Evaluation of furrow openers and packers for conservation tillage

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Evaluation of Furrow Openers for Conservation Tillage

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Abstract

Producers in the Canadian Prairies are increasingly adopting conservation tillage systems. A large part of the success of conservation tillage rests on the availability of equipment able to seed into standing stubble. In semiarid environments, wheat yields are often limited by poor stand establishment and low plant density. Consequently, furrow openers and packing systems that promote complete and rapid germination and emergence improve the odds of obtaining good yields. A series of field studies are being conducted at Swift Current to develop protocols for the evaluation of furrow openers and packing systems for reduced tillage systems. The testing protocol consisted of a number of measurements to evaluate the physical properties of the soil within the furrow (bulk density, aggregate size distribution, penetration resistance), estimators of the shape and conformation of the furrow (volume of soil disturbed by the opener, perimeter length, surface roughness, measurement of water status of the soil surrounding the seed (volumetric water content and evaporation rate) estimators of seedling emergence and speed of emergence, measurements of aboveground biomass accumulation by the plants up to the 3 leaf stage, and measurements of the depth of seeding and dispersion of seeds in the furrow area. This presentation will discuss the merits and limitations of the protocol based on the results of an exploratory test of a number of furrow opener-packer combinations.

Introduction

In the last few years, producers in the Canadian Prairies have become increasingly more interested in adopting conservation tillage practises. However, one of the main factors limiting the success of conservation tillage is the availability of seeding equipment capable of placing the seed into undisturbed soil through heavy crop residues (Erbach 1981).

In semiarid zones, poor stand establishment and low plant density often limits crop yields (Bouaziz and Bruckler 1989). Therefore any seeding implement that permits rapid and complete germination and emergence will increase the odds of obtaining good crop yields.

After seeding, germination (the resumption of active growth of the embryo) commences with imbibition when the seed takes sufficient water from the surrounding soil to initiate
its metabolic processes. The rate of water uptake by the seed depends on the difference of water potential between the seed and the soil, the extent of seed-soil contact, and the hydraulic conductivities of the soil and seed (Bewley and Black 1978). Of these factors, soil hydraulic conductivity and seed-soil contact are directly affected by the seeding operation. Studies have shown that germination (and emergence) of wheat is progressively delayed as the soil water potential is lowered from field capacity, but the percent of germination is not affected until a threshold potential is approached (Lindstrom et al. 1976). This threshold potential varies with plant species and for wheat it appears to be below -15 bars (Owen 1952). De Jong and Best (1979) determined that wheat emergence was similar in soils with textures ranging from heavy clay to sandy loam when the water potential and temperature of the soils was the same. They also found that the heat sum required for 50 % emergence did not change much for water potentials in the range of -1/3 to -10 bar, but increased linearly with seeding depth.

Temperature plays an important role in determining the rate of germination. In general germination and emergence is slower at lower temperatures (Lindstrom et al. 1976; De Jong and Best 1979), but the total emergence does not change.

In addition to the effects of temperature and moisture in germination and emergence, the bulk density, compaction and aggregate size distribution of the seed bed play an important role in determining seedling emergence. Corn emergence and yields decreased when the bulk density and penetration resistance of the seedbed increased (Phillips and Kirkham 1962). Regardless of soil strength, covering the seeds of wheat with soil improved germination by increasing seed-soil contact and reducing evaporative losses, but the percent emergence, rate of emergence, and coleoptile and total root length were severely reduced by increases in soil shear strength (Collis-George and Yoganathan 1985 a,b). Emergence and speed of emergence of cotton seedlings were reduced by moderate increases in penetration resistance of surface soil crusts (Bilbro and Wanjura 1982).

In addition to the direct effects of soil compaction, studies have shown a strong interaction between compaction and soil moisture. For example Johnson and Henry (1964) found that surface compaction reduced the rates of soil drying, especially in coarse-aggregate seedbeds, but reduced seedling emergence. Stout at el. (1961) showed that emergence of sugar beet in seedbeds with good soil moisture was best when minimal packing was used or when packing was done at the seed level and the seeds were covered with loose soil. However they found that when the seedbed moisture was limiting packing enhanced emergence only when there was adequate moisture in the layer below the seed.

