PERFORMANCE EVALUATION

of Five Liquid Manure Injection Systems

Brian Sexton, EIT
Environmental Practices Unit
Alberta Agriculture, Food and Rural Development
Lethbridge, Alberta, Canada

Blaine Metzger, AScT
Agricultural Technology Centre
Alberta Agriculture, Food and Rural Development
Lethbridge, Alberta, Canada

Virginia Nelson, M.Sc., EIT
Agricultural Technology Centre
Alberta Agriculture, Food and Rural Development
Lethbridge, Alberta, Canada

Alberta
AGRICULTURE, FOOD AND
RURAL DEVELOPMENT

September 2005

ABSTRACT

The past decade has seen a steady increase in the number of acres receiving liquid manure by injection in Alberta. Manure injection offers a number of advantages over broadcasting including minimized odour, placement of nutrients into the seedbed, and minimal nutrient loss. As the number of manure applicators practicing injection increases, knowledge of the expected performance of various injectors needs to be established.

Two low disturbance injectors (K-Hart and Yetter), two high disturbance injectors (Spike and Sweep), and an aerator (Aerway) were assessed for liquid placement, soil disturbance, and crop residue disturbance at rates ranging from 34,000 to 146,000 L/ha (3,000 to 13,000 gal/ac) and ground speeds ranging from 2.6 to 10.6 km/h (1.6 to 6.6 mi/h). Each system was also assessed for odour control at 67,000 L/ha (6,000 gal/ac) at 0, 4, and 24 h after injection. Draft tests were also performed for each injector, with the exception of the Aerway, at depths ranging from 8 to 15 cm (3 to 6 in).

All injectors provided acceptable liquid placement at all rates with the exception of the K-Hart, which placed liquid outside the furrows at rates above 79,000 L/ha (7,000 gal/ac), and the Aerway, which placed liquid on the field surface at all rates. Liquid placed within the furrow absorbed into the surrounding soil and followed fracture lines created by soil-tool interaction. The K-Hart, Yetter, and Aerway produced soil disturbance less than the 30% low disturbance guideline while the Spike and the Sweep produced soil disturbance in excess of 30%. Similar results were observed for crop residue disturbance. Immediately after injection, the Aerway produced the most odour while the Spike produced the least. With the exception of the Spike, odour from all injector treatments diminished significantly from 0 to 4 h and from 4 to 24 h after injection. Odour produced by all injector treatments at 4 and 24 h after injection was below detectable limits for the majority of the population. The high disturbance injectors required more draft than the low disturbance injectors at all depths.

INTRODUCTION

The amount of agricultural land injected with manure in Alberta increased from 12,373 to 17,001 ha (30,573 to 42,008 ac) between 1996 and 2001 (Statistics Canada, 2001). The increase may be attributed to improved on-farm environmental stewardship, desire for improved odour control, advancement in injection technology, and changes to legislation. In 2001, manure injected land accounted for about 18% of the total land area receiving liquid or slurry manure in Alberta (Statistics Canada, 2001).

With an increasing number of injection technology users, and a wide variety of injection technologies, the expected performance of injecting manure needs to be assessed. Knowledge of the expected performance of injection technologies allows applicators to inject manure while meeting the requirements of legislation, protecting the environment, and achieving the greatest benefit from the manure. The same knowledge allows regulators to assess manure-injected fields.

Broadcasting of liquid manure can create significant nuisance and potential adverse environmental impacts. Incorporation of broadcasted manure is required in Alberta to minimize such issues. Incorporation, however, is not compatible with direct seeding or forage production systems, as reflected in provincial legislation through the *Agricultural Operation Practices Act* (Province of Alberta 2004). Injection technology offers a unique solution to the above-mentioned issues.

Injection Technology

The American Society of Agricultural Engineers (2004) defines an injector as an implement used to insert materials into the soil. Injection technology typically falls into two categories: (i) high disturbance injection, and (ii) low disturbance injection.

