SEEDING AND AGRONOMIC PERFORMANCE DUE TO NO-TILL SEEDERS IN VARIOUS FIELD CONDITIONS

BY

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A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

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GENERAL ABSTRACT

No-till is defined as seeding directly into previously undisturbed soil (ASAE standards 1998). It is a farming procedure that conserves resources, namely soil and water. In the past, no-till practices and no-till seeders have been compared with conventional methods and conventional seeders, however, few studies show a comparison between no-till seeders in various environments. This project aims to compare the low disturbance hoe (H) and double disc (D) opener in various field conditions.

Two sites were evaluated: Residue site and Oat-stubble site at a location 25 km north of Brandon, Manitoba, Canada. In the Residue study, the effect of previous crop residue and seeding tools on canola yields was determined, and the seed row surface roughness (R_s) and subsequent weed production due to the two seeding tools were compared. In the Oat-stubble study, the effect of oat stubble height and seeding tools planting different crops was investigated. For both sites, seed placement was observed both inside and outside the wheel track, and the amount of hairpinned residue generated by the disc opener was assessed.

Comparing residues of pea (Pr), wheat (Wr), and canola (Cr), in the Residue site, pea as a previous residue allowed canola to be seeded the most uniformly, emerge the quickest, and have the highest plant stand. Wheat produced the most amount of hairpinned residue in both years, followed by canola and pea.

The disc opener seeded deeper than the hoe opener and more uniformly in 2001, but not 2002. The seed placement outside the wheel track was slightly deeper than inside the wheel track for both types of openers, however, they were not statistically significantly different. The disc opener was also shown to have a lower seed row roughness, as well as a lower weed percentage. However, the low negative correlation determined between seed row roughness and weed cover percentage indicated no strong linear association between the two variables. The Inter-row and Subtraction method were the two weed image analysis techniques introduced and compared. The different methods resulted in different weed percentages, with the Inter-row method generating more weed cover. The Subtraction method was the optimal weed image analysis technique because it takes into account crop competition that may reduce weed production.

The Oat-stubble study showed that the stubble height was significant factor when seeding into adequate soil moisture. The greatest amount of hairpinned residue was generated by the 400 mm stubble (S400), with the cultivated (S0) and 150 mm stubble (S150) thereafter. Evaluating three different stubble levels: S0, S150, and S400, the optimal stubble height was determined to be S150 for implementing no-till openers. The hoe opener had a significantly better seed depth uniformity than the disc opener in 2001 and seeded pea and wheat more uniformly than canola. Again, the seed placement outside the wheel track was slightly deeper than inside the wheel track for both types of openers, but not statistically significant.

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1. GENERAL INTRODUCTION

As early as the mid-1960's, concerns about erosion, time spent in the field, and increasing energy costs persuaded a small number of farmers in Manitoba and North Dakota to try directly seeding crops into the standing stubble from the previous year (Coutts et al. 1991). However, due to an inability to control weeds and an unavailability of proper seeding equipment, farmers did not embrace no-till agriculture. In the years since, advances in technology have improved weed control and seeding equipment is now able to cut through crop residue. As well, an understanding of the importance of crop residue and the erosion control that can be associated with residue's presence has caused many farmers to consider no-tillage.

No-till farming is an economically viable, erosion-proof crop production system in which the crop is planted directly into the previous crop's stubble with minimum soil disturbance (MNZTFA 1998). Cultural controls such as crop competition and rotations, along with the responsible use of herbicides are used to replace tillage. Today, the benefits of no-tillage have been confirmed by decades of continuous no-till cropping on numerous farms. Under this system, moisture is conserved, yields are improved, labour is minimized, and fuel consumption is reduced.

No-tillage or direct seeding technologies are being adopted worldwide as a movement toward sustainable agriculture. The effect of no-tillage on crops has been extensively documented. However, seed depth uniformity, subsequent crop emergence, and yield due to no-till openers are issues that need further investigation. In addition, the impact of soil disturbance levels on weed and crop emergence relative to conventional methods must be studied. Understanding the impact of no-till openers and soil disturbance on weed and crop emergence is an important link to the development of improved weed control and increased yields.

2. GENERAL LITERATURE REVIEW

2.1 Tillage and seeding practices

2.1.1 Conventional tillage Conventional tillage is defined as tillage operations traditionally performed in preparing a seedbed for a given crop and grown in a given geographical area (ASAE standards 1998). Conventional tillage mechanically manipulates the soil to produce a crop, destroying protective soil residues in the process. This method leads to the loss of nutrients, moisture, and soil stability, thereby inducing soil erosion. It may also hasten the germination of specific weeds. Prolonging these conditions can permanently damage arable land. Furthermore, since conventional farming includes cultivating and tilling, the power required to operate the machinery may double or even triple depending on the number of times the farmer wants to cultivate the field.

2.1.2 No-tillage (zero-tillage) No-till is defined as seeding directly into previously undisturbed soil (ASAE standards 1998). The only tillage is the soil disturbance in a narrow slot created by coulters, disc or runner seed furrow openers, hoe openers attached to the planter or drill (Dickey et al. 1992). It is a farming procedure that conserves resources, namely soil and water. The absence of soil erosion with no-tillage can result in higher crop yields, because less nutrient or organism loss occurs. This reduction in losses is due to the fact nutrients decompose slower with no-till; therefore, there is a more gradual release to fertilize the crop (Baker et al. 1996). Crop residue is the crop that remains on the field following the previous year's harvest and is essential for successfully implementing direct seeding techniques. By maintaining the crop residue, there is an increase in soil moisture, organic matter, nutrient cycling, a lower threat of certain weed populations, and a reduced risk of erosion.

2.1.3 No-till seeding (zero-till seeding) with low disturbance openers The purpose of a no-till seeder was to place seed and fertilizer into the ground without disturbing the soil. This is virtually impossible since there is always some sort of disturbance when the seed is planted. As new equipment became available and as farmers' understanding of no-till farming matured, the objective moved from one of no soil disturbance to a more practical minimum soil disturbance (MNZTFA 1998).

2.1.4 Direct seeding with any openers The terms ‘direct seeding’ and ‘direct drilling’ are interchangeable in describing the planting of seeds into undisturbed soil that does not have a “pre-existing seedbed.” Direct seeding is less intensive and less aggressive than conventional tillage. As well, it offers several benefits in comparison to conventional seeding system. These benefits may include a possible increase in crop yield and a lower time commitment to field operations.

2.2 Feasibility of no-till farming

2.2.1 Time efficiency Producers commonly report tractor hours are cut in half when using no-till methods (Monsanto Company 1994). This reduction in tractor use occurs because they do not need to cultivate the land in the fall or spring before seeding, resulting in substantial time savings. To put this time efficiency into perspective, a producer usually tills the land two or three times before seeding under conventional conditions and six or seven times under fallow conditions (Monsanto Company 1994). When a field is in fallow, it means that in the previous year the producer did not use it for farming operations. Conventional producers fallow some fields in order to let them rest in an attempt to replace the valuable nutrients that they lost from erosion after tillage operations. When a field remains at rest for a complete season, the soil hardens and packs itself tightly. Due to this tightness, farmers must perform extra tillage operations in order to loosen it.

2.2.2 Fuel and Labour Savings No-tillage operations save fuel. As previously noted, the time in which a tractor is in use decreases by fifty percent in no-till operations. This translates into a doubling of the life of the tractor. Fewer hours result in fewer repairs to the machine, and in turn extend the life of the equipment. Not only is the producer saving money on time and fuel, he or she is also saving money on labour. According to a survey done by Conserva Pak Seeding Systems (2002), fuel, labour, and repairs are 30 to 50 % lower with no-till than with conventional tillage systems.

2.2.3 Initial Capital Input Cost is crucial when adopting a new farming system. No-tillage systems need less equipment because there is no need for an additional tilling system. This results in an overall lower cost. However, a major factor that most producers face today when considering converting their farms to no-tillage practices is the increase in capital cost. This increase in cost is due to the purchasing of no-till seeders. Since conventional tillage machinery can be sold to other farmers or to equipment dealers, this lessens the concern.

2.2.4 Improvement of Organic Matter The most noticeable sign of a healthy soil is the presence of earthworms. The population of earthworms are larger in no-till fields than in tilled fields, presumably as a result of less disturbance (Bohlen et al. 1995). Two types of earthworms that are commonly found in no-till soils are night crawlers and shallow-dwelling worms. Night crawlers, which are deep-burrowing worms, are extremely prevalent as they use the stubble layer for food. The night crawlers are important because they form large permanent burrows in the root zone. As they burrow, the worms perform biological tillage by mixing crop residue from the stubble layer with the soil below (MNDZTFA 1997). The burrows improve drainage and increase soil aeration. Plant roots also dig through the soil using the burrows to obtain nutrients for themselves. The low disturbance of the soil associated with no-tillage keeps these burrows intact, and the stubble layer provides the worms with food and protects them from any temperature extremes. Any sort of soil disturbances could be fatal for the worms.

2.2.5 Soil comparison

A comparison of three soils: "native soil" that has never been broken, soil that has experienced conventional farming methods for the past one hundred years, and soil from no-tillage, reveals the difference that an increase in organic matter can make, and the effects of improved water infiltration. As shown in figure 2.1, the prevention of erosion has increased the topsoil depth, which contributes to increased nutrient and moisture availability and in turn increased crop yields.

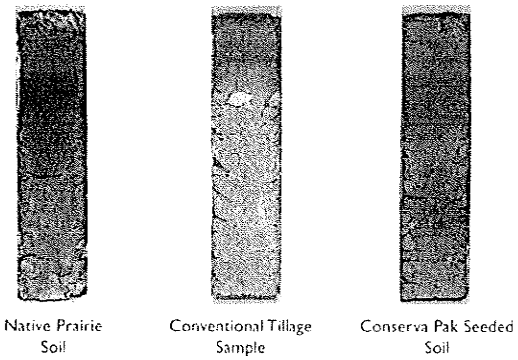


Fig. 2.1. Comparison of soils under different tillage systems (Conserva Pak 2002)

2.2.6 Water Conservation No-tillage has a definite effect on organic matter content and in turn, water infiltration. As the years of no-tillage increases, the organic matter content improves, and the water entry rate escalates. Organic matter helps to stabilize soil aggregates against disruption by raindrop impact and thus can help to maintain higher infiltration rates as the conducting pores do not become clogged by small particles (Conserva Pak 2002).

The key point in the no-till system that allows for retaining water is the standing stubble layer. The stubble layer is able to catch snow and hold the water that it supplies, reducing overall water losses due to evaporation. For every 250 to 300 mm of snow the stubble catches, there is a 25 mm return of water to the crop. Therefore, a farmer designs a system that captures the most snow possible. The optimal system must consist of a high stubble layer, because tall standing stubble can catch more snow than a low standing layer.

2.2.7 Greenhouse gas emissions Microbial processes in soils act as major sources and minor sinks for atmospheric N_2O and CO_2 (Duxbury et al. 1993). About 70% of the N_2O

emitted from the biosphere and atmosphere is derived from soil (Bouwan 1990), and agriculture accounts for 90% of the anthropogenic emissions of N_2O (Duxbury 1994). As well, CO_2 is released to the atmosphere when solid waste, fossil fuels (oil, natural gas, and coal), and wood and wood products are burned. Thus, when gas is used for operating agricultural machinery and stubble is burned, greenhouse gases are released o the atmosphere.

The three major factors that regulate N_2O fluxes are the quantities of available substrates for the nitrification and denitrification processes, ratios of process products, and diffusion and consumption of N_2O prior to escape into the atmosphere (Beauchamp 1997). Ultimately, climate, soil characteristics, cropping practices, and their interactions affect the nitrification and denitrification processes and hence the production emissions of N_2O. Although it is not possible to control the climate, it is possible to control cropping practices. While no-till has many benefits, greater losses of N_2O have been reported from soils under no-till than from soils under conventional tillage (Aulakh et al. 1984). However, Lemke et al. (1999) estimated total N_2O loss from conventional tillage was either equal to or greater than no-till, particularly during the spring thaw event. Therefore, the effect of the tillage system on the release of N_2O into the atmosphere is still unclear. But, it has been shown that the cultivation of tall-grass prairie soils with long-term input of N fertilizers may lead to changes in C mineralization and nitrification-denitrification patterns which can affect the gaseous composition of the soil profile (Ajwa et al. 1998).

Soil organic carbon (SOC) represents a large store of carbon, and changes in the amount of SOC may cause implications for atmospheric CO_2 concentrations (Janzen et al.

1998). Cultivation of virgin lands causes sharp decreases in organic matter during the first years of cultivation (Sotomayor and Rice 1999); a viable solution to this problem is no-till.

2.2.8 Crop rotation Crop rotation is a vital technique to implement with no-till farming. By varying the seeding and harvest schedule, it allows for the replenishment of lost nutrients within the soil and alters the herbicide spraying times. Spraying usually occurs around the third leaf stage of the plant, and when different crops are planted with different emergence rates, it results in different herbicide spraying times. Because the farmer is spraying at different times and not all weeds grow at the same time, they are able to remove more weeds. Therefore, instead of spraying at the same time every year and killing the majority of a particular weed and allowing certain weeds to dominate, they will alternate the herbicide spraying in order to remove a variety of different weeds. Furthermore, by implementing this technique the weeds are less likely to become resistant to the spray. These components help the farmer control weed populations without the excess use of herbicides. Crop rotation is an important tool in disease, weed, and pest management in no-till farming (MidWest Plan Service 1992). The crops farmers choose to plant every year are dependent upon the need to replenish nutrients, limit crop disease, and reduce certain weed populations. Crop rotation also tends to reduce the use of herbicides, which in turn reduces the potential of groundwater contamination.

2.3 Switching conventional tillage to no-tillage

Many farmers are reluctant to switch to no-till because they are unwilling to adopt a new farming technique, crop rotation, or fertility and weed management practices. Another factor that constrains no-tillage is the patience necessary for the soil to be conditioned for no-till. It may take a few years for the soil to be conditioned. No-till fields must be continuously no-tilled in order to reap the benefits of the system (MNZTFA 1998).

The extent to which the benefits of no-till are realized depends on local soil type and weather conditions. After realizing the benefits of no-till, many farmers are converting to no-tillage systems.

2.4 No-till seeders

There are a variety of no-till seeders used in the agricultural industry. No-till seeders consist of several components such as fertilizer openers, seeder openers, coulters, row preparation devices, and gage and press wheels (Figs. 2.2 and 2.3). Coulters are used to cut through crop residue. However, coulters may not be required on machines that have double-disc openers designed for cutting and opening seed slots (Price 1999).

Row preparation devices are used to deeply loosen soil ahead of the seeding unit and remove dry soil along with the residues, which brings the no-till opener into contact with moist underlying soil (Price 1999). They involve components such as: row cleaners (sweep, even-disc, staggered disc, and horizontal disc), which remove surface residue and soil from the row area, wide fluted coulter openers used in order to loosen a strip of soil behind a soil and residue cutting component, rollers (packer and basket) for clod pulverization and firming or smoothing loosened soil in the row area (ASAE standards 2001).

Gauge wheel attachment is ideal for quick and easy depth adjustment. Machines with gauge wheels provide more accurate seeding depth (MNZTFA 1997). Accurate depth control is extremely important in ensuring uniform plant emergence. For no-till, rear press wheels are often used to provide depth control and aid in seed-to-soil contact by closing and/or compacting the furrow (John Deere 2000).

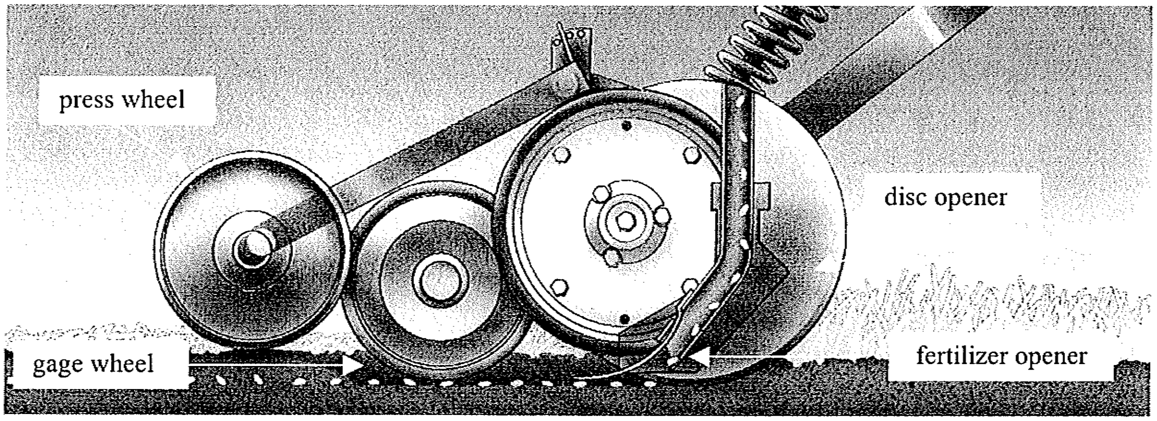


Fig. 2.2. No-till seeder; single disc opener (John Deere 2000)

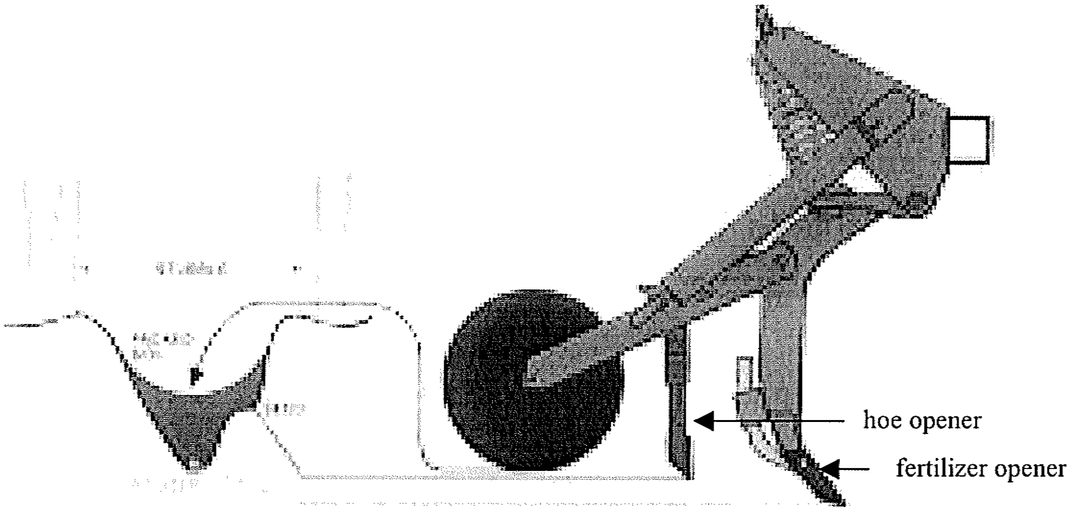


Fig. 2.3. No-till seeder; hoe opener (Conserva Pak 2002)

2.4.1 Disc openers There are single disc openers and double disc openers (Fig. 2.4a,b). Single disc openers are the economical choice and build higher furrow walls that protect seedlings from wind. Double disc openers have two side-by-side discs that contact each other at the bottom. They are considered high-speed openers that perform well in clean-till to minimum-till conditions and reduce soil disturbance, allowing higher operating speeds than a single disc (Hofman and Solie 1992). With the aid of a gauge wheel, disc openers provide precise seed placement and are able to move through tall stubble that would set back a hoe opener. According to the MNZTFA (1994), the advantages of employing disc drills are:

1. Good seed placement if straw and chaff are evenly spread.
2. Minimum soil disturbance.
3. Capable of banding fertilizer while seeding.
4. Good packing.