The main objective of any tillage system is to create a seedbed that fosters complete and fast seedling emergence and stand establishment. However for most cereal crops only 60 to 85% of the seed emerges, indicating the need for improving seed bed conditions. Lindwall and Erback (1983) indicated that agricultural engineers and equipment manufacturers often complain that they have little criteria in which to base the development of planting equipment. Although most researchers and agronomists are able to recognize a good seedbed on a qualitative basis, they have difficulties quantifying an optimum seedbed.

The objective of this study is to design a protocol for the evaluation of furrow openers and packing devices for zero tillage seeding systems, and to evaluate the suitability of the different measurements used in the protocol to quantify the state of the seedbed prepared.
Materials and Methods

An experiment consisting of 10 different furrow opener-packer combinations was established on June 4th, 1993 on a Swinton Loam, brown chernozemic soil (Ayres et al. 1985) at Swift Current. Three treatments were placed with a single 100 meter long pass using a Swift Current zero till disc drill (figure 3) (Dyck and Tessier, 1986) and Swift Current zero till hoe drill (figure 4), and a Versatile Noble 2000 hoe drill (figure 5). Remaining combinations of seed opener and packers (figures 6-8) were mounted on a self propelled tool bar (figure 2) and treatments placed adjacent to the seed drill treatments.

Hard red spring wheat (cv 'Lancer') was seeded into wheat stubble from the previous crop year ranging in height from 20 to 25 cm at a rate of 67 kg/ha. Fertilizer N (as urea) was applied at recommended rates (Saskatchewan Advisory Council 1987-1990) based on levels of NO$_3$-N in the 0-60 cm depth from soil samples taken the previous fall. Prior to seeding 37 kg/ha of N was broadcast while 3.7 kg/ha of N was banded or placed with the seed. Fertilizer P (as monammonium phosphate) was applied at 17.1 kg/ha based on levels of P$_2$O$_5$ in the 0-15 cm depth range. Winter annual weeds were controlled with a late fall application of 2,4-D. Grassy and broad leaf weeds were controlled in-crop with a dicloflop-methyl/bromoxynil mixture.

The experimental area was divided into four replicates. Due to constraints in the design of the equipment no attempt was made to randomize treatments or sampling sites within the replicates. All previously tracked areas were avoided as sampling sites.

Measurements of seed furrow characteristics such as straw incorporation into the furrow, penetration resistance, volume of disturbed soil, surface roughness ($R_s$) (Currence et al. 1970), aggregate size distribution, and soil bulk density were monitored in each of the four replicates. Soil temperature, and soil water were monitored in one replicate only. Aggregate size distribution, soil bulk density, soil temperature, and soil water were measured between the seed furrows as well as in the seed furrow.

A furrow strength meter designed and constructed by engineers at the Swift Current research station was used to measure the penetration resistance and compaction of soil along the furrow and across the furrow using (Dyck et al., 1993) to a depth of 70 mm. Measurements were made within 3 to 5 days after seeding in conjunction with soil moisture and soil bulk density measurements. Energy requirements to push a metal probe to the mean depth of seeding were calculated and used as a measure of resistance to coleoptile elongation.

Air temperature was monitored along with soil temperatures from seeding through to harvest. Soil temperatures were measured every 10 minutes at 1 cm and 5 cm depths with an hourly average recorded using a 21-X data logger and multiplexer (Campbell Scientific, Inc., P.O. Box 551, Logan, UT 84321, USA). Constantan-copper thermocouples were positioned in the soil using a 10 cm length of 3/4 inch diameter white PVC pipe capped with a white rubber stopper then filled with polyurethane foam insulation and placed into a hole created by a hand soil coring unit.

Soil cores 47.5 mm in diameter and 70 mm in depth were obtained using a hydraulic

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$^1$ Mention of trademark names or products does not imply an endorsement of these products or companies by the authors or the agencies they represent.
quick mount soil core sampler (Tessier et al., 1990) immediately after seeding to
determine soil bulk density and aggregate size distribution and levels of plant residue
incorporated into the furrow.

