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Evaluation of Furrow Openers and Packers for Conservation Tillage

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Abstract

Based on a series of exploratory field studies in 1993 at the Swift Current research station two additional field studies were conducted in 1994 to establish test protocols for the investigation and evaluation of seed furrows formed by direct seeding operations. Measurements of seed furrow physical properties such as soil temperature, soil bulk density, soil moisture, and penetration resistance were repeated. Changes to sampling procedures included a modified soil moisture probe and wave guide connector along with an increased number of soil moisture measurement sites and additional measurements from below the seed furrow. Manual sampling of soil from within the furrow boundaries for soil aggregate determination replaced mechanical core sampling. Furrow profile measurements were carried out on unpacked and packed seed furrows to evaluate the accuracy of lower furrow boundary excavation techniques. To improve the accuracy of correlations between seed furrow characteristics, speed of emergence, plant counts, and above ground biomass row sample lengths were increased from 0.5 meters to 1.0 meter. This paper discusses the ability of the protocol to quantify significant differences in seed furrow characteristics created by 16 opener and packer combinations and their correlation to crop growth.

Introduction

With the recent interest in conservation tillage practises producers from the Canadian prairies have begun to phase into their farming operations direct seeding operations. An initial lack of seeding equipment capable of placing seed into undisturbed soil through heavy crop residues (Erbach, 1981) has been responded to with recent developments and on going research into opener and packing systems that are promoted on the basis of improved seed and fertilizer placement, soil compaction, trash clearance abilities, and yields (Dyck and Tessier 1986). The criteria used by researchers and agronomists to evaluate the seedbed created has often in the past been based on a qualitative analyses where visual interpretation and experience are utilized. Lindwall and Erback (1983) indicated that agricultural engineers and equipment manufacturers often complain that the interpretations provide little criteria in which to base the development of planting equipment.

Much research has been done in the past to substantiate the interaction of seed furrow characteristics on one another and their effects on seed germination, emergence and plant growth; Owen 1952, Bewley and Black 1978, De Jong and Best 1979, Collis-George and Yonaganathan 1985 a,b, and Tessier et al. 1989 to name a few. The objective of this three year study begun in 1993 at Swift Current is to develop a protocol for the evaluation of furrow openers and packing devices for zero tillage seeding systems, by identifying measurements that effectively quantify differences in the seedbed and that impact on emergence and crop

establishment. A standardized system of measurements providing a quantitative basis for differentiating between seed furrows will provide engineers with the tools necessary to study the impact of opener and packer design changes on seed furrow characteristics.

The ultimate objective of any seed furrow evaluation is to identify seed furrow characteristics and ultimately seeding equipment which provides rapid and complete germination and emergence. Bouaziz and Bruckler in 1989 showed that in semiarid zones good stand establishment and plant density increased the odds of higher yields.

This paper discusses modifications to sampling procedures previously established in 1993 (Ulich et al. 1994), investigates new techniques and evaluates them on the basis of their ability to measure definitive differences between seed furrows and their effect on seed germination, emergence and plant growth.

Materials and Methods

Two field experiments were monitored in 1994 on a Swinton Loam, brown chernozemic soil (Ayres et al. 1985) at the Swift Current research station. The first field test was established on June 17th followed by a second test on August 3rd placed adjacent to the first site. Test 1 was monitored through to harvest, test 2 to the 5 leaf stage.

Both experiments were established as randomized complete block design with four replicates. Sixteen different seed furrows (treatments), 28 meters in length, were placed in each replicate using a factorial combination of four openers and four packer wheels mounted on a self propelled tool bar unit (Ulich et al. 1994). Openers and packer wheels were mounted on separate independently controlled tool bars.

The openers used were the Swift Current zero till disc (SCOT disc), Dyck knife, and Noble hoe (Figure 4). The fourth opener was the angle disc side banding opener (angle disc) designed by F.B. Dyck (Figure 1). The angle disc side banding opener places fertilizer with a single disk angled at 23° to the vertical and 7° to the direction of travel with minimal disturbance of the soil surface. The fertilizer is dropped through the tube near the rear of the disc to the bottom of the furrow. The seed is placed by a knife opener positioned about 25 cm behind the disc. This allows the first furrow to be backfilled and prevents seed from rolling down on top of the fertilizer. The knife cuts a small furrow for the seed in the shoulder of the first furrow placing the seed above and to the side of the fertilizer on undisturbed soil.

Opener and packer settings remained the same for both tests except that on test 2 depth was increased by 1 cm for the Dyck knife to ensure placement into moist soil. Packer wheels consisted of a 1 x 12 in. rubber "V" shaped wheel (lrbv), 2 x 12 in. rubber 'V' shaped wheel (2rubv), 2 x 12 in. flat rubber wheel (2rubv) and 2 x 21 in. steel 'V' shaped wheel (2stlv) (Figure 3). The 2rubf, 2rubv, and lrbv provided 90 lb of vertical load while the 2stlv applied 110 lb.

Hard red spring wheat (cv 'Lancer') was seeded at a rate of 67 kg/ha into wheat stubble from the previous crop year (stubble varied in height from 20 to 25 cm). Fertilizer N (as urea) was applied at recommended rates (Saskatchewan Advisory Council 1987-1990) based on levels of $\text{NO}_3\text{-N}$ in the 0-60 cm depth from soil samples taken the previous fall. Prior to seeding 55 kg/ha of N was broadcast. At seeding 3.7 kg/ha of N was banded (Dyck knife, Angle disc) or placed with the seed (Hoe, SCOT disc). Excavations revealed the angle disc placed fertilizer approximately 3.8 cm below and 2 cm to the side of the seed. The Dyck knife banded fertilizer approximately 3.2 cm directly below the seed. Fertilizer P (as monammonium phosphate) was

applied at 17.1 kg/ha based on levels of P_2O_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 equipment and procedures used to obtain measurements of seed furrow characteristics such as straw incorporation into the furrow, seed placement, penetration resistance, volume of disturbed soil, surface roughness (R_s) (Currence et al. 1970), lower furrow boundary perimeter, aggregate size distribution, soil bulk density, soil temperature, and soil water were the same as those used in 1993 (Ulrich et al.) with some exceptions that are documented in this paper.

