Effect of oat stubble height on the performance of no-till seeder openers

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Doan, V., Chen, Y. and Irvine, B. 2005. Effect of oat stubble height on the performance of no-till seeder openers. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada 47: 2.37 - 2.44. A two-year field study was conducted to investigate the seeding performance of two no-till seeders (disc and hoe openers), as influenced by stubble height (0, 150, and 400 mm) and tractor wheel track under three crops (canola, wheat, and pea). Seeding depth and the seed scattering index were measured for both openers, and the hairpinned residue was measured for the disc opener. The results showed that in the first year, seeds were placed significantly deeper in the soil with a 0 mm stubble height than that in the soil with 150 or 400 mm stubble heights for all the crops. This was also observed in the second year for the pea crop. The 150 mm stubble height resulted in a lower seed scattering index than the 0 and 400 mm stubble heights. Seeding outside the wheel track resulted in a greater seeding depth and more uniform seed placement than seeding inside the wheel track. The difference in seeding depth between the two openers varied with crop type. The vertical seed scatter index was significantly lower for all crops when seeding with the hoe opener. Another field study was conducted on seeding with the disc opener at five sites with different soil and residue conditions. The results show that the amount of hairpinned residue resulting from the disc opener was proportional to the amount of flat residue, and inversely proportional to the seedbed profile. Hairpinned residue was the major factor which increased the vertical seed scattering. Keywords: seeding depth, no-till, opener, stubble height, hairpinning, crop, wheel track.

INTRODUCTION

Flat and standing residues from the previous year are left in the field under no-till seeding management. Flat residue protects the soil surface from erosion by absorbing the impact energy of raindrops and reducing the soil particle detachment. Flat residue also reduces surface crust forming and sealing, which enhances water infiltration and crop emergence (Shelton et al. 1992). Standing residue increases available moisture by trapping snow in the stubble (SSCA 1994). Higher standing stubble has a higher potential of capturing more snow, which results in higher soil moisture content. Both stubble height and stubble density affect water evaporation (Nielsen 2003). Crop residue standing above the soil surface is five to ten times more effective in preventing wind erosion than the same mass of residue lying flat on the soil surface (Fox and Wagner 2001). Stacking residue also persists longer than flat residue that is in close contact with the soil (Tanaka 1986).

It is well recognised that residue conditions affect the seeding performance of no-till openers. Carter (1994) states that residues mechanically interfere with seeding operations. Green and Poisson (1999) point out that cereal stubble height should generally not exceed the seed row spacing, and taller stubble may cause plugging of seeding equipment. No-tillage seed openers must not only physically handle residues without blockage, but also must have the ability to micro-manage those residues close to the furrows to the benefit of the sown seeds and plants (Baker and Choudhary 1988). No-till openers must have the capacity of seeding a wide range of crops under various residue conditions with precision. Non-precise seed placement means uneven seed depth, which may lead to uneven crop emergence. Uneven crop emergence adversely affects crop performance because competition from larger, early-emerging plants decreases the yield from smaller, later-emerging plants (Thomison and Lentz 2002).

Another critical requirement for a no-till opener is low soil disturbance. Disc openers cause less soil disturbance than hoe openers because they create a narrower furrow (Janelle et al. 1993). Also, disc openers do not plug in taller stubble (Green...
Double disc openers have been included more in no-tillage opener designs than any other opener type (Baker et al. 1996). However, hoe openers are currently the most popular tools for no-till seeding in Western Canada (Chen et al. 2004c).

The limitations of disc openers are their capability of cutting through surface residues and penetrating hard soil to a specific depth (Payton et al. 1985). Insufficient downforce on disc openers may result in surface crop residue getting pushed into the furrow without being cut; this is known as hairpinning. Shallow seeding depths are more prone to hairpinning of residue than deep seeding depths (PAMI 1995). Hairpinned residue in dry soils interferes with seed-to-soil contact and in wet soils results in fatty acid fermentation that kills germinating seeds (Lynch 1977). Hoe openers do not cause residue hairpinning. Hoe openers create furrows by uplifting soil, which aids in seed covering and eliminates the need of press wheels for good seed-to-soil contact.

Soil cone index is an empirical measure of soil strength and widely used for assessment of compacting and loosening effects of agricultural implements (Bédard et al. 1997; Tessier et al. 1997). Soil cone index was also used to assess root growth and penetration (Gerard et al. 1982; Chen et al. 2004a). PAMI (1995) pointed out that soft moist soils are more prone to hairpinning of residue than hard soils. Effects of soil strength on the hairpinning of disc openers should be investigated.