While disc openers have been shown to perform well in heavy residue, most of these openers have do not perform well when the residue is wet or unevenly spread (personal communication with Dr. Byron Irvine, May 2001). When residue is not disturbed, it covers the soil surface, which results in slow soil warming in the spring. If the residue is too moist, hairpinning occurs. Hairpinning is when the disc opener may only bend the straw instead of cutting it, resulting in poor seed-to-soil contact.

Under conventional methods, farmers could not attempt to seed into a wet field since the tractor would get stuck in the fields. With no-tillage however, the stubble and residue left on the field act as a layer to prevent the tractor from sinking into the soil. This layer therefore, improves trafficability.

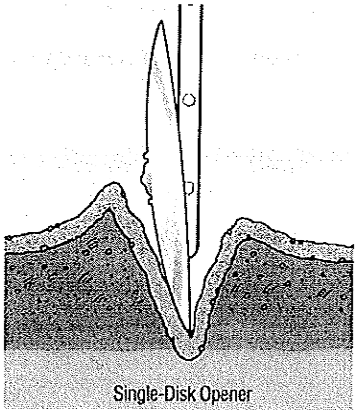


Fig. 2.4a. Single disc opener

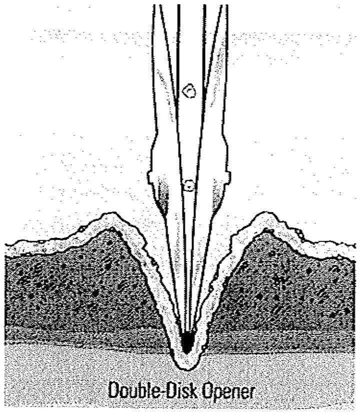


Fig. 2.4b. Double disc opener

2.4.2 Hoe openers A hoe opener (Fig. 2.5) is a shank-mounted, narrow, vertical forward-curved tool with a pointed or rounded edge (ASAE standards 2001) that is used for direct seeding systems and also for reduced tillage situations. Hoe openers provide good seed-to-soil contact (Fig. 2.6) when they can push through the residue. Under heavy residue conditions, hoe openers may be plugged as a result of dragging residue. Hoe openers require more drawbar force, leaving fields more disturbed, and operating at lower speeds (MidWest Plan Service 1992).

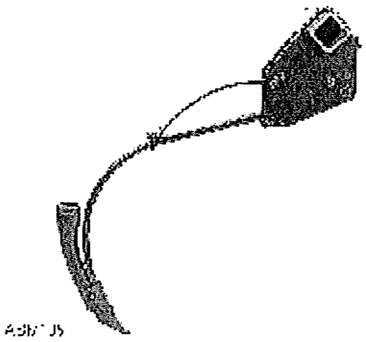


Fig. 2.5. Hoe opener (John Deere 2002)

Fig. 2.6. Good seed-to-soil contact using a hoe opener (John Deere 2002)

2.5 Compaction

2.5.1 Soil compaction Compaction results primarily from mechanical forces created by wheel or animal traffic, and/or tillage operations under moist soil conditions (Reeder and Smith 1992). Compaction is a widespread process of soil structure deterioration in agricultural systems, affecting crop production in all climates (Soane and Van Ouwekerk 1994). As the average size of tractors and other agricultural equipment increases, the compaction of soil due to farm machinery has become a major concern.

The primary effects of compactive forces on soil is a change in the physical properties of: (1) soil strength, the ability to resist penetration or displacement by an applied force, (2) bulk density, the degree to which soil particles are pressed together, (3) porosity, the ratio of the volume of the voids or pores to the total volume of the soil, and (4) pore size, the volume that contains air and/or water and is a function of bulk density (Reeder and Smith 1992). Soil compaction reduces soil pore size, alters the pore size distribution, and increases soil strength that subsequently causes reduction in air and water permeability, an increase in heat capacity and most importantly, an increase in root penetration resistance (Al-Adawi and Reeder 1996). Compacted soils with high strength reduce growth rates of crop roots and thus, limit the availability of water and nutrients to the plant (Bengough 1991). As soil compaction increases, plant growth decreases (Fig. 2.7).

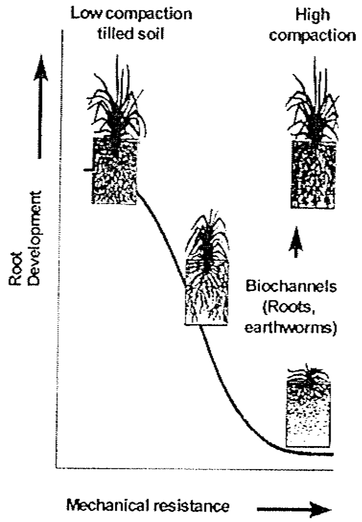


Fig. 2.7. A model of the effect of soil compaction on root development and the long-term improvement of the soil structure in undisturbed soils (Martino 1998)

Tilling and cultivating loosens the soil, which improves water infiltration, aeration, and root development. Normal tillage operations do not disturb soil deeper than approximately 20-25 cm, and in the case of no-till crop production, there is generally no disturbance (Wells et al. 2001). When no-tillage systems are implemented, the bulk density of the soil increases, which enhances the effect of compacting agents such as agricultural machinery and grazing animals. However, with no-tillage the amount of wheel compaction due to the tractor is drastically reduced. As mentioned previously, a producer usually tills the land two or three times before seeding under conventional conditions and six or seven times under fallow conditions (Monsanto Company 1994). Therefore, the compaction due to wheel traffic is increased dramatically with tillage systems. Research shows that the density of tilled soil is lower after primary tillage, but with secondary tillage, wheel traffic, and several wetting and drying periods, it becomes nearly equal in density to untilled soil by harvest (Simmons 2002).

The relationship between soil compaction and crop yield is complex. Most researchers agree that although a certain degree of compaction can be beneficial to crops, loading beyond this amount can be very detrimental and, therefore, soil compaction should be considered as an important factor, which should be managed in crop production systems (Schafer et al. 1990).

2.5.2 Penetration resistance Regions of high penetration resistance in the soil may arise as natural soil features or may be caused by farm machinery (Adamchuk et al. 2001). With no-till, there is only a minute amount of disturbance due to the opener. Therefore it is necessary to determine the change in penetration resistance due to decreased wheel traffic, but with an increased soil bulk density.

A wide variety of instruments have been developed to measure static or dynamic penetration resistance (Campbell and O'Sullivan 1991). Penetration resistance is dependent on the size, material, and shape of the probe that penetrates the soil, as well as soil properties. These soil properties include soil-metal friction, particle size distribution, water content, resistance to compression, internal friction, and cohesion (Adamchuk 2001). Recognizing the need to standardize both the apparatus and the test procedure, the American Society of Agricultural Engineers specified a soil cone penetrometer with a conical tip, which has become widely used to give an index of soil strength from a penetration test (ASAE standards 1999a).

Cone penetrometers are used to determine the density of the soil as well as for detecting compacted soil layers. The soil cone penetrometer has been used extensively to determine soil strength that indicates the likelihood of poor root growth and crop performance (Wells et al. 2001). This instrument provides a relatively rapid measurement of soil strength versus depth and, as such, can determine both the location and depth for which tillage is needed (Wells et al. 2001). The test is done by inserting a rod with an attached cone into the ground at a constant speed of 30 mm/s (72 in/min) (ASAE standards 1999a). The resistance (kg) of the cone as it is pushed in the ground is recorded in the memory of the cone penetrometer as cone index values. The pressure required to press the 30-deg circular cone through the soil, expressed in kilopascals, is an index of soil strength called the cone index (ASAE standards 1999a). The depth (mm) of the cone below soil surface is also recorded. Available penetrometers are able to record resistance values at depth increments of 0.01 to 1 m. The data logged within the penetrometer can be retrieved using PC based software for further analysis.

2.6 Residue cover

No-till seeding requires excellent residue management. With no-till, residue from the previous year is left on the field. The amount of residue cover has a major impact on soil loss reduction. It primarily affects soil temperature, moisture, and aggregation (Griffith et al. 1992). As well, it protects the soil surface from erosion by absorbing the impact energy of raindrops reducing the soil particle detachment, and reduces surface crusting and sealing which enhances infiltration and crop emergence (Shelton et al. 1992). As the amount of residue increases, the loss of soil due to erosion decreases (Fig. 2.8). However, only uniform residue distribution is an effective means of erosion control.

Uneven distribution of residue may result in clogging problems when seeding and poor seed-to-soil contact. Residue that remains standing above the soil surface is much more effective than equivalent amounts of residue lying flat on the soil surface in reducing or eliminating the potential for wind erosion (Hagen 1996).

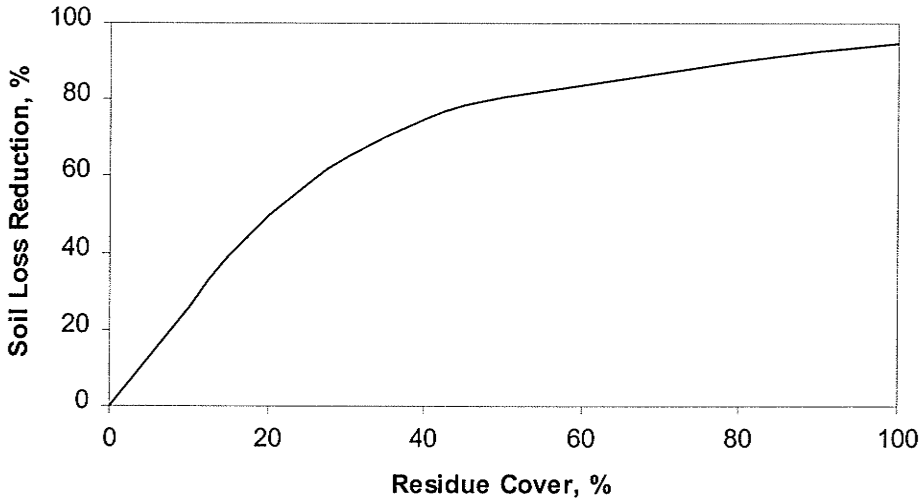


Fig. 2.8. The impact of residue cover on soil loss reduction (Reeder 1992)

2.7 Straw cutting

No-till seeding requires seeders capable of cutting through large quantities of crop residue, penetrating untilled soil, and depositing the seed 25-50 mm deep (Kushwaha et al. 1986). Under heavy crop residues, failure of the disc openers to cut through the surface residue resulted in the seed being placed either in the residue or on the soil surface (Personal communication with Dr. Byron Irvine, May 2001). A coulter may be used in front of the seed opener to cut through crop residue.

The rotational speed of coulters is important in straw cutting; however, the type of coulter is more vital. A study by Kushwaha et al. (1986) showed that increasing the rotational speed has no effect on the quantity cut, although the type of coulter has a great impact. A 460 mm diameter was the optimal diameter of coulters, cutting almost 100% of the crop residue used during testing.

2.7.1 Hairpinning Hairpinning (Fig. 2.9) occurs when crop residue is not cleanly cut, but simply pushed into the ground. Hairpinning is one of the leading causes for farmers to abandon no-till practices, as it often leads to two serious problems: 1) In dry conditions, hairpinned residue prevents direct seed-to-soil contact, which is critical for good seed germination; 2) In wet climates, direct contact between the seeds and the hairpinned residue often promotes disease problems (Great Plains Manufacturing 2002). In both environmental conditions hairpinning wicks away moisture, prohibits germination, and decreases yield.

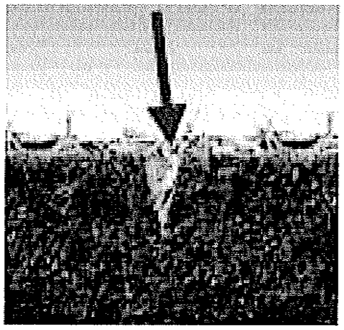


Fig. 2.9. Hairpinned residue (www.greatplainsmfg.com)

2.8 Soil roughness

There are two main types of roughening: oriented roughness and surface roughness. Oriented roughness is the formation of ridges or furrows by tillage and planting systems (Robichaud and Molnau 1990). Surface roughness is random roughness characterized by irregular occurrences of peaks and depressions (Burwell et al. 1969).

A reduction in yield may be due to the loss of soil by erosion from agricultural fields. Erosion from tilled fields can be reduced by tillage practices that leave rough porous surfaces covered by old crop residue. Soil micro-relief, also referred to as soil roughness, is an important surface characteristic that modifies the force of the wind acting on the surface, thereby affecting the ability of the wind to emit fugitive dust and erode soil (Stout and Zobeck 1996). In agricultural soils, tillage tools often create oriented roughness with ridges parallel to the tillage direction and random roughness created by the random orientation of clods or aggregates on the soil surface (Zobeck and Popham 1997). Changes in surface roughness affect exposed surface area, air movement, radiation exchange, evaporation, and erosion (Robichaud and Molnau 1990), which indirectly influence the moisture, temperature, and aeration of the soil (Currence and Lovely 1970). This in turn may affect crop growth and yield. Therefore, by measuring the soil surface roughness, the quantitative affect of tillage on soil roughness can be determined.

Tillage modifies the physical state of the soil surface by roughening or smoothing the soil surface. Although some soils appear smooth, most soils contain small surface depressions or roughness. Soils with higher micro-relief will often maintain higher infiltration rates than smooth soils because dense crusts tend to form in the depressions of uneven soils and over the entire surface of smooth soils (Zoebeck and Onstad 1987). Also, rough soil surfaces temporarily store more water in surface depressions than smooth soils, which increases the volume of surface storage and sediment trapping and therefore, lessens erosion.

Surface smoothing and residue burying operations such as disking reduce surface roughness. As well, raindrop impact, soil freezing and thawing and erosion can further reduce roughness (Unger and McCalla 1980).

According to Onstad (1984), there are three mechanisms by which soil surface may be altered: (1) soil particles are eroded from high points (ridges) and are deposited in depressions (furrows), (2) particles may be redistributed within the soil mass which leads to a more dense structure at the soil surface, and (3) aggregates can be broken down by rain drop action causing movement of fine materials into large voids in the soil matrix. Moreover, all three of the above mechanism may concurrently occur and affect the surface roughness.

Surface profilers are capable of measuring soil surface roughness. There are two types of surface profilers: contact and non-contact (Hirschi et al. 1987). Contact profilers touch the soil surface with a series of rods or pins, measuring the distance from the soil surface to a reference plane. Non-contact profilers measure the distance from the soil surface to a reference plane without touching the surface (Robichaud and Molnau 1990).

A manual seed row roughness meter (Fig. 2.10) is a type of contact profiler. It is a simple, manual method of measuring soil surface profiles. The seed row roughness meter is placed perpendicular to the soil surface while clasping the end handles in order to ease the pins to fit the form of the surface (Fig. 2.11). Releasing the handles captures the surface profile. To retrieve the surface profile from the seed row roughness meter, the shape was traced onto paper for digitization in the laboratory. The digital profile is then scaled to a Cartesian coordinate (Fig. 2.12) where the seed row roughness coefficient (R_s) is determined. The position of the original soil surface is assumed to correspond to a straight line fitted regression to the surface elevation of the digitized surface trace as shown in figure 10 (Tessier et al. 1989). Seed row roughness (R_s) is defined as the standard deviation of the relative elevation coordinates residuals with the regressed surface datum (Currence and Lovely 1970).