Selected areas of each replicate were covered with 6 mil transparent polyethylene sheets laid on the ground and secured by wood planks held in place by metal stakes to protect the seed furrows from erosion caused by rainfall events for the first three weeks after seeding. These protected areas were used for aggregate soil sampling, hydraulic conductivity, furrow shape, and penetration resistance measurements. The covered areas were not utilized on experiment 2 because rainfall events at this time of year were fewer and less intense.

The soil aggregate sampling procedure was changed from using a soil core 47.5 mm in diameter and 70 mm in length to using a small trowel and manually collecting all disturbed soil from a 15 cm section of the seed furrow. In 1993 soil cores were found to bias aggregate size by sampling beyond the furrow boundaries for narrow seed furrows. For ease of presentation a single geometric mean aggregate diameter and its standard deviation (Ulrich et al. 1994) was calculated and used in this paper to summarize a range of aggregate sizes obtained from a single soil sample.

The only change to seed position measurements was to record a reference point (the centre line of the seed furrow and soil surface) to allow placement of seed relative to the seed furrow boundaries at a later date.

To more accurately measure the lower furrow boundary, profile measurements were conducted on unpacked seed furrows in addition to packed furrows. A 4 meter long section of each treatment was left unpacked on two replicates for this purpose. Seed was located during excavation and the centre line of the future plant row and soil surface was recorded along with the profile. Cross sectional profiles were converted into a series of coordinate points by scanning the profiles and merging the images with a second image of parallel lines. Intersection points were then saved, digitized and used in calculations of cross sectional area of disturbed soil, lower furrow boundary and surface roughness. This data is in the process of being analysed and is not reported in this paper.

In 1993, penetration resistance measurements taken across the furrow produced cross sectional contour graphs of soil compaction that were tremendously variable. In 1994 measurements were taken along the furrow with concurrent soil moisture measurements to the 70 mm depth. Penetration measurements were conducted approximately 10 days after seeding during the period of crop emergence.

In 1993, soil moisture measurements were taken using a Trase System Model 6050X1 (Soil Moisture Corp, Santa Barbara, CA), and modified moisture probe (Selles et al., 1994). The moisture measurement equipment was altered in 1994 by placing the 1/8 inch diameter stainless steel rods of the probe in a fibreglass resin mould and designing a new connector (Figure 5). The fibreglass mould allowed ease of construction and reduced the impact on moisture evaporation in its vicinity by reducing the area of the probe covering the soil surface and allowed the use of a semi-transparent resin which more closely resembled the colour of the

soil. The connector designed for ease of measurement utilized brass strips within a plexiglass block to complete the electrical connection between the coaxial cable of the moisture meter and stainless steel rods of the moisture probe. The number of moisture measurements was increased from one replicate in 1993 to two replicates in 1994. In addition to the 70 mm probes (measured daily both in and between the seed furrow), commercial two rod moisture probes were used to monitor soil water levels on a weekly basis beneath the furrow to depths of 15 cm, 30 cm and 45 cm to monitor soil moisture movement below the seed furrow.

Soil evaporation measurements were not carried out in 1994 as labour resources were used instead to measure infiltration rates. The results of these measurements are in the process of being evaluated and are not reported in this paper.

Row lengths used to monitor emergence were increased from 0.5 meters to 1 meter lengths with emergence counts twice daily for a period of 20 days after seeding. The logistic function as described by (Schimpf et al., 1977) was used to calculate the number of days required to reach 50% emergence (GT50) (Ulrich et al., 1994). The maximum slope of the logistic function was used to measure the rate of emergence (MGR), used as an indicator of evenness of emergence. Percent emergence was calculated using the maximum plant count among all treatments within a given rep.

The row lengths used to measure above ground biomass, and record plant counts were also increased from 0.5 m to a 1.0 m. While biomass and grain yields were monitored through to harvest only above ground biomass levels at the 3 leaf and 5 leaf stage are reported in this paper as seed furrow characteristics primarily effect emergence rates, number of emerged plants, and early crop growth.

Results and Discussion

The first of two field tests was placed on June 17th with soil moisture levels to the 7 cm depth averaging 16.6% by volume followed by two weeks with mean temperatures of 17.7°C and total precipitation of 26.6 mm. The second test was placed on August 3rd under drier soil moisture conditions of 12.8 % near the surface followed by higher mean temperatures of 19.3°C, and precipitation of only 8.8 mm. On test 1 soil moisture to a depth of 7 cm in the seed furrow averaged 24.4% vol up to the three leaf growth stage. Test 2 had an average volumetric soil moisture levels in the seed furrow of 16.9% to the three leaf stage.

Seed Furrow Characteristics

Soil moisture was important in determining seed furrow characteristics as evidenced by the results of test 1 and test 2.

The angle disc produced significantly lowered bulk densities than the other openers on test 1 and test 2. The 2rubv wheel produced higher soil bulk densities than other packer wheels on test 1 but was not found significant. Opener and packer combinations produced slightly higher soil bulk densities when seeding into moist soil than when seeding into drier soil (Table 1).

Soil aggregate size differences between treatments were identified based on calculations of the geometric mean diameter. The angle disc with its lifting action in general created the largest proportion of large aggregates when averaged across packers. On test 2 the angle disc produced significantly larger soil aggregates than either the hoe opener or SCOT disc opener. The SCOT disc was found to produce the highest GMD (3.62 cm) among openers when seeding into moist soil and the lowest GMD (1.35 cm) when seeding into dry soil.