High disturbance injection. According to low disturbance seeding guidelines, high disturbance injection creates greater than 30% disturbance to the original soil surface (Hultgreen and Stock 1999). High disturbance injection technology typically involves shank mounted soil openers. These soil openers are often designed for tillage, seeding, or fertilizer placement and are adopted and/or modified for manure placement. A drop hose attached to the rear of the shank is used to deliver manure into the furrow created by the opener. Depending on the tool used, such injectors usually cause significant crop residue and soil disturbance, rendering them incompatible with direct seeding and forage production systems. Also, when these tools are used with conventional tillage cropping systems, fields sometimes require additional field operations prior to seeding, due to the rough field conditions created by high disturbance injectors.

Low disturbance injection. According to low disturbance seeding guidelines, low disturbance injection creates less than 30% disturbance to the original soil surface (Hultgreen and Stock 1999). Low disturbance injection technology typically involves disk type soil openers such as coulters and offset disks. These injectors are either modified seeding or fertilizer placement tools or designed specifically for manure application. The disk opens a furrow in the soil and a drop hose delivers the manure into the furrow. Past studies in western Canada have shown that dedicated disk-type manure injectors perform better than modified disk openers due to the unique design requirements of low disturbance manure injectors (Hultgreen and Stock 1999). These injectors usually create minimal crop residue and soil disturbance and are therefore compatible with most cropping systems, including direct seeding and forage production.

Performance of Injection Technology

Liquid placement. The purpose of manure injection is to place liquid or slurry manure in the soil. This allows placement of nutrients into the seedbed, minimization of odour, and reduction of nutrient losses by runoff and volatilization. Injection typically involves opening the soil to create a furrow and placing the manure in the furrow. The formed furrow provides enough surface area to facilitate the absorption of the manure into the surrounding soil.

Field conditions must be accounted for in the performance expectations of any injector. Liquid placement is affected by several factors, including:

- Soil moisture
- Opener design
- Furrow profile
- Soil type
- Application rate

Crop residue and soil disturbance. A reduction in the amount of crop residue on the soil surface may increase the amount of soil erosion due to wind and water. Crop residue is also important for increasing soil moisture retention and providing soil structure during injection.

Soil disturbance can reduce the stability of soil structure. Exposed and loose soil is prone to soil erosion from wind and water. Disturbance results in reduced moisture retention, organic matter, and fertility.

There are several variables affecting crop residue and soil disturbance before, during and after manure injection, such as:

- Opener design
- Ground speed during injection
- Injection depth
- Row spacing
- Crop type
- Crop condition (weather, growing health, crop stand, etc.)
- Soil type
- Soil moisture
- Soil condition (firmness, tilth, erodibility)
- Residue cover (condition after harvesting)

Odour. The amount and duration of odour produced during and after injection are affected by several factors, including:

- Manure projection distance
- Exposed surface area of the manure
- Rate of absorption
- Crop stand
- Weather conditions at time of injection

Manure injection minimizes all of the above factors thereby minimizing odour. The distance between the drop hose and the point of placement is typically several centimeters or, in some cases, zero if the drop hose is positioned in the furrow. The manure is placed in a furrow below the crop canopy, minimizing and protecting the exposed surface area from air movement. The creation of a furrow provides a surface area for the manure to absorb into. Essentially, the furrow surface area replaces the field surface area in a broadcasting situation. The manure is absorbed directly into the open soil, minimizing the duration of exposure. As such, injection is the preferred method of land application in situations where odour control is critical.

MATERIALS AND METHODS

The performance of a variety of injection technologies was evaluated to provide knowledge of the expected performance of manure injection technology for use in Alberta. Each technology was evaluated based on the following parameters:

- Liquid placement
- Soil disturbance
- Crop residue cover disturbance
- Odour

Site Description

Injector testing was performed at the Agricultural Technology Centre Research Farm. The farm is 91 ha (225 ac) in size and is located at S1/2 of NE2 TP8 R21 W of 4, about 3.4 km (2.1 mi) southeast of Lethbridge, Alberta, Canada.

Lethbridge soil series is the dominant soil (greater than 60% of the area) at the farm and Coaldale soil series is a significant soil (10 to 30% of the area) (Canada-Alberta Environmental Sustainable Agriculture (CAESA) - Soil Inventory Project Working Group 1998). The soil type was a heavy clay loam Dark Brown Chernozem. The soil was low in organic matter due to aggressive tillage and continuous straw removal prior to the previous three years. The soil was very dry and hard at the time of the testing with a gravimetric soil moisture content of 11% in the 0 to 20 cm (8 in) soil layer.