Soil cores taken for soil aggregate analyses were air dried and processed through a
rotary sieve (Chepil et al., 1943) into the following size categories _<0.42, 0.42<_<0.83,
0.83<_<2.0, 2.0<_<6.4, 6.4<_<12.7, and 12.7<_<38 mm. To simplify comparisons of
aggregate size distribution between treatments a single geometric mean diameter (GMD)
and its standard deviation (STD GMD) was calculated assuming a log-normal distribution
of aggregates. The geometric mean diameter and its standard deviation are calculated from
the following equations.

\[
(1) \quad \text{GMD} = e^{\Sigma m_i \ln d_i}
\]

\[
(2) \quad \text{STD GMD} = e^{(\Sigma m_i (\ln d_i)^2 - (\Sigma m_i \ln d_i)^2)^{1/2}}
\]

Where  \( m_i = \) the mass fraction of a set range of aggregate sizes
\( d_i = \) the arithmetic mean diameter of an aggregate size range

Soil cores for straw in the furrow were taken five days after seeding with the quick
mount soil core sampler. Samples were air dried, crushed and sieved through a U.S. No.
18 standard sieve (1 mm diameter) with the remaining straw weighed.

A soil roughness meter (Tessier et al., 1989) was used to measure profiles across the
surface of the furrow and across the excavated furrow. The surface roughness coefficient
was determined by creating a linear regression line across each furrow through surface
data points obtained from profile measurements and calculating the standard deviation of
these surface data points from the regression. Cross sectional area of disturbed soil and
the lower furrow boundary perimeter (figure 1) were also calculated.

Evaporation losses were monitored on the furrow and between using micro lysimeters
consisting of 50.8 mm diameter aluminum tubes, 70 mm in length. After insertion into
the soil the tube was removed (soil intact) and the bottom capped. The lysimeters were
weighed daily for a period of 54 days after seeding. Constant moisture micro lysimeters
were wetted daily to a moisture level equal to field capacity (28-29 % vol) to measure
the constant rate phase of evaporation. The constant moisture lysimeters showed a very
strong correlation with measured class A-pan evaporation rates having coefficients of
correlation of between 0.85 and 0.90. It has been shown that the cumulative amounts of
evaporated moisture (U) within this first phase are related to the hydraulic conductivity
of the soil (Ritche, 1972). Variable moisture lysimeters were wetted to a point near field
saturation and allowed to dry down to near air dry conditions (12-13 % vol) before being
wetted to characterize the second phase of evaporation or falling evaporation rate phase.
Within the falling rate phase a soil coefficient (\( \alpha \)) could be determined from the following
equation

\[
(3) \quad E = \alpha * t^{1/2}
\]

Where  \( E = \) Cumulative evaporation (mm)
\( t = \) time (days)
This soil coefficient has been shown to be directly related to the unsaturated hydraulic conductivity (Black et al. 1969).

Soil moisture within the furrow was monitored using time domain reflectometry technology (TDR) to the 70 mm depth. Measurements were taken daily for 30 days after seeding, and approximately every 5 days until day 60 using a Trase System Model 6050X1 (Soil Moisture Corp, Santa Barbara, CA) and modified moisture probe and computer program (Selles et al., 1994). The soil coefficient α was also calculated from changes in soil moisture as measured by the TDR soil moisture probes.

Seed placement was measured with the aid of a modified meter stick placed adjacent to the furrow and anchored to the soil with two 15 cm spikes. A 10 cm measuring stick was mounted at right angles to the meter stick through a sliding bracket on a 3/4 inch diameter shaft allowing two dimensional measurements on a horizontal plane. Seed placement was measured indirectly by measuring the point of plant emergence on the surface assuming a vertical rise of the coleoptile from the seed. Depth of a seed was determined by excavating individual plants (coleoptile and seed remnant intact) and measuring the distance between the chlorophyll free stem and the seed remnant (Tessier et al., 1989).

Emergence was monitored along four 0.5 meter lengths of each treatment twice daily for a period of 20 days after seeding. The logistic function as described by (Schimpf et al., 1977)

\[ N = \frac{M}{1 + e^{-\left(\frac{a-bt}{b}\right)}} \]

Where

- \( N \) = is the number of seeds that have germinated by time 't'
- \( M \) = is the maximum number of germinated seeds
- \( b \) = is the germination rate as reflected by a proportion of unit increase per unit time
- \( a \) = a constant of integration.

was used to calculate the number of days required to reach 50% emergence (GT50) by solving for 't' when 'N' was equal to 0.5M. The resulting value of GT50 along with percent emergence for each treatment based on the maximum emergence count among all treatments within a given rep was used to evaluate the effect of an opener and packer combination on germination rates and crop establishment.