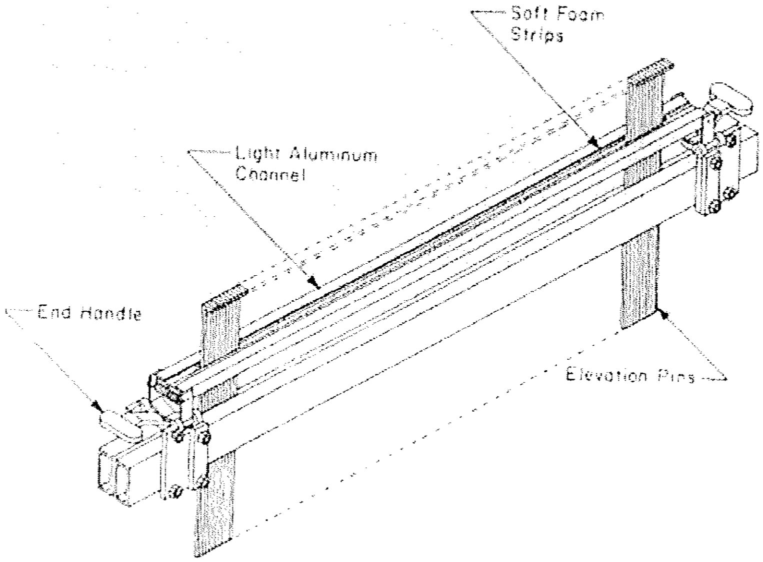


Fig. 2.10. Seed row roughness meter (Tessier et al. 1989)

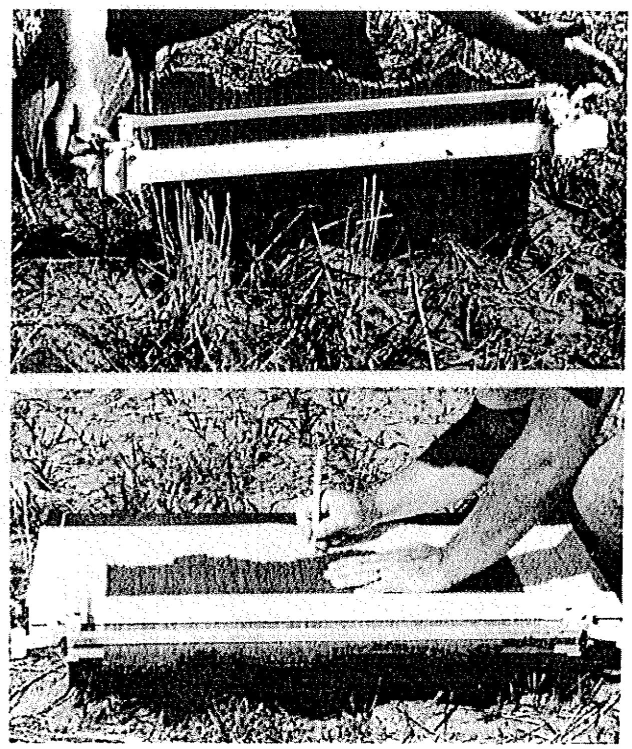


Fig. 2.11. To record the surface profile resulting from a furrow opener/firming wheel combination, position the seed row roughness meter over the seed row, release the pins, and trace the surface profile on paper as shaped by the roughness meter (Tessier et al. 1989)

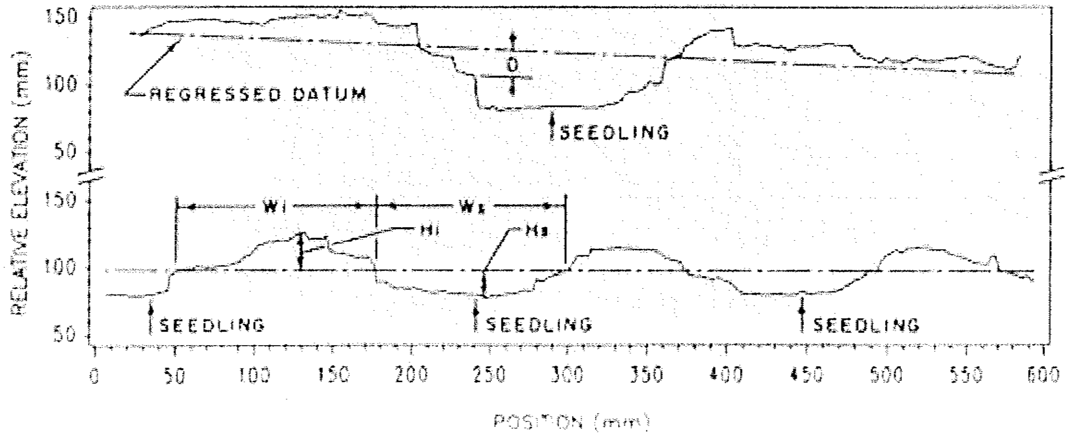


Fig. 2.12. Digitized and plotted surface profiles for a semi-deep furrow (above); narrow fertilizer knife used for seeding with an air seeder (below) (Tessier et al. 1989)

Another method of measuring surface roughness is implementing a laser profiling system (LPS). An LPS is a non-contact, high speed, and high power 3D laser profiler capable of acquiring 800 full 3D profiles per second with a standard vertical resolution of 0.25 mm. Each sensor is composed of a high power laser line projector and a highly sensitive progressive-scan charge couple device (CCD) camera.

The triangulation method is a common practice used for determining 3-D forms. It works by scanning the light source along the object to be measured (Fig. 2.13). Therefore, it is necessary to know the distance between the light source and the object, the distance between the detector and the object, and the angle between the optical axes of the detector and the light source (Fernando et al. 1994). By projecting a line of light onto the object with a bi-dimensional detector such as a CCD, the profile of the object can be traced. The R_s is determined the same way as described when using the manual seed row roughness meter.

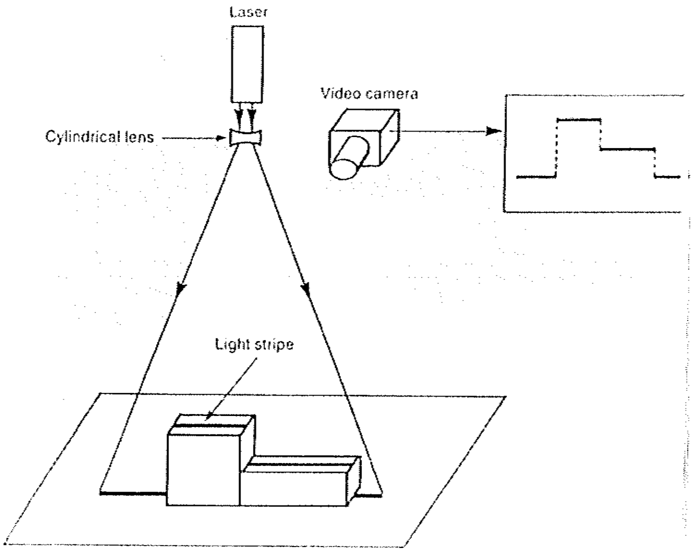


Fig. 2.13. Three-dimensional imaging by light stripe projection and tilted angle two-dimensional viewing (Dufour and Cielo 1984).

2.9 Seeding depth and crop emergence

The primary function of any seeding equipment is to place the seed in a soil environment that is favourable for rapid establishment of healthy, vigorous plants. Shallow seeding depth provides the best seed bed environment for most direct-seeded crops. Unlike tilled seedbeds (sowing at approximately 75 mm) no-tillers can and should seed shallow. Seeding depths in no-till fields are usually shallower (25-50 mm) to promote quick emergence and to allow the crop to get a head start on weeds (Coutts et al. 1991). Seeding at deeper depths deeper man delay crop emergence.

Cereal crops sown too deep have uneven emergence, poor root growth, and fewer tillers (MNZTFA 1997). Winter wheat sown deeper than 25 mm (1 in) has poor winter survival because of delayed emergence (MNZTFA 1997). Semi-dwarf wheat has short coleoptiles, which makes it hard for them to emerge from below 50 mm (Schoofs 1997). Small seed crops like canola, flax, and sorghum are very slow to emerge if sown deeper than 25 mm (MNZTFA 1997). Deep seeding also reduces plant vigour, making the plant more susceptible to diseases such as root rot (Duczek and Plenning (1982).

Not only does the seeding depth affect crop emergence, but also weed emergence. In some cases, tillage may be detrimental to weed species. Spring tillage or seeding disturbs the soil, exposing seeds to conditions that stimulate weed growth. On the other hand, with no-till, there are fewer disturbances and the weed species that exist deeper that 50 mm generally stay dormant.

2.9.1 Other factors affecting crop emergence In Manitoba, planting dates delayed beyond May 15, will result in yield reduction because the crops are more susceptible to heat risk and drought stress (Berglund and McKay 1998). Not only is the planting date important to plant emergence, but also are environmental conditions including moisture, temperature, and the exposure to light (Baskin and Baskin 1985).

Soil moisture is a pertinent factor governing crop development. The longer the fields have been in no-till, the higher the rate of water infiltration (Conserva Pak 2002). This means that it is easier for the plant to uptake the amount of water necessary for growth.

Temperature does not have any influence on the imbibition phase of germination except for its indirect action on water molecules, that is, viscosity and attraction to proteins (Tessier et al. 1988). The minimum air temperature for germination is 0°C for both the pea and wheat, and 0 to 5°C for canola (personal communication with Dr. Byron Irvine, August 2002).

Light is important for the stimulation of germination in any disturbed habitat (Scopel et al. 1994; Tester and Morris 1987). With no-till there is a decrease in soil disturbance and roughness, which decreases the amount of light penetration to some weed species that exist deeper in the soil. Furthermore, since crop seedlings are seeded at shallower depths, this may enhance the germination of the seedlings

.

2.10 Weeds

Weeds compete with crops for sunlight, moisture, nutrients, and space. The weeds in any particular field are affected by soil types, environmental conditions, crop rotations, herbicides used, and tillage. Controlling weeds without tillage is new and challenging, but not impossible. This control is evident in the clean, healthy crops grown by no-till farmers over a wide range of conditions.

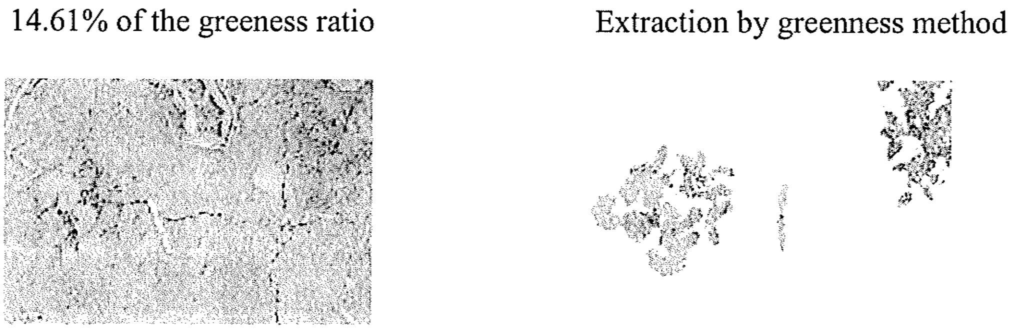
Herbicides are the primary method of weed control in mechanised agriculture (Cousen and Mortimer 1995), which enables farmers to increase crop yields by eliminating weed competition. However, these substances have the potential to cause damage to human health as well as other living organisms. Furthermore, herbicides are considered to be one of the main sources of non-point pollution from agriculture (Mannion 1995). There are two herbicidal approaches to reduce herbicide use: one is to apply herbicide to only weed-infested areas; the other is to apply some base level treatment to the whole field and increase the dose when patches are encountered (Tang et al. 1999).

For some species of weeds, distributions are stable (Combellack and Miller 1998) and precise weed mapping before spraying may provide the information required to spray specific areas where weeds dominate. Since many agricultural weeds are known to exist in patches, by mapping weed locations before spraying, increased buffers around weed patches could help to ensure effective control and reduce seed spread (Combellack and Miller 1998). In addition, with a large variation in weed occurrence, patch spraying based on the need for weed control may reduce treatment cost and herbicidal loading to the environment (Christensen et al. 1998). Simply put, better weed detection results in better weed management.

Application of a non-selective herbicide at seeding time is often a component of the system, but there are other controls available to the no-till farmer (MNZTFA 1998). Any technique that favours crop growth over weed growth results in cleaner fields and higher yields. As well, time of seeding, variety selection, optimum placement of seed and fertilizer, field border sanitation, and the selection and rotation of crops are all important in improving a crop's ability to compete with weeds (MNZTFA 1998).

According to Kelner and Gordon (1997), perennial weeds like Dandelion, Perennial Sow-thistle, Canada Thistle, and Quackgrass have the potential to increase under no-tillage systems. This observation is important, since it has been suggested that weeds with seeds that are spread by wind, such as dandelion and Canada thistle, might be more abundant in the borders of no-tillage fields because stubble and litter trap their seeds as they blow in (MAF 2002). As well, particular annual weeds seemed to decrease under no-tillage, while others appeared to increase. Thus, no-till crop production may be a viable way to control herbicide-resistant weeds, such as Green Foxtail and Kochia.

2.10.1 Image analysis techniques in weed measurement An image capture/processing system is a technique that uses a commercially available digital camera and a personal computer to detect weed coverage and distribution. Digital images are taken randomly in the field on dates which herbicide applications would normally be applied. Although the area of each picture was not consistent for each image captured, the area of the field covered by an image was kept at approximately 300 x 200 mm (Yang et al. 2000). In the image processing stage, green objects in each image are identified using a greenness method (Fig. 2.14) that compares the red, green, and blue (RGB) intensities. The RGB matrix is reduced to a binary form by applying the following criterion: if the green intensity consists of a pixel greater than the red and the blue intensities, then the pixel is assigned a value of one, otherwise the pixel is assigned a value of zero (Yang et al. 2000). Therefore, as shown below, the image of the weed can be differentiated from other objects within the field.



14.61% of the greeness ratio

Extraction by greenness method

Fig. 2.14. Weed differentiated from other objects within the field by greenness method (Yang et al. 2000)

2.11 Summary

No-till seeding is an economically viable option for farmers today. It is a method that does not allow operations that disturb the soil other than the planting operation (Dickey et al. 1992). With no-till, farmers are able to complete their farm work more quickly than when they conventionally cultivated, as well as build better soil to pass down to the next generation. In comparison with conventional-till, no-till conserves more moisture, reduces labour time allowing more time for management, improves yields, consumes less fuel, and is able to control erosion of the fields.

Crop rotation is a vital technique to implement with no-till farming. By varying the seeding and harvest schedule, it allows for the replenishment of lost nutrients within the soil and alters the herbicide spraying times. Crop rotation also tends to reduce the use of herbicides, which in turn reduces the potential of groundwater contamination.

No-till seeding requires seeders capable of cutting through large quantities of crop residue, penetrating untilled soil, and depositing the seed 25-50 mm deep (Kushwaha et al. 1986). There are a variety of no-till seeders used in the agricultural industry. The two types investigated in this study are disc and hoe openers. With the aid of a gauge wheel, disc openers provide precise seed placement and are able to move through tall stubble that would set back a hoe opener. However, hoe openers have the capability to seed into moist situations, while the disc opener does not. The disc opener may cause hairpinning (bending the straw into the furrow instead of cutting through it) if the residue is too moist.

Soil compaction increases with wheel traffic. As well, soil that is not tilled increases the bulk density, which results in strengthened soil. Compacted soils with high strength reduce growth rates of crop roots and thus limit the availability of water and nutrients to the plant (Bengough 1991). With no-till, the bulk density is higher than with conventional methods. On the other hand, with tillage there is more wheel traffic due to the increased equipment time on the field. Therefore, the compaction of soil due to tillage and no-till needs to be further investigated to determine which operation causes higher soil compaction. A cone penetrometer can be used to determine the soil strength.

A reduction in yield may be due to the loss of soil by erosion from agricultural fields. Erosion from tilled fields can be reduced by tillage practices that leave rough porous surfaces covered by old crop residue. Changes in surface roughness affect exposed surface area, air movement, radiation exchange, evaporation, and erosion (Robichaud and Molnau 1990), which indirectly influence the moisture, temperature, and aeration of the soil (Currence and Lovely 1970). This in turn may affect crop growth and yield. Therefore, by measuring the seed row roughness the quantitative affect of tillage on soil roughness can be determined.

The primary function of any seeding equipment is to place the seed in a soil environment that is favourable for rapid establishment of healthy, vigorous plants. Shallow seeding depth provides the best seed bed environment for most direct-seeded crops. Seeding depths in no-till fields must be 25-50 mm to promote quick emergence and to allow the crop to get a head start on weeds (Coutts et al. 1991).

The weeds in any particular field are affected by soil types, environmental conditions, crop rotations, herbicides used, and tillage. The time of seeding, variety selection, optimum placement of seed and fertilizer, field border sanitation, and the selection and rotation of crops are all important in improving a crop's ability to compete with weeds (MNZTFA 1998). Today, herbicides are the primary method of weed control in mechanised agriculture (Cousen and Mortimer 1995), which enables farmers to increase crop yields by eliminating weed competition. Weeds with seeds that are spread by wind, such as Dandelion and Canada Thistle, might be more abundant in the borders of no-tillage fields because their seeds are trapped by stubble and litter as they blow in (Manitoba Agriculture and Food 2001). Some annual weeds, such as green foxtail, seemed to decrease under no-tillage.

An image capture/processing system is a technique that uses a commercially available digital camera and a personal computer to detect weed coverage and distribution. Using the greenness method, the image of the weed can be differentiated from other objects within the field to determine the amount of weed cover.

Although the effect of no-tillage on crops has been extensively documented, there is little information of the uniformity of no-till openers on seed placement, subsequent crop emergence, and yield. Knowing the uniformity of seed placement indicates the precision of the seeder. If the maximum height of stubble can be determined, farmers can focus more on weeds and other factors instead of soil-to-seed contact. This information can be used to design the optimum ultra low disturbance opener, improve weed management techniques, and provide food for the world.

3. OBJECTIVES

The format of this thesis is written as two separate papers. The objectives of the first paper, Seed Placement and Crop Performance on Various Residue and Stubble Heights Using No-till Openers were:

To investigate the seeding performance and crop performance as influenced by the following factors:

- Type of residue
- Stubble height
- Type of seed opener
- Type of crop
- Field wheel tracks

The seeding performance was evaluated by hairpinning and seed placement, while the crop performance by speed of emergence and plant populations.

The objectives of the second paper, Seed Row Surface Roughness and Subsequent Weed Emergence due to No-till Seeders were:

Primarily, to determine the surface roughness and weed cover as affected by disc and hoe seed openers. Secondarily, to compare different imaging analysis techniques in order to determine the weed cover when crops and weeds are like in colour.

4. SEED PLACEMENT AND CROP PERFORMANCE ON VARIOUS RESIDUE AND STUBBLE HEIGHTS USING NO-TILL OPENERS

4.1 ABSTRACT

No-till farming is an economically viable, erosion-proof crop production system in which the crop is planted directly into the previous crop's stubble with minimum soil disturbance (MNZTFA 1998). Cultural controls such as crop competition and rotations, along with the responsible use of herbicides are used to replace tillage. The success of any no-tillage crop production system is the ability to (1) establish adequate plant stands and (2) effectively control the crop pest, most notably weeds (Tompkins 1985). A two year study was conducted to determine whether the previous crop type, stubble height, and type of seeder had an effect on the seed placement and subsequent speed of emergence. Two sites were evaluated: Residue site and Oat-stubble site.

In 2001, pea (Pr) as the previous residue was shown to be an ideal residue because it was able to seed canola deep and resulted in the most uniform seed placement, with wheat (Wr) and canola (Cr) residue thereafter. In 2002, there was generally no significant difference in seeding depths or speed of emergence between residues. However, canola was again seeded most uniformly in the pea residue. Wr generated the most amount of hairpinned residue for the Residue for both years.