Observations while seeding into moist soil indicated that soil adhered to the outside of the discs causing the soil to lift and fracture. Under drier conditions this lifting action was not observed, while at the same time penetration was restricted. The GMD was consistently lower across all treatments by an average of 1.16 cm when seeding into the drier soil of test 2.

Measurement of plant residues incorporated into the seed furrows from 4.75 cm diameter soil cores did not identify significant differences between treatments. This may be due in part because above ground residue levels were not distributed uniformly on the soil surface and that seed furrow treatments were placed parallel to the direction of combine travel. Higher levels of residue incorporation of the SCOT disc versus the hoe or Dyck knife in 1993 were not observed under similar moisture conditions of test 2 in 1994. On test 2 residues levels of the angle disc and SCOT disc dropped by an average of 45% compared to 33% for the Dyck knife and 21% for the hoe. Less incorporated plant residues on test 2 was due to a combination of lower residues on the surface and drier residues which broke more easily and were less likely to be forced into the firm soil surface.

The soil had on average more water at the surface at the establishment of test 1 (1.59 cm) than when test 2 was established (0.98 cm) (Table 2 and 3). When averaged for the first 21 days across packer treatments, the knife opener maintained more water on the furrow area than any other opener (Table 2 and 3) followed by the hoe opener. Although we did not detect significant differences among packer wheels, the lrubv wheel consistently maintained more water in the furrow area than any other packer (Table 2). On average furrows prepared with the lrubv packer had 0.13 cm and 0.06 cm more water than any other packer on test 1 and test 2, respectively.

Differences in penetration resistance among treatments observed on test 1 appear to be the result of differences in soil moisture levels within the seed furrow. On test 2 where the soil was drier, no effects of soil moisture on penetration resistance were observed. For analyses of soil compaction around the seed on test 1 we decided to use measurements from the polyethylene covered areas because erosion during rainfall events substantially changed the shape of the furrows. In addition covered areas had on average 5% less soil moisture content (v/v) with water more evenly distributed to a depth of 5 cm across all treatments.

With soil moisture as a covariate, the SCOT disc-lrubv(1.59 Mpa) and hoe-2rubv(1.53 Mpa) of test 1 had significantly higher penetration resistance around the seed than treatments of the Dyck knife(0.58 Mpa) or angle disc (0.95 Mpa) (Table 2). In general, the hoe opener tended to produce the most compacted furrows around the seed. Results of test 1 indicate that wide packers in combination with a narrow opener (SCOT disc) tended to produce low compaction around the seed (Table 2). However, the narrow lrubv in combination with the narrow opener produced the highest compaction measured. With the hoe opener, the 2rubv packer wheel produced higher compaction ($p < 0.10$) than any other opener. No significant differences were detected among packers with the angle disc or Dyck knife opener. However the angle disc showed significantly higher compaction than the Dyck knife opener. On test 2 the hoe-2rubv averaged 0.35 Mpa more than other treatments but was not found significant (Table 3). Least square means of resistance measurements to the 5 cm depth using soil moisture as a covariate on test 1 were highest for the hoe-2rubv (1.03 Mpa) followed by the SCOT disc- lrubv (0.88 Mpa), angle disc-2stlv (0.79 Mpa), and SCOT disc- lrubv (0.79 Mpa). All other treatments had significantly lower resistance measurements to the 5 cm depth.

Estimates of the energy requirements of the coleoptile to reach the soil surface were taken from the uncovered areas of both tests to reflect the true conditions under which emergence occurred. Analyses of results from test 1 showed significant differences among openers, and opener packer combinations with generally low levels for the Dyck knife(0.11 joules) and high levels for the hoe opener and 2" wide packer wheels(0.35 joules) and SCOT disc-lrubv (0.31

joules) (Table 2). No significant differences were observed among individual opener-packer combinations on test 2 (Table 3) indicating that opener packer combinations that were effective in increasing soil compaction under the moist soil conditions of test 1 may not have been as effective in drier soil moisture conditions. When seed depth was used as a covariate, least square mean values of energy requirements of the coleoptile to reach the soil surface were significantly higher for seed furrows created by the hoe opener when averaged across packer wheels on test 1, and significantly higher than the Dyck knife and angle disc on test 2.

Seed Placement, Germination and Plant Growth

Seed depths averaged 3.44 cm on test 1 and 3.32 cm on test 2 (Table 4 and 5). Combining the seed position measurements with furrow profile measurements, revealed the seeds were often placed below the lower furrow boundary. This along with visual evidence indicated that soil deposition into the seed furrow between the time of seeding and seed placement measurements had occurred. As a result of this it is difficult to substantiate any differences in mean seed depth or standard deviation of seed placement in the vertical direction that occurred between treatments immediately after the time of seeding. On test 2, where the seed furrows were less effected by erosion, we observed no significant differences in the standard deviation of seed depth or in mean seed depth among treatments. Partial correlation analyses of seed furrow physical characteristics resulted in a correlation of 0.27 between the geometric mean diameter and seed scatter in the horizontal direction on test 1 and 0.66 on test 2. Aggregate size within the seed furrow likely explains the slightly higher standard deviations across the seed furrows observed in test 1.

Quick, even, and complete plant emergence are required to increase the odds of obtaining higher crop yields. Correlation results from test 1 between , GT50 and PE ($r=-0.36$), MGR and PE ($r=0.11$) evidence that quick and even emergence lead to improved plant establishment. On test 2 germination of some treatments was hindered by a combination of dry soil conditions and shallow seed depths. Treatments with greater seed depths exhibited slower emergence than shallow seeded treatments but had greater germination and plant emergence. This resulted in delayed emergence being associated with an increase in the percentage of emerged plants (GT50 vs PE: $r=0.25$). Treatments with greater seed depths also displayed higher maximum germination rates linking higher MGR values with a higher percentage of emerged plants (MGR vs PE: $r=0.73$).