Little research has been done to study how stubble height, soil, and residue conditions affect the seeding performance, such as seeding depth and residue hairpinning. As seeding performance indicates the yield potential, knowing the benefits and limitations of no-till openers in handling different residue statuses is useful to improve the crop yields and the design of the openers.

The objectives of this study were (1) to investigate seeding depths as influenced by stubble heights and field wheel tracks under two no-till openers and three different crops, and (2) to examine the correlations between soil strength, residue status, residue hairpinning, and seeding depth of a disc opener.

**MATERIAL and METHODS**

**Experiment 1**

**Site description**  Experiment 1 was carried out in 2001 and 2002 to investigate the effect of stubble height on the performance of two no-till seed openers seeding three different crops. The field location and the soil type were the same as those in Doan et al. (2005). No-tillage was considered the appropriate tillage system for the field since the soil contained large rock debris. The field had been in no-tillage since 1999, with barley and oats planted in 1999 and 2000, respectively. Fertiliser (urea and mono-ammonium phosphate) was applied at the recommended rate. Seeding was performed on June 8, 2001 and May 17, 2002. The seeders were operated at 5 km/h. Different field plots were used in the second year to obtain the same treatments.

**Experimental design**  A split-plot experiment was designed with the randomised main plots at three different oat-stubble heights: 0 mm (S0), 150 mm (S150), and 400 mm (S400) (Fig. 1). The sub-plots consisted of three different crops: canola, pea, and wheat. Due to the difficulties in actual field operations, the sub-plots were not randomised. In 2001, each crop was seeded with two seed openers: disc and hoe. These two seed openers were described in Doan et al. (2005). In 2002, only disc was used. Each treatment was replicated four times, forming a total of 72 plots.

All plots were harvested at a 400 mm stubble height in the previous fall, and the S0 and S150 plots were created by swathing in the spring so as to eliminate the impact of different stubble heights on snow trapping during the winter and thus on soil moisture. Residue on the S0 plots was removed. Seeding was performed perpendicular to the oat stubble rows. In 2001, hoe was pulled along the north edge of the plots with one pass (3.7 m wide) and the remainder of the plots was planted with disc (Fig. 1). Calibrations for seeding rate and seeding depth were described in Doan et al. (2005). Under each crop type, the same seeding rate and depth was set for both seeders and all three stubble height treatments.

**Measurements of residue cover and soil moisture content**  Before the seeding, standing, and flat residue were collected separately, as stubble height treatments alter the ratio of flat to standing stubble. As in Doan et al. (2005), a 1-m² quadrat was randomly placed on the surface of each plot at three random locations. The flat straw contained within the quadrat was collected first and placed into a paper bag, and the remaining standing straw was cut with clippers and placed into a separate
Table 1. Description of sites and field activities in Experiment 2 for year 2001.

<table>
<thead>
<tr>
<th>Site</th>
<th>Soil texture</th>
<th>Residue type</th>
<th>Crop type</th>
<th>Seeding date</th>
<th>Seeding rate (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MZTRF-site1</td>
<td>clay loam</td>
<td>wheat</td>
<td>canola</td>
<td>May 29</td>
<td>6</td>
</tr>
<tr>
<td>MZTRF-site2</td>
<td>clay loam</td>
<td>flax</td>
<td>canola</td>
<td>May 29</td>
<td>6</td>
</tr>
<tr>
<td>Elm Creek</td>
<td>sandy loam</td>
<td>wheat</td>
<td>canola</td>
<td>June 4</td>
<td>6</td>
</tr>
<tr>
<td>Culross</td>
<td>clay</td>
<td>wheat</td>
<td>flax</td>
<td>June 4</td>
<td>50</td>
</tr>
<tr>
<td>Baldur</td>
<td>clay loam</td>
<td>barley</td>
<td>flax</td>
<td>June 6</td>
<td>50</td>
</tr>
</tbody>
</table>

Measurement of seeding depth
In each plot, seeding depth measurement was performed immediately following the seeding operation. All aforementioned measurements were performed at five different farms in Manitoba. The soil types ranged from sandy soil to clay, and the residue types included wheat, flax, and barley. Crop types included canola and flax, which were selected according to the farm’s rotation. At each site, the disc seeder was operated for five passes, forming five strip plots representing five replications on which field measurements were performed. Soil types, residue types, crop types, and field activities are listed in Table 1.