For seeding canola and wheat, the stubble height caused significantly different seed placement inside and outside the wheel track. In the pea plots, there was a significant difference between the 150 mm stubble (S150) and the 400 mm stubble (S400) inside the wheel track and between cultivated (S0) and S150 & S400 outside the wheel track. Crops

were seeded the most uniformly in the short stubble. S400 caused the majority of hairpinned residue in the Oat-stubble site for both years.

The seeding depth for all crops was higher than initially targeted. The D opener produced a greater seed depth than the H opener when planting canola for all sites. On the other hand, when seeding pea and wheat, the H opener had a greater seeding depth. Furthermore, the H opener had a significantly better seed depth uniformity than the D opener in the Oat-stubble (2001) and Residue site (2002). In the 2001 Residue site, the D opener had a better seed depth uniformity.

For the majority of the treatments, the seed placement outside the wheel track was slightly deeper than inside the wheel track. The seed depths inside and outside the wheel track were different, however, there was no statistically significant differences in all sites for both years.

4.2 INTRODUCTION

As early as the mid-1960's, concerns about erosion, time spent in the field, and increasing energy costs persuaded a small number of farmers in the prairies of North America to try directly seeding crops into the standing stubble from the previous year (Coutts et al. 1991). However, due to an inability to control weeds and an unavailability of proper seeding equipment, farmers did not embrace no-till agriculture. In the years since, advances in technology have improved weed control and seeding equipment is now able to deal with crop residue. As well, an understanding of the importance of crop residue and the erosion control that can be associated with residue's presence on soil surface has caused many farmers to consider no-tillage.

With no-till, flat and standing residue from the previous year is left on the field. Residue protects the soil surface from erosion by absorbing the impact energy of raindrops reducing the soil particle detachment, and reduces surface crusting and sealing, which enhances infiltration and crop emergence (Shelton et al. 1992). As the amount of residue increases, the loss of soil due to erosion decreases. However, only uniform residue distribution is an effective means of no-till. Crop residue must be spread evenly to avoid or reduce such problems as: equipment plugging; poor seed germination; disease, weed, and insect infestation; nitrogen tie-up in the chaff or straw rows; and cold soil (Green et al. 1999).

Crop residue standing above the soil surface is 5 to 10 times more effective in preventing wind erosion than the same mass of residue lying flat on the soil surface (Fox and Wagner 2001). Also, standing residues persist longer than flat residues that are in close contact with the soil (Tanaka 1986). Furthermore, higher standing stubble has the potential to capture more snow, which results in higher soil moisture. A low cutting height of 102 mm provides little protection against evaporation for sparse stands (Nielsen 2003). However, increasing the stubble height of dense stands (greater than 58 stems/m^2) from 305 to 508 mm does little to reduce evaporation further (Nielsen 2003). Cereal stubble height should generally not exceed the seed row spacing, and tall stubble may cause plugging of seeding equipment (Green et al. 1999). Therefore, research has been done on moisture availability due to stubble heights, but not the optimum stubble height for precise seeding depths and subsequent crop growth.

Crop rotation is a vital technique to implement with no-till farming. By varying the seeding and harvest schedule, it allows for the replenishment of lost nutrients within the soil and alters the herbicide spraying times. Crop rotation also tends to reduce the use of herbicides, which in turn reduces the potential of groundwater contamination. As well, it reduces the levels of fertilizer required since the crop variance replenishes many of the nutrients. Studying a variety of past residues will show what crop should be implemented in no-till in order to acquire favourable plant growth.

Today, most no-till seeders are adaptations of conventional tillage machinery and not specifically designed for no-tillage. No-tillage seeding machines must not only physically handle residues consistently without blockage, but also have the ability to micro-manage those residues close to the slot and to utilize them to the benefit of the sown seeds and plants (Baker and Choudhary 1988). They must have the capability to seed into ever changing soil conditions. The debate over which type of no-till seeder works best for planting continues.

Vertical double disc openers have been included on more no-tillage drill designs than any other opener design to date (Baker et al. 1996). However, hoe openers are currently the most popular tools for no-till seeding in Western Canada (Chen et al. 2002). Disc openers do not plug in taller stubble (Green et al. 1999) and cause less soil disturbance than hoe openers because they create a narrower furrow. Soil thrown out of the furrow makes maintaining a uniform seeding depth more difficult (Tompkins 1985). A narrower slot results in more precision in seed placement (Successful Farming 1983), which is vital for high yield. Non-precise seed placement means uneven plant spacing and depth, which may lead to uneven emergence. Uneven emergence affects crop performance because competition from larger, early-emerging plants decreases the yield from smaller, later-emerging plants (Thomison and Lentz 2002).

The limitations of disc openers are the high penetration forces required; their biological intolerance of sub-optimal soil conditions; and their tendency to tuck (or 'hairpin') residue into the slot, which in dry soils interferes with seed-to-soil contact, and in wet soils results in fatty acid fermentation that kills germinating seeds (Lynch 1977). In addition, disc openers are unable to separate the seed from the fertilizer in the slot due to the V-shape of the slot (Baker et al. 1996).

Hoe openers may be beneficial because they have the capability to seed into high moisture situations, while disc openers do not. With hoe openers, soil uplifting occurs, which aids in seed covering and eliminates the need of press wheels for good seed-to-soil contact. Other advantages of hoe openers over disc openers are that they do not cause hairpinning and they are less affected by forward speed than angled discs (Baker et al. 1996). There have been many studies on the benefits and limitations of hoe and disc seeders, but few comparing the crop performance between the two.

Soil compaction also affects seeding performance and crop performance. The soil cone index has been used extensively to assess soil strength, an indicator of the likelihood of poor root growth and crop performance (Wells et al. 2001). Studies have shown that if the soil cone index value is greater than 2-3 MPa (300-435 psi), the crop growth is limited (Ehlers et al. 1983). Tracked furrows (furrows inside the wheel track), were found to have a larger mean cone index than non-tracked furrows (furrows outside the wheel track) and plant beds in some conditions (Isaac et al. 2002). However, very few studies have been done to see if plant growth inside the wheel track is different from outside the wheel track due to different cone indices.

The objective of this study was to investigate the seeding performance and crop performance as influenced by the following factors:

- Type of residue
- Stubble height
- Type of seed opener
- Type of crop
- Field wheel tracks

The seeding performance was evaluated by hairpinning and seed placement, while the crop performance by speed of emergence and plant populations.

If the optimal crop rotation and stubble height can be determined, farmers can maximize production while minimizing erosion. Knowing the uniformity of seed placement indicates the precision of the opener and the yield potential. Finally, the realization of the benefits and limitations of the disc and hoe opener can be used to design the optimum ultra low disturbance no-till opener.

4.3 MATERIALS AND METHODS

4.3.1 Site description

Field studies were carried out in 2001 and 2002 at a location approximately 25 km north of Brandon, Manitoba, Canada. The two study sites were named Residue site and Oat-stubble site, respectively. The soil type in both sites is Newdale clay loam, which consists of clay-loam (45% clay, 40% silt, and 15% sand), 5% organic matter, and large rock debris. The Residue site was in summer fallow and no-tillage for the two previous years, with canola, pea, and wheat as previous residues. The Oat-stubble site had been in no-tillage since 1999, with barley and oats planted in 1999 and 2000, respectively. In 2001 pea, wheat, and canola were planted on different heights of oat stubble. Different plots were used for both sites in the second year of study to maintain the same treatments. Soil, crop, residue types, and field activities are summarized in Table 4.1 and the weather conditions of the sites are summarized in Table 4.2.

Table 4.1. Site description and dates of field activities

Terms		Residue site	Oat-stubble site
Previous residue	(2001/2002)	canola pea wheat	oat (400mm) oat (150mm) oat (cultivated)
Crop type	(2001/2002)	canola	canola pea wheat
Tillage practice	(1999/2000)	summer fallow / no-till	no-till / no-till and cultivated
Seeding date	(2001/2002)	June 8 / May 14	June 8 / May 17

Table 4.2. Growing season precipitation and degree days ($T_{min} = 5$ °C) in 2001 and 2002 measured at a random location in the field.

Field season	Rainfall (mm)					Degree days				
	May	June	July	Aug	Total	May	June	July	Aug	Total
2001	70	168	31	53	322	251	297	422	566	1536
2002	5	65	31	93	193	110	362	468	354	1303
30 year average	52	72	73	72	270	200	328	416	382	1328

4.3.2 Seeding equipment

Disc seeder The ST Agri-Tech disc seeder (Fig. 4.1a) was 3.7 m (12 ft) wide, with 12 seed Ponik openers at a 0.3 m spacing with fertilizer applied between alternate seed rows.

This Ponik opener consists of a drag arm carrying two large offset discs (Janelle et al. 1995). The smaller disc (380 mm diameter) is oriented vertically, whereas the larger disc (460 mm diameter) is angled relative to both the direction of travel and the vertical axis. This orientation enables the discs to cut through residue and soil, as well as displace a volume of soil forming a seed furrow. The adjustable gauge wheel (410 mm diameter by 100 mm wide) for seeding depth control was located beside the small disc and a steel press wheel (360 mm diameter by 13 mm wide) was located behind the discs. A spring-loaded parallel linkage system applied the down force on the opener (Gratton et al. 2003). The seeder were operated at 5 km/h.

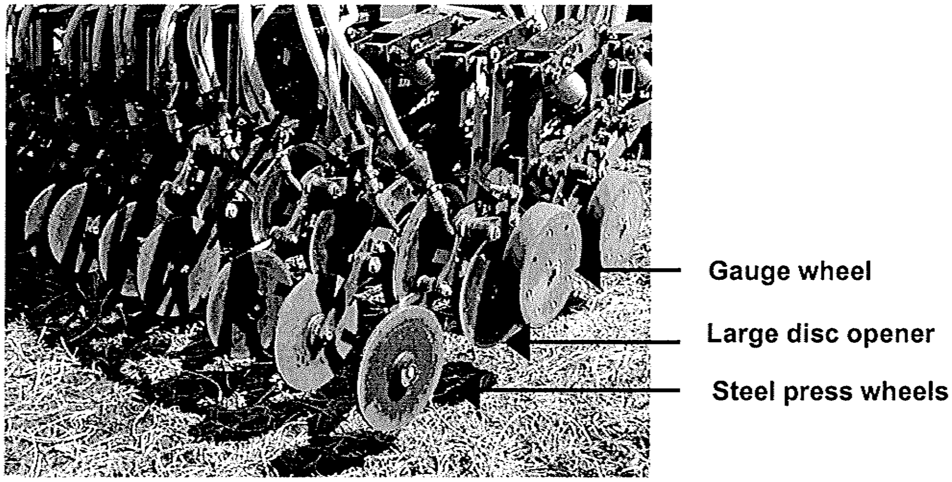


Fig. 4.1a. Double disc opener, ST Agri-Tech seeder

Hoe seeder The Conserva Pak hoe seeder (Fig. 4.1b) seeds and fertilizes in one pass. The fertilizer opener is mounted to a shank, and the seed delivery tube drops fertilizer behind the shank. The seed opener is arranged behind the shank assembly and the vertical height of the shank and the seed opener can be adjusted to achieve different depths of seed placement relative to the fertilizer. However, the press wheel controls the overall depth of the opener. In addition, the vertical position of this wheel can be adjusted to achieve desired depths for seed placement and fertilizer placement. The seeder used had four ranks, which are four separate rows of the seed openers. Furthermore, this seeder had 16 openers on 0.225 m centers and thus, had two less disturbance zones than the disc opener despite having a narrower row spacing than the planter with the disc openers. The fertilizer placement for this planter was 30 mm beside and 25 mm below the seed row. The seeder was operated at 5 km/h.

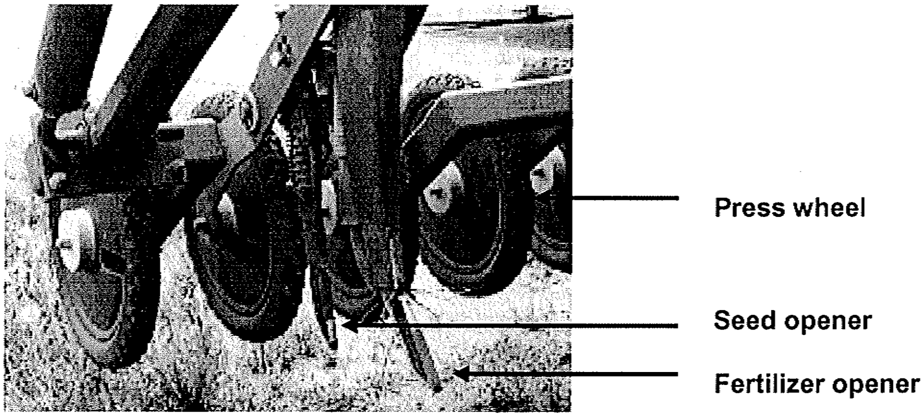


Fig. 4.1b. Conserva Pak hoe seeder

4.3.3 Experimental design

Residue study In the Residue study, the effect of previous crop residue and seeding tools on canola yields was determined in an on-going rotation trial. A split-plot experiment was designed with a completely randomized design (CRD) of main plots, consisting of three different residues: canola (Cr), wheat (Wr), and pea (Pr), and two sub-plots: sown with low disturbance hoe (H) and disc (D) seeders. Each treatment was replicated four times except for Wr, which was replicated eight times due to the farmer's rotation. Field layout and plot sizes are shown in figure 4.2a.

Oat-stubble study In the Oat-stubble study, the effect of stubble height and seeding tools on planting different crops was investigated. A split-plot experiment was designed with a CRD of main plots, which constituted of three different oat stubble heights: 400 mm (S400), 150 mm (S150), and tilled (S0), and sub-plots that consisted of three different crops: canola (Cc), pea (Pc), and wheat (Wc). Each treatment was replicated four times.

Seeding in the Oat-stubble site was performed perpendicular to the stubble rows (Fig. 2b). In 2001, the H opener was pulled along the north edge of the plots with one pass planted (3.7 m wide) and the remainder of the plots were planted with the D opener. However, in 2002, only the disc opener was used. Field layout and plot size are shown in figure 4.2b.

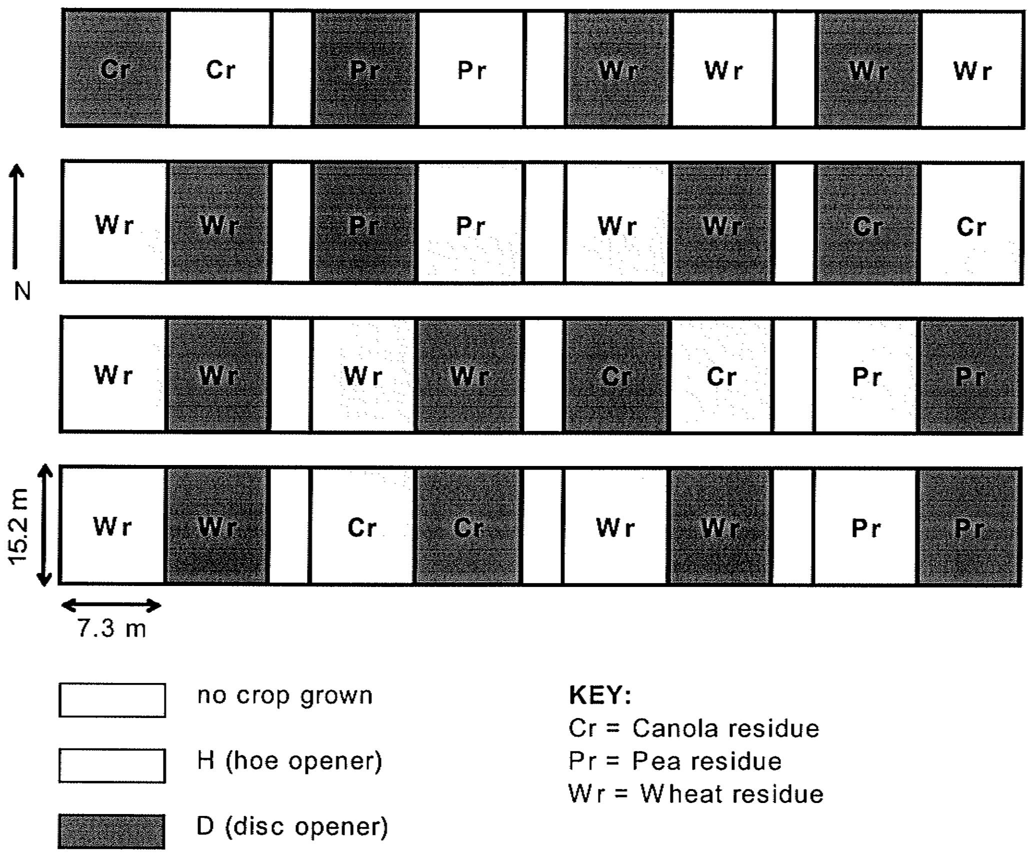


Fig. 4.2a. Field layout of Residue site

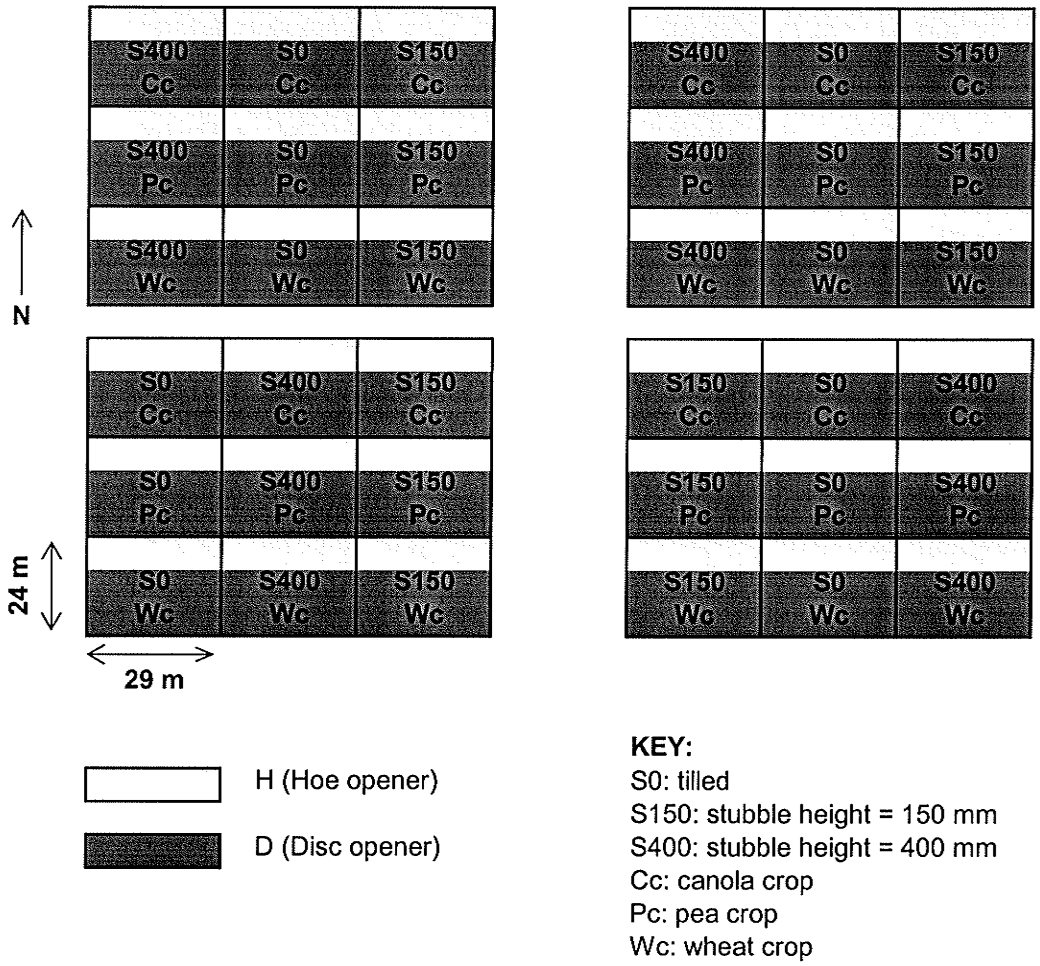


Fig. 4.2b. Field layout of Oat-stubble site

4.3.4 Field measurements

Residue cover A 1 m^2 quadrate was randomly placed on the surface of each plot. The flat straw contained within the quadrate was manually picked up and placed into one paper bag, and the remaining standing straw was cut with clippers and placed into another. Flat straw is more susceptible to hairpinning; therefore, flat and standing straw were collected separately. Sampling was performed at three random locations per plot. The residue samples were oven-dried at 60°C for 72 h (ASAE standards 1999b) and then weighed to determine the dry mass of the residue per hectare (kg/ha).

