higher moisture retention with zero tillage due to differences in organic matter content and the texture of the surface horizon. Lal (1976) found plants on ploughed plots to be more sensitive to drought than those on zero till plots.

Pidgeon and Soane (1977) found higher moisture with zero tillage in the 0 - 6 cm horizon and a corresponding large decrease in air-filled porosity. They suggested that there was a large risk of anaerobic conditions occuring early in the season with zero till during wet periods. Boone et al. (1976) found water from a large rain tended to pond on zero till plots due to slaking of the zero till plot surface. Slower infiltrations was found due to the absence of large vertical soil cracks. This study was conducted on a fine textured river soil in the Netherlands with a corn crop. The frequency of ponding also was found to increase as the period for which the soil remained untilled lengthened.

Shanholtz and Lillard (1969) working with corn in trials in Virginia reported reduced slaking and sealing of the soil surface of zero till plots. This was attributed to the mulch absorbing raindrop impact energy and preventing splash erosion. The net result was reduced runoff. Baeumer and Bakerman (1973), Lal (1976), Cannell and Finney (1976) and Cannell et al. (1977) found infiltration with zero till to be enhanced. This was primarily due to greater numbers of earthworm channels, decaying roots and continuous pores open to the surface. Ellis et al.

(1977) found continuous cracks to extend down over 0.8 m from the soil surface after direct drilling a clay soil. While cracking did occur on conventional tilled plots the depth of penetration was much less.

Bentley _et al_. (1978) in trials in Edmonton, found soil water on continuously cropped zero till soils to be at least equal to soils fallowed the preceding year. Also, the moisture was more uniform on zero till fields; for example, knolls, slopes and depressions all had similar soil moisture contents. Van Ouwerker and Boone (1970) found that even though higher moisture contents were measured on zero till plots, available soil moisture was equal to conventional tillage due to a general decrease in pore size. This is contrary to Baeumer and Bakerman (1973) who found that zero till soils with similar moisture contents to conventionally tilled soils generally had a lower soil water tension which indicates a smaller resistance to water uptake by plant roots and a higher conductivity of soil water.

Soil Compaction and Aeration

Many researchers have expressed concerns about the possibility of increased compaction and soil strength under zero till. The extent to which this happens under zero till varies greatly. Van Ouwerkerk and Boone (1970) characterized zero till soils as being more homogeneous with increased bulk density and resistance fo penetration. The differences observed between zero till plots and conventionally tilled plots was limited to the plow layer, with few or no differences below 30 cm.

Bakerman and de Wit (1970) from the Netherlands found peats, loams and clays with a good structure in the subsoil to offer no problems for plant growth after zero tillage was used. However, on one loamy sand with little stability of aggregates, the root below 15 cm was negligible after three years without tillage due to increased soil strength. Boone et al. (1976) found that zero till did not improve physical soil properties and recommended zero till not be practised on at least two soil types in the Netherlands. These were sandy soils on which the soil structure was inadequate for root crops when tillage was not performed and on fine textured soils which were found to have aeration problems when under zero till management.

Finney and Knight (1973) measured differences in wheat root growth and soil properties on well drained sandy loam soils in England. Seminal root extension was found to be restricted on zero till plots. This was attributed to the higher bulk density in the 0 - 10 cm depth and a smaller proportion of pores of equivalent or greater diameter than the main root axis found under zero tillage. Although pore size was reduced with zero till, there was a greater continuity of soil pores. Bulk density was only found to be higher in the 0 - 10 cm horizon; in deeper horizons bulk density was equal to that found in ploughed plots. Differences in crop growth in these trials were found only in the development of the seminal root system and not in adventitious root development, shoot development or grain yield.

Restrictions in root growth have also been observed by Stibbe and Ariel (1970) in Israel. Higher penetrometer readings were reported in the top 20 cm of zero till plots. The increase in soil strength caused shallow rooting and thereby restricted the amount of soil moisture available to the plants. Consequently, lower yields were obtained from zero till plots in all but the driest years where zero till yields were equal. No explanation is given for the higher yields obtained in the drier years. It should be noted that in these trials, previous crop residues were burnt and zero till plots were established on fields already compacted from previous years traffic and tillage pans.

Gantzer and Blake (1978) measured the changes in soil physical properties in field trials carried out over 5 years with continuous corn in Minnesota. The differences in soil physical properties observed were found to be generally limited to the surface samples (0 - 30 cm). Bulk density of soils under zero tillage were found to be increased, despite the fact that the mean number of channels one mm. in diameter and larger created by earthworms and decomposing rootlets were significantly greater for zero tillage. Higher volumetric water contents plus increased bulk densities resulted in lower air-filled porosity and hydraulic conductivity on zero till plots. Gantzer and Blake (1978) expressed concern that restricted gaseous exchange may develop more easily under zero tillage due to higher moisture contents and lower air-filled porosity.

Lindwall and Anderson (1977) found that localized compaction from sprayer traffic on zero till plots caused yield reductions which ranged from 24 to 51 percent. Reduced yields were a result of ineffective drill operation in the compacted areas.

Many researchers have observed changes in soil physical properties, but have not found these changes to adversely affect crop growth. Baeumer and Bakerman (1973) found a decrease in the number of large air filled pores, but stated that air-filled porosity seldom falls below 10 percent, a value thought to be the minimum for plant growth. Van Ouwerkerk and Boone (1970) found pore space to be between 2 and 4 percent lower on zero till soils. Boone et al. (1976) on trials initiated on grass sod found aggregate size under zero till to become large and aggregate size distribution to become more homogeneous. Aggregates with a diameter less than 0.3 mm disappeared and aggregates were found to be more stable the longer the soil remained untilled. The increase in aggregation lead to reduced pore volume, but it was found that at similar air contents the untilled soil had somewhat higher gas diffusion coefficients than ploughed soils.

Boone et al. (1976) observed the development of a weak platy structure between 2 and 4 cm on zero till plots. This structure did not, however, become a serious barrier to air and water movement.

Pidgeon and Soane (1977) from Scotland found bulk density to be higher in the 0 - 15 cm horizon than that in ploughed plots. The increase in bulk density corresponded to a decrease in total porosity from 49 to 44 percent. The bulk density measurements at the 0 - 21 cm depth were found to reach an equilibrium after 3 years of zero till. Bulk density below 21 cm reached an equilibrium after only 1 year. Soil strength as measured by cone resistance, increased in the 3 - 33 cm depth under zero tillage in each year of the study and had not reached an equilibrium after 7 years of zero tillage, even though bulk densities had. The increased cone resistance was attributed to increases in aggregate strength. Cannell and Finney (1973) also observed increased bulk density and soil strength with zero tillage, but noted that these increases were small and usually insignificant on light or high organic matter soils. Pores although smaller on zero till plots were more continuous and drainage was equal or better than on conventionally tilled plots. Hodgson et al. (1977) stated that increased soil strength and bulk density observed with zero tillage had only a small effect on barley root distribution in the soil profile. They found proportionally more roots in the 12.5 - 32.5 cm depth and proportionally less roots in the 2.5 - 12.5 cm depth under zero tillage as compared to conventional tillage.

Zero tillage has also been found to enhance soil physical properties in some situations. Cannel et al. (1977) found zero till soils to crack appreciably in dry weather, and fissures tended to be deeper and more continuous than with conventional tillage. Soil cracking, in combination with greater earthworm activity facilitated aeration and water movement, despite the greater bulk density of the topsoil. Higher concentrations of oxygen were measured at 15 cm in zero till plots as compared to conventional tillage. No differences in oxygen concentration were measured at 60 cm between tillage treatments. Cannell and Finney (1973) and Ellis et al. (1977) also found higher earthworm populations with zero tillage. Cannell and Finney (1973) found the increased earthworm population improved aeration, aggregate stability and increased the number of continuous channels available.

Tomlinson (1974) found where zero tillage was initiated on a grass sod, bulk density near the surface was lower than on tilled plots. Blevins et al. (1978) also established zero till plots on a grass sod. No difference in bulk density in the 0 - 8 cm horizon between zero till and conventionally tilled plots could be detected. Lal (1976) in Nigeria, found lower bulk density on zero till plots due to increased earthworm activity and less crusting. Penetrometer readings at the 20 cm depth were also lower on zero till plots than on ploughed plots.

Significant differences in soil strength were not found by Ellis et al. (1977) working in England. They did, however, note improved soil tilth as the length of zero tillage crop production increased. Increased corn yields as found by van Doren et al. (1976) were in part attributed to the stabilization of a desireable soil structure by zero tillage. Baeumer and Bakerman (1973) noted that soil trafficability was increased under zero till crop production.

Straw Management in Zero Till Crop Production

By definition, zero tillage omits any soil manipulation except for that done during the seeding operation. This limits the number of things which man can do to influence plant growth and soil characteristics on zero till plots. Management of previous crop residues, while always a factor in crop production becomes increasingly important with zero tillage. Straw management may affect the effectiveness of seeding, germination and seedling growth, nutrient availability, moisture content and temperature of the soil and erosion of the soil surface.

Research on crop residue management on zero till soils is limited. Most zero till trials tend to leave all the residues on the surface. However, in England, Israel and Netherlands, many studies on zero tillage have been conducted where previous crop residues have been burnt (Ellis and Lynch, 1977; Stibbe and Ariel, 1970; Bakerman and de Wit, 1970). Little research has been conducted to deliberately measure the effect of crop residue management on crops grown using zero till crop production techniques.

Effect of Plant Growth

Reports of poor crop stands on zero till plots have been frequent. In the majority of cases reported, poor stands were associated with poor performance of seeding equipment in penetrating crop residues and placing the seed into moist soil. Lindwall and Anderson (1977) found that seeds in contact with decomposing residues often failed to emerge and suggested residues should be isolated away from the seed zone. Baeumer (1970) found drilling into the straw mulch reduced seedling emergence by 30 percent. Mock and Erback (1977) found seeding depth was much more variable in zero till plots as compared to conventionally tilled plots. Variable seeding depth resulted in uneven germination, which was attributed to poor penetration of surface residues. Pittman and Horricks (1972) and Austenson et al. (1978) also report reductions in stand due to shallow seeding and poor seed coverage when crops are sown into heavy residues. Pittman and Horricks (1972) also believed phytotoxins produced during decomposition of residues by microbes may have caused some stand reductions.

Work conducted at Letcombe Laboratory in England by Lynch (1977) has shown that wet wheat straw which had started to decompose, contained water soluble phytotoxic materials which retarded the extension of young seedling roots, leading to necrosis of the apical meristem and death of the plants. The phytotoxic materials were found to be acetic acid and smaller amounts of propionic and butyric acid which formed under anaerobic conditions. Methods which are being tried at Letcombe to overcome the toxic effect of straw include: improvements in drill designs to enable separation of seed and straw; chemical methods which increase aeration around the seed, and chemical treatment of the straw to minimize the possibility of the production of toxins occuring at the stage when seedlings are most susceptible to damage (Ellis and Lynch, 1977). Lindwall and Anderson (1977) recommend residues not exceed 3000 to 4000 kg/ha if hoe, lister shovel or double disc drills are to be effective.

In order to achieve more effective seeding, some researchers have removed residues by burning prior to seeding. Soane and Pidgeon (1974) and Cannell *et al*. (1977) have recommended burning of residues in the United Kingdom, as a good means of providing a good environment for germination for zero till crops. Pidgeon and Ragg (1979) suggest five advantages of burning residues on heavy soils in Scotland. Burning residues eliminates baling which can be damaging to the soil. Burning also facilitates sowing of winter cereals at the optimum time; baling may delay sowing. In wet conditions, there is a risk of toxic residues from decomposing straw harming the subsequent crop. Covering of the soil with residues reduces the surface tilth formed by alternate wetting and drying or freezing and thawing. Burning negates the insulating value of residues. The risk of slug damage is increased by the presence of trash, and burning allows for faster warming and drying of the soil in the spring. Stibbe and Ariel (1970) in Israel found burning to be advantageous in minimizing the carry over of plant diseases, and in restricting the population of field rodents.

Dawley *et al*. (1964) have suggested burning only be done when stubble land is being prepared for cropping, and then only as a preseeding spring practice.

One of the greatest advantages of zero tillage crop production is higher available soil moisture. Burning of crop residues on zero tilled soil has been shown by Gauer (1980) to reduce surface soil moisture compared to when a mulch was maintained. Thus, the practise of burning must be carefully scrutinized to ensure its overall benefits. Often, more effective seeding equipment would be a more desireable alternative to that of burning.

Effect of Soil Fertility and Organic Matter

Little work has been done which examines the influence of straw management practices on soil fertility under zero till crop management. Drew and Saker (1978) suggest burning crop residues may contribute to the development of concentration gradients of P and K. Ferguson and Gorby (1964) and Ferguson (1967) found that application of straw at rates up to 9000 lb/acre did not affect grain yield. They suggest under Manitoba conditions, straw decomposition rates are low and nitrogen deficiencies would not normally be induced, as cereal crops are well adapted to compete successfully with saprophytic microorganisms for nitrate. Hedlin *et al*. (1957), however, found that the yield and protein of wheat was higher when wheat straw residues were burned. Work by Ferguson (1967) and Hedlin et al. (1957) used conventional tillage, therefore the same situation may not be found with zero tillage. Tomar (1980) working in Manitoba found that straw did not necessarily decrease nitrogen response and yield. Tomar found that it was only when the straw was incorporated into the soil that the lower nitrogen response was found. He attributed this to greater amounts of applied and soil nitrogen being immobilized by microbes in the degradation of the incorporated straw. Plots where straw was left on the soil surface gave nitrogen response similar to plots where straw was absent. Russell(1950) states that there is a critical nitrogen content of the residue which determines whether there will be a net increase or decrease in available nitrogen. The critical level is between 1.2 and 1.8 percent nitrogen. Release of nitrogen takes place in the early stages of decay when the nitrogen content exceeds 1.8 percent, and immobilization of soil nitrogen occurs if the residues have a nitrogen content less than 1.2 percent.

A study by Brown and Dickey (1970) shows the relation between the rate of decomposition of wheat straw residues when buried, or placed either on or above the soil in Montana. Buried straw decomposed about 3 times faster than straw on the soil, and about 4 times faster than straw kept above the soil.

McCalla and Duley (1943) measured the decomposition of wheat straw left as a mulch on the soil surface in Nebraska. When the mulch was left for a period of six months, a two ton application had lost two thirds; a four ton application lost one half, and an eight ton application lost only one third of the added material. Where straw was left on the surface for 18 months, there was little residue left except from the 8 ton application. The rate of decomposition was found, in this trial, to be inversely rated to the total amount of residues present.

Effect on Soil Moisture

One of the main attributes of zero till crop production is the increased moisture availability. The increase in soil moisture is generally due to the undisturbed presence of crop residues and surface mulches.