Measurement of hairpinned residue
As hairpinning is not a concern with hoe openers, measurements of hairpinning were performed only for the plots seeded with disc opener. Immediately following the passage of disc, hairpinning was evaluated by taking soil monoliths with a seed row sampler that was 25 mm wide, 51 mm deep, and 203 mm long (Chen et al. 2004b). The sampler was pushed down vertically into the soil was 25 mm wide, 51 mm deep, and 203 mm long (Chen et al. 2004b). The sampler was pushed down vertically into the soil and retrieved from the soil. The excess soil was shaved off. Three soil monoliths were collected along the centre of the seed row at three random locations of each plot seeded with disc.

In the laboratory, soil mineral particles within the monolith were washed away using a plant root-washer. The extracted material was placed in an envelope and oven-dried at 60°C for 72 h. The dilemma of using the washing method was that the extracted material included not only hairpinned residue, but also coarse fractions of organic matter that had existed before the seeding operation. To resolve this dilemma, Eq. 1 was used to isolate the hairpinned residue. The hairpinned residue is expressed as dry mass per meter length of furrow which is independent of seed opener spacing.

\[ H_p = \frac{M - M_o}{L} \]  

where:

- \( H_p \) = hairpinned residue (g/m),
- \( M \) = mass of extracted material from the sample taken along a seed row (g),
- \( M_o \) = mass of extracted material from the sample taken between seed rows (g), and
- \( L \) = length of sampler (m).

Measurement of seeding depth
In each plot, seeding depth was measured at six random locations, three inside the wheel track and three outside the wheel track. At each location, five random plants were used for this measurement. The seeding depth of wheat was measured using the chlorophyll-free stem and the coleoptile’s length, and that of canola was measured using canary seed as described in Doan et al. (2005). For the measurement of pea, a mark was made on the plant at ground level; the plant was removed from the ground and the entire stem length below the mark was taken as the effective seeding depth of Pea (Chen et al. 2004b).

Experiment 2
Field trials
Experiment 2 was conducted in 2001 to investigate hairpinning and seeding depth of disc opener under different soil and residue conditions. Seeding with the disc seeder was performed at five different farms in Manitoba. The soil types ranged from sandy soil to clay, and the residue types included wheat, flax, and barley. Crop types included canola and flax, which were selected according to the farm’s rotation. At each site, the disc seeder was operated for five passes, forming five strip plots representing five replications on which field measurements were performed. Soil types, residue types, crop types, and field activities are listed in Table 1.

Measurement
Soil strength was assessed using the soil cone index which was measured at a depth of 100 mm. Residue cover was assessed by both standing and flat residues since flat residue is more prone to hairpinning than standing residue. These measurements were performed shortly before the seeding using the same procedures as described in Doan et al. (2005). Again, the seeding depth of canola was measured using canary seed as in Doan et al. (2005). The seeding depth of flax was assessed by measuring the distance between the original soil surface and the fertiliser granular which was placed with the seeds. The reason for using the fertiliser as a reference was that fertiliser could be more easily found in soil than flax seeds. It was assumed that the error caused by using the fertiliser placement as the flax seed placement was negligible. This seeding depth measurement was performed immediately following the seeding operation. All aforementioned measurements were performed at six random locations in each plot. The same data analysis as Doan et al. (2005) was performed.

RESULTS and DISCUSSION
Experiment 1
Residue cover
In both years, S0 had the least flat residue and no standing residue (Table 2) as the plots were swathed right above the ground, and the residue was removed. S150 had more flat residue and less standing residue than S400. This was expected because at harvest, less straw was cut off the top of the plant in the S400 plots than in the S150 plots, to obtain the taller standing stubble. The level of total residue cover obtained for S150 and S400 should have been similar, as it was in 2002. However, this was not the case in 2001, the reason remaining unknown, as both years were managed in the same manner.

Soil moisture content
The soil moisture content at both 0-50 and 50-100 mm in depth was highest in S400, followed by S150.
Table 2. Crop residue cover measured before seeding trials in Experiment 1.

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment*</th>
<th>Residue cover (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flat</td>
<td>Standing</td>
</tr>
<tr>
<td>2001</td>
<td>S0</td>
<td>690</td>
</tr>
<tr>
<td></td>
<td>S150</td>
<td>3456</td>
</tr>
<tr>
<td></td>
<td>S400</td>
<td>1786</td>
</tr>
<tr>
<td>2001</td>
<td>S0</td>
<td>765</td>
</tr>
<tr>
<td></td>
<td>S150</td>
<td>3392</td>
</tr>
<tr>
<td></td>
<td>S400</td>
<td>2834</td>
</tr>
</tbody>
</table>

* S0, S150, and S400 refer to stubble heights of 0, 150, and 400 mm, respectively.