Continuous cropping had been performed in the previous three years, with the most recent crop being silage barley. The average percent residue cover was 91.5% and the average straw length was 6.4 cm (2.5 in).

Injection Methods

A specialized three-point hitch machine (Figure 1) with castor wheels was used to inject liquid. The machine allowed the mounting of different injectors and included a 1,600 L (350 gal) supply tank coupled with a distribution manifold with five outlets. A flexible 4.4 cm (1.75 in) (inside diameter) drop hose, attached to each outlet, supplied liquid to each injector. A valve system allowed the liquid to be cycled into the tank for agitation. A gas powered trash pump mounted on the machine provided liquid to the injectors at a desired flow. An electronic flow meter with a cab-mounted monitor allowed accurate flow rate measurement. The same liquid application unit was used for four of the five manure application systems. The fifth system, the Aerway, was a separate machine in design and concept (Figure 2).

Figure 1. Injection machine

Figure 2. Aerway machine

An injection depth of 15 cm (6 in) was used for all injectors. A 30 cm (12 in) spacing was used, except for the Aerway, which had a 19 cm (7.5 in) spacing.

Injectors Tested

Yetter. The Yetter Avenger injector (Figure 3) consisted of a 64 cm (25 in) offset disk angled at five degrees to the direction of travel. A 38 cm (15 in) rubber cleaning wheel was mounted to the exposed side of the disk and a metal scraper was mounted on the protected side of the offset disk. A drop hose was located directly behind the offset disk. The Yetter included a set of concave furrow closing disks attached to the frame to the rear of the drop hose. The closing disks create high soil disturbance and were therefore removed during testing.

Figure 3. Yetter Avenger injector

K-Hart. The modified K-Hart injector was a K-Hart fertilizer bander modified to perform liquid manure injection (Figure 4). The original bander consisted of a 46 cm (18 in) coulter and a drop hose housing for fertilizer. Modifications were made to the drop hose housing to accommodate a liquid manure drop hose.

Figure 4. Modified K-Hart injector

Sweep. The Sweep injector consisted of a 26.7 cm (10.5 in) wide sweep opener mounted on a 5 cm (2 in) wide C-shank (Figure 5). A metal tube was mounted directly behind the sweep to accommodate a drop hose.

Figure 5. Sweep injector

Spike. The Spike injector consisted of a 5 cm (2 in) wide spike opener mounted on a 5 cm (2 in) wide C-shank (Figure 6). A metal tube was mounted directly behind the spike to accommodate a drop hose.

Figure 6. Spike injector

Aerway. The Aerway consisted of a series of knives mounted on an axle (Figure 7). A drop hose was mounted behind each knife set. The knives were spaced 19 cm (7.5 in) apart. The spikes penetrated the soil creating a soil aeration effect. Liquid was then delivered to the soil surface and spike holes through the drop hoses.

Figure 7. Aerway Aerator

Liquid Injection Rates

Using each injector, water was injected at rates ranging from 34,000 to 146,000 L/ha (3,000 to 13,000 gal/ac) (Table 1) except for the Aerway, which achieved 34,000 to 89,000 L/ha (3,000 to 7,900 gal/ac) only, due to the ground speed limitations of the tractor. The range was selected to determine how each injector performed at various application rates. Rates ranged from agronomic to excessive based on typical hog manure nutrient contents (Province of Alberta 2001). The various rates were achieved by adjusting the tractor ground speed. Ground speeds ranged from 2.7 to 7.2 km/h (1.7 to 4.5 mi/h) for the Aerway and 2.6 to 10.6 km/h (1.6 to 6.6 mi/h) for all other injectors.