Unger (1978 a), in Texas, found precipitation stored as soil water, growing season water use and precipitation efficiency were increased as the rate of wheat straw used in a mulch increased. As a consequence, sorghum grain and forage yields were also increased. Hill and Blevins (1973) found the presence of a killed sod mulch on zero till plots, almost eliminate the loss of moisture by direct evaporation. Triplett *et al*. (1970) and Moody *et al*. (1963) with zero till corn trials have shown that the presence of a mulch was effective in reducing water runoff and in increasing infiltration. Both of these trials attributed higher corn yields to higher moisture availability from the mulch treatment.

Army et al. (1960) studied the effect of surface residues on soil moisture losses during the fallow period. Plant residues were found to greatly reduce evaporation at the soil surface. However, if rains were infrequent the mulched treatment eventually lost as much moisture as the bare ground. The plant residues were found to decrease water loss in two ways. Plant residues, especially when standing, increase the thickness of relatively nonturbulent air above the soil, and therefore, are effective in reducing vapour transported away from the surface. Plant residues also resulted in lower daytime soil temperatures, and therefore, caused lower vapour pressure of the soil water. Good and Smika (1978) reported that retention of a mulch with chemical fallow conserved on the average 9.3 inches of water during each fallow year over a period of 8 years. Stubble mulching stored 6.8 inches of water in the soil profile.

Schneider et al. (1978) showed the impact of stubble retention and stubble height on stored water and wheat yields at Williston, North Dakota. The extra snow trapped on plots where 35 cm stubble was retained resulted in approximately 3 times as much stored water as where there was no stubble and a 35 percent increase in wheat yields. Studies at Swift Current, Saskatchewan showed that variable height swathing improves moisture storage (Johnson, 1977). Alternating stubble heights of 15 and 22.5 cm trapped 4 cm more water from snow than a uniform stubble height of 15 cm.

Gauer (1980) working in Manitoba, found that soil moisture was higher, particularly in early spring at the 0 - 60 cm depth, when stubble and mulch remained on the surface of zero till plots as compared to conventionally tilled plots. When the mulch was removed and only stubble was left, zero till plots still retained more moisture than conventional tilled plots. However, the difference was smaller and did not persist as long as when a mulch was present. In the same experiment, another treatment involved burning both the stubble and straw mulch. The moisture contents of zero till plots having this treatment were not found to differ signifcantly from the conventionally tilled treatment. However, during periods of dry weather, moisture depletion was shown to be slower on the zero till plots.

Effect of Soil Temperature

Soil temperature on zero till fields may be affect by straw management. Moody et al. (1963) found surface residues on zero till corn plots resulted in lower soil temperatures and retardation of early corn growth. Unger (1978 b) working with sorghum on a clay loam soil in Bushland, Texas, found that by adding progressively higher rates of mulch to the soil surface there was a respective decrease in average soil temperature means, maximums, minimums and standard deviations. This was found to be true throughout the growing season, however, during the winter period when soil temperatures approached or fell below 0°C, the mulch had the opposite effect. The insulating values of the mulch caused higher average soil temperature means, maximums and minimums. Anderson and Russell (1964) working at Lethbridge also found soil temperatures to decrease as the quantity of mulch increased. The effect of the mulch became much less important as crop shading of the soil increased. Anderson and Russell (1964) recommend limiting straw residues to between 4000 and 5000 lbs/acre, unless higher amounts may be placed on the soil surface in such a way so that complete shading of the soil would not occur.

Work in Manitoba by Gauer (1980) shows the influence of tillage method and straw management on soil temperature. Where all the previous crop residue was retained, soil temperatures were lower on zero till plots. The conventional till plots which had the residues worked in had warmer soil temperatures. Gauer found maximum soil temperatures were often 1 - 2° C higher on conventional till but minimum temperatures were not affected much. No difference in soil temperatures were observed after mid-July when the crop shaded the ground. On plots where crop residues were raked off and only stubble remained, soil temperatures were found to be higher on the zero till plots as compared to conventionally tilled plots. This was attributed to greater heat transfer into zero till soils due to increased bulk density, and to decreased heat loss. An increased boundary layer created by the standing stubble minimized the heat loss from this treatment. Where all residue and stubble was removed by burning, no differences in soil temperature were observed between zero till and conventional till treatments.

Effect on Soil Crusting

Crusting of conventionally tilled soils is a problem which may be overcome through the use of residues and zero tillage. Sanford et al. (1973) found after a heavy rain, hot dry winds caused crust formation on conventionally tilled plots but not on zero till plots. The crust on the conventionally tilled plots had to be mechanically broken to allow for emergence of double cropped soybeans in Mississippi. Edwards (1977) suggested that 300,000 acres of sugar beets and 3,000,000 acres of cotton are replanted each year in the United States due to soil crusting. Edwards (1977) states that a vegetative cover could largely reduce these crusting problems.

One report which is contradictory to the work showing residues to decrease crust formation, comes from Letcombe Laboratory in England. Ellis et al. (1977) report that burning of residues on zero till plots has been found to increase the aggregate stability in the surface layer. Increased aggregate stability retards aggregate breakdown and reduces the incidence of surface slaking which causes soil crusts to form.

MATERIALS AND METHODS

Location and Details

Site Description

Two soil types differing in texture and drainage were used. The experimental sites used at Graysville were located on the University of Manitoba, Plant Science Weed Research Station (legal description 24-6-6W). The soil was a well drained Riverdale fine sandy loam (Ellis and Shafer, 1943) with the surface layer consisting of 76 percent sand, 15 percent silt and 9 percent clay.

The experiments at Sanford were located on the Herb Weidman farm (legal description 23-8-2W). The soil was a poorly drained Osborne clay (Ehrlich et al, 1953). The soil consisted of greater than 80% clay.

Cropping history and date of last tillage operation for all of the experiments conducted in this study are given in Table 1.

Precipitation and Temperature Data

Meteorological data was obtained from the Monthly Record of Meteorological Observations of Environment Canada. Meteorological data for Graysville came from the Murta farm 2 miles west of the experimental area and data for the Sanford site came from the W. Schrof farm 5 miles north of the experimental area. Meteorological data for the sites for 1978 and 1979 are given in Appendix A.

TABLE 1. Location and general description of experiments

Expt. No.	Location	Year	Crop Sown	Previous Crop	Year of last tillage
1	Graysville Site 1	1978	Wheat	Wheat	Spring 1976
2	Graysville Site 1	1979	Wheat	Rapeseed	Spring 1976
3	Graysville Site 2	1979	Wheat	Barley	Spring 1978
4	Sanford	1978	Wheat	Wheat	Spring 1976
5	Sanford	1979	Wheat	Wheat	Spring 1976
6	Graysville Site 1	1978	Rape	Wheat	Spring 1976
7	Graysville Site 1	1979	Rape	Wheat	Spring 1976
8	Graysville Site 2	1979	Rape	Wheat	Spring 1978
9	Sanford	1979	Rape	Wheat	Spring 1976

Experimental Design and Plot Description

The design of the experiment was a randomized split split block using four replicates. Figure 1 illustrates the randomized split split block design used in these experiments and the treatments are presented in Table 2. All sites were designed for three planting dates, but due to wet springs at Sanford and poor weed control at Graysville, some experiments were conducted using only one or two planting dates. Table 3 lists the dates and rates of seeding used in the trials.

The method of tillage used was zero tillage (ZT) or conventional tillage (CT). The method of cultivation used to prepare the conventionally tilled treatment is given in Table 4.

1 ZT B	1 CT R	2 CT S	2 ZT B	3 CT S	3 ZT R
1 ZT R	1 CT S	2 CT R	2 ZT S	3 CT R	3 ZT B
1 ZT S	1 CT B	2 CT B	2 ZT R	3 CT B	3 ZT S

FIGURE 1. Typical plot layout for one block

TABLE 2. Treatment list for split split plot design

Factors	Description	
Blocks	Blocks (4)	
Main plot	Planting dates (3)	
Sub plot	Tillage methods (2):	Zero tillage
		Conventional tillage
Sub-sub plot	Straw management (3):	Burn
		Rake
		Spread

TABLE 3. Planting date and rate

Expt. No.	Year	Crop	Location	Planting date	Seeding rate (kg/ha)
1	1978	Wheat	Graysville	3.5.78 17.5.78 2.6.78	45
2	1979	Wheat	Graysville	23.5.79 31.5.79 7.6.79	70
3	1979	Wheat	Graysville	23.5.79 31.5.79 7.6.79	70
4	1978	Wheat	Sanford	7.6.78	45
5	1979	Wheat	Sanford	7.6.79 14.6.79	70
6	1978	Rapeseed	Graysville	17.5.78 2.6.78 7.6.78	4.0
7	1979	Rapeseed	Graysville	23.5.79 31.5.79 27.6.79	5.0
8	1979	Rapeseed	Graysville	31.5.79 27.6.79	5.0
9	1979	Rapeseed	Sanford	7.6.79 14.6.79	5.0

TABLE 4. Methods used to prepare conventional tilled plots

Location	Year	Experiment	Implement	Time and No. of operations
Graysville	1978	1 & 6	Tandem disc Tandem disc Harrow	Fall (2) Spring (2) Spring (2)
Graysville	1979	2,3,7 & 8	Tandem disc Tandem disc[1] Harrow	Fall (2) Spring (2) Spring (2)
Sanford	1978	4	Deep tiller Harrows	Spring (2) Spring (2)
Sanford	1979	5 & 9	Deep Tiller[2] Cultivator Harrow	Fall (2) Spring (1) Spring (2)

1 Additional packing was also performed on rapeseed trials prior to seeding in 1979.

2 Disc was used for a secondary tillage operation on the second planting date.

Straw management treatments were burning (B), raking (R) or spreading (S). The straw management treatments were started after the harvest of the previous crop but before any tillage operations. The straw of the previous crop was spread evenly over the entire experimental area so as to start with equal amounts of straw on each plot. The straw on plots designated to be burnt (B) was first raked inwards from the borders; then all of the straw, including standing stubble was burnt using a propane torch. The straw from the plots designated to be raked (R) was removed with the aid of a dump rake. Wire mesh was fitted to the tines to prevent the straw from slipping between the tines. The rake was operated over each plot two times, once in each direction. This treatment removed the loose straw but left the standing stubble and chaff. Straw from the plots which were designated to have the spread treatment (S) was uniformly distributed over the entire plot area.

Individual plots at Sanford measured 6.1 x 15.2 meters. Plots at Graysville Site 1 were 2.5 x 7.5 meters. Larger plots were started at Graysville in 1978 at Site 2; these plots were 5 x 20 meters.

Wheat and rapeseed was grown at each site in separate experiments in both years, except at Sanford in 1978 where only wheat was grown. To reduce the risk of diseases and volunteer crop problems, the two crops were rotated in the second year; i.e., wheat was sown on the rapeseed stubble and rapeseed was sown on the wheat stubble.

Seeding

Seeding at Graysville sites was accomplished using a Model 620 International Harvester Company press drill. The drill was modified for direct stubble seeding by the addition of large cutting coulters placed directly in front of each run of double discs (Chinsuwan, 1976). Zero till plots were sown with the cutting coulter operating approximately 1 cm below the desired seeding depth to ensure trash cutting and penetration of the double discs. Conventional till plots were sown without the aid of the front cutting coulter. This drill was found to work satisfactorily in the light soil.

Problems with seeding equipment were encountered at Sanford in the heavy clay soil. In the first year, a Melroe 702 triple disc zero till drill was used. While penetration with this drill was satisfactory, plugging with moist clay and straw between runs was a problem. It the second year, a Haybuster 1206 zero till drill and Massey Ferguson No. 36 discer were used. The discer was used to sow the conventionally tilled wheat. The Haybuster was used for the zero till wheat and all rapeseed treatments.

The seeding rates are shown in Table 3. Pedigree seed was used in all experiments. Varieties used were: Tower rapeseed and Sinton wheat. In 1978 the rapeseed was treated with Gammason Plus with mineral oil as a sticking agent. In 1979, Furadan and Benlate T were added to the rapeseed.

Fertilizer

The rates of fertilizer used are given in Table 5. Phosphate was applied as ammonium phosphate (11-55-0) with the seed. Additional nitrogen, in the form of ammonium nitrate (34-0-0) was broadcast prior to seeding. Potassium was applied as potassium chloride (0-0-60) and sulfur as 0-0-0 (90). These were also broadcasted prior to seeding.

Weed Control

The pesticides used in the various experiments are given in Appendix B. Pre-emergent herbicides were not used, and post emergent herbicides were generally applied to both zero till and conventional till plots to standardize weed control and herbicide effects on the crop.

TABLE 5. Fertilizer rates used in experiments

Year	Expt. No.	Crop	Location	N	P_2O_5	K_2O	S
				Kg/ha			
1978	1	Wheat	Graysville	82	36	0	0
1979	2	Wheat	Graysville	146	45	43	0
1979	3	Wheat	Graysville	146	45	43	0
1978	4	Wheat	Sanford	50	35	0	0
1979	5	Wheat	Sanford	146	45	0	0
1978	6	Rapeseed	Graysville	75	20	24	12
1979	7	Rapeseed	Graysville	107	21	63	24
1979	8	Rapeseed	Graysville	107	21	63	24
1979	9	Rapeseed	Sanford	107	21	0	0

Sampling Procedures

Emergence

Plant counts were taken biweekly starting on the third week after seeding unless otherwise specified. Plant counts were taken in conjunction with dry weight samples. Table 6 indicates the area sampled from each experiment. Data was standardized to give emergence in number of plants/m^2.

TABLE 6. Sample area for plant counts and dry weights

Year	Expt. No.	Crop	Location	Area sampled
1978	1	Wheat	Graysville	2 - 1/2 m rows 15 cm row spacing
1979	2	Wheat	Graysville	2 - 1 m rows 15 cm row spacing
1979	3	Wheat	Graysville	4 - 1 m rows 15 cm row spacing
1978	4	Wheat	Sanford	No samples taken
1979	5	Wheat	Sanford	2 - 1/4 m^2
1978	6	Rapeseed	Graysville	2 - 1/2 m rows 15 cm row spacing
1979	7	Rapeseed	Graysville	2 - 1 m rows 15 cm row spacing
1979	8	Rapeseed	Graysville	2 - 1/4 m^2
1979	9	Rapeseed	Sanford	2 - 1/4 m^2

Shoot dry matter accumulation

Plants were cut off at ground level, placed in paper bags and either frozen or put directly into the oven where they were dried to constant weight (72 hours) at 80C and then weighted. Data was standardized and reported as grams of oven dried material per square meter.

Tiller counts

Tiller counts were taken at each sampling date in 1978. In 1979, tiller counts were taken only once, at 13 weeks after seeding. The tiller counts were taken at the same time as were dry weight samples using the same samples. Data was standardized and given as fertile tillers per square meter.