Above ground biomass yields were monitored from two 0.5 meter long rows taken in each treatment at the three leaf, five leaf, ligule of last leaf visible, antithesis, soft dough and mature stages of growth. Grain yields were also measured. Because seed furrow characteristics primarily effect emergence rates and the number of emerged plants, above ground biomass yields and grain yields are not discussed in this paper.

**Results and Discussion**

Because opener designs impact on the effectiveness of packing systems by establishing the width of the furrow, volume of disturbed soil, and degree of soil fractured tabulated results were separated by opener type as the primary identifier. Packer wheels were selected to compliment the furrow created by the opener.
Furrow Shape and Soil Properties

Table 1 summarizes the results of furrow shape measurements as well as soil aggregate, soil bulk density, and incorporated plant residue measurements.

Least square mean values of area with tillage depth as a covariate showed the SCOT disc had significantly less disturbed soil than the hoe openers or Dyck knife. These differences were also reflected in the least square mean values of furrow perimeter lengths.

Significant differences in surface roughness coefficients were observed between treatments. The Versatile Noble hoe had an average surface roughness coefficient of 16.1 compared to 8.2 for the Swift Current zero till hoe opener. The vertical banding operation with the Dyck knife resulted in a measured roughness value of 17.9 compared to an average roughness value with no banding and side banding of 12.2.

No significant differences in soil bulk density, geometric mean aggregate diameter, or incorporated plant residues were observed between treatments. The SCOT disc had generally higher levels of straw incorporation while, visually, the 3/8" disc packer appeared to compound the problem of residue incorporation by pushing straw deeper into the furrow.

Increasing cross sectional areas of disturbed soil were related to higher temperatures at the 1 cm \((r=0.22)\) and 5 cm \((r=-0.32)\) depths. Increasing surface roughness decreased soil temperatures at the 1 cm \((r=-0.35)\) and 5 cm \((r=-0.31)\) depth. Larger aggregates increased soil temperatures at the 1 cm depth \((r=0.22)\).

Soil moisture

Although there were no significant differences in seed furrow soil moisture between furrow treatments differences in the rates of moisture loss were observed. Soil coefficients are summarized for both constant moisture and variable moisture lysimeters as well as from TDR probes in table 2.

The soil coefficient \((\alpha)\) for variable moisture lysimeters was significantly affected by opener-packer treatments at the 5% level of significance. The three seed drills produced seed furrows with soil coefficients less than 4.5 mm/day\(^{1/2}\) while the individual mounted SCOT disc opener-packer combinations gave soil coefficients > 4.5 mm/day\(^{1/2}\). Single degree of freedom comparisons showed this difference to be significant indicating a higher continuity of pore space was created by the individual mounted SCOT disc opener-packer combinations. Soil coefficients measured from variable moisture lysimeters were inversely related to those calculated from TDR probes indicating water flow into the furrow from the soil volume beneath the sampled depth.

Correlation analyses showed increasing levels of surface roughness increased the soil coefficient for constant rate lysimeters \((r=0.53)\) and variable rate lysimeters \((r=0.16)\). Increasing soil aggregate size reduced the soil coefficient for constant moisture lysimeters \((r=-0.47)\) but increased the soil coefficient for variable rate lysimeters \((r=0.16)\).
Table 3 summarizes the results of seed location measurements, soil temperature at the depth of seeding, the rate of plant emergence and percent emergence, as well as the energy requirements to push a metal probe to the mean depth of seeding.

Seeding depths varied between 1.5 and 5 cm. Significant differences in the standard deviation of seed placement in the vertical direction were observed between treatments. The Dyck knife with side banding and to a lesser extent with vertical banding reduced the standard deviation of seed placement in the vertical direction as compared to no banding. This may be due to the seed being placed well behind the opener onto soft soil. There was very little difference in horizontal seed scatter between openers.

Energy requirements to push a metal probe to the mean depth of seeding were found to be significantly affected by opener and packer design. Not surprisingly energy measurements were found to be strongly correlated with the depth of seeding ($r=0.82$) and to a lesser extent, with soil bulk density ($r=0.17$). The 2" rubber 'v' wheel that resulted in a slight increase in soil bulk density also produced a consistently high energy measurement of 0.211 joules. No significant differences in furrow strength meter measurements between treatments were identified due to the variability in readings.

Significant differences in percent emergence were found between treatments, but no significant differences in the rate of emergence were detected. Based on percent emergence the treatments could be separated into two groups; those greater than or equal to 90% which included all three drills, and those between 70% and 80% which included knife, hoe and disc openers.