Soil moisture content To determine the soil moisture content a 20 mm diameter probe was used to collect five random samples per plot at depths 0 to 50 and 50 to 100 mm. Each sample (0 to 50 or 50 to 100 mm) was sealed in an air-tight plastic bag to retain moisture and transported to the laboratory where the soil samples were weighed, oven-dried at 105°C for 24 h (Chen et al. 2002), and weighed again to determine the soil moisture content.

Soil cone index Soil penetration resistances were taken at six random locations inside the wheel track and outside the wheel track of the seeder in the Residue site, in order to determine the soil strength. In the Oat-stubble site, samples were randomly taken at 36 locations over the entire field.

A Rimik electronic soil penetrometer (Model CP 20 Agridy Rimik Pty. Ltd., Toowoomba, Australia) was used for these measurements. The soil penetrometer was comprised of an inbuilt data logger, an 800 mm shaft, and a cone with a base area of 129 mm^2 and an apex angle of 30^0. At each location, the penetrometer was inserted into the soil at a velocity less than 30 mm/s (ASAE standards 1999a). The mean value of the penetration resistance at each 25 mm depth interval was recorded to a depth of 400 mm. Penetration resistance was divided by the base area of the cone to determine the cone index.

Hairpinning Immediately following the seeding trials, hairpinning was determined by taking soil monoliths with a seed row sampler that was 25 mm wide, 51 mm deep, and 203 mm long (1 x 2 x 8 in). Hairpinning is only a concern with disc seeders; however, soil monoliths were also taken in the non-disc plots to provide background information in order to determine the actual hairpinned residue as discussed below.

The width of the monolith was selected to cover the 25 mm soil disturbance caused by a typical double disc opener (PAMI 1995), and the depth was chosen to be greater than the seeding depth. The sampler was aligned along the center of the seed row and pushed down vertically into the ground using a wooden mallet. A flat spade was used to retrieve the sampler from the ground and a knife was used to shave off excess soil at the end of and under the sampler. Before the sampler was pushed into the soil, loose residue and chaff on the soil surface were carefully removed by hand (Chen et al. 2002). Three samples were randomly collected from each plot, placed into a paper bag, and transported to the laboratory.

Each soil monolith was placed in a pail of water to remove the residue from the soil. The buoyancy of the residue allowed it to float to the water surface separating itself from the sinking soil. Soil mineral particles within the residue were washed away using a plant root-washer. The remaining organic materials (referred to as extracted material hereafter) was placed in an envelope and oven-dried at 60 °C for 72 hours to determine the dry mass. The extracted material of the background samples subtracted by the extracted material from the plots seeded with the D opener was considered as the actual hairpinned residue, which is independent of seed opener spacing (Eq. 1).

$$H_p = \frac{M - M_O}{L} \qquad (1)$$

where H_P = hairpinned residue (g/m)

M = mass of extracted material from a treatment plot (g)

M_o = mass of extracted material from the background plots (g)

L = length of sampler (m)

Speed of crop emergence The speed of crop emergence was determined only for the Residue site. Three random locations were chosen in each plot with three rows at each location (a total of nine rows per plot). At each row, a length 600 mm was staked out and the number of canola plants within this length were counted on the 4th, 7th, 10th, 17th, and 24th day after the first emergence. The speed of emergence (S_E) per unit row length was calculated as (Tessier et al. 1991):

$$S_E = \frac{\sum\left(N_i / d_i\right)}{L \bullet s} \qquad (2)$$

Where d_i = days

N_i= number of newly emerged seedlings counted per day d_i

L = length of row counted (m)

s = row spacing (m)

The final plant count (on the 24th day) was used to determine the plant population (plants/m^2).

Seed placement Seed placement was assessed by measuring the seeding depth of the crop. The chlorophyll-free stem and the coleoptile's length (from seed remnants to onset of green stem) is a good representation of the effective seeding depth (Tessier et al. 1991) of cereal crops. However, it is not possible to measure the seeding depth of canola using this method because canola seeds do not remain in the soil. For the purpose of seeding depth measurements of canola crop, a 1:1 portion of canaryseed were mixed with the canola seeds at a rate of 6 kg/ha of each crop. Canaryseed exhibit the same properties and growth characteristics as canola (Agri-fax 1998), as well, their seeds remain in the soil. Therefore, the chlorophyll-free stem and coleoptile's length of canaryseed seedling was measured as the effective seeding depth of the canola. After using the canaryseed plants for seeding depth measurements, they were killed using Liberty herbicide.

For the pea crop, the location of the seed could not be clearly identified. A mark was made on the plant at ground level, the plant was removed from the ground, and the length below the mark was taken as the effective seeding depth (MZTRA et al. 2001).

For all seed depth measurements, five random plants within each row at each location were removed from each plot. There were six locations in each plot: three inside the wheel track and three outside the wheel track. Seed depths inside and outside the wheel track were assessed in order to determine if wheel track significantly affected seed placement.

4.3.5 Data analysis

Analysis of variance (ANOVA) was performed on the field data. Means between treatments were compared using Duncan's multiple range tests at a significance level of

0.1. The uniformity of seeding depth was characterized by the standard deviation of measured seeding depths.

4.4 RESULTS AND DISCUSSION

4.4.1 Residue site

Residue cover Wr had the highest amount of standing residue in 2001 (Table 4.3). This was expected since wheat is classified as a high residue producing crop (MAF 2002). The standing wheat stubble benefits seedlings by protecting them from wind, increasing available moisture by trapping snow in the stubble, and usually results in a significant gain in yield (SSCA 1994). Pr and Cr are considered to be low residue crops, which mean they do not have the same snow trapping potential as high residue crops. Pr had the least amount of standing straw cover, followed by Cr. In 2002, the amount of standing residue was relatively the same for all previous residue types.

Residue protects the soil surface from erosion by absorbing the impact energy of raindrops reducing the soil particle detachment, and reduces surface crusting and sealing, which enhances infiltration and crop emergence (Shelton et al. 1992). As the amount of residue increases, the loss of soil due to erosion decreases. In 2001, the flat residue was greatest to lowest for Pr, Cr, and Wr. In 2002, the reverse order was observed. In general, the flat residue cover was greater in 2001 than 2002. Conversely, the standing residue was higher in 2002 than 2001. The total residue cover in 2002 was approximately 65% higher than 2001.

Table 4.3. Crop residue cover measured before seeding trials for Residue site

	Straw cover (kg/ha)		
Treatment	Flat	Standing	Total
2001			
*Cr	928.60	176.95	1105.55
Wr	586.97	454.80	1041.77
Pr	1810.30	36.10	1846.40
2002			
Cr	274.07	2915.94	3190.01
Wr	303.28	2955.37	3258.65
Pr	208.89	2855.93	3064.82

*Cr=canola residue; Wr=wheat residue; and Pr=pea residue

Soil moisture content Gravimetric soil moisture was measured a few days before seeding. In the 2001 season, the soil moisture content was 16.4 and 21.9% at 0-50 mm and 50-100 mm, respectively. In 2002, the soil moisture was 9.8 and 20.6% at 0-50 mm and 50-100 mm, respectively. The low rainfall in 2002 contributed to the lower soil moisture content at 0-50 mm depth. As shown in Table 4.2, the precipitation for the seeding months for both years differed by 163 mm (168 mm of rainfall in 2001 and 5 mm in 2002).

Soil cone index The top 100 mm of soil at the Residue site had very low soil strength. In both years, the cone index inside the wheel track was generally higher than outside the wheel track (Fig. 4.3a), an effect to be expected since wheels from agricultural machinery cause soil compaction. However, at deeper depths the soil strength appears to vary both inside and outside the wheel track (data not shown), which may mean that compaction due to wheel traffic may only affect the soil strength of depths approximately less than 100 mm.

Cr had the highest cone index followed by Wr and Pr, respectively (Fig. 4.3b). This shows that Pr as a previous residue may cause the soil to become less compacted. In 2002, there was little variation in soil strength with different residues. The lack of rainfall made the entire field dry, which resulted in similar cone indices. The soil cone index was also slightly higher than the previous year due to the low amount of rainfall. Interpreting the penetration resistance measurement, the compaction rating for both years was little to none according to Murdock et al. (1995).

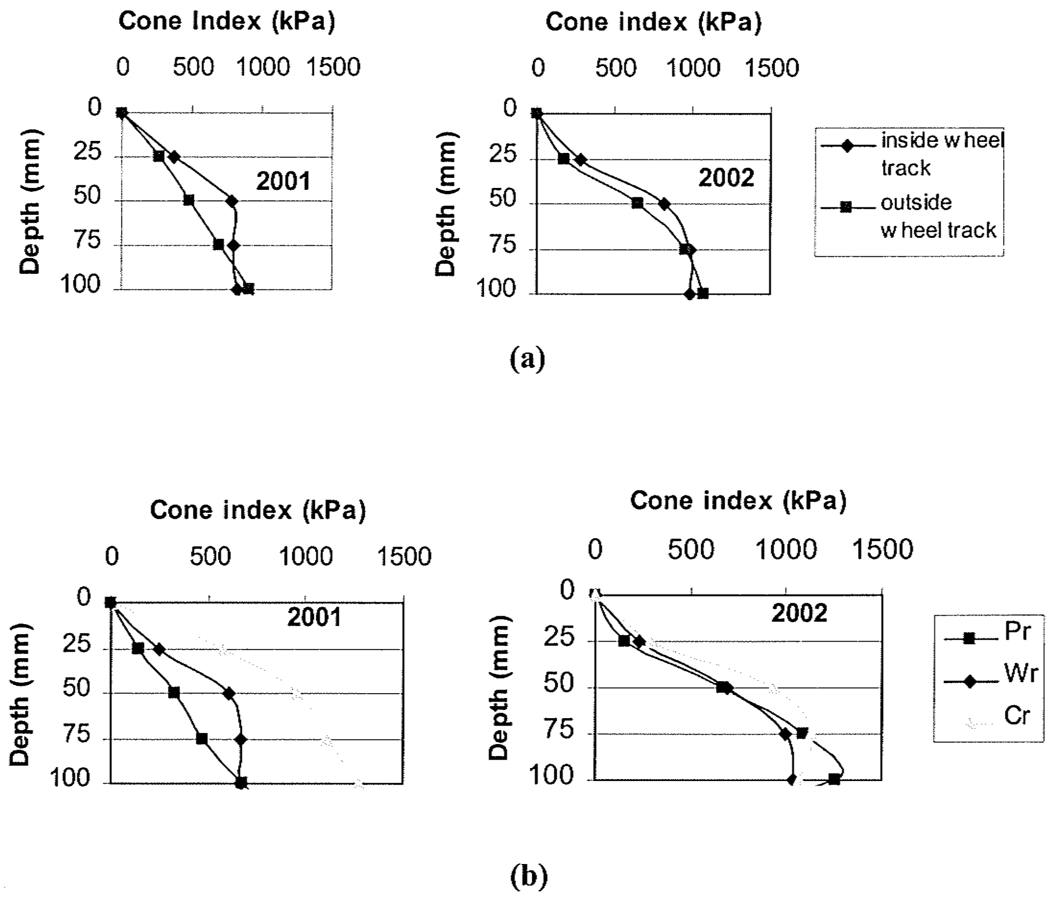
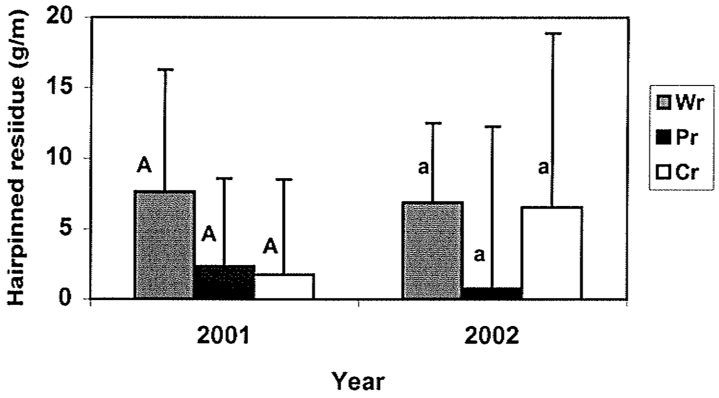


Fig. 4.3. Soil cone indices of Residue site; (a) inside and outside wheel track; (b) different crop residues

Hairpinning In 2001, Wr had the highest amount of hairpinned residue (7.6 g/m). This is significantly higher than the background residue. The Pr (2.3 g/m) and Cr (1.8 g/m) were only slightly higher than the background (Fig. 4.4). This is due to the fact that wheat residue is less brittle than pea or canola residue, is therefore more susceptible to hairpinning.

In 2002, the amount of hairpinned residue was 6.9, 6.6, and 0.8 g/m for Wr, Cr, and Pr, respectively. Again, Wr had the highest amount of hairpinned residue, followed by Cr and Pr. However, there was no significant difference of hairpinning between any of the residues.



Values with the same lowercase or uppercase letters are not significantly different at P<0.1 according to Duncan's multiple test range.
Wr=wheat residue; Pr=pea residue; and Cr=canola residue

Fig. 4.4. Hairpinned residue (H_p) for D opener on Residue site

Seeding placement The target seeding depth for planting canola for both seasons was 10 mm. As shown in the Tables 4.4, the actual seeding depth of canola was much greater than the target seeding depth. A greater seeding depth may be caused by erosion. Water and wind erosion occur and the seed furrows eventually fill with soil placing more soil on top of the seed and hence, a greater seeding depth would be measured.

The uniformity of seeding depth is reflected by the standard deviations. The lower the standard deviation means a more uniform seeding depth. The seed depth uniformity varied from seeder to seeder and from residue to residue for the two years of study.

Effect of opener On average, the D opener produced a 12% greater seed depth than the H opener when seeding canola (Table 4.4). The type of opener made a significant difference in seed uniformity for both inside and outside the wheel track in 2001, and only inside the wheel track in 2002 (Table 4.4). In 2001, the D opener had a 42% more uniform seed placement than the H opener. Whereas in 2002, the H opener had 26% greater seed uniformity. The drier and more compacted soil in 2002 may have caused the reversal in seeding depth between openers, since H openers penetrate better than D openers in harder soil. Also, changes in soil texture and soil conditions over short distances may have caused the changes in opener penetration depths.

Effect of residue type The different types of residues in the 2001 Residue site had a statistically significant effect on seed depth (Table 4.4). Pr resulted in the highest seeding depth because pea as the previous crop makes the soil softer. This also agrees with the soil penetration data in 2001, where Pr had the lowest cone index (55 kPa) at a depth of 10 mm (targeted seeding depth of canola) when compared to Wr (92 kPa) and Cr (235 kPa). Subsequently, Wr had the next greatest seeding depth followed by Cr. In 2002 however, the residue had no significant effect on the seeding depth (Table 4.4). The cone index of Pr

(25 kPa) was only somewhat lower than Wr (60 kPa) and Cr (54 kPa), which was apparently not enough to make a difference in seeding depth. This may be a result of the dry soil condition at seeding time.

The seed placement for both years was the most uniform for Pr. Wr had a better or comparable seed depth uniformity when compared Cr. Therefore, seeding into Newdale clay loam soil with pea as the previous crop will aid in the uniformity of crop growth.

Effect of wheel track For the majority of the treatments (Table 4.4), the seed placement outside the wheel track was slightly deeper than inside the wheel track although the differences were not statistically significant. Since the seeding depth was measured from the surface of the soil to the seed, the compaction of the seed rows by the tractor wheels may have caused the decrease in depth inside the wheel track. For both years of study, the penetration resistance was slightly lower outside the wheel track. A softer soil usually results in a greater seeding depth (Chen et al. 2003).

The average seed uniformity inside the wheel track (5.93) was better than outside the wheel track (1.86) in 2001 and vice versa in 2002 (3.27 and 2.55 in and outside the wheel track, respectively). The 2001 year showed a statistically significant difference in the uniformity of seed placement inside and outside the wheel track, but the 2002 year did not (data not shown). The significance difference in 2001 may be due to the soil conditions. With adequate soil moisture (2001), the wheels have an opportunity to even out the seed depths. If a seed is placed higher than another seed, the wheels of the tractor will depress the soil on top of the seed and hence, push the higher seed down to be closer to the depth of the other seed. Whereas, in drier seeding conditions (2002), the soil will not depress as easily which, results in similar seed uniformities in and outside the wheel track.