Hairpinned residue of disc opener

The amount of hairpinned residue obtained was statistically significantly different between the different stubble height treatments (Fig. 3). When compared to S0 and S150, S400 had a much higher value of hairpinned residue. This difference may be due to the fact that wind and field machines could have flattened the standing residue down in the S400 plots, thus generating more flat stubble for openers to cut through. The fact that the row spacing (300 mm) of the disc seeder was less than the stubble height (400 mm) could also contribute to the high values of hairpinned residue in the S400 plots. In contrast, the shorter stubble in the S150 plots had less chance of being pushed down by wind and machines, and therefore being cut by the openers, because the opener spacing (300 mm) was greater than the stubble height (150 mm). This occurred despite the fact that there was a greater level of flat residue in the S150 plots. However, effects of length of the surface residues were not determined and may have a significant influence on hairpinning.

Effect of stubble height on seeding depth and seed scattering index

The effect of stubble height on the seeding depth interacted with the effect of crop type. Under each crop type, seeding depth altered significantly with the stubble height (Table 3). In 2001, the seeding depth of S0 was significantly higher than that of S150 and S400 for all crops. This was also observed in 2002 and S0 for both years (Fig. 2). This trend was possibly attributable to the taller standing stubble which trapped a layer of still air close to the soil surface and slowed down the evaporation of soil moisture (Baker et al. 1996; Cutforth and McConkey 1997). Statistical analysis was not performed on soil moisture data as the soil samples taken were pooled together for each treatment before the determination of the soil moisture content.

Effect of stubble height on seed placement for different crops in Experiment 1.

Table 3. Stubble height effect on seed placement for different crops in Experiment 1.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Treatment*</th>
<th>Mean (mm) 2001</th>
<th>Seed scatter index (mm) 2001</th>
<th>Mean (mm) 2002</th>
<th>Seed scatter index (mm) 2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canola</td>
<td>S0</td>
<td>50.1a**</td>
<td>7.8a</td>
<td>4.7a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S150</td>
<td>37.2c</td>
<td>3.8b</td>
<td>3.0b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S400</td>
<td>47.0b</td>
<td>7.0a</td>
<td>4.5a</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>S0</td>
<td>30.0a</td>
<td>3.9a</td>
<td>5.4a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S150</td>
<td>27.0b</td>
<td>3.1a</td>
<td>5.4a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S400</td>
<td>26.3b</td>
<td>3.6a</td>
<td>4.9a</td>
<td></td>
</tr>
<tr>
<td>Pea</td>
<td>S0</td>
<td>43.4a</td>
<td>6.1ab</td>
<td>18.0a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S150</td>
<td>36.1b</td>
<td>5.6b</td>
<td>16.2a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S400</td>
<td>34.5b</td>
<td>6.9a</td>
<td>14.6a</td>
<td></td>
</tr>
</tbody>
</table>

* S0, S150, and S400 refer to stubble heights of 0, 150, and 400 mm, respectively.

**Values with the same letters within each crop treatment and year are not significantly different as P < 0.1 according to Duncan’s multiple range test.
Effect of opener type on seeding depth and seed scattering index

The general trend was that seeds were placed more uniformly outside the wheel track than inside the wheel track, as indicated by its lower seed scatter indices (Fig. 5c, 5d). Significant differences in seed scattering index were observed for wheat and pea in 2001 and for pea in 2002, while the other treatments had comparable seed scattering indices. It was also observed by Doan et al. (2005) that the wheel track had adverse effects on the uniformity of seed placement.

Experiment 2

Soil strength Values of cone index along the depth profile for all sites are shown in Fig. 6. According to the interpretation of Murdock et al. (1995), the compaction rating for all sites was little to none. However, a hardpan existed at the 60 mm depth at the Baldur site (Fig. 6e), according to the concept of the profile analysis method (Chen and Tessier 1997). The peak value of the cone indices, 1600 kPa, is close to the agronomical threshold of 1800 kPa (Letey 1995). Hence, this hardpan could be a potential limiting factor for plant root development, especially if the soil is drier, as soil strength increases with soil dryness (Francis et al. 1987). A compacted layer was also observed at a 40 mm depth at the MZTRF–Site 1, and at a 60 mm depth at the Culross site.

The soil cone index for the seedbed was taken as the average of the soil cone indices at the 0-20 and 20-40 mm depths, and they were used to assess the effect of soil cone index on residue hairpinning. The cone indices of the seedbed for the five sites are listed in Table 4.