Table 1. Application rates

Application Rate L/ha (gal/ac)	Crop Available Nitrogen[z] kg/ha (lb/ac)	Description
34,000 (3,000)	54 (48)	Agronomic
56,000 (5,000)	108 (96)	Conmmon Practice
79,000 (7,000)	161 (144)	Conmmon Practice
101,000 (9,000)	215 (192)	Conmmon Practice
124,000 (11,000)	267 (240)	Excessive
146,000 (13,000)	323 (288)	Excessive

[z] Estimated amount of crop available nitrogen applied if an equivalent amount of liquid hog manure was applied. Manure nutrient content values used for estimate were obtained from the *Agricultural Operation Practices Act* (Province of Alberta 2001).

A randomized complete block design with 4 replications was used. The site consisted of 24 plots, each measuring 2 m (6 ft) in width by 30 m (98 ft) in length. Each plot was divided into six equal segments, each being a different application rate, increasing along the length of the plot. Site plan and dimensions are shown in Figure 8.

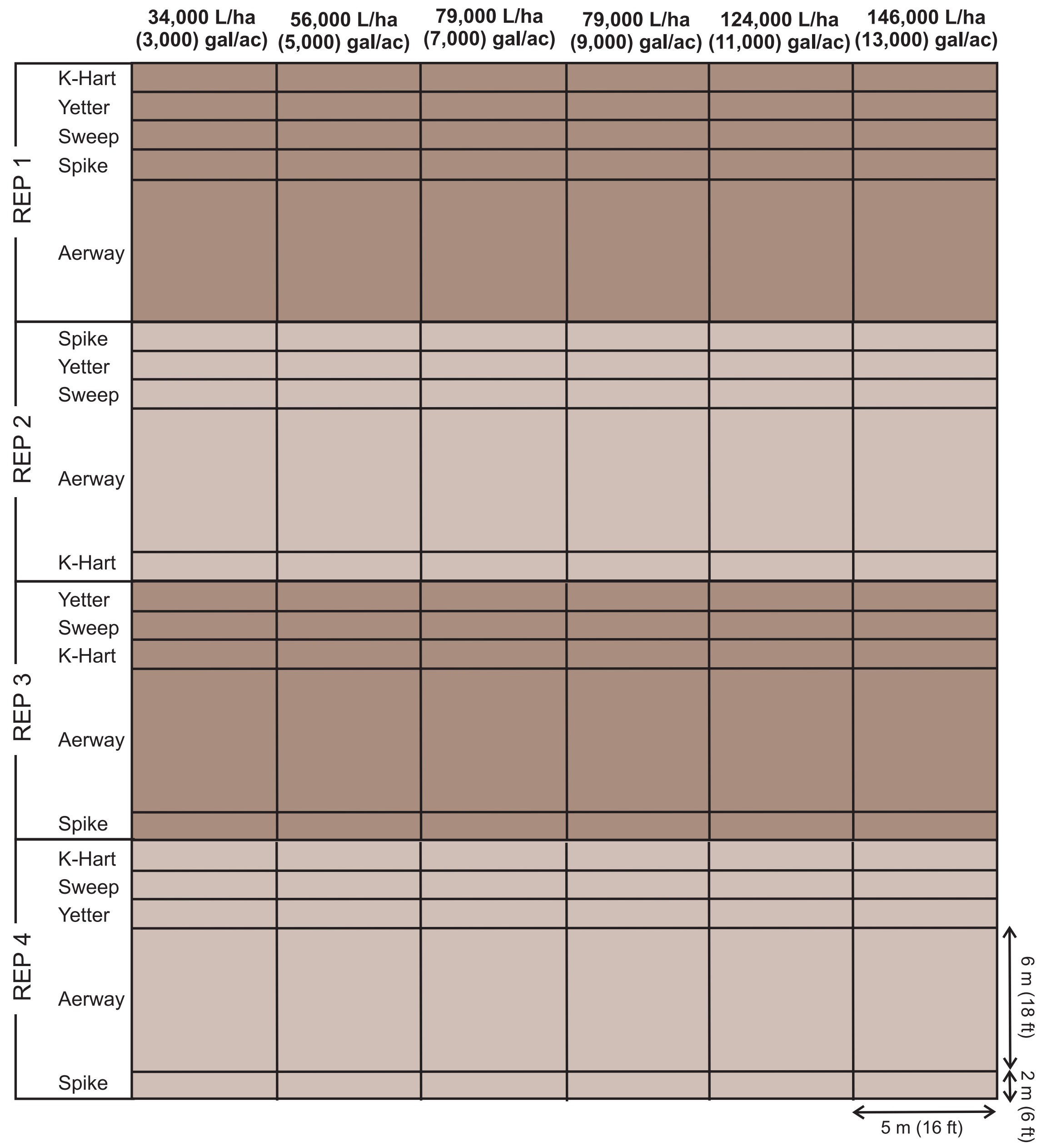

Figure 8. Liquid placement and soil and crop residue disturbance site plan

Liquid Placement Assessment

The liquid placement assessment was carried out over several days, with soil conditions remaining constant. Liquid placement assessments and observations were performed on all application rates. Observations were made for pooled liquid, wet soil, or any other evidence of liquid presence immediately after injection. The following rating system was used to evaluate each application as follows: 1 - no evidence, 2 - evidence in furrow only and 3 - evidence outside of furrow.

A low rating was an indication of good liquid placement while a high rating was an indication of poor placement. The furrow was defined as the width of opening of the soil at the soil surface after the opener had passed.