Table 4.4. Canola seeding depth and uniformity for Residue site

	Inside wheel track		Outside wheel track		Average	
Treatment*	Mean	SD	Mean	SD	Mean	SD
Opener						
2001						
D	40.70 a	2.05 a	40.78 a	1.31 b	40.74 a	1.68 b
H	36.66 b	2.38 b	36.69 b	2.38 a	36.68 b	2.38 a
2002						
D	43.12 a	3.99 a	40.94 a	2.62 a	42.03 a	3.31 a
H	36.24 b	2.45 b	37.72 a	2.75 a	36.98 b	2.61 b
Residue						
2001						
Cr	29.93 c	1.84 ab	29.88 c	3.30 a	29.91 c	2.57 a
Wr	35.00 b	2.29 a	35.13 b	1.45 b	35.07 b	2.12 a
Pr	54.77 a	1.44 b	54.81 a	1.18 b	54.79 a	1.31 b
2002						
Cr	40.91 a	4.92 a	41.94 a	2.94 a	41.43 a	3.93 a
Wr	39.21 a	3.10 b	39.22 a	3.10 a	39.22 a	3.10 a
Pr	39.40 a	1.79 c	36.94 a	1.61 b	38.17 a	1.70 b

*Values with the same letters within each opener, residue treatment, or year are not significantly different at $P<0.1$ according to Duncan's multiple test range. Mean values are in mm.

D=disc; H=hoe; Cr=canola residue; Wr=wheat residue; and Pr=pea residue.

Crop performance The crop performance was determined separately for inside and outside the wheel track. The type of opener and residue played a significant role in the speed of crop emergence (Table 4.5). For both years the D opener showed an average of a 46 % faster emergence rate.

The type of residue was a significant factor in 2001. Observations showed that Pr provided the greatest speed of canola emergence, followed by Wr and Cr. In 2002, there was no significant difference in the speed of emergence between Pr and Wr. Furthermore, the speed of emergence of canola for the Pr and Wr was lower than in 2001, due to limited soil moisture of the latter year. The dramatic increase in speed of emergence in Cr was due to the vast amounts of volunteer canola that started to grow in and between the crop rows, and it was difficult to exclude them from the plant counts. The large standard deviations of Cr in 2002 are also due to volunteer canola growth.

Although the speed of emergence was affected by the type of opener, the plant population was not (Table 4.5). For both years of study, the type of residue significantly affected the plant population, and the trends were similar to those of speed of emergence.

Table 4.5. Speed of emergence and plant population for Residue site

Treatment	Speed of emergence (plant/day/m^2) Mean	Speed of emergence (plant/day/m^2) SD	Plant population (plant/m^2) Mean	Plant population (plant/m^2) SD
Opener				
2001				
D	23.63 a	12.88	77.25 a	38.81
H	14.03 b	8.21	73.45 a	45.49
2002				
D	24.67 a	16.85	123.06 a	112.16
H	18.17 b	29.41	109.09 a	112.8
Residue				
2001				
Cr	17.39 b	11.20	69.06 b	47.07
Pr	21.31 a	10.93	88.44 a	38.05
Wr	18.31 ab	12.42	71.99 b	40.64
2002				
Cr	38.57 a	40.08	237.92 a	151.67
Pr	15.31 b	10.94	72.98 b	45.74
Wr	15.89 b	10.87	76.67 b	54.52

*Values with the same letters within each opener, residue treatment, or year are not significantly different at $P<0.1$ according to Duncan's multiple test range.
Cr=canola residue; Wr=wheat residue; and Pr=pea residue.

4.4.2 Oat-stubble site

Residue cover S0 had the least flat residue and no standing residue (Table 4.6). S150 had more flat residue than S400. This is expected because since the standing residue of S400 is higher than S150, which means when the stubble was cut, less stubble was cut off the top to obtain 400 mm of standing stubble, leaving less flat stubble. As a result, there would be a lower level of flat residue and a higher level of standing for S400 when compared to S150. The total residue was approximately 25% higher in 2002.

Table 4.6. Crop residue cover measured before seeding trials for Oat-stubble site

	Residue cover (kg/ha)		
Treatment*	Flat	Standing	Total
2001			
S0	689.85	0.00	689.85
S150	3456.40	361.05	3817.45
S400	1785.70	581.75	2367.45
2002			
S0	764.90	0.00	764.90
S150	3392.40	443.10	3835.50
S400	2833.60	1163.00	3996.60

*S0=cultivated; S150=150 mm stubble; and S400=400 mm stubble

Soil moisture content Gravimetric soil moisture content was measured a few days before seeding for both seasons and was deemed adequate for proper germination for both years. The soil moisture content was highest in S400, followed by S150 and S0 for both years (Fig. 4.5). This trend is due to the standing stubble that traps a layer of still air close to the soil surface, which slows down the exchange of water vapour between the soil and the atmosphere (Baker et al. 1996). Standing stubble also reduces wind velocity, which reduces the amount of drying. Therefore, greater standing straw results in higher soil moisture content.

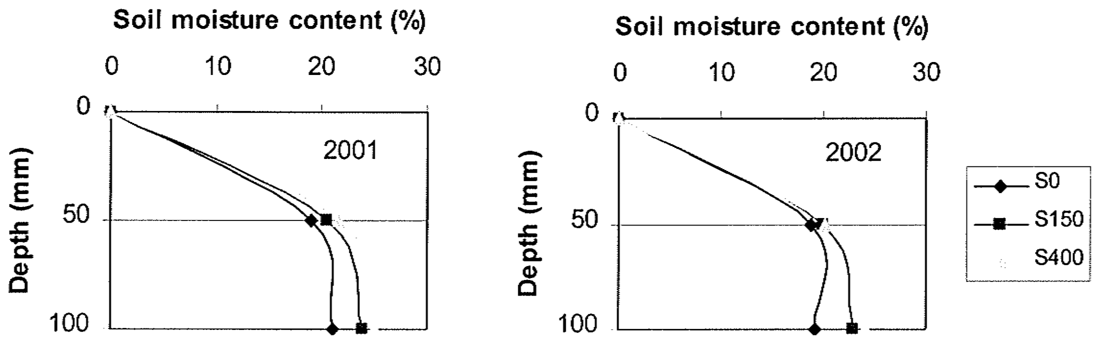


Fig. 4.5. Soil moisture content of Oat–stubble site

Soil cone index The average soil strength over the entire field was very similar for both years up to a depth of 100 mm (Fig. 4.6). The cone index was generally higher in 2002, a result of lower precipitation that results in lower soil strength. Again, interpreting the penetration resistance measurement, the compaction rating for both years was little to none according to Murdock et al. (1995).

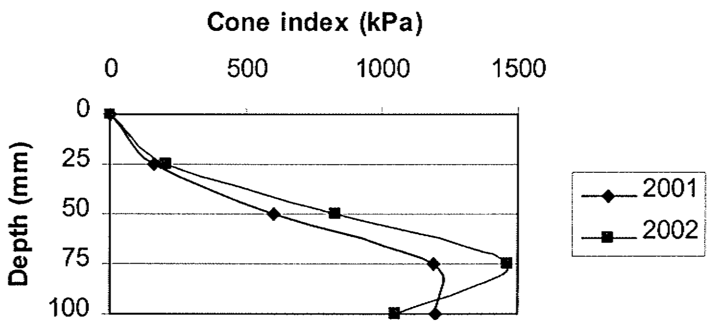
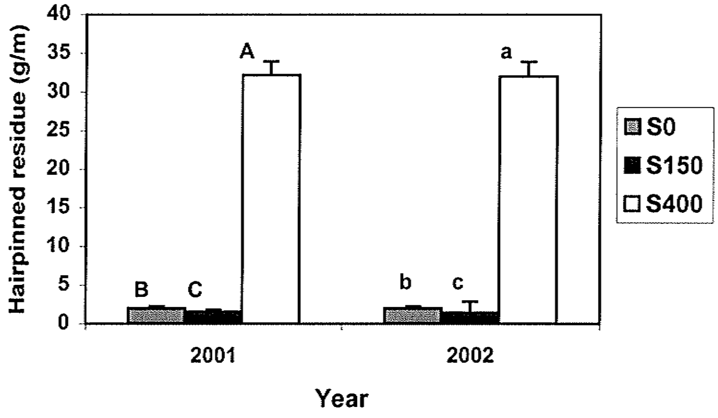


Fig. 4.6. Soil cone indices of Oat-stubble site

Hairpinning The stubble height caused significant differences in hairpinned residue for the 2001 trial. Although flat residue is more prone to hairpinning, S150 (greatest amount of flat residue) did not have the most hairpinned residue. S400 had a high value of hairpinned residue (32.2 g/m) when compared to S150 and S0 with 1.5 and 2.0 g/m, respectively (Fig. 4.7). This difference may be due to the small equipment (lower clearance) that was used in the study. With a lower clearance, there is more potential to push high standing straw down with the wheels of the tractor and seeder and thus, generate more flat stubble to cut through. In the shorter stubble (S150) the stubble was short enough not to be pushed down by the openers, but S400 was not. This resulted in less hairpinned residue for S150 than S400, but relatively the same amount as S0 (although significantly different).



Values with the same lowercase or uppercase letters are not significantly different at P<0.1 according to Duncan's multiple test range.

Fig. 4.7. Hairpinned residue for D opener on Oat - stubble site

Seed placement The target seeding depth was 40, 20, and 10 mm for pea, wheat, and canola, respectively. In 2001 and 2002, both wheat and canola exceeded the target seeding depth, whereas the actual seeding depth of pea was very close to the target (Tables 4.7 & 4.8). Most likely, the deep seeding depth of Cc is due to the operator setting. However, wheat and pea are larger seeds, which means, the seeds have the potential to bridge at the slot near the bottom of the furrow and not fall completely to the bottom like canola.

Effect of opener For the wheat and pea crops, the H opener seeded 16 and 50% deeper than the D opener, respectively. The D opener had a 24% greater seeding depth when seeding canola. H openers penetrate better than D openers when there is a significant amount of crop residue on the soil surface in no-till situations. Also, since soil texture and soil conditions can vary greatly over short distances, changes in opener penetration depths can occur (Chen et al. 2002). Again, a greater seed depth may also be due to the operator setting. For most cases in 2001, the standard deviation was significantly lower when seeding with the H opener, indicating better seed depth uniformity.

Effect of stubble height In 2001, the average seeding depth in S0 was the greatest and was significantly different than S150 & S400 for all treatments. There was no statistically significant difference in seeding depth between Wc and Pc for both years. For Cc and Wc, the stubble height generally caused significantly different seed placement inside and outside the wheel track in 2001.

In 2002, a similar trend was observed. The greatest seeding depth was found mostly in S0. However, there was no significant difference in seeding depths between all treatments with the exception of S0 in Pc 2002. This insignificance is due to the fact that the residue was dry enough for the disc to cut through all residues and place the seed at relatively the same depth for each residue cover (S0, S150, and S400).

The stubble treatment had a significant effect on the average uniformity inside and outside the wheel track. S150 had better uniformity than S0 and S400 for all treatments in 2001. The stubble effect was less pronounced for Wc, the reasons were unknown. Similar trends were observed in 2002 for Cc and Pc, however, the effects of stubble on the uniformity of seeding depth were less pronounced. This is once again due to the dry weather, which in turn made it easy for the D opener to cut through all residue heights.

Effect of wheel track In 2001, S0 had the highest seeding depth outside the wheel track and was significantly different than S150 and S400. Inside the wheel track, there was a significant difference in seeding depth for all stubble heights. However, the highest seeding depth varied from stubble to stubble. In 2002, there was no significant difference in seeding depth for all stubble treatments, except for Pc outside the wheel track. Again, the seed depths inside and outside the wheel track were different, however, the differences were not statistically significant.

Table 4.7. Opener effect of seed placement for the Oat-stubble site 2001

	Inside wheel track		Outside wheel track		Average	
Treatment*	Mean	SD	Mean	SD	Mean	SD
Cc						
D	49.08 a	7.25 a	50.13 a	7.06 a	49.61 a	7.16 a
H	39.08 b	5.23 b	40.71 b	5.18 b	39.90 b	5.21 b
Wc						
D	21.04 b	6.03 a	27.67 b	2.55 a	24.56 b	4.29 a
H	30.13 a	2.92 b	32.08 a	2.75 a	31.11 a	2.84 b
Pc						
D	36.13 b	7.92 a	31.15 b	5.61 a	33.64 b	6.77 a
H	37.92 a	6.10 b	46.58 a	5.14 a	42.25 a	5.62 b

*Values with the same letters within each crop treatment are not significantly different at P<0.1 according to Duncan's multiple test range. Note that all mean values are in mm. D=disc opener; H=hoe opener; Cc=canola crop; Wc=wheat crop; and Pc=pea crop.

Table 4.8. Crop effect on seed placement for the Oat-stubble site 2001 and 2002

	Inside wheel track		Outside wheel track		Average	
Treatment*	Mean	SD	Mean	SD	Mean	SD
Cc						
2001						
S0	44.75 b	7.04 a	55.50 a	8.49 a	50.13 a	7.77 a
S150	37.50 c	3.18 b	36.94 c	4.47 b	37.22 c	3.83 b
S400	50.00 a	8.51 a	43.81 b	5.39 b	46.91 b	6.95 a
2002						
S0	38.25 a	4.72 a	38.50 a	4.61 a	38.38 a	4.67 a
S150	37.75 a	3.10 b	37.00 a	2.81 b	37.38 a	2.96 b
S400	37.25 a	4.27 b	36.25 a	4.78 a	36.75 a	4.53 a
Wc						
2001						
S0	28.31 a	4.83 a	31.44 a	3.01 a	29.88 a	3.92 a
S150	26.00 b	3.82 a	28.00 c	2.40 a	27.00 b	3.11 a
S400	22.44 c	4.63 a	30.19 c	2.57 a	26.31 b	3.60 a
2002						
S0	34.50 a	5.46 a	37.00 a	5.36 a	35.75 a	5.41 a
S150	35.25 a	5.14 a	36.50 a	5.62 a	35.88 a	5.38 a
S400	38.25 a	4.42 a	38.75 a	5.36 a	38.50 a	4.89 a
Pc						
2001						
S0	37.19 ab	6.50 b	49.69 a	5.77 a	43.44 a	6.14 ab
S150	38.25 a	6.37 b	33.94 b	4.85 a	36.10 b	5.61 b
S400	35.63 b	8.17 a	33.44 b	5.55 a	34.54 b	6.86 a
2002						
S0	66.00 a	18.99 a	70.00 a	16.97 a	68.00 a	17.98 a
S150	61.50 a	16.51 a	60.25 b	15.87 a	60.88 b	16.19 a
S400	60.75 a	17.49 a	63.50 ab	17.60 a	62.13 b	17.55 a

*Values with the same letters within each stubble level, crop treatment, or year are not significantly different at P<0.1 according to Duncan's multiple test range. Note that all mean values are in mm.

Cc=canola crop; Wc=wheat crop; Pc=pea crop; S0=cultivated; S150=150 mm stubble height; and S400=400 mm stubble height.

4.5 CONCLUSIONS

Pea as the previous residue caused canola to be seeded deepest, followed by the wheat and canola residue in the 2001 Residue site. In 2002, the deepest seeding depth of canola from greatest to lowest was in the canola, wheat, and pea residue, respectively. For both years, pea residue caused the most uniform seed placement, with wheat and canola residue thereafter.

The effect of stubble height was significant for 2001. For seeding canola and wheat, the stubble height caused significantly different seed placement inside and outside the wheel track. In the pea plots, there was a significant difference between short stubble (S150) and the tall stubble (S400) inside the wheel track and between cultivated (S0) and S150 & S400 outside the wheel track. Crops were seeded the most uniformly in the short stubble. Overall, a stubble height of 150 mm appears to be the optimal stubble level for seeding.

The seeding depth for all crops was higher than initially calibrated. The disc opener produced a greater seed depth than the hoe opener when planting canola for all sites. On the other hand, when seeding pea and wheat, the hoe opener had a greater seeding depth. The seed depth was the greatest when seeding into pea residue in the Residue site in 2001, because pea as a previous crop makes the soil softer. In 2002, there was no statistically significant difference in seed depth due to previous residue or stubble height. This may be due to the dry 2002 seeding conditions.

For the majority of the treatments, the seed placement outside the wheel track was slightly deeper than inside the wheel track. Although the seed depths inside and outside the wheel track were different, there were no statistically significant differences in all sites for both years.

A lower standard deviation indicates a better seed depth uniformity. For all treatments in the Oat-stubble site (2001), the standard deviation was lower when seeding with the hoe opener. Therefore, the hoe opener had a significantly better seed depth uniformity than the disc opener in the Oat-stubble (2001) and Residue site (2002). The disc opener had a better seed depth uniformity in the 2001 Residue site.

In the Residue site, wheat residue generated the most amount of hairpinned residue for both years. The tall stubble (400 mm) caused the greatest amount of hairpinned residue in the Stubble site for both years. The speed of emergence for canola was most optimal in pea residue for the 2001 Residue site, followed by wheat and canola residue. Subsequently, the plant population was the greatest in pea, then wheat and canola residue. In 2002, canola residue caused the greatest speed of canola emergence, highest plant population, and was the only significant previous residue. The volunteer canola, which was included in the plant counts contributed to these results.

5. SEED ROW SURFACE ROUGHNESS AND SUBSEQUENT WEED EMERGENCE DUE TO NO-TILLAGE SEEDERS

5.1 ABSTRACT

There has been little research on the weed emergence due to different no-tillage openers. A two year study has been carried out to investigate the effect of the hoe (H) and double disc (D) opener on seed row surface roughness (R_s) and weed cover.

A contact and non-contact surface profiler was used to assess R_s. The D opener produced a 17 and 3% smaller R_s than the H opener in 2001 and 2002, respectively. The weed cover using the D opener was 10% lower in 2001 and 32% lower in 2002 than the H opener. It appeared that higher R_s resulted in greater weed cover.

Two different image analysis approaches named Inter-row method and Subtraction method were implemented and compared to assess the weed cover in like weed and crop colour. The Inter-row method was on average 25% higher weed cover than the Subtraction method. However, the Subtraction method provides a better representation of weed and crop growth conditions in the field. The Inter-row method was highly correlated to the Subtraction method (r=0.74). Therefore, both methods may be used to determine weed cover.