Significant differences in GT50 were observed among packer wheels when averaged across openers on test 1 (Table 4). The lrubv wheel which produced seed furrows that required only 0.36 more days to 50% emergence than the 2" wide packer wheels was found significant

10). The maximum slope of the logistic curve used as an indicator of evenness of emergence showed no significant differences between openers, packers, or opener-packer combinations. The angle disc and Dyck knife produced significantly higher percentages of emerged plants (91%) than either the hoe opener (84%) or SCOT disc (80%) in moist soil of test 1. The hoe opener however proved to be more consistent under different seeding conditions producing an average of 84% emergence on both test 1 and 2 while the SCOT disc, angle disc, and Dyck knife had crop establishment levels drop by 1%, 15%, and 20% on test 2.

Both tests exhibited positive correlations between PE and plant growth at the 3 leaf stage and 5 leaf stage (test 1: 3leaf($r=0.40$), 5leaf($r=0.64$), test 2: 3leaf($r=0.41$), 5leaf($r=0.40$)). Partial correlations of percent emergence with bulk density, aggregate size, incorporated plant residue, soil moisture and compaction, soil temperature, and seed position were conducted to determine the impact of seed furrow characteristics on crop establishment levels. From the correlations larger soil aggregates ($r=-0.43$), and higher bulk densities ($r=-0.97$) were linked with lower

percentages of emerged plants on test 1. Increased seed depths ($r=-0.84$), and increased seed scatter in the vertical direction ($r=-0.84$) and horizontal direction ($r=-0.50$) were also negatively correlated with percent emergence on test 1. Higher soil temperatures at the depth of seeding increased the percentage of emerged plants ($r=0.96$). Low levels of plant residues on the surface along with the possibility that incorporated residues may have provided channels for coleoptile emergence resulted in a positive correlation between plant residues incorporated into the furrow and PE ($r=0.94$). Higher penetration resistance measurements to the depth of seeding ($r=0.91$) appeared to be linked with improved crop establishment as was higher soil moisture levels within the seed furrow ($r=0.87$) on test 1. Of the seed furrow characteristics measured on test 2, larger soil aggregates ($r=-0.43$), estimates of energy requirements measured to the mean seed depth ($r=-0.57$) and soil moisture ($r=0.46$) adversely affected crop establishment. Because of dry soil conditions on test 2 and observations of very dry soil in the top portions of the furrow it is believed that measurements of the 7 cm probes were measuring soil moisture confined to the bottom of the seed furrow below the depth of seeding resulting in a negative correlation between soil moisture and PE.

Conclusion

The soil bulk density sampling procedure provided quick samples for future processing at a time when available labour resources and time were at a minimum. Differences between treatments and the similar trends observed on the two field tests indicate that the procedure is accurate and the results valuable. Soil sampling with the 4.75 cm diameter core can result in sampling beyond the furrow boundaries on narrow furrows as occurred in 1993. There was no evidence this happened in 1994.

The change to manual sampling for soil aggregates in 1994 had the advantages of simplicity, being fast, and more representative as sample size was larger and sampling did not extend beyond the furrow boundaries. Aggregate size measurement is essential to understanding soil moisture movement in the seed furrow, soil to seed contact, and seed scatter within the seed furrow.

Neither openers nor packers significantly affected the levels of residue incorporation in 1994. The uneven distribution of residues on the soil surface prevented us from making an accurate determination of treatment effects. Ensuring consistent levels of above ground plant residue is essential when comparing opener and packer effects on residue incorporation. It is also recommended that a larger sample for incorporated residue determination be obtained. This can be done manually if samples are obtained from a set row length. The disadvantage of a larger sample is increased processing time to separate residues from soil.

Discrepancies between lower seed furrow boundaries and seed position measurements gave evidence that seed depth measurements based on the chlorophyll free length of the coleoptile are the combined measurement of original seed depth and soil deposition into the seed furrow. The depth of these deposits will vary between locations but small stakes placed in the seed furrow immediately after seeding would provide a measure of soil deposition occurring between seeding and the time of seed position measurements.

The correlations between GT50, MGR, and PE and the link of PE with crop growth would indicate that the measurement procedures used to obtain them are valuable tools in understanding the effects of seed furrow characteristics on germination and ultimately on crop establishment.

Measurements of penetration resistance were useful in determining differences in soil compaction levels around the seed and estimating energy requirements of the coleoptile to reach

the soil surface. A study of soil compaction within the seed furrow requires more detailed soil moisture measurements obtained from additional incremental measurements to the depth of tillage within the seed furrow. An alternative is to sample in covered areas protected from precipitation and where drier soil moisture levels exist across all seed furrows. Measurements used to estimate the relative energy requirements of the coleoptile to reach the soil surface should be conducted on uncovered areas to better reflect the conditions under which emergence is occurring.

Seed furrow characteristics such as larger soil aggregates in the seed furrow, lower soil moisture levels and soil temperatures reduced levels of crop establishment. Higher soil bulk densities in the furrow were linked with lower percentages of emerged plants when seeding occurred in soil with a volumetric soil moisture content of 16.6% to 7 cm but not at 12.8%. Estimates of energy requirements of the coleoptile to reach the soil surface were generally higher in dry soil than moist soil. Higher energy requirements on dry soil (13.9% vol to 7 cm) were linked with poor crop establishment but improved crop establishment in higher volumetric soil moisture levels of 21.5% vol.