Grain harvest procedures

Grain was harvested using a stationary thresher or a Hege small plot combine. Table 7 indicates sample size and method of harvesting for each experiment. Harvested samples were dried to constant weight (14 days) in the drying room at 38C. Samples were cleaned of chaff and weed seeds and then weighed. Data was standardized and yields reported in kilograms per hectare.

Measurement of soil physical properties

Soil temperature, moisture and bulk density were measured on selected plots during the two year test. This data was collected by Gauer (1980).

TABLE 7. Method of harvest and area sampled

Year	Expt. No.	Crop	Location	Method of harvest	Number of sub-samples	Area of sub-sample
1978	1	Wheat	Graysville	Hand sample & stationary thresher	1	1 x 3 m
1979	2	Wheat	Graysville	Hege plot combine	1	1.2 x 6.3 m
1979	3	Wheat	Graysville	Hege plot combine	2	1.2 x 15.2 m
1978	4	Wheat	Sanford	Hege plot combine	1	1.2 x 9.7 m
1979	5	Wheat	Sanford	Hege plot combine	2	1.1 x 10.3 m
1978	6	Rapeseed	Graysville	Hand sample & stationary thresher	1	1 x 3 m
1979	7	Rapeseed	Graysville	Hand sample & stationary thresher	1	1 x 3 m
1979	8	Rapeseed	Graysville	Hege plot combine	2	1.2 x 15.2 m
1979	9	Rapeseed	Sanford	Swath & Hege combine	2	2.4 x 10.3 m

Statistical Analysis

The results of the experiments were analysed as a split split plot design with four replications according to Little and Hills (1975).

An example of a typical analysis of variance table for a split split plot experiment (Table 8) shows the complexity of this type of design and the number of interactions which are involved. Since the tillage x straw interaction was the main consideration in this study, treatments were established so as to obtain the most information about the influence of straw management practices on the development of crops grown either on zero till or conventionally tilled plots. The planting date treatment was included to determine if the tillage x straw interaction could be altered by seeding at different times during the spring. In most instances the tillage x straw interaction was unaffected by different planting dates. To avoid excess repetition, planting dates are only mentioned when they were found to influence the tillage x straw interaction. Also the portion of the data showing the effect of planting date as an independent factor will not be reported or discussed. Analysis of variance was conducted with the aid of an IBM computer. Significant differences were detected using the LSD test at the five percent level.

TABLE 8. Analysis of variance for split split plot experiment

Source of variation	DF
Replicates	3
Planting date	2
Error 1	6
Method of tillage	1
Date x tillage	2
Error 2	9
Straw management	2
Date x straw	4
Tillage x straw	2
Date x tillage x straw	4
Error 3	36
Total	71

RESULTS AND DISCUSSION

Wheat Experiments

Experiment 1: The effects of straw management, method of tillage and planting dates on emergence, shoot dry matter accumulation, tillering and final yield of wheat at Graysville in 1978.

Emergence

Crop emergence was determined from a composite of three samples taken during the growing season. Emergence counts were averaged and the data is presented in Table 9. While the triple interaction between planting date, method of tillage and straw management was not found to be significant, a number of interesting trends can be observed. In the first two planting dates, zero till plots with straw removed by burning appeared to have greater wheat emergence that zero till plots with straw spread or removed by raking. Emergence data from conventionally tilled plots at all dates resulted in a trend opposite to that found on zero till plots. Emergence on conventionally tilled plots on which straw was spread appeared to be the highest, followed by raking and burning.

Zero till plots at the third planting date had a trend opposite to that found in the earlier planting dates. Emergence data showed that zero till plots with straw spread appeared to have more plants than zero till plots where straw was removed by burning.

TABLE 9. Effects of straw management, method of tillage and planting date on emergence of wheat at Graysville in 1978

Planting date	Method of tillage	Straw management		
		Burn	Raked	Spread
		plants/m^2		
1	Zero till	206[1,2]	188	187
	Conventional till	226	200	243
2	Zero till	226	206	193
	Conventional till	216	229	253
3	Zero till	154	167	173
	Conventional till	149	208	196

1. Non-significant interaction (p=0.05)
2. Average of 3 samples

The factor which limited emergence on zero till plots at the first two planting dates was the effectiveness of the drill to cut trash and place the seed in moist soil. Therefore, zero till plots which had the least amount of residue, such as burned plots, had the highest emergence. Data from Blackshaw (1979), also working at Graysville in 1978, shows that drier soil conditions existed at the third date of seeding. Soil water potential was measured at -6.0 bars. At earlier planting dates soil water potential was -2.0 bars. Although soil moisture for individual plots was not available for this experiment, Gauer (1980) has shown soil moisture was lower on zero till plots where straw was removed by burning as compared to plots where straw was spread. The data from the third planting date shows that, in periods of moisture stress, straw mulch can be advantageous in promoting wheat emergence on zero till plots.

Although individual treatment means reported in Table 9 were not significant, significant differences in the planting date x straw interaction, the tillage x straw interaction and the method of tillage were observed (Table 10). Data from the planting date x straw interaction shows that fewer plants emerged at the third planting date as compared to the two earlier dates. While straw management had no significant effect at the first two planting dates, plots with straw removed by burning had fewer plants emerge as compared to plots with either straw raked off or spread at the third planting date. As mentioned earlier, this reduced germination was the result of greater moisture stress on plots where straw was removed by burning.

When the effects of the tillage x straw interaction are examined it was found that on zero till plots, spreading straw resulted in the lowest emergence counts. As observed earlier, this was generally true except at seeding date three where soil moisture limited emergence.

Higher plant emergence was noted on conventionally tilled plots where straw was spread than on plots which had straw removed by burning. The reason for increased emergence on conventionally tilled plots with straw spread can be attributed to less crusting and better physical condition of the soil surface caused by incorporation of the straw. When the effects of straw management were averaged over all planting dates and methods of tillage, significant differences were not observed.

However, the method of tillage was found to cause significant differences in plant counts. Thirteen percent more plants emerged on conventionally tilled plots as compared to zero till plots. Poor drill performance on zero till plots was the major reason for this observation.

TABLE 10. Effects of straw management, method of tillage and planting date on emergence of wheat at Graysville in 1978

Treatment		Wheat emergence[1] plants/m^2
Planting date x straw		
1	Burn	216
	Raked	194
	Spread	215
2	Burn	221
	Raked	217
	Spread	223
3	Burn	152
	Raked	188
	Spread	185
LSD (0.05)		32
Tillage x straw		
ZT	Burn	195
	Raked	187
	Spread	185
CT	Burn	197
	Raked	212
	Spread	231
LSD (0.05)		26
Straw management		
	Burn	196
	Raked	187
	Spread	185
LSD (0.05)		ns
Tillage method		
Zero tillage		189
Conventional tillage		213
LSD (0.05)		ns

1. Average of three samples

Dry Matter Accumulation

Although differences in emergence were noted between plantingdates (Table 11), no interactions between dry matter accumulation and planting dates were noted (Table 12). Although low seeding rates (45 kg/ha) were used in this experiment, plots with low plant densities apparently were able to compensate with higher plant growth rates.

TABLE 11. Effect of straw management and tillage methods on shoot dry matter accumulation of wheat at Graysville in 1978

Treatments	Sampling dates (weeks after seeding)				
	2	5	7	9	11
	g/m²				
Tillage x straw					
ZT Burn	2.4	85	336	620	752
Raked	2.2	94	353	482	624
Spread	2.5	78	377	496	569
CT Burn	2.4	102	364	619	727
Raked	2.9	93	316	501	691
Spread	2.8	97	318	560	607
LSD (0.05)	ns	ns	ns	ns	ns
Straw management					
Burn	2.4	93	350	619	740
Raked	2.5	93	335	491	658
Spread	2.6	88	347	528	588
LSD (0.05)	ns	ns	ns	96	82
Tillage method					
Zero tillage	2.3	86	355	532	648
Conventional tillage	2.7	97	333	560	675
LSD (0.05)	ns	ns	ns	ns	ns

TABLE 12. Effects of straw management on root dry matter and number of seminal and crown roots at Graysville in 1978

Treatment	Root weight[1]	No. of crown roots[2]	No. of seminal roots[3]
	g/m^2	Ave. roots/plant	Ave. roots/plant
Burn	28.8	7.3	5.8
Rake	28.5	6.9	5.6
Spread	28.5	6.0	5.5
LSD (0.05)	ns	0.8	ns

1. Sampled 4 weeks after seeding
2. Sampled 5 weeks after seeding
3. Sampled 5 weeks after seeding

Differences in dry matter accumulation for the tillage x straw interaction were not found to be significant in this experiment. Straw management practices, however, did cause differences in dry weight accumulations to occur by the ninth week after seeding. Plots which had straw removed by burning had 26 percent more dry matter than plots with straw spread. Intermediate dry weights were obtained from plots where straw was removed by raking.

The increased dry matter collected from plots which had straw burned has a number of possible explanations. Warmer soil temperatures were measured on plots where straw was removed by burning as compared to the other straw treatments by Gauer (1980) on similar plots in 1979. Warmer temperatures may have resulted in a more developed root system early in the year. The ability of a more developed root system to extract moisture later in the season when soil moisture was declining would have the net effect of increasing vegetative dry matter. Data collected from root samples supports this theory and is presented in Table 12. While only significant differences were measured in the number of crown roots, all three parameters measured (root weight, number of crown and seminal roots) seem to indicate the presence of a more developed root system on burned plots.

Higher dry matter production on burned plots as compared to plots with straw spread or raked may be related to the availability of nitrogen. Hedlin et al. (1957) found that incorporating crop residues decreased yields of the subsequent crop. The reduction in yield was attributed to immobilization of nitrogen by soil microbes during decomposition of the residues. For this reason, plots with straw burned would have less nitrogen immobilized and more available nitrogen for plant growth, resulting in higher dry matter production. Even though 80 kg/ha of nitrogen was added to all plots in this experiment, the applied nitrogen apparently may not have been sufficient to compensate for differences in immobilization associated with the various straw management practices. Plots where straw was removed by burning may also have had higher mineralization rates, than where straw was spread or raked, due to higher soil temperatures.

Pittman and Horricks (1972) and Lindwall and Anderson (1977) attributed some of the growth reduction found on plots where straw remained to the presence of phytotoxic decomposition products. Phytotoxins would not be present where residues were removed by burning; therefore, plants on burned plots would not be inhibited, resulting in higher dry matter production compared to plots where the straw was spread or raked.

The method of tillage did not result in significant differences in dry matter accumulation in this experiment. There was, however, a tendency for plants on conventionally tilled plots to have higher dry matter accumulation than plants on zero till plots at 4 of the 5 sampling dates. These results are consistent with data collected for emergence (Table 10).

Tiller Counts

Results of tiller counts taken at 5, 9 and 11 weeks after seeding are given in Table 13. Neither the results of the tillage x straw interaction or straw management practices resulted in significant differences in tiller counts. However, there was a tendency for tillering to be higher when the straw was removed by burning as compared to where straw was spread or raked. The increased tillering on plots where straw was removed by burning may partially account for the increased dry matter production on the burned plots (Table 11).

Tiller counts were shown to be affected by the method of tillage. The total number of tillers were found to decrease from the fifth to the eleventh week after seeding on both zero till and conventionally tilled plots. This trend in tiller mortality has been reported by Milthorpe and Moorby, 1974. They attributed tiller mortality to competition for substrate, especially nitrogen. The tiller mortality rates were also found to be higher on conventionally tilled plots than on zero till plots. After eleven weeks, 34 percent of the tillers had died on conventionally tilled plots compared to 27 percent on zero till plots. The reason for the differential in mortality rates can be attributed to differences in plant competition. Higher plant populations measured on conventionally tilled plots would indicate greater plant competition occured compared to zero till plots. The differential plant competition resulted in zero tillage plots having approximately 5 percent more tillers/m^2 than conventionally tilled plots.

TABLE 13. Effect of straw management and tillage methods on tiller counts of wheat at Graysville in 1978

Treatment	Sampling dates(weeks after seeding)		
	5	9	11
	tillers/m^2		
Tillage x straw			
ZT Burn	562	533	425
Raked	575	454	393
Spread	553	482	415
CT Burn	624	460	443
Raked	553	472	360
Spread	594	456	371
LSD (0.05)	ns	ns	ns
Straw management			
Burn	593	497	434
Raked	564	463	376
Spread	574	469	393
LSD (0.05)	ns	ns	ns
Tillage method			
Zero tillage	564	490	411
Conventional tillage	591	463	391
LSD (0.05)	ns	ns	18

Wheat Yield

The results of final grain yields are presented in Table 14. Significant differences arising from the interaction between method of tillage and straw management were not observed for final grain yield.

Grain yield, however, did show a highly significant response to straw management. The average grain yield for the burn treatment was 2097 kg/ha. The yields from other treatments were 1829 and 1834 kg/ha, for straw raked and straw spread respectively. These yield differences corresponded to a 14 percent yield advantage for the burn treatment. The higher grain yields measured on plots where straw was removed by burning were due to the higher rates of growth (Table 11) and apparently higher tiller numbers (Table 13) measured on plots having the burn treatment as compared to plots where straw was spread or raked.

While the effects of tillage were not found to be significant, there was a tendency for yields to be higher on conventionally tilled plots. The apparent higher grain yield on conventionally tilled plots may have been due to higher plant populations (Table 9) and apparent greater vegetative growth (Table 11) as compared to zero till plots.

TABLE 14. Effect of straw management and tillage methods on yields of wheat at Graysville in 1978

Treatments		Grain Yield
Tillage x straw		kg/ha
ZT	Burn	2061
	Raked	1785
	Spread	1804
CT	Burn	2133
	Raked	1874
	Spread	1864
LSD (0.05)		ns
Straw Management		
	Burn	2097
	Raked	1829
	Spread	1834
LSD (0.05)		185
Tillage method		
	Zero tillage	1884
	Conventional tillage	1957
LSD (0.05)		ns

<u>Experiment 2</u>: The effects of straw management, method of tillage and planting date on emergence, shoot dry matter accumulation, tillering and final yield of wheat at Graysville, Site 1 in 1979.[1]

Emergence

Crop emergence was determined from a composite of six samples taken during the growing season. Emergence counts were averaged and are presented in Table 15. The results of the tillage x straw interaction were found to have a significant effect on wheat emergence. Zero till plots where

[1] Site 1 at Graysville is a continuation of the 1978 Graysville experiment and corresponds to having continuous zero tillage plots for three years.

straw was removed by burning or raking had the highest plant populations; zero till plots with straw spread and the conventionally tilled plots had between 5 and 10 percent fewer plants.