To measure the effects of seed furrow characteristics on the number of days to 50% emergence (GT50) and percentage of emerged plants a partial correlation analyses was run including plant growth measurements, soil bulk density and energy measurements, seed placement measurements, soil temperature and the geometric mean aggregate diameter. Higher energy requirements resulted in reduced emergence rates ($r=0.49$) but also resulted in a higher percentage of emerged plants ($r=0.44$). Similarly increasing levels of soil bulk density reduced emergence rates ($r=0.54$) but created a higher final plant count ($r=0.44$). A possible explanation for this is higher values of bulk density and probe energy requirements indicate a higher level of soil to seed contact which increased the number of germinated plants but at the same time reduced the emergence rate because of increased resistance to coleoptile elongation. This provides evidence that an opener packer system providing good soil to seed contact with a loose soil covering would likely improve both germination rates and the percentage of emerged plants.

Increasing quantities of plant residue in the furrow did not cause a delay in emergence, but reduced the number of emerged plants ($r=0.75$). Visual observations indicated that straw on surface of the furrow improved germination rates possibly due to increased levels of retain soil moisture. Residue amounts deeper in the seed furrow may have resulted in poor seed placement and poor soil to seed contact reducing final plant counts.

No effect of soil temperature on crop growth was observed because the experiment was established later in the growing season when soil temperatures were not limiting.

Increasing seed depths did not reduce emergence rates ($r=-0.35$) or final plant counts ($r=-0.62$). Increased levels of vertical seed dispersion were found to delay emergence
but increased the percentage of emerged plants \(r=0.79\). These relationships can be explained in part by the generally shallow seed depths and delayed germination of some seeds.

**Conclusions**

Limitations of the experimental layout from a statistical standpoint prevent us from establishing definitive differences between the effects of different seed furrow openers or packers. However, the evaluation of measurement techniques and broad assumptions on the tendencies of openers and packers to effect soil furrow characteristics and ultimately crop establishment can be made. This is the first year in a three-year project and the results are preliminary. Future experiments will help to clarify early findings.

Better soil sampling techniques for soil aggregate and bulk density measurements that do not obtain soil from beyond the furrow boundaries are required. Our results indicate that the movement of soil water into the seed furrow from lower depths must be monitored in conjunction with evaporative losses to fully understand the effects of openers and packers on soil moisture.

The SCOT disc had lower levels of disturbed soil but higher amounts of plant residue incorporated into the furrow than the hoe or Dyck knife openers. Changes to fertilizer placement using the Dyck Knife significantly affected levels of surface roughness and plant residues amounts incorporated into the furrow.

Increases in the cross-sectional area of disturbed soil, and reduction in surface roughness were linked with increased soil temperatures. Increases in surface roughness increased the soil coefficient indicating higher rates of moisture loss. Smaller aggregates increased the movement of soil moisture to the surface at higher soil moisture levels (constant moisture lysimeters) and slowed water movement to the surface when soil conditions were dryer (variable moisture lysimeters).

Low levels of plant residue in the furrow, increased soil compaction around the seed, and low relative estimates of the energy requirements of the coleoptile to reach the surface improved germination rates and increased the percentage of emerged plants. This indicates that opener and packer designs which avoid residue incorporation, adequately pack the soil around the seed to provide good soil to seed contact and at the same time create a loose covering of soil over the seed to allow a rise of the coleoptile with relative ease and prevent excessive evaporative moisture losses will lead to increased emergence rates and higher plant concentrations.
References


Table 1. Summary of cross sectional areas of disturbed soil, cross sectional perimeter of lower furrow boundary, surface roughness coefficient, geometric mean soil aggregate diameter, and soil bulk density as measured in the furrow, and plant residue amounts incorporated into the furrow.