The Dyck knife and angle disc provided seed furrow characteristics and seed depths that generally produced higher percentages of emerged plants under moist soil conditions. The hoe opener on the other hand provided more consistent levels of crop establishment under both dry and moist soil conditions. Packer wheels had a significant impact on the percentage of emerged plants only in combination with particular openers with the greatest variation in crop establishment levels between individual opener-packer combinations occurring in drier soil moisture conditions.

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Table 1. Physical seed furrow characteristics as measured on test 1 and test 2, 1994. Significant differences ($p < 0.10$) are identified between openers, packers, and opener-packer combinations by different letters.

TEST 1	Dyck Knife	Angle Disc	Hoe	SCOT Disc	Mean
GMD (mm)	2.87	3.48	3.12	3.62	3.27
Bulk density (gm/cm ³)	1.22 c	1.14 a	1.21 bc	1.18 b	1.19
Plant residue incorp. (gms/5cm row length)	0.69	0.78	0.52	0.68	0.67
TEST 2					
GMD (mm)	2.19 bc	2.50 c	1.83 ab	1.35 a	1.96
Bulk density (gm/cm ³)	1.16 b	1.08 a	1.18 b	1.16 b	1.15
Plant residue incorp. (gms/5cm row length)	0.46	0.45	0.41	0.36	0.42

GMD- Geometric mean aggregate diameter

Table 2. Average soil water levels (cm) and penetration resistance measurements from within the seed furrows of test 1, 1994. Significant differences ($p < 0.10$) are identified between openers, packers, and opener-packer combinations by different letters.

Packer	Dyck Knife	Angle Disc	Hoe	SCOT Disc	Mean
Average cm of soil water to 7 cm depth in the furrow to day 21 after seeding.					
All	1.70 b	1.49 a	1.59 ab	1.56 a	1.59
Energy to push probe to depth of seed (Joules)--No cover					
2RUBV	0.17 bcde	0.11 abc	0.38 h	0.19 bcdef	0.19
2RUBF	0.13 abcd	0.21 cdef	0.27 fg	0.22 defg	0.19
2STLV	0.10 ab	0.15 bcde	0.40 h	0.24 efg	0.21
1RUBV	0.05 a	0.19bcdef	0.19 bcdef	0.31 gh	0.19
Mean	0.11 a	0.16 b	0.31 d	0.24 c	0.21

Least square mean values of soil compaction 1 cm below and 1 cm above mean seed depth(MPA) (soil moisture used as covariate)--polyethylene cover

2RUBV	0.61 abc	0.87 bcdef	1.53 g	0.84 abcdef	0.96
2RUBF	0.69 abcd	1.01 cde	1.24 fg	0.83 abcde	0.94
2sTLv	0.59 ab	1.00 cde	1.10 ef	0.83 abcde	0.88
1RUBV	0.45 a	0.93 bcde	1.03 def	1.59 g	1.00
Mean	0.58 a	0.95 b	1.22 c	1.02 b	0.94

Least square mean values of energy(J) to push probe to 5 cm depth (soil moisture used as covariate)--polyethylene cover

2RUBV	0.42 a	0.59 abc	1.03 d	0.63 abc	0.67
2RUBF	0.70 abc	0.67 abc	0.70 abc	0.56 ab	0.66
2sTLv	0.65 abc	0.79 bcd	0.55 ab	0.62 abc	0.65
1RUBV	0.48 a	0.79 bcd	0.59 abc	0.88 cd	0.69
Mean	0.56	0.71	0.72	0.67	0.67

Table 3. Average soil water levels (cm) and penetration resistance measurements from within the seed furrows of test 2, 1994. Significant differences ($p < 0.10$) are identified between openers, packers, and opener-packer combinations by different letters.

Dyck Knife	Angle Disc	Hoe	SCOT Disc	Mean
Average cm of soil water to 7 cm depth in the furrow to day 21 after seeding.				
1.09 b	0.89 a	0.98 a	0.94 a	0.98
Energy to push probe to depth of seed (Joules)--No cover				
0.13 a	0.16 a	0.22 b	0.18 ab	0.17
Least square mean values of soil compaction 1 cm below and 1 cm above mean seed depth(MPA) (soil moisture used as covariate)--No cover				
0.84	1.03	1.19	1.03	1.02
Least square mean values of energy(J) to push probe to 5 cm depth (soil moisture used as covariate)-- No cover				
0.70	0.78	0.81	0.82	0.78

Table 4. Seed placement, plant emergence (GT50, MGR), and crop establishment (PE) from test 1, 1994. Significant differences ($p < 0.10$) are identified between openers, packers, and opener-packer combinations by different letters.

Packer	Dyck Knife	Angle Disc	Hoe	SCOT Disc	Mean
Standard deviation of seed across the furrow (cm)					
All	0.87	0.98	0.90	0.83	0.89
Standard deviation of seed in vertical direction (cm)					
2RUBV	0.94 cde	0.75 abcd	0.45 a	0.51 ab	0.66
2RUBF	0.68 abcd	0.60 ab	0.83 bcd	0.64 abcd	0.69
2sTLv	0.60 ab	0.55 ab	0.79 bcb	1.00 de	0.74
1RUBV	0.81 bcb	0.72 abcd	0.71 abcd	1.21 e	0.86
Mean	0.66	0.69	0.76	0.84	0.74
Mean depth of seed (cm)					
2RUBV	3.20 bc	3.63 bcde	3.42 bcd	2.98 ab	3.31
2RUBF	2.43 a	3.57 bcd	4.02 de	3.84 cde	3.46
2sTLv	2.26 a	3.10 bc	4.72 f	3.82 cde	3.48
1RUBV	2.50 a	3.60 bcde	3.58 bcde	4.39 e	3.52
Mean	2.60 a	3.47 b	3.94 c	3.76 bc	3.44
Number of days to 50% emergence (GT50)					
2RUBV	6.98	7.15	7.26	6.97	7.09 a
2RUBF	6.51	7.27	7.48	7.56	7.21 a
2sTLv	7.09	7.40	7.45	6.99	7.23 a
1RUBV	7.71	7.38	7.87	7.28	7.56 b
Mean	7.07	7.30	7.51	7.20	7.27
Maximum slope(germination rate) of logistic curve(MGR)					
Mean	10.7	10.5	10.4	10.2	10.45
Percentage of emerged plants					
Mean	90.0 c	91.9 c	84.4 b	80.4 a	86.7

Table 5. Seed placement, plant emergence (GT50, MGR), and crop establishment(PE) from test 2, 1994. Significant differences ($p < 0.05$) are identified between openers, packers, and opener-packer combinations by different letters.