5.2. INTRODUCTION

Weeds compete with crops for sunlight, moisture, nutrients, and space. The weeds in any particular field are affected by various factors including soil type, opener type, environmental conditions, crop rotations, herbicide use, and tillage. Controlling weeds without tillage is a new and challenging task, but it is not impossible.

In mechanised agriculture, herbicides are the primary method of weed control which enables farmers to increase crop yields by eliminating weed competition (Cousen and Mortimer 1995). Application of a non-selective herbicide at seeding time is often a component of the no-till system, but there are other controls available to the farmer (MNZTFA 1998). Any technique that favours crop growth over weed growth will result in cleaner fields and higher yields. Time of seeding, variety selection, optimum placement of seed and fertilizer, field border sanitation, and the selection and rotation of crops are also important in improving a crop's ability to compete with weeds (MNZTFA 1998). Furthermore, a properly selected opener will create an acceptable amount of disturbance while providing accurate seed and fertilizer placement for optimal germination and plant development (SSCA 1994), therefore, reducing weed growth potential.

According to Kelner and Gordon (1997), perennial weeds like dandelion, perennial sow-thistle, Canada Thistle, and Quackgrass have the potential to increase under no-tillage systems. This is an important observation, since it has been suggested that weeds with seeds that are spread by wind, such as dandelion and Canada thistle, might be more abundant in the borders of no-tillage fields because their seeds are trapped by stubble and litter as they blow in (MAF 2001). In addition, certain annual weeds seemed to decrease under no-tillage, while others appeared to increase. Therefore, studies have been done to determine whether no-till or conventional till result in more weeds, however, there has been little research on the weed growth due to different no-tillage openers.

Disc and hoe openers are the two dominant seeding tools of seeding small grains and cereal crops. Disc openers generally cause less soil disturbance than hoe openers because they create a narrower furrow (Janelle et al. 1993). More soil disturbance may or may not cause an increase in weed emergence. It is unknown whether soil disturbance may bring deeper weed seeds close enough to the surface to germinate or, bury weeds that are close to the surface so that they do not grow. Not only can openers cause disturbance, but gage and press wheels may also contribute to some variation in the soil surface.

Surface profilers are capable of measuring soil surface roughness. There are two types of surface profilers: contact and non-contact (Hirschi et al 1987). Contact profilers touch the soil surface with a series of rods or pins, measuring the distance from the soil surface to a reference plane. Non-contact profilers measure the distance from the soil surface to a reference plane without touching the surface (Robichaud and Molnau 1990).

To detect weed coverage and distribution, an image capture/processing system is a technique that may be implemented. This image capture/processing system uses a commercially available digital camera and a personal computer to determine the weed area. Digital images are taken randomly in the field on dates which herbicide applications would normally be applied. In the image processing stage, green objects in each image are identified using a greenness method that compares the red, green, and blue (RGB) intensities. The RGB matrix is reduced to a binary form by applying the following criterion: if the green intensity consists of a pixel greater than the red and the blue intensities, then the pixel is assigned a value of one, otherwise the pixel is assigned a value of zero (Yang et al. 2000). As shown below the image of the weed can be differentiated from other objects within the field. Unfortunately, this method can only be used when the weed colour is different from the colour of the crop. Therefore, there is a need to determine the amount of weed cover for fields that have similar crop and weed colour.

The primary objective of this research was to determine the surface roughness and weed cover as affected by disc and hoe seed openers. The secondary objective was to compare different imaging analysis techniques in order to determine the weed cover when crops and weeds are like in colour.

5.3 MATERIALS AND METHODS

5.3.1 Seeding equipment

Disc seeder The ST Agri-Tech disc seeder (Fig. 5.1a) was 3.7 m (12 ft) wide, with 12 seed Ponik openers at a 0.3 m spacing with fertilizer applied between alternate seed rows. This Ponik opener consists of a drag arm carrying two large offset discs (Janelle et al. 1995). The smaller disc (380 mm diameter) is oriented vertically, whereas the larger disc (460 mm diameter) is angled relative to both the direction of travel and the vertical axis. This orientation enables the discs to cut through residue and soil, as well as displace a volume of soil forming a seed furrow. The adjustable gauge wheel (410 mm diameter by 100 mm wide) for seeding depth control was located beside the small disc and a steel press wheel (360 mm diameter by 13 mm wide) was located behind the discs. A spring-loaded parallel linkage system applied the down force on the opener (Gratton et al. 2003).

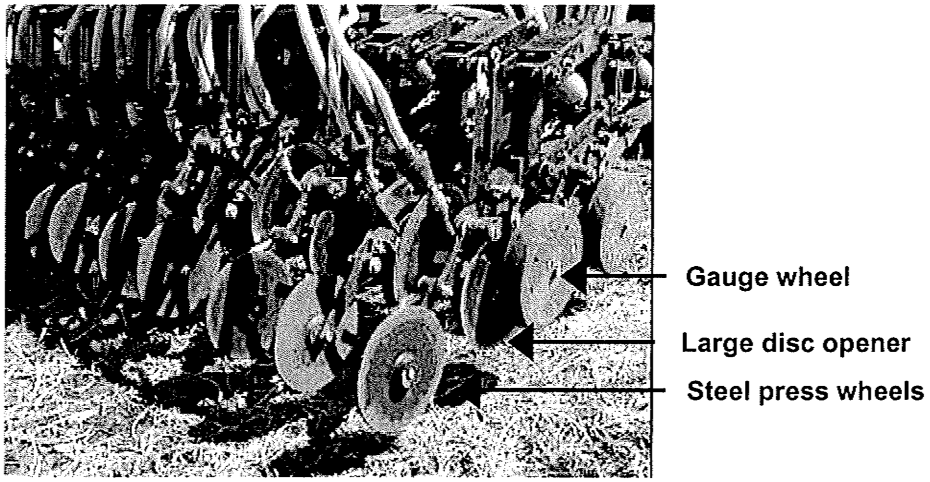


Fig. 5.1a. Double disc opener, ST Agri-Tech seeder

Hoe seeder The Conserva Pak hoe seeder (Fig. 5.1b) seeds and fertilizes in one pass. The fertilizer opener is mounted to a shank, and the seed delivery tube drops fertilizer behind the shank. The seed opener is arranged behind the shank assembly and the vertical height of the shank and the seed opener can be adjusted to achieve different depths of seed placement relative to the fertilizer. However, the overall depth of the opener is controlled by the press wheel. In addition, the vertical position of this wheel can be adjusted to achieve desired depths for seed placement and fertilizer placement. The seeder used has four ranks, which are four separate rows of the seed openers. The fertilizer placement for this seeder was 30 mm beside and 25 mm below the seed row. Furthermore, this seeder had 16 openers on 0.225 m centers and thus, had two less disturbance zones than the disc opener despite having a narrower row spacing than the planter with the disc openers. The fertilizer placement for this planter was 30 mm beside and 25 mm below the seed row. The seeder was operated at 5 km/h.

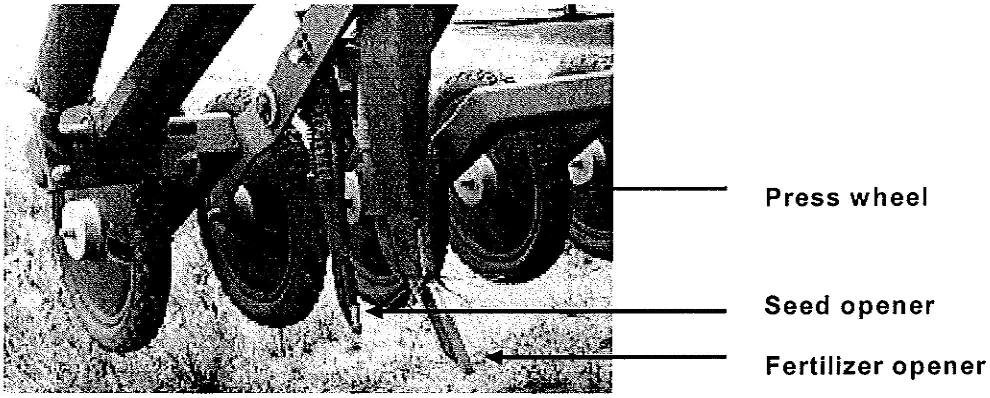


Fig. 5.1b. Conserva Pak hoe seeder

5.3.2 Site description and experimental design

Field studies were carried out in 2001 and 2002 at a location approximately 25 km north of Brandon, Manitoba, Canada. The soil type is Newdale clay loam, which consists of clay-loam (45% clay, 40% silt, 15% sand), 5% organic matter, and large rock debris. The site was in summer fallow and no-tillage for the two previous years, respectively. The plots used for this study were the same plots used in a previous experiment. They consisted of previous canola, pea, or wheat residue depending on the rotation. Canola was the crop seeded on June 8, 2001 and May 14, 2002. In 2002, different plots were used to maintain the same treatments. The weather conditions of the site are summarized in Table 5.1.

Table 5.1. Growing season precipitation and degree days (T_{min}=5°C) in 2001 and 2002

	Rainfall (mm)					Degree days				
	May	June	July	Aug	Total	May	June	July	Aug	Total
2001 field season	70	168	31	53	322	251	297	422	566	1536
2002 field season	5	65	31	93	193	110	362	468	354	1303
30 year average	52	72	73	72	270	200	328	416	382	1328

The experimental design was a completely randomized design (CRD). Two types of seeder treatments were imposed, the no-till low disturbance hoe (H) and disc (D) seeders. Each treatment was replicated 16 times. Seeder treatment plot size was 7.3 m x 15.2 m.

5.3.3 Field measurements

Seed row roughness The seed row roughness was measured immediately after seeding to characterize the soil disturbance due to the seeders. The labour intensity of the contact profiler in 2001, led to the implementation of the non-contact profiler in 2002. Both profilers were used to determine the physical shape (soil surface elevation) of the soil surface perpendicular to the seed row.

Contact surface profiler In 2001, a seed row roughness meter constructed by Tessier et al. (1989) as shown in figure 5.2 was used. Three random soil surface samples were taken from each plot. The soil profiles were scaled to Cartesian coordinates in mm (Fig. 5.3) and the position of the original soil surface was assumed to correspond to a straight line fitted by regression to the surface elevation trace (Tessier et al. 1989). The characteristics of the seed row furrows are defined as follows: W_i is the width of inter-row soil disturbance, H_i is the heaved soil height, W_s is the width of seed row depression, and

H_s is the height of the soil depression according to Tessier et al. (1989). The seed row roughness coefficient (R_s) is defined as the standard deviation of the relative elevation coordinates residuals with the regressed surface datum (Currence and Lovely 1970).

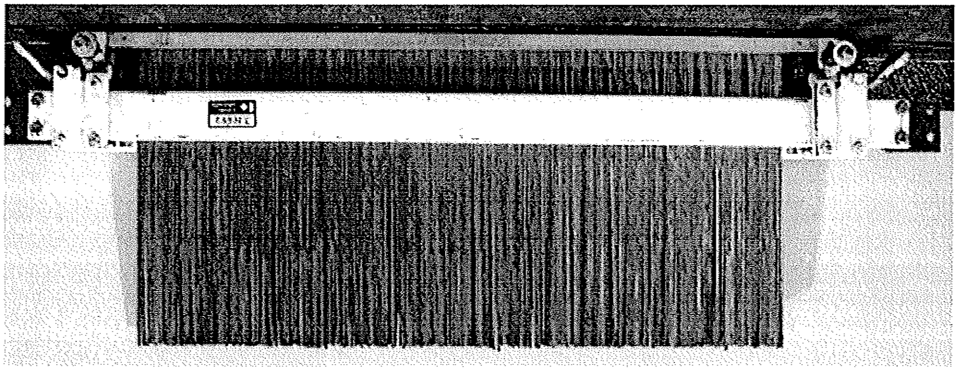


Fig. 5.2. Seed row roughness meter

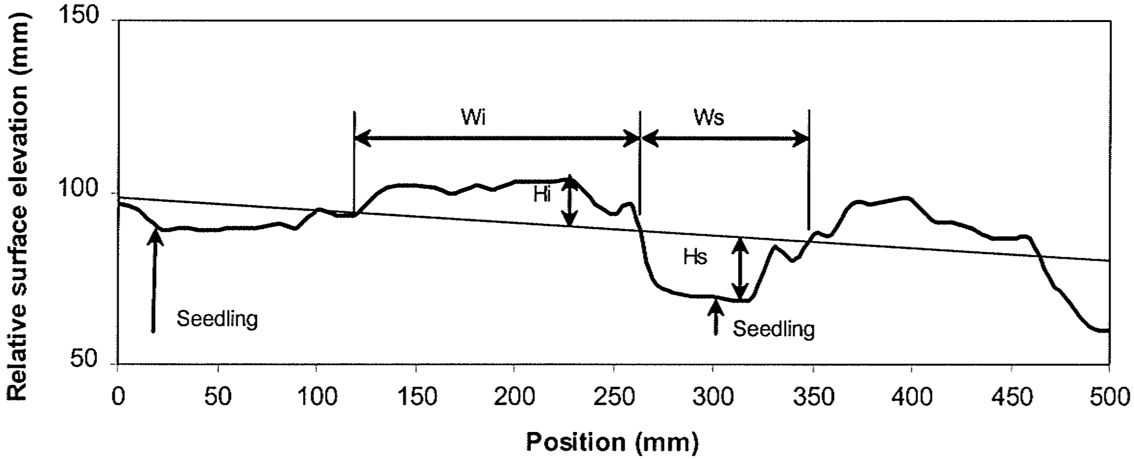


Fig. 5.3. Typical traced surface profile across a seed row scaled to Cartesian coordinates for the D opener

Non-contact profiler In 2002, an INO laser profiling system (2740, rue Einstein, Sainte-Foy, Quebec, G1P 4S4) (Fig. 5.4) with LPS Lib Version 1.0 software was used to capture the soil profile. The characteristics of the laser profiling system (LPS) are shown in Table 5.2.

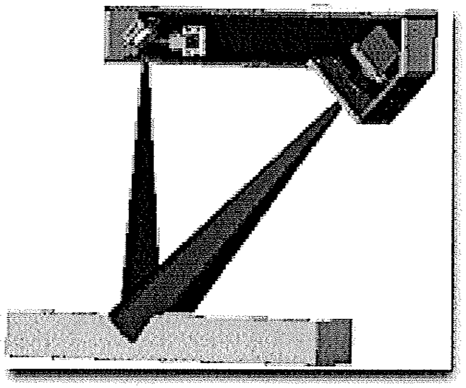


Fig. 5.4. INO Laser Profiling System (LPS)

Table 5.2. Characteristics of the LPS sensor (INO 2001)

Depth accuracy (z)	1 mm
Lateral resolution (x)	2 mm (at 1m)
Number of points/profile	640
Speed (profile/s)	5 - 10
Laser power (Max.)	5 W
Operating voltage	110 V
Power consumption (Max.)	500 W

The distance between the LPS and the soil surface was set at approximately 1 m, and the angle between the optical axes of the detector and the light source was 45°. The soil profile was traced by projecting a line of light perpendicular to the seed rows. The soil profile recorded as a data (dat) and bitmap (bmp) file with the LPS (Fig. 5.5) was converted into a spread sheet. The seed row characteristics of the furrow, regression line, standard deviation, and seed row roughness were determined in the same manner as with the contact profiler (Fig. 5.6).

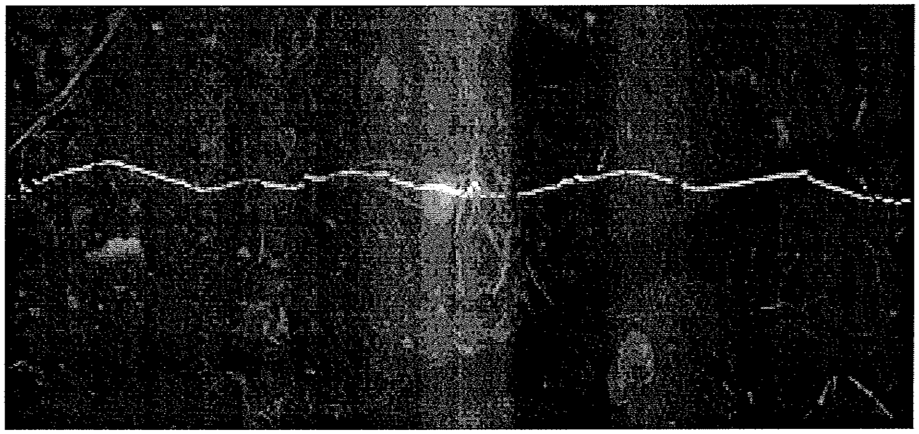


Fig. 5.5. **Typical soil surface profile across the seed rows measured with the LPS in bit map (bmp) format**

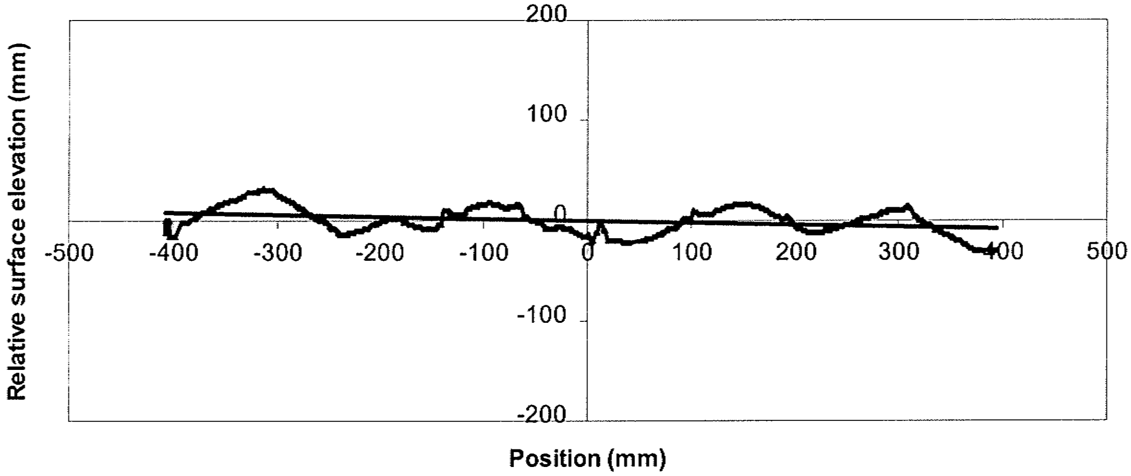


Fig. 5.6. **A typical soil surface profile from the data file converted into a spreadsheet and scaled to Cartesian coordinates**

Weed analysis Weed measurements were performed immediately prior to spraying. A quadrant was placed randomly on each plot. Digital images were taken of the plots with an Olympus camedia digital camera C-2000 Z in 2001 and a Kodak DC120 Zoom in 2002. The digital camera captured the image of a 1040 x 760 and 1040 x 840 mm quadrant used for the D and H opener, respectively. Different size quadrants were used since opener spacings were different. The camera was held perpendicular to the ground at a height of approximately 1 m. This allowed the entire quadrant to be fully enclosed in the photo. In both years, two images per plot were taken in the north and south sections of the canola plots. In 2002, to determine the biomass, weeds within the quadrant were removed. A second image was also taken directly after the weed removal to try a different weed analysis approach. The removed weeds were placed in separate mesh bags and transported to the laboratory for analysis. In the lab, samples were oven-dried at 60°C for 72 h (ASAE standards 1999b) and weighed to determine the biomass of the weeds per hectare (kg/ha).