TABLE 15. Effect of straw management and tillage methods on emergence of wheat at Graysville in 1979

Treatment		Wheat Emergence [1]
Tillage x straw		plants/m^2
ZT	Burn	125
	Raked	124
	Spread	112
CT	Burn	115
	Raked	112
	Spread	116
LSD (0.05)		10
Straw management		
	Burn	120
	Raked	118
	Spread	114
LSD (0.05)		ns
Tillage method		
	Zero tillage	120
	Conventional tillage	114
LSD (0.05)		6

[1] Average of 6 subsamples

The reasons for the differences found in plant counts may be attributed to the quality of the seedbed and to the effectiveness of the seed drill to penetrate trash. The quality of seedbed was found to be superior on zero till plots due to the greater firmness and higher amount of soil moisture. The dry loose seedbed of conventionally tilled plots was not as favourable and therefore, resulted in lower emergence. As indicated in Experiment 1, even though the seedbed on zero till plots may be more favourable, emergence will depend on the effectiveness of the drill used, to penetrate and place the seed in good contact with moist soil. The drill used in this study often failed to penetrate straw and place the seed in favourable position for germination and emergence. Often the seed was deposited on top of decaying straw rather than in moist soil. Lindwall and Anderson (1977) reported that seeds in contact with decomposing residue often failed to emerge. Approximately 5 percent more plants emerged on zero till plots than on conventionally tilled plots in this experiment.

Shoot Dry Matter Accumulation

Table 16 contains the results of wheat dry matter samples taken 3, 5, 7, 9, 11 and 13 weeks after seeding. The tillage x straw interaction was not found to be significant in this trial. Straw management, however, was found to have a significant effect on dry matter accumulations at most sampling dates. Dry weights, five weeks after seeding, were found to be 96, 79 and 81 g/m^2 for burned, raked and straw spread plots, respectively. This corresponds to approximately 18 percent more plant material on plots where straw was removed by burning than where straw was either spread or raked. This trend was also noted at 13 weeks after seeding. The greater dry matter production on plots where straw was removed by burning can be attributed to the higher plant populations measured on these plots (Table 15).

TABLE 16. Effect of straw management and tillage methods on shoot dry matter accumulation of wheat at Graysville in 1979 (Site 1)

Treatments	Total dry weight (g/m^2)					
	Sampling time (weeks after seeding)					
	3	5	7	9	11	13
	g/m^2					
Tillage x straw						
ZT Burn	13	91	344	586	855	932
Raked	14	84	315	552	766	877
Spread	12	82	304	590	761	879
CT Burn	12	101	338	616	823	924
Raked	11	74	318	520	804	869
Spread	13	79	321	566	716	832
LSD (0.05)	ns	ns	ns	ns	ns	ns
Straw management						
Burn	12	96	341	601	839	928
Raked	13	79	317	538	785	873
Spread	13	81	313	578	738	855
LSD (0.05)	ns	12	28	57	93	ns
Tillage method						
Zero tillage	13	86	321	576	794	896
Conventional tillage	12	85	326	567	781	875
LSD (0.05)	ns	ns	ns	ns	ns	ns

Between 5 and 13 weeks, plots with the burned treatment increased in dry matter from 96 to 932 g/m^2, which is a 9.7 fold increase. Dry matter on raked and straw spread plots increased 11 and 10.5 fold, respectively. The lower growth rate on burned plots may be attributed to the following. The higher plant population measured on the burned treatments may have depleted soil moisture reserves more quickly than plants from the other treatments. This hypothesis is supported by work conducted by Gauer (1980). Gauer showed soil moistures to be lower on plots where straw was removed by burning as compared to either straw raked or straw spread treatments at the end of the growing season.

Other reasons for the slower growth rate may be due to the disappearance of early soil temperature and nitrogen differences favouring the burned treatment. As the crop grew, shading of the soil occurred and differences in soil temperature associated with the treatments diminished. Therefore, as the season progressed, the soil temperature on plots where straw was removed by burning is found to be similar to the soil temperature of other plots. Data from Gauer (1980) shows that the average soil temperature at the 5 cm depth on burned, raked and straw spread plots on July 17 was 19.6, 21.2 and 18.1 C, respectively. At the end of August, the average soil temperatures for the burned, raked and spread plots were similar. They were 20.2, 19.4 and 19.4 C for burned, raked and straw spread plots, respectively.

<u>Tiller Counts</u>

The results of tiller counts taken 13 weeks after seeding at Site 1 at Graysville in 1979 are presented in Table 17. In this experiment, neither the method of tillage or straw management had a significant effect on tiller production. Tiller counts on conventionally tilled plots tended to be higher than counts from zero till plots. The apparent higher number of tillers on conventionally tilled plots may be due to reduced competition caused by the lower plant populations measured on conventionally tilled plots (Table 15). While tiller counts were similar for all straw management practices on zero till plots, conventionally tilled plots where straw was removed by burning tended to produce more tillers than either raked or straw spread plots. Tomar (1980) has shown that twice as much nitrogen was recovered in plants from plots where straw was removed as compared to where straw was incorporated. It is possible, therefore, that reduced tillering on conventionally tilled plots with straw incorporated may have been due to reduced nitrogen availability.

TABLE 17. Effect of straw management and tillage methods on tiller counts of wheat at Graysville (Site 1) in 1979

Treatments		Tiller counts
Tillage x straw		tillers/m^2
ZT	Burn	410
	Raked	423
	Spread	390
CT	Burn	485
	Raked	423
	Spread	410
LSD (0.05)		ns
Straw management		
	Burn	450
	Raked	423
	Spread	400
LSD (0.05)		ns
Tillage method		
	Zero tillage	410
	Conventional tillage	440
LSD (0.05)		ns

Wheat Yield

Final grain yields for the 1979 Site 1 Graysville experiment are presented in Table 18. Significant differences in grain yields were not detected in this experiment. Differences measured in emergence (Table 17) and vegetative growth (Table 16) were not reflected in final grain yields. Under conditions of high fertility neither the method of tillage or straw management practices had any significant effect on final yields.

TABLE 18. Effect of straw management and tillage methods on yields of wheat at Graysville (Site 1) in 1979

Treatment		Grain Yield
Tillage x straw		kg/ha
ZT	Burn	3080
	Raked	3000
	Spread	3060
CT	Burn	3141
	Raked	3091
	Spread	3143
LDS (0.05)		ns
Straw management		
	Burn	3111
	Raked	3045
	Spread	3101
LSD (0.05)		ns
Tillage method		
	Zero tillage	3047
	Conventional tillage	3125
LSD (0.05)		ns

Experiment 3: The effect of straw management, method of tillage and planting date on emergence, shoot dry matter accumulation, tillering and final yield of wheat at Graysville at Site 2 in 1979

Experiment 3 was established to give additional information about the individual treatments and to determine if any differences could be detected in regards to the length of time zero tillage had been conducted. In 1979, zero till plots on Site 1 had not been tilled for three years. Zero till plots at Site 2 were in their first year of establishment in 1979.

Emergence

Crop emergence was determined from a composite of six samples taken during the growing season. Emergence counts were averaged and are presented in Table 19. Differences in plant populations were small and no significant differences were found. While differences were non-significant, there was a tendency for emergence to be lower on zero till plots where straw was spread as compared to where straw was raked or burned. This trend was similar to the results of plant counts taken in Experiment 2 (Table 15). The apparent lower plant populations on zero till plots where straw was spread may be attributed to less effective drill operation under trashy conditions.

TABLE 19. Effect of straw management and tillage methods on emergence of wheat at Graysville (Site 2) in 1979

Treatment		Wheat Emergence[1]
Tillage x straw		plants/m^2
ZT	Burn	122
	Raked	125
	Spread	115
CT	Burn	122
	Raked	120
	Spread	120
LSD (0.05)		ns
Straw management		
	Burn	122
	Raked	122
	Spread	118
LSD (0.05)		ns
Tillage method		
	Zero tillage	121
	Conventional tillage	120
LSD (0.05)		ns

1. Average of 6 samples

Shoot Dry Matter Accumulation

Data from plant dry matter samples taken 3, 5, 7, 9, 11 and 13 weeks after seeding are given in Table 20. The tillage x straw interaction was not found to be significant in this experiment. However, both the method of tillage and straw management were found to have significant effects independent of each other.

TABLE 20. Effect of straw management and tillage method on shoot dry matter accumulation of wheat at Graysville (Site 2) in 1979

Treatment	Sampling dates (weeks after seeding)					
	3	5	7	9	11	13
	g/m^2					
Tillage x straw						
ZT Burn	21.2	75	267	500	724	756
Raked	17.2	75	261	488	628	678
Spread	16.2	67	246	448	638	681
CT Burn	19.4	79	307	574	695	799
Raked	18.4	68	302	480	655	726
Spread	18.7	71	265	470	663	733
LSD (0.05)	ns	ns	ns	ns	ns	ns
Straw management						
Burn	20.3	77	287	537	709	777
Raked	17.8	71	282	484	641	702
Spread	17.5	69	256	459	650	707
LSD (0.05)	2.6	ns	33	52	66	81
Tillage method						
Zero tillage	18.2	72	258b	479	663	705
Conventional tillage	18.8	73	292a	508	671	752
LSD (0.05)	ns	ns	21	ns	ns	ns

Removal of straw by burning resulted in the highest dry matter accumulation on both zero till and conventionall tilled plots. There was approximately 10 percent more dry matter on plots where straw was removed by burning as compared to either of the straw raked or straw spread treatments 13 weeks after seeding. The data also indicates, that initially, the plots with the raked treatment had a growth advantage over plots with the straw spread treatment, but by the end of the season there were no differences between the raked and spread treatments. It is possible that warmer soil temperatures on the raked plots provided the initial growth advantage. As the season progressed, the difference in soil temperature would have diminished. Gauer (1980) shows the average soil temperature at the 5 cm depth to be 18.1 and 21.4 C for the straw spread and raked treatments, respectively, on July 17. Later in the season, on August 28, the soil temperatures were virtually the same: 20.3 and 19.7 C for straw spread and straw raked, respectively. Gauer (1980, Table 8) also found higher accumulated soil degree days above 10 C, on plots having the burned treatment as compared to where straw was spread or raked. More optimum soil temperatures may have contributed to the increased dry matter production on plots where straw was removed by burning.

Significant differences in dry matter were also detected due to the method of tillage. Conventionally tilled plots produced approximately 6 percent more dry matter than zero till plots, when sampled 13 weeks after seeding. Significant differences in dry matter accumulation could not be attributed to the method of tillage in either Experiment 1 or 2. The small advantage in dry matter on conventionally tilled plots may have been due to slightly greater weed growth observed on zero till plots in this experiment.

<u>Tiller Counts</u>

Data from tiller counts taken 13 weeks after seeding is presented in Table 21. Only straw management had a significant effect on tillering in this experiment. Approximately 10 percent more tillers were produced on plots where straw was removed by burning than where straw was raked or spread.

The greater tiller production on burned plots may be attributed to nitrogen on burned plots being more available early in the season, before the applied nitrogen became available. The increased tiller production may be responsible for the higher dry matter accumulation measured on plots where straw was removed by burning (Table 20).

A similar but non-significant response to straw management was measured for tillering in Experiment 2 (Table 17).

TABLE 21. Effect of straw management and tillage methods on tiller counts of wheat at Graysville (Site 2) in 1979

Treatment		Tiller Counts
Tillage x straw		tillers/m^2
ZT	Burn	408
	Raked	367
	Spread	344
CT	Burn	405
	Raked	378
	Spread	388
LSD (0.05)		ns
Straw management		
	Burn	407
	Raked	373
	Spread	366
LSD (0.05)		19
Tillage method		
	Zero tillage	373
	Conventional tillage	390
LSD (0.05)		ns

Wheat Yield

The results of final grain yields are presented in Table 22. In this experiment, only the effects of straw management were found to cause significant differences in grain yield. Plots where straw was removed by burning, had grain yields 7 and 9 percent higher than yields obtained from plots with the raked and straw spread treatments, respectively. The higher yield on plots with the burn treatment can be attributed to the greater number of tillers measured on these plots as compared to where straw was raked or spread.

TABLE 22. Effect of straw management and tillage methods on yields of wheat at Graysville (Site 2) in 1979

Treatment		Grain yield
Tillage x straw		kg/ha
ZT	Burn	2856
	Raked	2504
	Spread	2588
CT	Burn	2798
	Raked	2786
	Spread	2604
LSD (0.05)		ns
Straw management		
	Burn	2827
	Raked	2645
	Spread	2596
LSD 90.05)		218
Tillage method		
	Zero tillage	2650
	Conventional tillage	2730
LSD (0.05)		ns

A comparison of Experiment 2 and Experiment 3, which differ in the length of time zero tillage was used, failed to show any strong differences. Experiment 2 generally had higher grain yields than Experiment 3. This was likely due to better previous management, which resulted in lower weed populations in Experiment 2.

Experiment 4: Effect of straw management and method of tillage on final yield of wheat at Sanford in 1978

Adverse weather conditions prevented the establishment of a full sized experiment at Sanford in 1978. Seeding was delayed and consequently only one date of seeding was established. Final grain yields were the only measurement obtained from this site in 1978.

Wheat Yield

Results of final yields are presented in Table 23. Significant differences were detected from the effects of the tillage x straw interaction. The data indicates that yields on conventionally tilled plots were independent of the straw management practice used. However, straw management had a significant effect on yields of zero till plots. Zero till plots, where straw was spread, yielded 14 percent less than zero till plots where straw was removed by burning. The lower yields on zero till plots with straw spread can be attributed to problems of seeding through a trash cover. Moist conditions at the time of seeding often caused straw to be pushed into the seed slot instead of being cut by the leading coulter. Seed was, therefore, deposited on top of the straw instead of in moist soil. Consequently, the seed either failed to germinate or germinated more slowly than where the seed had good contact with moist soil. The resulting plants were often slower in development, weaker and incapable of producing high yields.

TABLE 23. Effect of tillage method and straw management on yield of wheat at Sanford in 1978

Treatments		Grain Yield
Tillage x straw		kg/ha
ZT	Burn	1395
	Raked	1354
	Spread	1195
CT	Burn	1237
	Raked	1223
	Spread	1295
LSD (0.05)		140
Straw management		
	Burn	1316
	Raked	1288
	Spread	1245
LSD (0.05)		ns
Tillage method		
	Zero tillage	1314
	Conventional tillage	1252
LSD (0.05)		ns

Experiment 5: The effects of straw management, method of tillage and planting date on emergence, shoot dry matter accumulation, tillering and final yield of wheat at Sanford in 1979

Wet spring conditions which hampered seeding at Sanford in 1978 also caused difficulties in seeding and less than ideal seedbed conditions in 1979. The adverse weather conditions permitted the establishment of only two dates of seeding at Sanford in 1979.