Residue cover MZTRF–Site 1, Elm Creek, and Culross sites with wheat residue (Table 1) had higher residue cover (Table 4), as wheat is normally classified as a high residue-producing crop. All sites had more flat residue than standing residue. The Elm Creek site had extremely high total residue cover (7196 kg/ha), while the MZTRF – Site 2 represented the least total residue cover (2741 kg/ha) among the five sites.

Hairpinned residue Values of hairpinned residue varied among the sites (Table 4). MZTRF–Site 2 with flax residue had the lowest hairpinned residue (1.5 g/m), followed by the Baldur site with barley residue. Wheat residue was more prone to

Fig. 4. Seed placement for two seed openers under three different crops for Experiment 1 in 2001: (a) seeding depth; and (b) seed scattering index. Values with the same letters within each type of crop are not significantly different at \( P < 0.1 \) according to Duncan’s multiple range test.
hairpinning. Among the three sites with wheat residue, the Elm Creek site had the highest hairpinned residue (8.8 g/m), the MZTRF–Site the lowest (2.3 g/m), and the Culross site somewhere in between (4.7 g/m). These levels of hairpinned residue were within the range of hairpinned residue (1.1-12.8 g/m) reported by Chen et al. (2004b) for no-till seeding on wheat residue.

**Seeding depth and seed scattering index** Seeding depths for the Elm Creek and Baldur sites were slightly lower than those of the other three sites (Table 4). Values of seeding depth and seed scattering indices were generally low when compared to those obtained in Experiment 1. The high value of hairpinned residue and the low seeding depth at the Elm Creek site were attributable to its high flat residue cover and low seedbed cone index. As the result of high hairpinned residue, this site showed a high seed scattering index. These observations are further explained by the following discussion.

### Correlations between measured variables

The amount of hairpinned residue is inversely proportional to the seedbed cone index ($r = -0.79$) (Table 5). Low soil strength favours hairpinning. The amount of hairpinned residue is also proportional to the amount of flat residue ($r = 0.96$). The seeding depths of the disc opener were not affected by the seedbed cone index ($r = 0.04$). The seeding depths had weak relationships with the flat residue, standing residue, and hairpinned residue ($r = -0.49$, -0.48, and -0.56). The same was true for the soil cone index and the seed scattering index ($r = -0.66$). However, these results do not contradict the observation from Experiment 1 that residue interferes with seeding operation and results in reduced seeding depth, and that soft soil favours more uniform seed placement. Hairpinned residue enhance the seed scattering ($r = 0.93$), as observed in Experiment 1.

### CONCLUSIONS

The effect of the seed opener on seeding depth depends on the type of crop. When seeding canola, the disc opener had a 24% greater seeding depth than the hoe opener, whereas when seeding wheat and pea, the disc opener seeded approximately 20% shallower than the hoe opener. Overall, the hoe opener resulted in a better uniformity of seeding depth than the disc opener.

The existence of stubble interferes with the seed placement. Longer stubble height resulted in reduced seeding depth and reduced uniformity of seed placement. Surface residue also affects the extent of hairpinning of a disc opener. Seeding into soil with 400 mm stubble height with the disc seeder at a 300 mm row spacing resulted in much more hairpinned residue

### Table 4. Measured variables for all sites in Experiment 2 for 2001.

<table>
<thead>
<tr>
<th>Site</th>
<th>Seedbed cone index (kPa)</th>
<th>Residue cover (kg/ha)</th>
<th>Hairpinned residue (g/m)</th>
<th>Seeding depth (mm)</th>
<th>Seed scattering index (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MZTRF-site1</td>
<td>816.6</td>
<td>3803</td>
<td>1137</td>
<td>4940</td>
<td>2.3</td>
</tr>
<tr>
<td>MZTRF-site2</td>
<td>702.2</td>
<td>2270</td>
<td>471</td>
<td>2741</td>
<td>1.5</td>
</tr>
<tr>
<td>Elm Creek</td>
<td>285.6</td>
<td>6205</td>
<td>991</td>
<td>7196</td>
<td>8.8</td>
</tr>
<tr>
<td>Culross</td>
<td>212.1</td>
<td>4120</td>
<td>0</td>
<td>4120</td>
<td>4.7</td>
</tr>
<tr>
<td>Baldur</td>
<td>929.7</td>
<td>2852</td>
<td>958</td>
<td>3810</td>
<td>2.1</td>
</tr>
</tbody>
</table>
occurrence of hairpinning. Hairpinned residue could be the major factor which enhances seed scattering.

A greater seeding depth was observed outside the wheel track than inside the wheel track. Reducing wheel tracks before seeding operation will improve the uniformity of seeding depth.

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