<table>
<thead>
<tr>
<th></th>
<th>LSQM</th>
<th>LSQM</th>
<th>Surf</th>
<th>Pit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment Opener</td>
<td>Area (mm²)</td>
<td>Area (mm²)</td>
<td>Perim (mm)</td>
<td>Rough</td>
</tr>
<tr>
<td>SCOT Hoe DRW2</td>
<td>3740</td>
<td>4798</td>
<td>4236</td>
<td>8.1</td>
</tr>
<tr>
<td>Noble Hoe DRW3</td>
<td>5442</td>
<td>4164</td>
<td>3763</td>
<td>17.0</td>
</tr>
<tr>
<td>Noble Hoe 2”V-W</td>
<td>4599</td>
<td>3921</td>
<td>2983</td>
<td>15.2</td>
</tr>
<tr>
<td>Mean</td>
<td>4594</td>
<td>4294</td>
<td>3661</td>
<td>13.4</td>
</tr>
<tr>
<td>SCOT Disc DRW1</td>
<td>2598</td>
<td>3033</td>
<td>2505</td>
<td>11.2</td>
</tr>
<tr>
<td>SCOT Disc 3/8”D</td>
<td>2819</td>
<td>3520</td>
<td>2565</td>
<td>12.4</td>
</tr>
<tr>
<td>SCOT Disc 1”W</td>
<td>3970</td>
<td>3336</td>
<td>2973</td>
<td>14.9</td>
</tr>
<tr>
<td>SCOT Disc 3/8”D&amp;CH</td>
<td>2212</td>
<td>3582</td>
<td>2415</td>
<td>10.0</td>
</tr>
<tr>
<td>Mean</td>
<td>2900</td>
<td>3368</td>
<td>1615</td>
<td>12.1</td>
</tr>
<tr>
<td>DK (SB) 1”W&amp;CH</td>
<td>5136</td>
<td>4458</td>
<td>3375</td>
<td>11.0</td>
</tr>
<tr>
<td>DK (NB) CH</td>
<td>4210</td>
<td>4200</td>
<td>3519</td>
<td>13.4</td>
</tr>
<tr>
<td>DK (VB) 2”V-W</td>
<td>4921</td>
<td>3931</td>
<td>3224</td>
<td>17.9</td>
</tr>
<tr>
<td>Mean</td>
<td>4756</td>
<td>4196</td>
<td>3373</td>
<td>14.1</td>
</tr>
</tbody>
</table>

Area= cross sectional area of furrow  LSQM= least square mean
STD= Standard Deviation  GMD= geometric mean diameter
BD= soil bulk density  Pit Res= Plant residue incorporated in the furrow
Soil Temp= mean temperature to 3 leaf growth stage
Perim= cross sectional length of lower furrow boundary

Figure 1. Cross section of seed furrow showing area calculation and lower boundary perimeter.
Table 2. Table of soil coefficients (mm/day$^{1/2}$) as measured from variable moisture lysimeters, constant moisture lysimeters and TDR probes, both in the furrows and between the furrows.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Opener</th>
<th>Packer</th>
<th>Between Furrows</th>
<th>In Furrows</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lysimeters</td>
<td>TDR probes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Moist</td>
<td>Moist</td>
</tr>
<tr>
<td>Noble Hoe</td>
<td>DRW3</td>
<td>7.86</td>
<td>3.29</td>
<td>10.52</td>
</tr>
<tr>
<td>Noble Hoe</td>
<td>2&quot;V-W</td>
<td>8.19</td>
<td>4.65</td>
<td>9.40</td>
</tr>
<tr>
<td>SCOT Hoe</td>
<td>DRW2</td>
<td>-</td>
<td>2.66</td>
<td>7.43</td>
</tr>
<tr>
<td>SCOT Disc</td>
<td>DRW1</td>
<td>-</td>
<td>2.63</td>
<td>10.54</td>
</tr>
<tr>
<td>SCOT Disc</td>
<td>3/8&quot;D</td>
<td>8.19</td>
<td>4.65</td>
<td>9.27</td>
</tr>
<tr>
<td>SCOT Disc</td>
<td>1&quot;W</td>
<td>8.19</td>
<td>4.65</td>
<td>10.66</td>
</tr>
<tr>
<td>SCOT Disc</td>
<td>3/8&quot;D&amp;CH</td>
<td>8.10</td>
<td>4.32</td>
<td>7.92</td>
</tr>
<tr>
<td>DK (SB)</td>
<td>1&quot;W&amp;CH</td>
<td>8.19</td>
<td>4.65</td>
<td>10.69</td>
</tr>
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<td>DK (NB)</td>
<td>CH</td>
<td>8.19</td>
<td>4.65</td>
<td>10.45</td>
</tr>
<tr>
<td>DK (VB)</td>
<td>2&quot;V-W</td>
<td>8.10</td>
<td>2.86</td>
<td>9.77</td>
</tr>
</tbody>
</table>

SB= side banding (seed 1" above and 1" to the side of fertilizer)  
NB= no banding  
VB= vertical banding (seed 1" above the fertilizer)
Table 3. Mean depth of seeding, standard deviation of seeds in the vertical direction, standard deviation of seeds across the furrow, and energy requirements to push a 1.8 mm diameter metal probe to the mean depth of seeding.