Emergence

Crop emergence was determined from a composite of six samples taken during the growing season. Emergence counts were averaged and are presented in Table 24. The date x tillage interaction was found to have a significant effect on wheat emergence in this experiment. Data indicates that very poor emergence was achieved. At the first planting date an International triple disc drill was used on both zero till and conventionally tilled treatments. The drill was equipped with front cutting coulters which were used on the zero till plots to improve penetration. Emergence was less than 50 percent at the first planting date. Poor emergence, on date 1 zero till plots can be attributed to the failure of the drill to effectively open the soil for seed placement and the failure of the packer wheels to cover the seed with soil, to prevent dessication. Poor emergence, on date 1 conventionally tilled plots, can be attributed to the dry lumpy seedbed found on the conventionally tilled plots (see Gauer, 1980, p. 67). Rainfall did not occur for some time after seeding;

consequently many seeds which germinated shortly after seeding failed to develop. The majority of plants which did grow, germinated only after rain fell, when the soil surface was thoroughly moistened again.

TABLE 24. Effect of planting date, straw management and tillage methods on emergence of wheat at Sanford in 1979

Treatment		Wheat Emergence[1]
		plants/m^2
Date x tillage		
Date 1	Zero tillage	78
	Conventional tillage	84
Date 2	Zero tillage	104
	Conventional tillage	142
LSD (0.05)		22
Tillage x straw		
ZT	Burn	90
	Raked	93
	Spread	91
CT	Burn	107
	Raked	112
	Spread	120
LSD (0.05)		ns
Straw management		
	Burn	98
	Raked	102
	Spread	107
LSD (0.05)		ns
Tillage method		
	Zero tillage	91
	Conventional tillage	113
LSD (0.05)		16

1. Average of 6 samples

Zero till plots at the second **planting date** were seeded with a Haybuster drill. This drill performed better than the International drill but still did not result in a high emergence. Less than adequate soil penetration and problems with seed placement and coverage were associated with the Haybuster drill. The conventionally tilled plots at the second planting date were seeded with a discer. The discer which is well adapted to seeding in heavy wet soils seemed to result in greater emergence than that obtained using a double disc drill and cultivator. Approximately 75 percent of the seed sown by the discer emerged, which is normal for this type of seeding machine. Variations in seeding depth and seed placement inherent in the discer often prevent higher emergence percentages than those measured in this experiment.

The straw management x tillage interaction did not exhibit a significant effect on emergence in this experiment. As post seeding rains were necessary for germination on all plots, the differences in effectiveness of seeding through trash covers observed at Graysville, were not observed in this experiment.

Plant populations were found to be 24 percent higher on conventionally tilled plots as compared to the zero till plots. The main reason for the large differences, as mentioned earlier is due to the relative ineffectiveness of the zero tilldrills on a heavy dry soil as compared to the discer.

Shoot Dry Matter Accumulation

Data from dry matter samples taken 3, 5, 7, 9, 11 and

13 weeks after seeding are presented in Table 25. The tillage x straw interaction resulted in significant differences 3 and 5 weeks after seeding. No differences were noted later. At both of these sampling dates, there was a definite trend for zero till plots with straw spread to have lower dry matter accumulations than either of the other zero tillage treatments. There were no differences attributed to the straw management practice on conventionally tilled plots.

TABLE 25. Effect of tillage method and straw management on shoot dry matter accumulation of wheat at Sanford in 1979

Treatments	Sampling date (weeks after seeding)					
	3	5	7	9	11	13
	g/m^2					
Tillage x straw						
ZT Burn	7.3	69c	250	482	583	780
Raked	8.0	56b	239	483	634	755
Spread	5.4	39a	205	413	581	720
CT Burn	5.0	47ab	181	405	491	717
Raked	4.9	47ab	158	390	481	540
Spread	6.1	49ab	170	386	435	570
LSD (0.05)	2.6	12	ns	ns	ns	ns
Straw management						
Burn	6.2	57.7b	215	444	537	748
Raked	6.5	51.6ab	198	436	558	647
Spread	5.7	44.2a	188	399	508	645
LSD (0.05)	ns	8.6	ns	ns	ns	93
Tillage methods						
Zero tillage	6.9	54.6	231b	459b	599b	752
Conventional tillage	5.3	47.6	170a	393a	469a	609
LSD (0.05)	1.2	ns	33	53	66	134

Slower plant growth on zero till plots with straw spread as compared to where straw was raked or burned, may be attributed to lower soil temperatures. Data taken from Gauer (1980, p. 94) shows the average weekly soil temperature at the 5 cm depth at week 1, on zero till plots with straw spread to be approximately 1.5 C lower than the soil temperature of the other zero till plots.

The effects of straw management, while not significant at every sampling date tended to result in higher dry matter accumulations on raked and burned plots and lower on straw spread plots. Thirteen weeks after seeding, plots where straw was removed by burning produced significantly more dry matter than plots where straw was either raked or spread. Burned plots as reported by Gauer (1980, p. 50) accumulated more soil degree days than plots which had either the raked or straw spread treatments. This factor may have contributed to higher plant growth and dry matter accumulations measured on plots where straw was removed by burning. The warmer soil temperatures on burned plots may also have increased mineralization which would also increase nitrogen availability and plant growth.

As mentioned in other experiments, plots where straw was removed by burning may have also had lower amounts of immobilized nitrogen, allowing for higher available nitrogen and greater dry matter production.

Zero till plots were found to produce higher amounts of dry matter than conventionally tilled plots at all sampling dates. Dry matter samples taken 13 weeks after seeding show zero till plots produced 26 percent more dry matter than conventionally tilled plots. The higher dry matter on zero till plots, as compared to conventionally tilled plots, can be attributed to the higher soil moisture reserves measured by Gauer (1980, p. 67) on zero till plots at Sanford in 1979.

The data collected from dry matter samples does not coincide with plant counts taken. It would appear that the higher plant populations measured on conventionally tilled plots may have resulted in competition between crop plants; consequently plants from conventionally tilled plots were smaller and weaker. Plants from zero till plots with lower populations were able to utilize the available substrates more efficiently resulting in greater dry matter accumulations from fewer plants.

Tiller Counts

The results of tiller counts taken 13 weeks after seeding are presented in Table 26. No differences in the tiller counts were detected. Plants on plots with low stand densities (Table 24) were able to compensate by increased tillering such that no significant differences in tiller counts per square meter were found. There was, however, a trend for higher tillering to occur on plots where straw had been removed by burning as compared to raking or spreading and on zero tillage plots as compared to tilled plots. These trends help to explain some of the differences found in dry matter accumulations (Table 25).

TABLE 26. Effect of straw management and tillage method on tiller counts of wheat at Sanford in 1979

Treatments		Tiller counts
Tillage x straw		tillers/m^2
ZT	Burn	404
	Raked	413
	Spread	381
CT	Burn	402
	Raked	349
	Spread	355
LSD (0.05)		ns
Straw management		
	Burn	403
	Raked	381
	Spread	369
LSD (0.05)		ns
Tillage method		
	Zero tillage	399
	Conventional tillage	369
LSD (0.05)		ns

Wheat Yields

Results of final grain yields are presented in Table 27. In this experiment the planting date x tillage x straw interaction was found to be significant. At the first planting date, no significant differences were found. However, at the second planting date, zero till plots where straw had been spread produced significantly more grain than any other treatment.

TABLE 27. Effect of planting dates, tillage methods and straw management on yield of wheat at Sanford in 1979

Treatments		Grain Yield
Planting date x tillage x straw		kg/ha
Date 1		
ZT	Burn	1406
	Raked	1398
	Spread	1399
CT	Burn	1459
	Raked	1310
	Spread	1449
Date 2		
ZT	Burn	1495
	Raked	1477
	Spread	1791
CT	Burn	1585
	Raked	1611
	Spread	1412
LSD (0.05)		266
Tillage x straw		
ZT	Burn	1581
	Raked	1572
	Spread	1689
CT	Burn	1730
	Raked	1566
	Spread	1555
LSD (0.05)		ns
Straw management		
	Burn	1656
	Raked	1569
	Spread	1622
LSD (0.05)		ns
Tillage method		
	Zero tillage	1614
	Conventional tillage	1617
LSD (0.05)		ns

The higher yields found on zero till plots where straw was spread may be attributed to the greater amount of moisture available on these plots. Data from Gauer (1980, Figures 19, 22 and 24) shows that gravimetric water content on zero till plots where straw was spread was higher than for any other treatment.

Higher vegetative growth and apparent higher tiller counts observed on zero till plots and plots where straw was removed by burning as compared to the other tillage and straw management treatments, were not reflected in final grain yields.

Rapeseed Experiments

Experiment 6: The effects of straw management, method of tillage and planting date on emergence, shoot dry matter accumulation and grain yield of rapeseed at Graysville in 1978

Excessive weed growth both on zero till and conventionally tilled plots at the earliest planting date required that those plots be abandoned. Therefore, only two planting dates were included in this experiment.

Emergence

Data on crop emergence taken two weeks after seeding is presented in Table 28. Significant differences were found to occur as a result of the triple interaction (date x tillage x straw). Although there were no differences in emergence at the first planting date, there were differences at the second planting date. Emergence was found to be highest on zero till and conventionally tilled plots when the straw from the previous crop was spread and lowest on plots where straw was removed by burning.

TABLE 28. Effect of planting date, straw management and tillage method on emergence of rapeseed at Graysville in 1978

Treatment		Rapeseed emergence
Planting date x tillage x straw		plants/m^2
Date 1		
ZT	Burn	58
	Raked	50
	Spread	60
CT	Burn	79
	Raked	63
	Spread	73
Date 2		
ZT	Burn	58
	Raked	69
	Spread	87
CT	Burn	31
	Raked	43
	Spread	51
LSD (0.05)		40
Tillage x straw		
ZT	Burn	58
	Raked	60
	Spread	74
CT	Burn	55
	Raked	53
	Spread	62
LSD (0.05)		ns
Straw management		
	Burn	56
	Raked	56
	Spread	68
LSD (0.05)		ns
Tillage method		
	Zero tillage	64
	Conventional tillage	60
LSD (0.05)		ns

The trends observed in crop emergence in this experiment are similar to those from Experiment 1, which is the wheat experiment which parallels this rapeseed experiment. The reason for the increased emergence on plots with straw spread at the last planting date appears to be due to drier soil conditions being present at that time (see Experiment 1). Plots with straw spread were able to maintain higher amounts of available moisture during this period of declining soil moisture and therefore resulted in greater germination and emergence of crop plants.

At the second planting date, emergence on zero till plots was higher than emergence on conventionally tilled plots. The higher emergence on zero till plots can be attributed to the ability of zero till plots to conserve greater amounts of moisture than conventionally tilled plots.

Final Shoot Dry Matter

Plant dry matter samples were collected at harvest in 1978. The data is presented in Table 29. There were no differences in plant growth as measured from dry matter samples taken at harvest. The small differences which were observed were similar to trends observed for emergence data (Table 28). Plots where straw was burned seemed to give the highest dry matter production at the first planting date, whereas the plots where straw was either raked or spread gave higher dry matter production at the second planting date.

There was also a tendency at both planting dates for dry matter production to be highest on zero till plots as compared to conventional tilled plots. Emergence data also showed a similar trend (Table 28).

TABLE 29. Effect of planting date, straw management and tillage method on final shoot dry matter of rapeseed at Graysville in 1978

Treatment		Planting date 1	Planting date 2
		g/m²	
Tillage x straw			
ZT	Burn	273	372
	Raked	325	394
	Spread	330	365
CT	Burn	320	365
	Raked	238	332
	Spread	246	345
LSD (0.05)		ns	ns
Straw management			
	Burn	311	310
	Raked	211	363
	Spread	288	355
LSD (0.05)		ns	ns
Tillage method			
	Zero tillage	319	377
	Conventional tillage	268	308
LSD (0.05)		ns	ns

Rapeseed Yield

The results of final grain yield are presented in Table 30. Significant differences in grain yields were found to occur as a result of the triple interaction. At the first planting date, all zero till plots had similar yields. However, conventionally tilled plots where straw was either raked or spread produced significantly less grain than those plots where straw was removed by burning. Work conducted by Tomar (1980) supports the trend established in the rapeseed yields. Tomar has shown yields could be reduced when straw was incorporated into the soil. If straw was present but not incorporated, this had little effect on nitrogen availability and subsequent yields. Thus, the low yields found on conventionally tilled plots where straw was either raked or spread can be attributed to the reduced availability of nitrogen on these plots.

At the second planting date, there again were no differences in yields between straw management practices on zero till plots. There was, however, a tendency for conventionally tilled plots having the burn treatment to yield less than either of the other two straw management treatments. The low yields found on conventionally tilled burned plots can be attributed to the low emergence measured on these plots (Table 28).

The net effect of the method of tillage in this experiment was for zero till plots to produce 23 percent more rapeseed than conventionally tilled plots. Increased crop emergence (Table 28) plus greater moisture and nitrogen availability are reasons for the higher rapeseed yield on zero till plots.

TABLE 30. Effect of planting date, straw management and tillage methods on yield of rapeseed at Graysville in 1978

Treatment		Grain Yield
Planting date x tillage x straw		kg/ha
Date 1		
ZT	Burn	1024
	Raked	1087
	Spread	912
CT	Burn	970
	Raked	638
	Spread	657
Date 2		
ZT	Burn	957
	Raked	879
	Spread	889
CT	Burn	657
	Raked	851
	Spread	892
LSD (0.05)		271
Tillage x straw		
ZT	Burn	991
	Raked	983
	Spread	900
CT	Burn	813
	Raked	745
	Spread	776
LSD (0.05)		ns
Straw management		
	Burn	902
	Raked	864
	Spread	837
LSD (0.05)		ns
Tillage method		
	Zero tillage	958
	Conventional tillage	777
LSD (0.05)		236

Experiment 7: The effect of straw management, method of tillage and planting date on emergence, shoot dry matter accumulation and grain yield of rapeseed at Graysville (Site 1) in 1979 [1]

Emergence

Crop emergence was determined from a composite of five samples taken during the growing season. Emergence counts were averaged and the data is presented in Table 31.

TABLE 31. Effect of straw management and tillage methods on emergence of rapeseed at Graysville (Site 1) in 1979

Treatments		Rapeseed emergence[2]
Tillage x straw		plants/m^2
ZT	Burn	76
	Raked	80
	Spread	70
CT	Burn	69
	Raked	71
	Spread	67
LSD (0.05)		ns
Straw management		
	Burn	72
	Raked	75
	Spread	68
LSD (0.05)		ns
Tillage method		
	Zero tillage	76
	Conventional tillage	69
LSD (0.05)		ns

1. Site 1 at Graysville was a continuation of the 1978 Graysville experiment and corresponds to having zero till plots for three years.