Two methods of weed detection were implemented in this study: Inter-row method and Subtraction method. In the Inter-row method (Eq. 1), the weed cover was determined using the area between the crop rows and finding the percentage of greeness cover within that area (Fig. 5.7). The area of each inter-row within the quadrant was included in the analysis. According to Yang et al. (2000), weed coverage between rows (inter-row) in a given area adequately represents the probability of weed coverage within the rows. The Inter-row method was used in both years. In 2002, the Subtraction method (Eq. 2) was also used. With the Subtraction method, the percentage of green area of the second image (crop only) is subtracted from the percentage of green area of the first image (crop and weeds) to determine the weed cover percentage (Fig. 5.8).

The American Phytopathological Society (APS) 2002 Assess: Image Analysis Software for Plant Disease Quantification was used to perform the weed analysis. Each image was loaded into the program, calibrated, and the threshold panel was adjusted to acquire the correct green threshold. In thresholding, an object of interest is separated from its background by assigning a threshold pixel value to it. Not all images had the same threshold due to different lighting conditions when the photos were taken, thus making the "greenness" of each picture different.

(a) (b)

Fig. 5.7. Sample of weed cover determined by the Inter-row method using ASSESS; (a) area of inter-row (hi-lighted box) selected; (b) thresholding applied to area and percentage of greenness (weed) determined

$$W = \frac{\sum A_n}{A_{tot}} \times 100 \qquad (1)$$

Where W : weed cover percentage (%)
A_n : weed (greenness) area of the n^{th} inter-row
A_{tot} : total area

$$W = A_1 - A_2 \qquad (2)$$

Where W : weed cover percentage (%)
A_1 : surface area covered by crop and weeds (%)
A_2 : surface area covered by crop only (%)

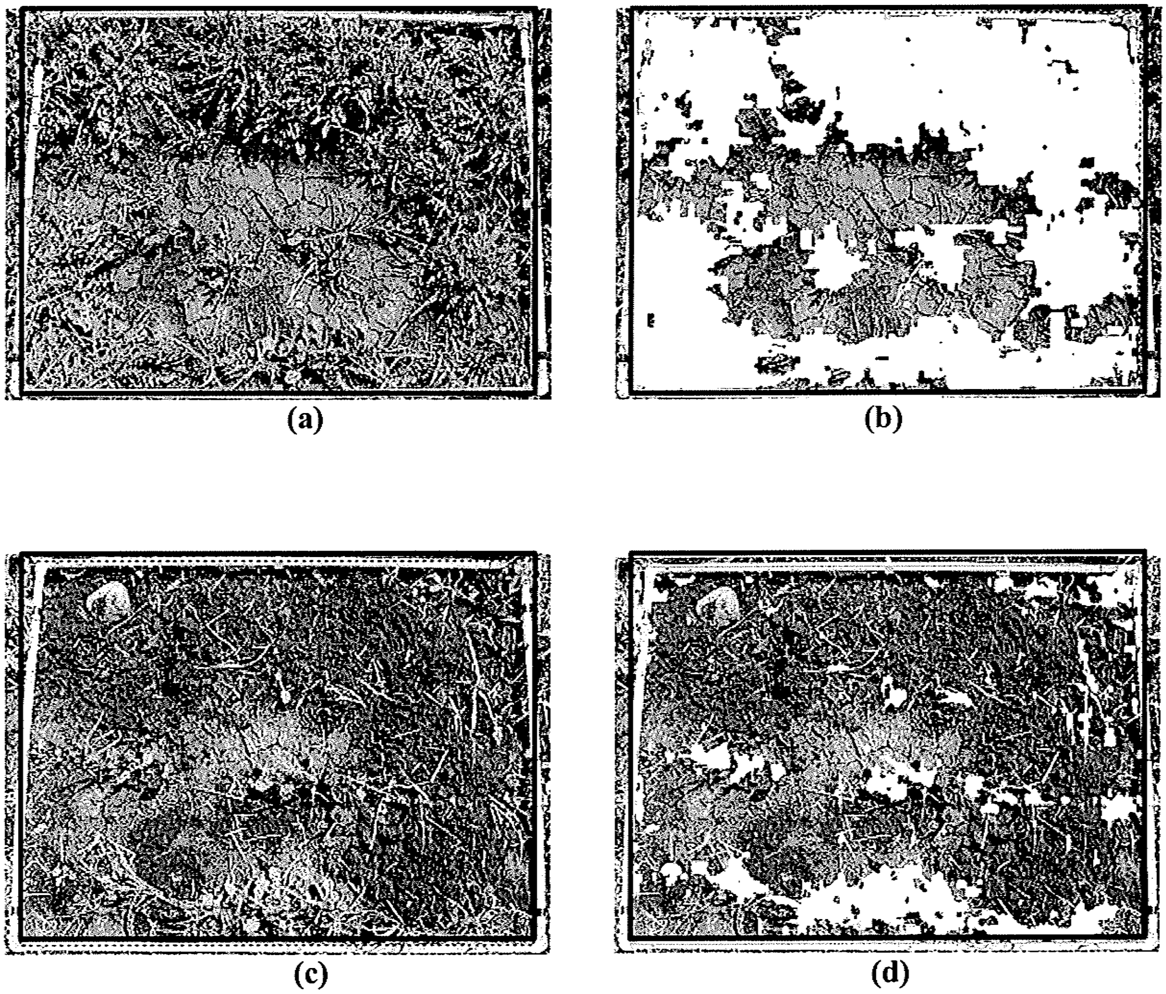

(a) (b) (c) (d)

Fig. 5.8. Sample of weed cover determined by the Subtraction method using ASSESS; (a) area of entire quadrant; (b) thresholding applied to crop and weeds; (c) removal of weeds from quadrant; (d) thresholding applied to crops

5.3.4 Data analysis

Analysis of variance (ANOVA) was performed on the field data. The GLM procedure was used to determine significant differences of treatments at a 0.1 significance level. Contrast statements were also used to compare the different treatments.

5.4 RESULTS AND DISCUSSION

5.4.1 Seed row roughness

Seed row roughness (R_s) depends on the type of opener and the seed row depression created by the press wheel action. Using the D opener, R_s was 20 and 3% lower in 2001 and 2002, respectively, when compared to the H opener (Table 5.3). A greater R_s is expected with the H opener because disc openers generally cause less soil disturbance than hoe openers because they create a narrower furrow (Janelle et al. 1993).

There was also no significant difference in the other characteristics of seed row (W_i, H_i, W_s, and H_s) between the D and H opener due to a strong variation in the data as indicated by the high standard deviations (Table 5.3). Nevertheless, some general trends were observed. The width of the seed row depression (W_s) was greater for the H opener in 2001 and 2002 than the D opener. The cutting width of the D opener is not as wide as that of the H opener, therefore, it would create a narrower furrow. The H_s is smaller with the D opener for both seasons because the D opener rolls and cuts through the soil, whereas the H opener pulls and cuts through the soil. Hence, the H opener has the potential to pull more soil, creating a deeper furrow and consequently a greater H_s.

The width of the inter-row heaved soil (W_i) was higher in 2001 and 2002 for the D opener when compared to the H opener. This was predicted since the D opener creates a smaller furrow width (W_s) than the H opener, which means a greater W_i. The heaved inter-row soil height (H_i) as expected, was lower with the D opener than the H opener for both years because D openers generally do not produce as much lateral soil disturbance as H openers.

Table 5.3. Seed row roughness and seed row characteristics of furrows

Opener	Seed row (mm)			Inter-row heaved soil (mm)				Seed row furrow (mm)			
	Spacing	R_s	SD	W_i	SD	H_i	SD	W_s	SD	H_s	SD
2001											
D	305	11.52 a*	11.52	166.94 a	52.07	13.94 a	6.14	114.50 a	30.42	18.56 a	8.76
H	229	13.80 a	13.80	119.30 a	48.68	17.63 a	9.86	118.81 a	22.24	19.56 a	8.30
2002											
D	305	20.22 a	5.00	177.20 a	73.30	37.40 a	14.88	116.87 a	22.53	30.13 a	8.03
H	229	20.74 a	5.04	141.00 a	40.89	39.27 a	12.07	122.47 a	58.24	34.00 a	20.38

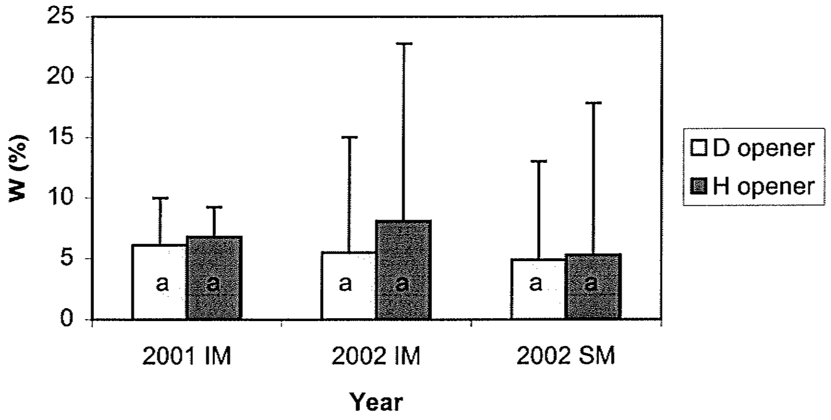
* Values with the same letters within each opener treatment are not significantly different at P<0.1 according to the GLM procedure of SAS.

Rs=seed row roughness; Wi=width of inter-row disturbance; Hi=height of heaved soil; Ws=width of seed row depression; and Hs=height of soil depression

5.4.2 Weed cover

It appears that a greater amount of weed growth is associated with a higher R_S. The plots seeded with the H opener resulted in more weed cover than the D opener for both years and both methods. In 2001 and 2002, using the Inter-row method, there was a 10 and 32% difference in the amount of weeds between the two openers, respectively. Implementing the Subtraction method (2002), showed an 8% difference in weed cover between openers. However, since the variability in the data was high, the standard deviation did not allow a statistically significance difference to be determined.

The biomass (not shown) was determined to be 15.9 kg/ha (SD=6.4) for the D opener and 20.8 kg/ha (SD=7.2)for the H opener. The biomass was approximately 31% higher for the H opener. There was no significant difference between the weed biomass when seeding with the two openers; again, due to the highly variable data.



Values with the same letters within are not significantly different at $P<0.1$ according to the GLM procedure of SAS.
IM=Inter-row method and SM=Subtraction method

Fig. 5.9. Weed cover (W) for the D and H opener for 2001 and 2002

The weed cover for the D and H opener are shown in figure 5.9. Differences in precipitation between seasons affected crop and weed establishment. In 2001, rainfall was sufficient to provide good crop germination and emergence, thus, crops flourished. Sufficient rainfall also increases weed growth. However, since the crops grew rapidly, they were able to produce a canopy over the weeds, which hindered weed growth by blocking the sunlight. In 2002, there was little rainfall, which resulted in poor crop growth and the emergence of volunteer canola (Table 5.1). Therefore, although the precipitation in 2001 favoured more crop/weed germination and growth, there is a lower weed percentage when compared with 2002 because in 2001, the competition of growth was won by the crops.

5.4.3 Comparison of weed analysis techniques

The assumption made by Yang et al. (2000) that weed cover between rows adequately represents the probability of weed cover within rows was presumed correct and the Inter-row method was implemented. The Inter-row method represents the weed cover within crop rows, it does not take into account crop effects, which may limit the growth of weeds. Therefore, the Inter-row method only determines the weed percentage without crop competition and would result in higher weed values than in reality. The Subtraction method subtracts the greenness percentage of the crops from the greenness percentage of the entire quadrant (crop and weeds). It takes into account weed growth over the entire field. It determines the weed cover within the crop row and the inter-row. The weed growth within crop rows should actually be lower than the inter-row because the crops give the weeds competition by consuming the nutrients necessary for growth, and limiting sunlight by producing a canopy over the weeds (if there is faster crop emergence). However, the Subtraction method does not consider the weeds that may be underneath the crop, therefore, may give weed values lower than in reality. Using the Inter-row method provided on average, a 25% higher weed percentage because the weeds within the crop row and inter-row are assumed equal. The actual weed cover should probably be an average of weed cover between the two methods. However, the Subtraction method more likely represents weed growth in typical field conditions.

In order to determine how closely related the two methods were to each other, a correlation was performed. The correlation coefficient was 0.74, which indicates an adequate positive association between the two methods. Considering the Subtraction method provides a better representation of weed growth in a field, the Inter-row method was compared against the Subtraction method. The correlation between the two methods is show in figure 5.10. The Inter-row method produced weed percentages close to the Subtraction method. Therefore, the Inter-row method and the Subtraction method may both be valid for determining weed cover, however, further research should be done to prove or disprove this assumption.

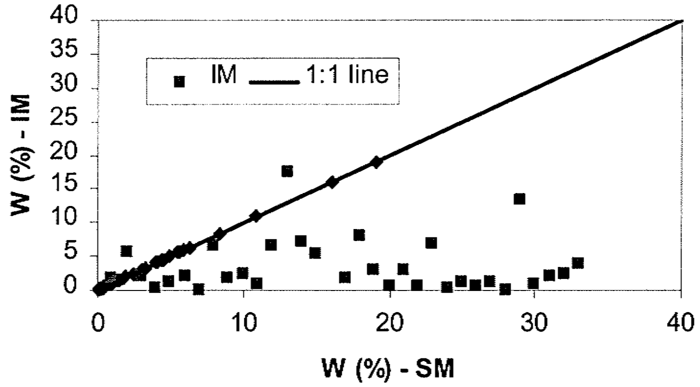


Fig. 5.10. Comparison of weed cover (%) between the Inter-row method (IM) and the Subtraction method (SM)

5.5 CONCLUSIONS

The seed row surface roughness and the weed cover of the disc opener have been compared with the hoe opener. The disc opener was shown to have a lower heaved soil height, width of seed row depression, and height of seed row depression, but a greater width of inter-row disturbance. These seed row characteristics of furrows led to the lower seed row roughness created by the disc opener when compared with the hoe opener.

The lower seed row roughness of the disc opener resulted in a lower weed percentage than the hoe opener. However, the correlation between the seed row roughness and weed cover was negatively low. Furthermore, there were no significant differences between the two openers due large variance in data, which led to high standard deviations.

The Inter-row and Subtraction methods resulted in different weed cover percentages. When statistically comparing the methods of analysis, the correlation (0.74) showed that both methods may produce similar results.

6. GENERAL SUMMARY

This project demonstrated the capability of the low disturbance hoe opener and double disc opener in various field conditions. In this two year study, the weather conditions were very different. 2001 was wet, whereas 2002 was dry, which led to different seeding conditions and crop performance.

In the Residue site, pea as a previous residue allowed canola to be seeded the most uniformly, emerge the quickest, and have the highest plant stand in 2001. In 2002, pea remained the dominant previous residue if volunteer canola was neglected in the plant counts. Between the three previous residues, wheat had the most amount of hairpinned residue in both years. Therefore, pea as a previous residue is optimal in no-till rotations.

The disc opener seeded deeper than the hoe opener and more uniformly in 2001, but not 2002. The seed placement outside the wheel track was slightly deeper than inside the wheel track for both types of openers, however, the difference was not significantly different. The disc opener was also shown to have a lower R_s as well as a lower weed cover percentage. However, the low negative correlation determined between R_s and weed cover percentage, indicates no strong linear association.

Two weed image analysis techniques were introduced and compared: the Inter-row and Subtraction method. The two methods resulted in different weed cover percentages, with the Inter-row method generating more weed cover. The Subtraction method was the optimal weed image analysis technique because it does not neglect crop competition that may reduce weed production.

The Oat-stubble study showed that the stubble height was a significant factor when seeding into adequate soil moisture. The tall stubble (400 mm) caused the most amount of residue to be hairpinned, with the cultivated and short stubble (150 mm) thereafter. Seed placement by the no-till seeders was the most uniform in the short stubble, followed by the tall stubble and cultivated plots. Therefore, evaluating the three different stubble levels, the most favourable stubble height was determined to be 150 mm for implementing no-till openers.

The hoe opener had a significantly better seed depth uniformity than the disc opener in 2001 and seeded pea and wheat more uniformly than canola. In 2002, there was no comparison between openers due to limited field space. Again, the seed placement outside the wheel track was slightly deeper than inside the wheel track for both types of openers, but not statistically significant.

7. RECOMMENDATIONS

Based on the research conducted in the field located 25 km north of Brandon, the following recommendations are suggested:

1. Results should be compared over seasons with like weather and seeding conditions. This would provide more conclusive data.
2. When determining the seed row surface roughness, the LPS method should have been implemented in both years in order to attain a better comparison. Using the manual seed row roughness meter was not as accurate as the LPS.
3. The Subtraction method should be used to analyze the amount of weed cover and the weed biomass should be calculated for consecutive years. Furthermore, SAS can be carried for the Subtraction method and weed biomass to see if there is an interaction between the two.
4. A stubble height of 150 mm is the best to seed into.
5. Use the hoe seeder if you want uniform crops.
6. Good no-till seeders will help farmer's accept no-till systems. Continuing to research and improve no-till seeders will aid in the acceptance of this environmentally friendly system.
7. Finally, choose a site location that is not 2.5 hours away. You will get more sleep and can keep a closer eye on your crops.

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