<table>
<thead>
<tr>
<th>Treatment Opener</th>
<th>Packer</th>
<th>Emerged GT50 Plants (%)</th>
<th>Depth (cm)</th>
<th>STD Vert (cm)</th>
<th>STD Across (cm)</th>
<th>Soil Temp (°C)</th>
<th>Energy (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCOT Hoe DRW2</td>
<td>10.0</td>
<td>98.6 2.97 0.98 0.73</td>
<td>16.5</td>
<td>0.1013</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noble Hoe DRW3</td>
<td>11.8</td>
<td>91.2 5.07 1.17 0.87</td>
<td>15.9</td>
<td>0.2183</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noble Hoe 2&quot;V-W</td>
<td>11.3</td>
<td>73.0 3.23 0.86 0.88</td>
<td>16.5</td>
<td>0.2116</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCOT Disc DRW1</td>
<td>12.2</td>
<td>89.9 3.82 1.28 0.58</td>
<td>16.6</td>
<td>0.1442</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCOT Disc 3/8&quot;D</td>
<td>11.8</td>
<td>76.4 1.48 0.92 0.71</td>
<td>17.2</td>
<td>0.0260</td>
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<td>SCOT Disc 1&quot;W</td>
<td>9.9</td>
<td>75.0 2.27 1.00 0.55</td>
<td>16.8</td>
<td>0.0310</td>
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<tr>
<td>SCOT Disc 3/8&quot;D&amp;CH</td>
<td>11.2</td>
<td>69.6 2.39 0.83 0.98</td>
<td>17.4</td>
<td>0.2546</td>
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<tr>
<td>DK (SB) 1&quot;W&amp;CH</td>
<td>10.0</td>
<td>79.1 1.54 1.05 0.78</td>
<td>16.6</td>
<td>0.0124</td>
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<tr>
<td>DK (NB) CH</td>
<td>10.0</td>
<td>78.4 4.06 1.34 0.73</td>
<td>16.4</td>
<td>0.0672</td>
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<tr>
<td>DK (VB) 2&quot;V-W</td>
<td>10.3</td>
<td>71.6 1.54 0.81 0.95</td>
<td>16.9</td>
<td>0.2116</td>
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Emergence Rate = number of days to 50% emergence as calculated by equation 4
STD Vert = standard deviation of seeds in vertical direction
STD Across = standard deviation of seeds across the furrow
Soil Temp = mean soil temperature to 3 leaf stage at depth of seed
Energy = energy to push a metal probe to the mean depth of seeding
CH = chain
Specifications

- Overall dimensions - 8 1/2 ft wide x 11 ft long
- Opener tool bars - three - 3 x 3 x 72 inch bars 24 inches apart
- Packer tool bar - one - 3 x 3 x 72 inches
- Morris amazone seed and fertilizer attachments
- Power train - 60 H.P. 4 cyl. Deutz diesel, double Vickers variable volume hydrostatic piston pumps driving piston motors in planetary wheel hub reducers on the front wheels
- Steering - controlled independent front wheel speed and rear castor wheels.

Figure 2. Swift Current Self Propelled Tool Bar.
Note: Offset disc design and Morris Steel Press wheel 1 3/4 x 25 in. (DRW 1)

Figure 3. The Swift Current 0-Till (SCOT) Disc drill.

Note: Knife opener 1/2" wide Morris Steel press wheels 1 3/4 x 25 in capped with 1/2 x 1/2 in square steel rod (DRW 2).

Figure 4. Swift Current Zero-Till (SCOT) Hoe Drill.
Note: Hoe shank, and 4" x 22" V-shaped steel packer wheel (DRW 3).

Figure 5. Versatile Noble 2000 Hoe drill.

Figure 6. Dyck knife (DK) opener with banding boot and 1 x 12 in gage packer wheel.
Figure 7. Flat disc, 2 x 12 in. rubber V rubber, and 1 x 12 in. rubber packer wheels mounted on Dutch Industries spring loaded packer attachment.

Figure 8. Individual openers used for tool bar mounting: SCOT disc, Dyck knife (DK) Noble hoe.