2. Average for five sub-samples

No differences in plant emergence could be attributed to the tillage x straw interaction or to the effects of straw management. While the differences caused by the tillage treatment were not significant, there was a tendency for zero till plots to have more plants emerge as compared to conventionally tilled plots. The apparent greater emergence on zero till plots can be attributed to the firm moist seedbed found on these plots.

Shoot Dry Matter Accumulation

Data from plant dry matter samples taken 3, 5, 7, 9 and 11 weeks after seeding are given in Table 32. At 3 and 5 weeks after seeding, the data from the tillage x straw interaction indicates that zero till plots which had straw removed by raking had higher amounts of dry matter production. These observations are supported by the same treatment having a tendency to have higher emergence counts as seen in Table 31. The early advantage for zero till plots with straw removed by raking can be explained by the slightly higher soil moistures measured by Gauer (1980) on these plots. Gauer measured soil moisture at 20 percent on these plots on May 24. The next highest soil moisture reading was 19 percent measured on zero till plots where straw had been spread. Later in the growing season, no difference in dry matter could be attributed to the tillage x straw interaction.

At 11 weeks after seeding, significant differences in dry matter accumulation could be attributed to straw management practices. Plots where straw was removed by burning produced 14 percent more dry matter than plots where straw was removed by raking. A 24 percent difference in dry matter production existed between plots which had been burned and those where straw was spread. Higher dry matter on plots which had straw removed by burning is probably due to higher amounts of available nitrogen.

No differences in dry matter accumulation could be attributed to the method of tillage.

TABLE 32. Effect of straw management and tillage methods on shoot dry matter accumulation of rapeseed at Graysville (Site 1) in 1979

Treatment		Sampling date (weeks after seeding)				
		3	5	7	9	11
Tillage x straw		g/m^2				
ZT	Burn	28	115	444	647	974
	Raked	30	146	420	662	823
	Spread	29	108	361	605	745
CT	Burn	29	132	394	728	954
	Raked	28	109	401	720	870
	Spread	28	107	381	554	805
LSD (0.05)		ns	31	ns	ns	ns
Straw management						
	Burn	28	123	419	688	964
	Raked	29	127	410	691	847
	Spread	28	107	370	580	775
LSD (0.05)		ns	ns	ns	ns	134
Tillage method						
	Zero tillage	29	122	408	638	847
	Conventional tillage	28	116	392	667	876
LSD (0.05)		ns	ns	ns	ns	ns

Rapeseed Yield

The results of final grain yield are presented in Table 33. Neither the tillage x straw interaction or the effects of straw management alone resulted in any differences in rapeseed yields. The method of tillage, however, resulted in a significant difference in grain yields. Grain yields on zero tillage were found to be 17 percent higher than the grain yields from conventionally tilled plots. The higher yields on zero till plots were attributed in part to the apparent higher plant stands measured on zero till plots (Table 31). Higher soil moisture, particularly, in period of declining soil moisture as measured by Gauer (1980, Tables 18, 21 23) may also explain the higher grain yields found on the zero till plots.

TABLE 33. Effect of straw management and tillage methods on yields of rapeseed at Graysville (Site 1) in 1979

Treatment		Grain Yield
Tillage x straw		kg/ha
ZT	Burn	2002
	Raked	1927
	Spread	1937
CT	Burn	1642
	Raked	1807
	Spread	1568
LSD (0.05)		ns
Straw management		
	Burn	1822
	Raked	1867
	Spread	1751
LSD (0.05)		ns
Tillage method		
	Zero tillage	1955
	Conventional tillage	1671
LSD (0.05)		219

Experiment 8: The effect of straw management, method of tillage and planting date on emergence, shoot dry matter accumulation and grain yield of rapeseed at Graysville (Site 2) in 1979

Experiment 8 was established to give additional information about the individual treatments and to determine if any differences could be established in regards to the length of time zero tillage had been conducted. In 1979 zero till plots on Site 1 had not been tilled for three years. Zero till plots at Site 2 were in their first year of establishment in 1979.

Excessive weed growth on both zero till and conventionally tilled plots at the first planting date required that those plots be abandoned; therefore only two planting dates were included in this experiment.

Emergence

Crop emergence was determined from a composite of 5 samples taken during the growing season. Emergence counts were averaged and the data is presented in Table 34. The number of plants emerged was not found to be affected by either the tillage x straw interaction or the straw management practices. The method of tillage, however, did significantly influence the emergence counts. Approximately 22 percent more plants emerged on zero till plots as compared to conventionally tilled plots. This observation was also noted in the results of plant counts from Experiment 7 (Table 31). The higher emergence measured on zero till plots can be attributed to the more favourable seedbed conditions. The seedbed on zero till plots was characterized as being more firm and moist than the seedbed of conventionally tilled plots.

TABLE 34. Effect of straw management and tillage methods on emergence of rapeseed at Graysville (Site 2) in 1979

Treatment		Rapeseed emergence[1]
		plants/m^2
Tillage x straw		
ZT	Burn	79
	Raked	77
	Spread	80
CT	Burn	64
	Raked	63
	Spread	66
LSD (0.05)		ns
Straw management		
	Burn	71
	Raked	70
	Spread	73
LSD (0.05)		ns
Tillage method		
	Zero tillage	79
	Conventional tillage	65
LSD (0.05)		8

1. Average for 5 sub-samples

Shoot Dry Matter Accumulation

Data from plant dry matter samples taken 3, 5, 7, 9 and 11 weeks after seeding are given in Table 35. The tillage x straw interaction was not found to have significant effects on dry matter accumulation except at 9 weeks after seeding. At this sampling date, zero till plots where straw was removed by burning had the greatest amount of dry matter production, compared to all other treatments.

TABLE 35. Effect of straw management and tillage methods on shoot dry matter accumulation of rapeseed at Graysville (Site 2) in 1979

Treatment	Sampling time (weeks after seeding)				
	3	5	7	9	11
	g/m^2				
Tillage x straw					
ZT Burn	24	129	392	694	778
Raked	17	113	246	560	680
Spread	20	137	374	576	755
CT Burn	19	136	384	511	741
Raked	15	150	395	505	676
Spread	20	127	370	577	714
LSD (0.05)	ns	ns	ns	74	ns
Straw management					
Burn	21	133	388	602	759
Raked	16	131	371	532	678
Spread	20	132	372	576	735
LSD (0.05)	3	ns	ns	52	70
Tillage method					
Zero tillage	20	126	371	610	738
Conventional tillage	18	138	383	531	711
LSD (0.05)	ns	ns	ns	46	ns

The effect of straw management practices was such that plots where straw was removed by raking produced the lowest amount of dry matter. There were no differences between dry matter production on plots where straw was burned or those on which straw was spread. The lower dry matter production on raked plots is supported by emergence counts (Table 34), which shows a tendency for raked plots to have lower emergence. The tendency for lower emergence and dry matter accumulation in this experiment is not consistent with data collected from Experiment 7. In Experiment 7, raked plots tended to have the highest plant counts and were intermediate in dry matter accumulation between plots which had been burned and those where straw had been spread.

There were no significant differences in dry matter accumulation resulting from either tillage treatments. However, there was a trend for zero till plots to have greater dry matter production than conventionally tilled plots.

Rapeseed Yield

The results of final grain yield are presented in Table 36. None of the treatments had any significant effect on the yield of rapeseed. The effect of straw management on the yield of rapeseed, while not significant, is similar to the trend established for dry matter accumulation, 11 weeks after seeding (Table 35). Plots with straw removed by burning had the highest grain yield and dry matter accumulation; plots with straw removed by raking, the lowest.

Rapeseed yields also tended to be higher on zero till plots as compared to conventionally tilled plots. This is similar to the effect which tillage methods had on dry matter accumulation (Table 35).

A comparison between Site 1 (Experiment 7) and Site 2 (Experiment 8) at Graysville in 1979, shows that trends were similar in both experiments. However, the trends were stronger in Experiment 7 and the final grain yields much higher. The higher grain yields measured in Experiment 7 can be attributed to higher soil fertility and lower weed populations which was a consequence of past management. One exception to the general trends established in Experiment 7 was found in Experiment 8. Plots where straw was removed by raking produced the lowest dry matter production and grain yields in Experiment 8 but in Experiment 7, plots where straw was spread resulted in the lowest yield. Both experiments showed a slight advantage for zero tillage as the method of tillage needed to give the highest yields. There does not appear to be any trend or significant difference between the two experiments which would indicate that the number of years since tillage was performed would be of major concern.

TABLE 36. Effect of straw management and tillage methods on yield of rapeseed at Graysville (Site 2) in 1979

Treatment	Grain yield
Tillage x straw	kg/ha
ZT Burn	1008
Raked	954
Spread	862
CT Burn	949
Raked	832
Spread	980
LSD (0.05)	ns
Straw management	
Burn	979
Raked	893
Spread	921
LSD (0.05)	ns
Tillage method	
Zero tillage	941
Conventional tillage	920
LSD (0.05)	ns

Experiment 9: The effect of straw management, method of tillage and planting date on emergence, shoot dry matter accumulation and grain yield of rapeseed at Sanford in 1979

Rapeseed was grown at Sanford in 1979 only. Plots were prepared in 1978 but a prolonged wet period made seeding difficult and consequently, rapeseed was not sown in 1978. Only two planting dates were possible in 1979 due to wet spring conditions.

Emergence

Crop emergence was determined from a composite of five samples taken during the growing season. Emergence counts were averaged and the data is presented in Table 37. The results of the tillage x straw interaction were found to have a significant effect on rapeseed emergence. The data shows that plots established using zero tillage gave higher emergence counts than conventionally tilled plots. Although not shown to be significant, there was a tendency for the burn treatment to result in the highest emergence on zero till plots whereas the raked treatment gave the highest emergence on conventionally tilled plots. The tendency for higher emergence on zero till plots where straw was removed by burning can be attributed to the good soil seed contact made in the absence of crop residues and to the higher soil temperatures measured by Gauer (1980, p. 94). Soil moisture data collected by Gauer (1980, Figures 19, 22, 24) indicate that, of all the conventionally tilled plots, those which had straw removed by raking had the highest soil moisture at the time of emergence. This observation explains the higher emergence measured on the conventionally tilled raked plots.

Data from emergence counts shows that 19 percent more rapeseed plants grew on zero till plots than on conventionally tilled plots. As was found in the other experiments, zero tillage provided a firm moist seedbed which was conducive to rapeseed emergence.

TABLE 37. Effect of straw management and tillage methods on emergence of rapeseed at Sanford in 1979

Treatments	Rapeseed Emergence[1]
Tillage x straw	plants/m^2
ZT Burn	94
Raked	86
Spread	86
CT Burn	71
Raked	84
Spread	72
LSD (0.05)	13
Straw management	
Burn	82
Raked	85
Spread	79
LSD (0.05)	ns
Tillage method	
Zero tillage	89
Conventional tillage	75
LSD (0.05)	8

1. Average for 5 sub-samples

Shoot Dry Matter Accumulation

Data from plant dry matter samples taken 3, 5, 7, 9, 11 and 13 weeks after seeding are given in Table 38. The tillage x straw interaction was not found to have a significant effect on the dry matter production of rapeseed. Straw management, however, was found to have a significant effect on dry matter accumulations at some of the sampling dates. Plots where straw was removed by burning tended to produce the highest amounts of dry matter. The lowest dry matter production was obtained from plots where straw was spread. The higher dry matter accumulations on burned plots may be attributed to the higher amounts of available nitrogen associated with this practice.

TABLE 38. Effect of straw management and tillage methods on shoot dry matter accumulation of rapeseed at Sanford in 1979

Treatments	Sampling date (weeks after seeding)					
	3	5	7	9	11	13
	g/m^2					
Tillage x straw						
ZT Burn	16.2	140	381	677	868	1015
Raked	13.8	111	333	563	624	948
Spread	16.2	120	361	648	610	898
CT Burn	6.1	64	246	532	699	825
Raked	7.3	70	256	442	744	754
Spread	3.7	49	251	459	660	745
LSD (0.05)	ns	ns	ns	ns	ns	ns
Straw management						
Burn	11.1	102	314	604	783	920
Raked	10.5	90	294	502	684	851
Spread	9.9	85	306	554	638	822
LSD (0.05)	ns	ns	ns	72	128	ns
Tillage method						
Zero tillage	15.4	124	358	629	700	954
Conventional tillage	5.7	61	251	478	703	775
LSD (0.05)	1.6	16	83	85	ns	93

Highly significant differences in dry matter accumulation could be attributed to the method of tillage. Higher dry matter production was measured on zero till, as compared to conventionally tilled plots, at most sampling dates. Thirteen weeks after seeding, 954 and 775 g/m^2 of plant dry matter were produced from zero till and conventionally tilled plots, respectively. This corresponds to a 23 percent advantage for zero till plots. The higher dry matter production measured on zero till plots can be attributed to the greater emergence (Table 37) and the greater available soil moisture on these plots.

Rapeseed Yield

The results of final grain yields are presented in Table 39. The tillage x straw interaction was not found to have a significant effect on rapeseed yields. However, the independent effect of the method of tillage and straw management practices were found to result in significant differences.

Plots where straw was removed by burning yielded 23 percent more rapeseed than plots where straw was spread. Burned plots yielded 9 percent more than plots where straw was removed by raking. Even though 100 kg/ha of nitrogen was added to this experiment, the increased yields on plots with straw removed by burning may be partially due to higher availability of soil nitrogen on burned plots. Accumulated soil degree days as measured by Gauer (1980) indicate that burned plots accumulated more heat units than any other straw management treatment. The accumulated soil degree days above 5 C were 811, 792 and 777 for straw burned, raked and spread, respectively. The higher amount of available heat on the burned plots besides allowing for higher growth rates of the rapeseed plants may have also increased the rate of mineralization. The possible increase in mineralization and reduced immobilization due to lack of incorporated straw should have resulted in more soil nitrogen being available to plants on burned plots. This line of reasoning is further supported by the fact that the treatment in which the greatest amount of straw was incorporated, straw spread on conventionally tilled plots, tended to have the lowest yields.

Zero till plots produced 32 percent more rapeseed than conventionally tilled plots. The higher yields found on zero till plots can be attributed to the higher plant numbers (Table 37) and greater vegetative growth (Table 38) observed on zero till plots.

TABLE 39. Effect of straw management and tillage methods on yield of rapeseed at Sanford in 1979

Treatment		Grain yield
Tillage x straw		kg/ha
ZT	Burn	1639
	Raked	1426
	Spread	1433
CT	Burn	1259
	Raked	1220
	Spread	928
LSD (0.05)		ns
Straw management		
	Burn	1449
	Raked	1323
	Spread	1180
LSD (0.05)		166
Tillage method		
	Zero tillage	1499
	Conventional tillage	1136
LSD (0.05)		138

GENERAL DISCUSSION

Wheat Experiments

Emergence

Data collected from trials on the sandy loam soil has shown that emergence of wheat under zero tillage is equal to wheat emergence when conventional methods of seedbed preparation are used. These findings are supported by work by Bauemer and Bakerman (1973), Donaghy (1973) and Hodgson et al. (1977).