Dyck Knife	Angle Disc	Hoe	SCOT Disc	Mean
Standard deviation of seed across the furrow (cm)				
0.84 b	0.99 c	0.71 ab	0.68 a	0.81
Standard deviation of seed in vertical direction (cm)				
0.84	0.77	0.70	0.75	0.77
Mean depth of seed (cm)				
3.05 a	3.49 b	3.52 b	3.22 ab	3.32
Number of days to 50% emergence (GT50)				
8.27	7.99	7.48	8.91	8.16
Maximum slope(germination rate) of logistic curve(MGR)				
3.2	4.8	6.6	4.9	4.9
Percentage of emerged plants				
70.1 a	76.7 ab	84.6 b	69.2 a	75.2

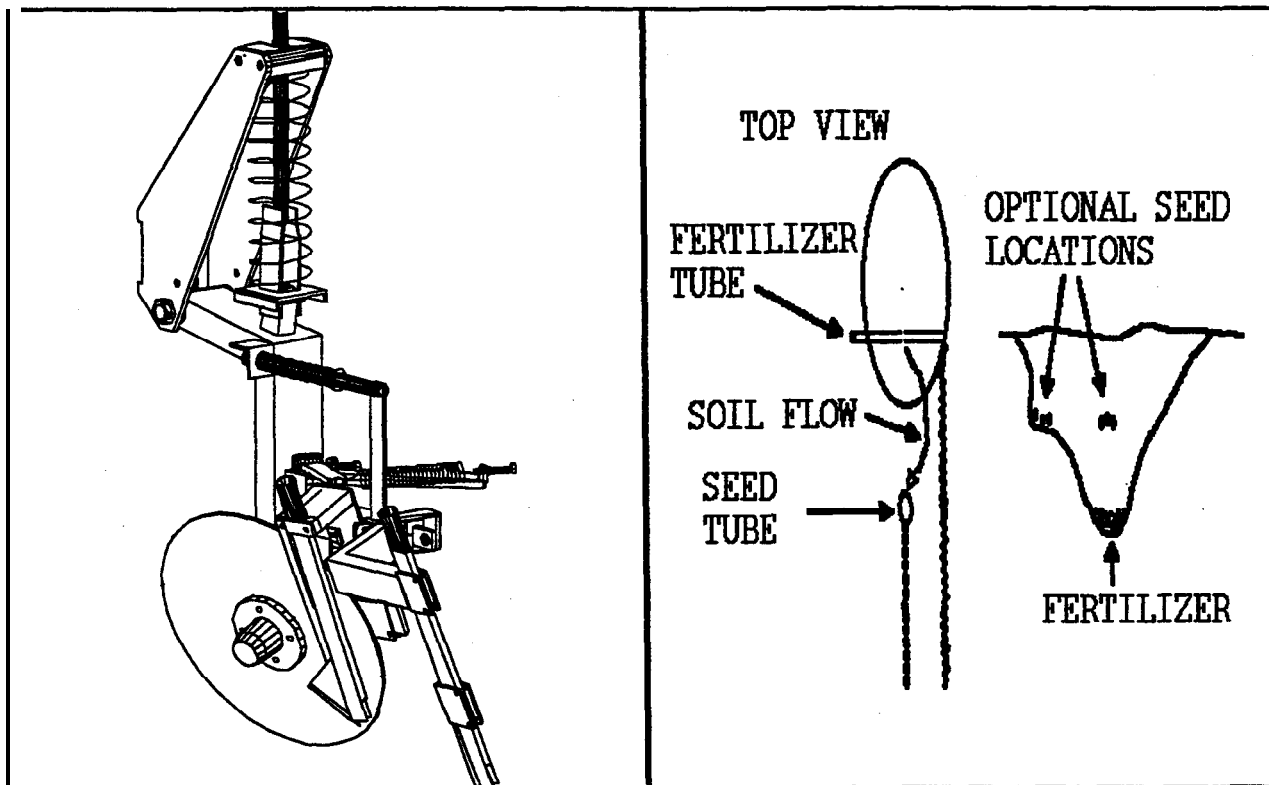
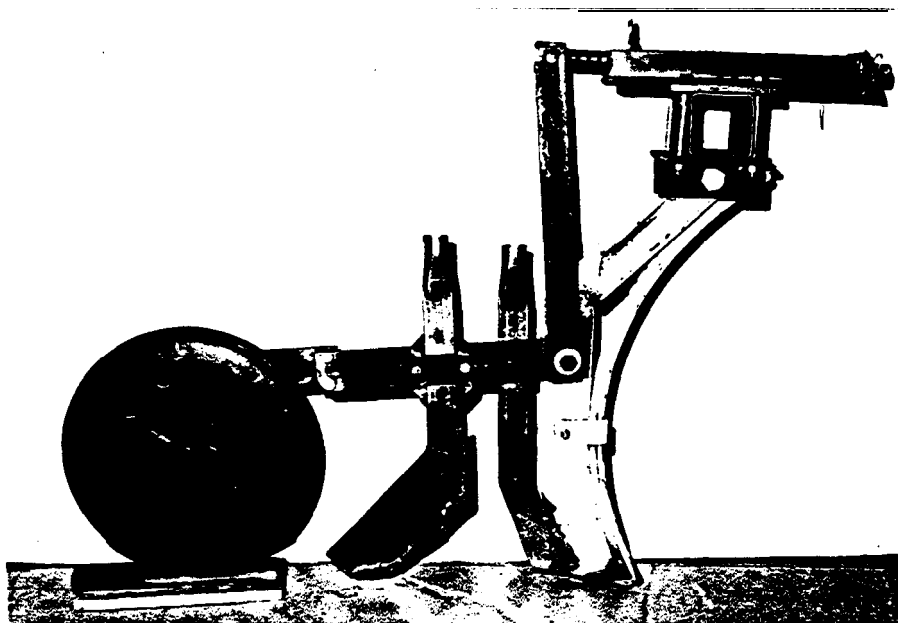


Figure 1. Angle disc and side banding opener with cross sectional view of furrow showing seed and fertilizer placement.



Note: The gauge packer wheel shown in photograph was not used in 1994 tests
 Figure 2. Dyck knife with banding boot and gauge packer wheel.

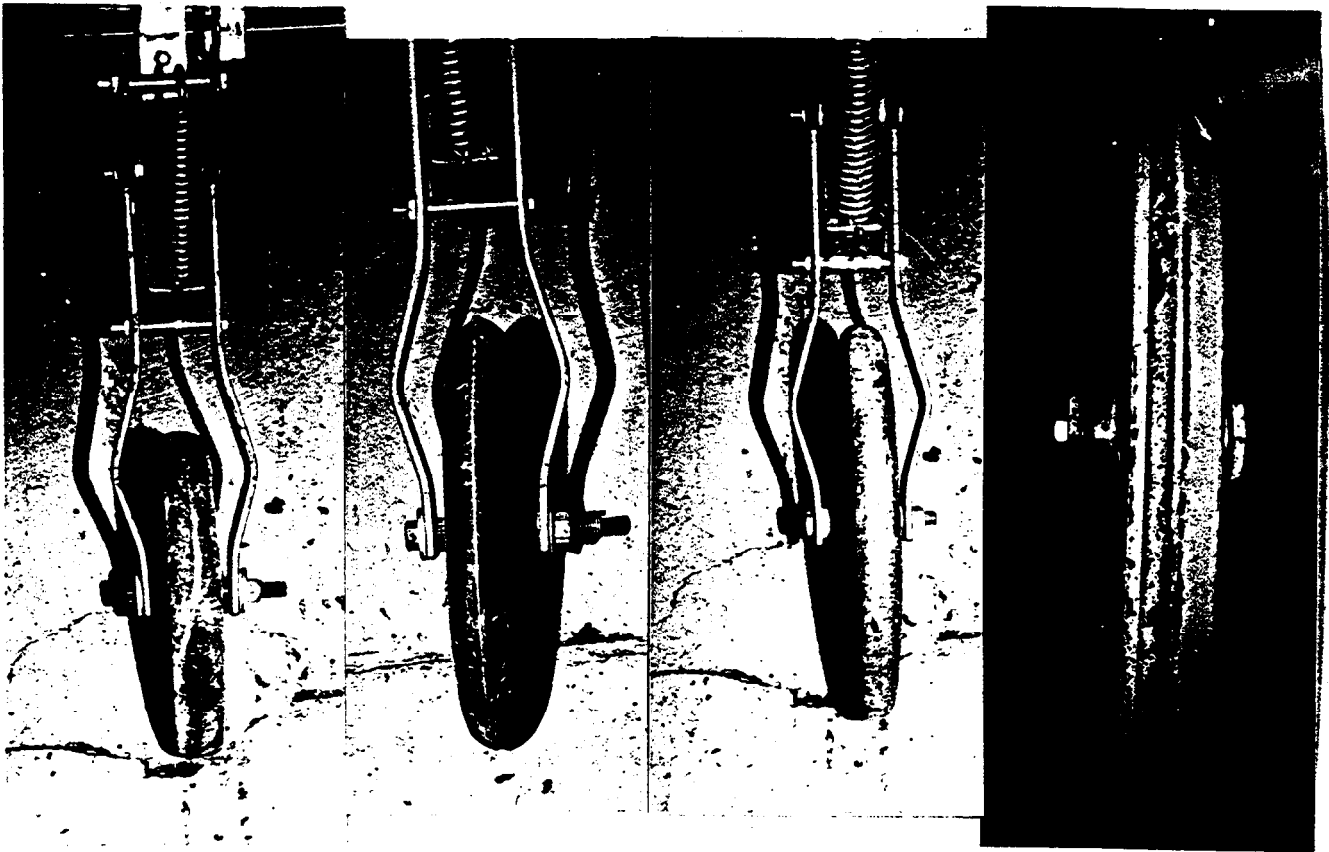


Figure 3. The 2 X 12 in. flat rubber packer wheel (2rubf), 2 X 12 in. rubber 'V' shaped wheel (2rubv), 1 X 12 in. rubber 'V' shaped wheel (1rubv), and 2 X 21 in. steel 'V' shaped packer wheel (2stlv) mounted on Dutch Industries spring loaded packer attachments.