Results of these studies further indicate that there was a distinct trend for emergence to be higher on zero till plots where straw was either completely removed by burning or reduced by raking. Lower emergence on zero till straw spread plots can be attributed to the ineffectiveness of the zero till drills to penetrate the mulch and place the seed in good soil contact. Soane and Pidgeon (1974) and Cannell et al. (1977) have also recognized this problem. They have recommended burning of residues in the United Kingdom to facilitate zero till seeding and ensure good soil seed contact.

Under conditions of low soil moisture, emergence was found to be highest under zero tillage when straw was spread, as compared to either removing the straw by burning or raking. Zero till straw spread plots conserved more moisture than other zero till straw treatments; therefore, greater emergence was obtained.

Straw management practices on conventionally tilled plots were not found to affect emergence except in the first year of the study. In this case, emergence was higher under conventional tillage where straw was spread as compared to where straw was removed by raking or burning. Emergence was increased in this case because the incorporated straw seemed to reduce the degree of soil crusting.

Emergence counts from the study conducted on the heavy clay soil indicates that emergence on zero till plots was lower than on conventional tillage plots. Baeumer and Bakerman (1973) also found that emergence could be reduced with zero till on heavy wet clay soils. They attributed the reduced emergence under zero till to cooler soil temperatures on zero till plots.

Emergence data collected by Donaghy (1973) on a heavy clay soil shows that emergence was equal on zero till and conventionally tilled plots. These differences in findings can be attributed to differences in residue cover and soil moisture. Donaghy worked on a well drained Red River clay while this study was conducted on a poorly drained Osborne clay.

The major problems which caused reduced emergence using zero tillage techniques on the heavy clay soil, were the high degree of smear slots and hairpinning. Christianson (1980) at Letcombe, United Kingdom, also observed smear slot and hairpinning on zero till winter wheat plots in experiments on clay soils. Smear slots develop when a double or triple disc is operated in moist soils. The soil on both sides of the slot becomes compacted and often the packer wheels fail to close the slot. Rapid drying of the slot occurs since little or no soil cover is provided. Seeds deposited in the slot often either fail to germinate or fail to develop a root system through the compacted soil layer. Rainfall is necessary to ensure seed germination and development when smear slots are encountered. The heavy clay soil was found to be very conducive to smear slots, since this type of soil can become plastic, especially when soil moisture is high.

The other problem encountered on clay soils and to a lesser degree on light soils was hairpinning of crop residues. Hairpinning occurs when the surface residues are pushed into the seed slot instead of being cut and pushed away. The reason hairpinning was a greater problem on the clay soil than on the sandy loam soil was due to the higher moisture content of the clay soil. Clay soils dry more slowly than sandy soils and therefore often have higher soil moisture. Cutting of residues is more difficult where wet soil conditions exist. Straw pushed in the seed slot prevents seed from coming into contact with moist soil. The seed is suspended above the soil in the straw. In this situation, rainfall is needed to settle the seed to where it can germinate. When a seed slot with hairpinning is covered by soil, conditions are established which could lead to anaerobic respiration and the production of phytotoxic compounds. Gauer (1980, Figure 26) has demonstrated that oxygen diffusion rates were at times reduced on zero till plots, which would further indicate anaerobic conditions could develop on zero till plots. Phytotoxins have been reported by Pittman and Horricks (1972), Lindwall and Anderson (1977) and Lynch et al. (1977) as being a cause of reduced emergence and crop growth on zero till plots.

Data collected and observations made on the sandy loam soil and particularly on the heavy dry soil, indicates that emergence under zero tillage could be improved. The development of drills adapted to zero till seeding which do not create problems with smear slots and hairpinning would be most desireable. Seeding zero till fields can sometimes be delayed 2 or more days past the time when conventionally tilled fields are being sown. The development of a drill which would not plug with trash and soil on zero till fields when these fields are in a moist conditions would, therefore, be desireable.

Dry Matter Accumulation

Tillage x straw interactions were not reported in any of the wheat experiments on the sandy loam soil. There was, however, a definite response to straw management practices. Greater dry matter production was measured on burned plots in all of these trials. Plots having the burned treatments were shown by Gauer (1980) to have higher soil temperatures and greater accumulated soil degree days. Warmer soil temperatures on burned plots may influence plant growth in a number of ways. Wilkinson (1966) has stated that cereal roots appear to grow downward into the soil following the 12 C isotherm. Therefore, straw management practices which hasten the downward movement of the 12 C isotherm may enhance root growth and distribution in the soil. Warmer soil temperatures also promote increased root branching. Better developed root systems will enable the plant to utilize soil moisture and nutrients to a greater advantage. Root growth data collected at Graysville supports the theory of greater root development on burned plots. Donaghy (1973) also shows that root penetration was slightly superior under zero tillage as compared to cultivation.

Increased soil temperatures have been shown to increase plant growth by allowing for increased rates of ion uptake, greater assimilation of ions into organic forms, increased translocation of nutrients and assimilates, and expanded sink capacity of the root (Neilson and Cunningham, 1964).

Another way in which the warmer soil temperatures on burned plots may affect crop growth is by altering the availability of soil nitrogen. Mineralization of soil nitrogen is an energy dependent process and, therefore, is temperature dependent. Higher soil temperatures on burned plots could be expected to result in increased mineralization and availability of nitrogen.

Burned plots are also characterized by their lack of straw. The presence of straw on plots has been shown to reduce plant growth in two ways. Hedlin et al. (1957) has shown that when crop residues are returned to the field, yield reductions were found. They attributed the reduction in yields to immobilization of the soil nitrogen during the breakdown of crop residues. When residues were burnt, no yield reductions were measured.

The other way in which crop residue may interfere with plant growth has been examined by Lynch (1977) and others (Pittman and Horricks, 1972; Lindwall and Anderson, 1977). Lynch has shown that decomposing residues contain water soluable phytotoxic material which can retard growth of crop plants. Since burned plots have no decomposing surface residues, problems with phytotoxins are less likely to occur and restrict plant growth.

Drew and Saker (1978) have suggested that burning crop residues may contribute to the development of concentration gradients for P and K. Therefore, greater availability of P and K on burned plots may be another factor contributing to higher dry matter production observed.

Due to the nature of the experiments and the limited number of parameters which could be measured, it is difficult to know how much each of the factors listed above contributed to the differences in growth observed.

The response of wheat dry matter production to the method of tillage was such that in one of the three trials conducted on the sandy loam soil (Experiment 3), conventionally tilled plots resulted in greater dry matter accumulation than zero till plots. In the other two trials, no differences could be detected between methods of tillage. Slightly higher weed growth may have been the reason for the lower dry matter production on zero till plots in Experiment 3. Since this was the establishment year for zero tillage on this site, weed growth was not restricted by the benefit of having the site in zero tillage for a number of years.

Elliot et al. (1977) working in the United Kingdom, on a sandy loam soil, found similar results to those obtained in this study. They found that in most years, vegetative growth of cereals under zero tillage were not different from when conventional methods were used. Elliot et al. (1977) found lower vegetative growth on zero till plots in the first year of their trial. They attributed the lower vegetative growth to poor stands caused by presence of straw and inexperience in operating a zero till drill. Hodgson et al. (1977) also working in the United Kingdom, found vegetative growth on zero till plots to be mainly lower than under conventional tillage.

Contrary to the results obtained in this study, Donaghy (1973) found on a sandy loam soil, wheat dry matter to be higher on zero till plots than conventionally tilled plots. Donaghy (1973) measured as much as a 72 percent difference in dry matter between zero till and conventional till wheat, eight weeks after emergence.

Dry matter accumulation in trials on heavy clay soils were found to be influenced by the tillage x straw interaction during early plant development. While no differences between straw management practices on cultivated plots were observed, straw management did influence vegetative growth on zero till plots. At 3 and 5 weeks after seeding, dry matter production was found to be significantly lower on zero till straw spread plots as compared to zero till plots where straw was removed by raking or burning. The slower growth rate on zero till straw spread plots can be explained by cooler soil temperatures caused by surface mulch on these plots. Shanholtz and Lillard (1969), Mock and Erbach (1977), Siemens and Oschwald (1978) and Unger (1978b) have also reported slow initial growth due to lower soil temperatures under zero tillage where the straw was spread.

Since the heavy clay soils at Sanford are typically cooler than the sandy loam soils found at Graysville, the cool soil temperatures with zero till straw spread were found to restrict early plant development at Sanford but not at Graysville. The slower plant development indicates that the effect of straw management on zero till plots may be more critical on heavy poorly drained soils than on well drained light soils. As the season progressed and soil temperatures became more similar, differences in dry matter production diminished. Shanholtz and Lillard (1969) also found that the effects of lower soil temperature on plant growth under zero tillage disappeared rapidly as soil root zone temperatures increased.

The response to straw management practices were such that dry matter production on plots where straw was removed by burning or raking was found to be higher than on plots where straw was spread. This situation parallels the results found in trials on the sandy loam soil and can be explained in the same manner. The response to the method of tillage showed dry matter production on zero till plots to be higher than on conventionally tilled plots. Donaghy (1973) found similar results at Sanford in 1971. Reduced competition and higher moisture reserves seem to be the reasons for the greater plant development observed on zero till plots.

Tiller Counts

The tillage x straw interaction was found to influence tillering in only one of the four wheat trials. In this trial, straw management had no influence on tillering of wheat on zero till plots. However, tiller counts were found to be affected by straw management practices on conventionally tilled plots. Tiller counts were found to be higher on conventionally burned plots than on plots where some or all residues remained. The reason for higher tiller production on conventionally tilled burned plots is probably due to nitrogen availability. According to Tomar (1980) only where straw is incorporated will nitrogen availability be seriously affected. The reduced nitrogen available on conventionally tilled straw spread plots may have resulted in reduced tiller counts.

Although the method of straw management did not have a large impact on tillering, in all experiments there was a tendency for tillering to be higher on burned plots. Tiller competition for the available nitrogen would explain the reason for higher tiller counts on burned plots. The trend for higher tillering on burned plots also helps explain the higher dry matter production measured on these plots.

The method of tillage was not found to have a distinct impact on tillering. Donaghy (1973), Elliot et al. (1977), and Hodgson et al. (1977) found that tillering of wheat grown under zero tillage was always equal and sometimes greater than tiller production under conventional tillage. Tiller counts on zero till and conventionally tilled plots indicate that tillering was influenced by initial plant densities. Plots where lower emergence was recorded usually had a greater number of tillers. In Experiment 1 where emergence was greater on conventionally till plots, zero till plots were found to have a greater number of tillers. In Experiment 2, zero till plots had greater wheat emergence but lower tillering. Higher tillering on plots with low plant densities may be explained in terms of competetion. The greatest amount of tillering occured on plots where plant competition was lowest.

Data from tiller counts at both Graysville and Sanford indicate that the method of tillage affects tillering only through its influence on crop emergence and the resulting competition.

Wheat Yield

The tillage x straw interaction was not found to influence grain yields on trials conducted on sandy loam soils. However, the method of straw management was shown to have a strong affect on grain yields. Higher yields were measured from plots having straw removed by burning in more experiments conducted on the sandy loam soil. The higher yields could be attributed to greater tiller production on plots where straw was burned. Higher nitrogen availability may also have been a factor which contributed to the higher yields.

The method of tillage could not be shown to affect grain yields at Graysville. Donaghy (1973), Finney and Knight (1973) and Elliot et al. (1977) also found no response of wheat or barley yields to the method of tillage on a sandy loam soil.

Wheat trials conducted on the heavy clay soils were found to response to the tillage x straw interaction. While grain yields on conventionally tilled plots were not affected by straw management practices, straw management practices did influence grain yields on zero till plots. In 1978, zero till plots having the burned or raked treatments gave significantly higher yields than plots where straw was spread. Although emergence data was not collected for this experiment, observations made at the time of seeding indicate that seed placement was poor on zero till plots where straw was spread.

The poor yield on these plots can be attributed to poor drill penetration of the surface trash which resulted in reduced plant stands and grain yields.

In 1979, while there were no differences among treatments at the first planting date, differences were detect at the second plant date. At the second planting date, zero till plots where straw was spread yielded significantly more than either burned or raked zero till plots. A period of drought occurred during the summer which coincided with kernel development of plants sown at the second planting date. This dry period affected yields on all plots in this experiment. The higher yields on zero till plots which had straw spread can be attributed to the higher moisture availability measured on these plots (Gauer 1980). The ability to delay the effects of drought using zero tillage with a mulch has also been demonstrated by Shanholtz and Lillard (1969).

In this experiment, although not significant, grain yields were approximately 5 percent higher on zero till plots.

In all trials, straw management had no effect on grain yields on conventionally tilled plots, but in trials conducted on the heavy clay soil, straw management had a significant effect on grain yield on zero till plots. These results suggest that straw management is a more important management tool when wheat is being grown without tillage and especially when zero tillage crop production techniques are being used on heavy clay soils.

The overall effect of the method of tillage on grain yields on the heavy clay soil was found to be small, as was found on the sandy loam soils of Graysville. Research conducted by Donaghy (1973), Cannell et al. (1977), Hodgson et al. (1977) and Bentley et al. (1978) also indicates that zero till wheat results in yield at least equal to conventional till wheat.

Rapeseed Experiments

Emergence

Rapeseed emergence on the sandy loam soil was not found to be highly dependent on straw management practices. In only one of the three rapeseed trials at Graysville, was emergence affected by straw management practices. At planting date 2 in 1978, rapeseed emergence was shown to be higher on plots where straw was spread. Higher soil moisture on the straw spread plots was the primary reason for the higher emergence.

Straw residues were not shown to interfere with rapeseed emergence in trials on sandy loam soils, whereas straw residues often contributed to poor seed placement and emergence in wheat experiments. Rapeseed at Graysville also had a tendency for greater emergence on zero till plots. The response of wheat to the method of tillage for emergence was less well defined.

The reason for the differences between wheat and rapeseed emergence can be attributed to the size of seed.

Rapeseed which has a small seed, responds well to a firm moist seedbed which allows for shallow seed placement. The small size of rapeseed allows the seed to move through surface residues more easily and come into contact with moist soil more readily than wheat kernels. A moist, firm seedbed characteristic of zero till plots was often much more difficult to obtain on conventionally tilled plots. Therefore, rapeseed emergence was more consistent on zero till plots. These results are supported by work by Donaghy (1973). Donaghy found that there was a tendency for greater rapeseed emergence to occur under zero tillage conditions as compared to conventional tillage.