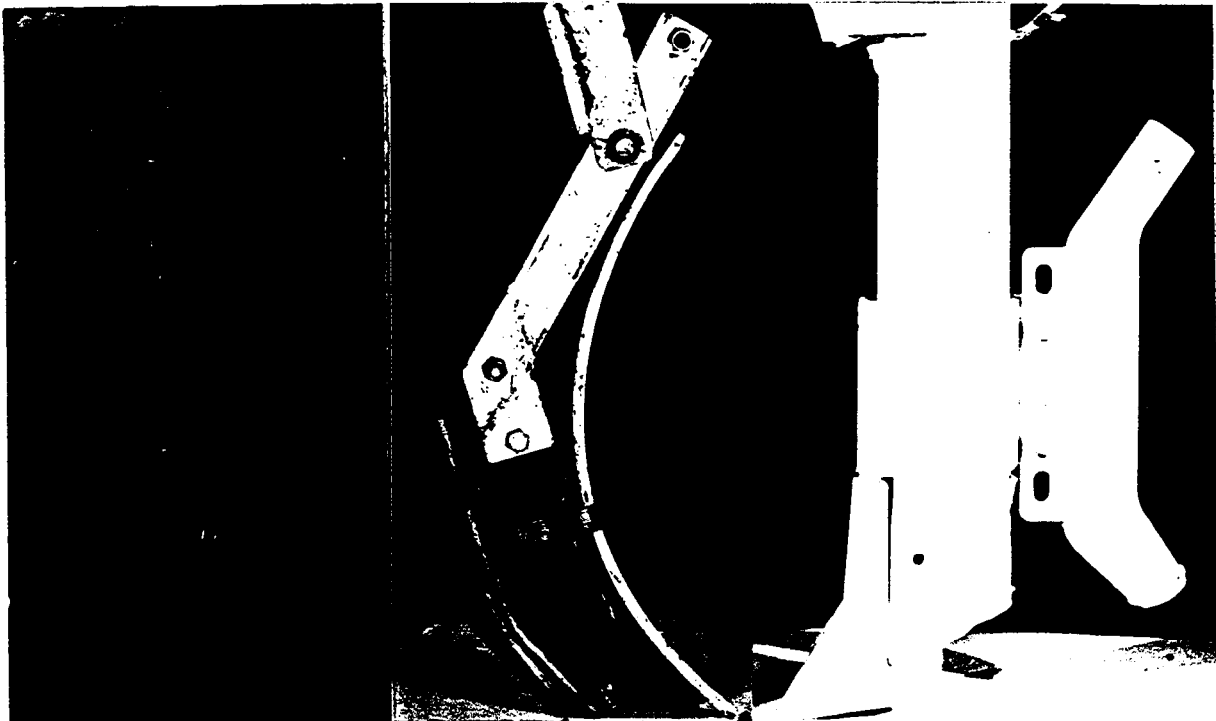


Figure 4. The Swift Current Zero Till Disc (SCOT disc), Dyck Knife, and Noble hoe opener.

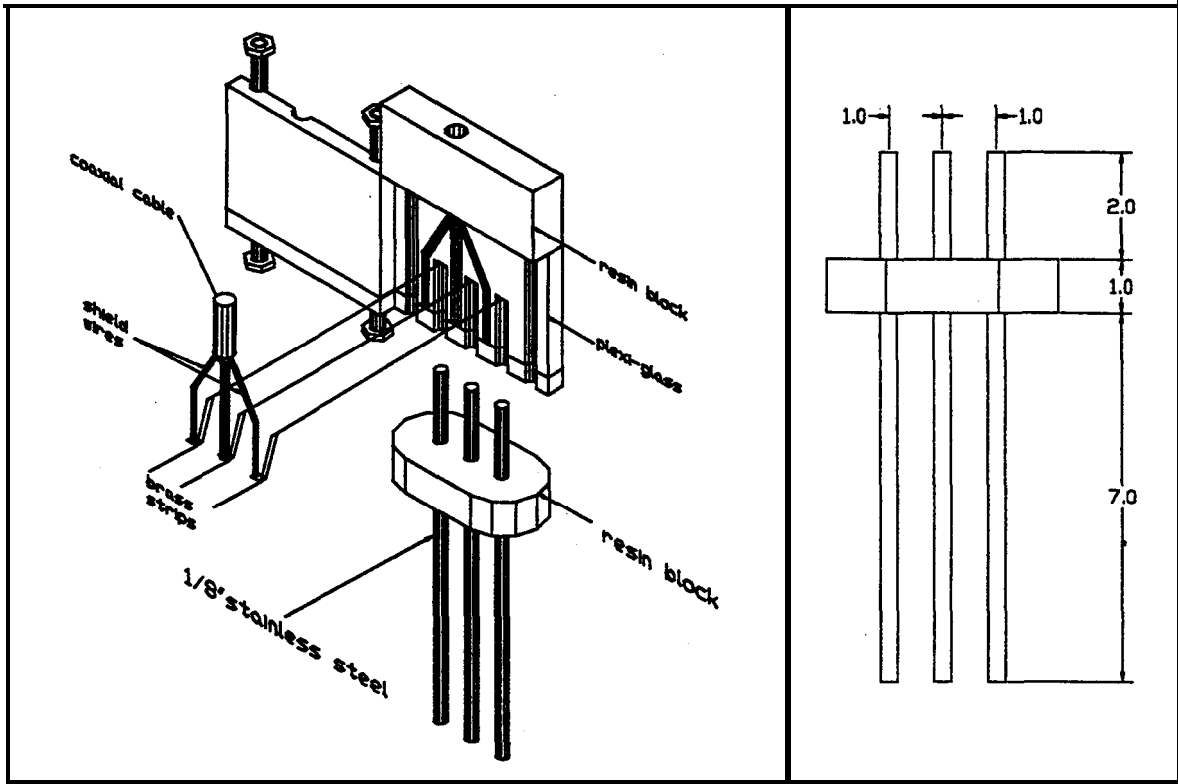


Figure 5. Exploded view of connector used to complete electrical connection between the time domain reflectometry moisture meter and probe. Probe dimensions in cm.