The tillage x straw interaction was shown to have a significant effect on rapeseed emergence on heavy clay soils. Rapeseed emergence on zero till plots tended to be higher where straw was removed by burning. Burning straw allowed for warmer soil temperatures and better soil seed contact. Also, burned plots were free from the presence of phytotoxins formed during straw degradation.

The cooler nature of the heavy clay soils appears to magnify the effects which straw management practices can have on soil temperature and crop emergence. Soil temperature differences caused by straw management practices did not appear to effect the emergence of rapeseed at Graysville. Data from Gauer (1980) indicates that there was a 26 percent difference in accumulated soil degree days above 5 C between straw practices on clay soils at Sanford but only a 15 percent differences on the sandy loam soils at Graysville.

The effect of the method of tillage on rapeseed emergence at Sanford was similar to the results obtained at Graysville. Rapeseed emergence was found to be higher under zero till as compared to where cultivation was used. These results are supported by work by Donaghy (1973) who found zero till rapeseed emergence on clay soils to be equal or greater than rapeseed grown using conventional methods.

Dry Matter Accumulation

The effect of the tillage x straw interaction while found to be significant at certain sampling dates in the rapeseed experiments, failed to indicate which combination of treatments was superior.

The effect of straw management alone was found to be much more distinct. In three of the four rapeseed trials, there was a definite advantage on plots where straw had been removed by burning. Since emergence was not generally found to be superior on burned plots, the advantage that the burned treatments had over the straw management practices can probably be attributed to differences in nitrogen availability. As mentioned earlier, in the discussion of wheat results, removing straw from plots by burning may increase availability of nitrogen by decreasing immobilization, increasing mineralization or both.

The effects of the method of tillage on dry matter accumulation was similar to the trend observed for rapeseed emergence. In three of the four rapeseed trials, dry matter production was higher on the zero till plots than on tilled plots.

The greater dry matter production can probably be attributed to more rapid germination and emergence associated with the zero till plots. Greater dry matter production of rapeseed under zero tillage was also noted by Donaghy (1973).

Rapeseed Yield

The tillage x straw interaction was not found to have a large affect on rapeseed yields in trials conducted on a sandy loam soil. Rapeseed yield on zero till plots on the sandy loam soil were not influence by straw management practices. However, in one of the three trials at Graysville, straw management practices were shown to affect rapeseed yields on conventional tilled plots. In this case, the burned treatment resulted in higher yields than raking or spreading straw. The higher yields was attributed to greater nitrogen availability on burned plots. At the second planting date, however, the burned treatment resulted in the lowest yield. The low yield was attributed to poor seedling establishment on the conventionally tilled burned plots.

Rapeseed yields were found to be highly dependent upon tillage methods. Up to 23 percent more rapeseed was produced on zero till plots as compared to conventionally tilled plots on the sandy loam soil. The higher yields could be attributed to better emergence and more rapid plant growth on zero till plots.

Rapeseed yields in the trial conducted on the clay soil was found to be affected by both straw management practices and the method of tillage.

Rapeseed yields from plots where straw was burned were up to 23 percent higher than yields obtained from other straw management treatments. The high yields associated with burning may be attributed to higher available nitrogen and warm soil temperatures on these plots. Yield responses to straw management practices were not found on the sandy loam soil. The reason for this may be related to the thermal conductivity and heat capacities of the two soil types. The heavy clay soils at Sanford warm more slowly than the fine sandy loam at Graysville. Therefore, straw management practices which influence soil temperature will have a greater influence on plants being grown in the cooler clay soil where temperatures are suboptimal. Straw management practices which promote warmer soil temperatures particularly on cool soils such as burning appear to result in the greater germination and crop development.

Rapeseed yields from trials at Sanford were found to be highly dependent on the method of tillage, as was found at Graysville. Zero till rapeseed plots gave yields 32 percent higher than conventionally tilled plots. The high yields on zero till plots can be attributed to more favourable seedbed and moisture conditions. Equal or higher rapeseed yields on zero till plots, as compared to conventional tillage, have also been demonstrated by Vez and Viellioud (1971) and Cannell _et al_. (1977).

Donaghy (1973) found zero till rapeseed to produce higher yields in only 1 out of 7 trials. In six other trials, yields on zero till and conventionally tilled plots were equal. Bakerman and de Wit (1970) found, however, that winter rapeseed yields were usually lower with zero tillage than with conventional tillage.

CONCLUSIONS

Results of this study have demonstrated that wheat can be grown in Manitoba using either zero tillage or conventional tillage without reductions in yields. The effect of straw management practices were found to vary with method of tillage and soil types.

The effects of straw management practices on conventionally tilled wheat were found to be greatest in the Graysville trials. Emergence was generally not affected by straw management practices on conventionally tilled plots. However, dry matter accumulation, tillering and final yields were affected. The effects of straw management on conventional tilled wheat is thought to be primarily due to differences in nitrogen availability caused by the straw management practices. The earlier planting dates and higher yields at Graysville placed greater demands on the available nitrogen than did conventional tilled wheat at Sanford, making the effect of straw management more apparent at Graysville.

Applying fertilizer by banding instead of broadcasting, as in these trials, could make nitrogen more readily available for plant growth and could possibly reduce the impact of straw management on conventional till wheat measured in these trials.

Straw management practices were found to influence all stages of growth on zero till wheat and the effects were more noticeable on the clay soils than on the sandy loam soils. Removing straw by burning generally resulted in higher emergence, dry matter production, tillering and yield. The reasons for better crop development on zero till plots where straw was removed by burning can be attributed to: more effective seeding in absence of trash; warmer soil temperatures; and higher nitrogen availability as compared to zero till plots with straw spread. In some trials, zero tillage with straw spread resulted in higher emergence and grain yields. The primary reason that the straw spread treatments gave better results was due to the higher soil moistures associated with maintenance of the surface straw mulch; in these trials, soil moisture was considered to be the limiting factor for crop development.

While the straw burned treatment generally resulted in higher yields on zero till plots, this should not be taken as a recommendation for burning. Rather, it should be used as an indication that alternative management practices are needed to more fully utilize the benefits of leaving straw on.

Development of zero till drills which are capable of operating in trashy conditions should enhance wheat emergence on straw spread plots. Evaluation of cultivars which are less sensitive to lower soil temperatures would also reduce the need for burning. Research into the methods and timing of fertilizer placement should increase yields under zero till where straw is spread. Banding fertilizer should greatly enhance fertilizer efficiency on mulched zero till soils as compared to broadcasting.

Rapeseed was found to be well suited to production under zero tillage. Rapeseed yields were as much as 32 percent higher under zero tillage as compared to conventional tillage. The higher yields under zero tillage were usually accompanied by greater emergence and dry matter production. Straw management practices were not found to have a large impact on emergence of conventional till rapeseed. However, it was observed that under dry soil conditions, rapeseed emergence could be enhanced when straw was spread.

While removing residues by burning was found to increase rapeseed emergence on zero till plots on the clay soils, burning had little effect on rapeseed emergence on the sandy loam soil. Rapeseed emergence under zero tillage was generally much less dependent on straw management practices than was found for zero till wheat emergence. This was attributed to the difference in the size of the kernels of wheat and rapeseed and their germination requirements.

Rapeseed dry matter production was found to be greater when residues were removed by burning, probably due to higher nitrogen availability in the absence of straw.

Wheat and rapeseed production under zero tillage has been shown to be technically feasible in this study. Commercial adoption of zero tillage is therefore more dependent on economic and sociological factors than on the ability of the crops to adapt to this system.

RECOMMENDATIONS

1. Studies should be initiated to develop zero till drills which are more effective in trashy conditions and under a wide variety of soil moisture conditions.
2. Phytotoxicity of degrading residues under zero till conditions needs to be evaluated under Manitoba conditions.
3. Varietal evaluations should be conducted to identify those varieties which would respond to the cooler soil temperatures encountered on mulch covered zero till fields.
4. Studies are required which will evaluate fertilizer placement techniques on zero till soils. Plants which are grown under zero tillage may differ in root distribution and nutrient extraction patterns than plants grown under conventional methods.
5. Development of fertilizer banding equipment which will operate under zero till conditions with a minimum of soil disturbance could help increase fertilizer efficiency under zero tillage.

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APPENDIX A-1. Meteorological data (temperature)

Location	Month	Mean Temperature (°C)					
		1978		1979		Long term average*	
		Max.	Min.	Max.	Min.	Max.	Min.
Graysville	May	20.8	6.5	14.3	0.5	18.0	3.5
	June	24.5	8.9	24.4	7.1	24.0	9.5
	July	26.5	12.7	28.2	12.9	27.0	12.5
	Aug.	25.4	9.0	24.7	8.7	25.5	11.0
	Sept.	22.4	6.8	20.1	6.6	19.0	5.2
Sanford	May	22.3	7.0	13.0	2.0	n/a	n/a
	June	23.5	9.0	24.2	9.0	n/a	n/a
	July	25.2	12.2	26.8	12.0	n/a	n/a
	Aug.	24.6	9.7	23.3	9.0	n/a	n/a
	Sept.	21.3	8.0	19.9	6.5	n/a	n/a

* 25 year average from 1946 to 1971

APPENDIX A-2. Meteorological data (precipitation)

Location	Month	Average precipitation (mm)		
		1978	1979	Long term Average*
Graysville	May	125.5	79.5	54.3
	June	43.5	68.5	81.8
	July	101.6	39.2	71.1
	August	38.8	44.0	63.2
	Sept.	95.7	38.6	51.8
Sanford	May	145.96	68.8	n/a
	June	42.2	57.0	n/a
	July	100.0	35.6	n/a
	August	30.9	34.9	n/a
	Sept.	82.1	19.3	n/a

* 25 year average from 1946 to 1971

APPENDIX B. Pesticides used in Experiments

Expt. No.	Planting Date	Crop	Date of Application	Pesticide	Rate (Kg AI/ha)
1	3.5.78	Wheat	6.5.78	Glyphosate	1.30
			10.5.78	Paraquat	.84
			30.5.78	Dichlofop	.70
			7.6.78	Bromoxynil &	.42
				MCPA	.42
1	17.5.78	Wheat	10.5.78	Glyphosate	1.40
			30.5.78	Dichlofop	.70
			7.6.78	Bromoxynil &	.42
				MCPA	.42
1	2.6.78	Wheat	10.5.78	Glyphosate	1.40
			30.5.78	Glyphosate &	.56
				Bromoxynil	.42
			23.6.78	Dichlofop	1.10
2	23.5.79	Wheat	23.5.79	Glyphosate	1.10
			31.5.79	Paraquat	.56
			16.6.79	Dichlofop &	.84
				Bromoxynil	.28
2	31.5.79	Wheat	23.5.79	Glyphosate	1.10
			31.5.79	Paraquat	.56
			5.5.79	Paraquat	.56
			16.6.79	Dichlofop &	.84
				Bromoxynil	.28
			4.7.79	Barban &	.14
				Benzoylprop ethyl	.56
			10.7.79	Bromoxynil	.42
2	7.6.79	Wheat	23.5.79	Glyphosate	1.10
			31.5.79	Paraquat	.56
			8.6.79	Paraquat	.56
			23.6.79	Dichlofop &	.84
				Bromoxynil	.28
			4.7.79	Barban &	.14
				Benzoylprop ethyl	.56
			10.7.79	Bromoxynil	.42

Expt. No.	Planting Date	Crop	Date of Application	Pesticide	Rate (KG AI/ha)
3	23.5.79	Wheat	23.5.79	Glyphosate	1.10
			31.5.79	Paraquat	.56
			16.5.79	Dichlofop &	.84
				Bromoxynil	.28
3	31.5.79	Wheat	23.5.79	Glyphosate	1.10
			31.5.79	Paraquat	.56
			6.6.79	Paraquat	.56
			16.6.79	Dichlofop &	.70
				Bromoxynil	.28
			9.6.79	Dichlofop &	.70
				Bromoxynil	.28
3	7.6.79	Wheat	23.5.79	Glyphosate	1.10
			31.5.79	Paraquat	.56
			8.6.79	Paraquat	.56
			23.6.79	Dichlofop &	.70
				Bromoxynil	.28
			9.7.79	Dichlofop &	.70
				Bromoxynil	.28
4	7.6.78	Wheat	7.6.78	Glyphosate &	.56
				Dicamba &	.20
				MCPAK	.50
			28.6.78	Dichlofop &	1.10
				Bromoxynil	.42
5	7.6.79	Wheat	11.6.79	Glyphosate	.56
			1.7.79	Dichlofop	.84
			11.7.79	Dicamba	.20
5	14.6.79	Wheat	16.6.79	Glyphosate &	.56
				Dicamba	.21
			1.7.79	Dichlofop	.84
			11.7.79	Dicamba	.20
6	17.5.78	Rapeseed	10.5.78	Glyphosate	1.40
			30.5.78	TCA	5.60
			3.6.78	Malathion	1.20*
			7.6.78	Dichlofop	1.10
			12.6.78	Benazolin	.70
			14.6.78	Malathion	1.20*
6	2.6.78	Rapeseed	10.5.78	Glyphosate	1.40
			30.5.78	Glyphosate &	.56
				Bromoxynil	.42
			3.6.78	Malathion	1.20*
			12.6.78	Benazolin	.70
			23.6.78	Dichlofop	1.10
			30.6.78	Malathion	1.20*

Expt. No.	Planting Date	Crop	Date of Application	Pesticide	Rate (KG AI/ha)
7	23.5.79	Rapeseed	23.5.79	Glyphosate	1.10
			11.6.79	Dalapon	1.75
			11.6.79	Dichlofop	.70
			16.6.79	Benazolin	.70
			23.6.79	Dichlofop	.70
7	31.5.79	Rapeseed	23.5.79	Glyphosate	1.10
			6.6.79	Paraquat	.56
			11.6.79	Dalapon	1.75
			16.6.79	Dichlofop	.70
			23.6.79	Benazolin	.70
			4.7.79	Dichlofop	.70
7	27.6.79	Rapeseed	23.5.79	Glyphosate	1.10
			27.6.79	Glyphosate	.56
			9.7.79	Dichlofop	.70
			16.7.79	Dowco 290	.30
			18.7.79	Niclofen	1.50
8	31.5.79	Rapeseed	23.5.79	Glyphosate	1.10
			6.6.79	Paraquat	.56
			16.6.79	Dichlofop	.84
			23.6.79	Benazolin	.84
8	27.6.79	Rapeseed	23.5.79	Glyphosate	1.10
			27.6.79	Glyphosate	.56
			9.7.79	Dichlofop	.70
			16.7.79	Niclofen	1.50
9	7.6.79	Rapeseed	11.6.79	Glyphosate	.56
			30.6.79	Dalapon	.84
			3.7.79	Dichlofop	.70
9	14.6.79	Rapeseed	11.6.79	Glyphosate	.56
			30.6.79	Dalapon	.84
			3.7.79	Dichlofop	.70

* Litres of product/hectare