A cross section of randomly selected furrows was made using a hand shovel. Observations of liquid placement and liquid movement within the soil profile were made and documented using the cross section.

Photographs were taken of each treatment surface (Figure 9) immediately after injection. The photographs were taken at a constant height of 127 cm (50 in) from the field surface, pointing directly down on the field surface (Figure 10).

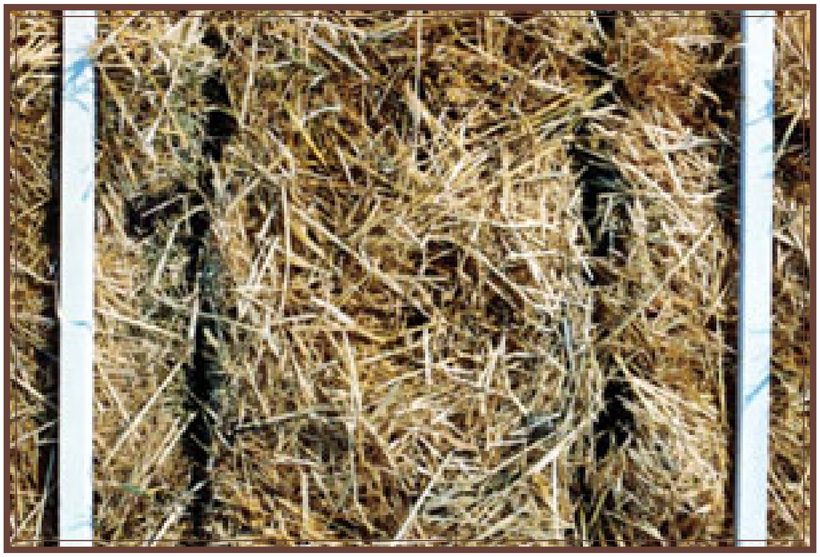

Figure 9. Example of collected image

Figure 10. Image collection equipment

Crop Residue Cover and Soil Disturbance Assessments

Crop residue cover and soil disturbance were measured in the same trial as the liquid placement (Figure 8). The disturbance measurements were made on the highest and the lowest ground speeds for each injector (lowest and highest application rates, respectively).

The disturbed opener sub-soil profile and the surface disturbance were measured. A tape measure was used to measure the disturbed sub-surface soil profile. The surface soil disturbance was measured by laying a tape measure across the injected area. Any disturbed soil on 2.5 cm (1.0 in) intervals was counted across the entire disturbed area and a percent of disturbed area was calculated. The fractured soil and open furrow area widths were measured with a tape measure. Soil throw from an injector of each type was also measured as surface disturbance. Soil throw was measured from the center of the furrow to the average and maximum distances of disturbed soil. The Aerway soil disturbance was determined by measuring the width, length, and depth of several spike hole profiles.

Crop residue cover measurements were made using the rope method. A rope with twenty-five marks on 10 cm (4 in) increments was placed across the injection area. Every piece of straw or chaff intercepting an increment on the rope was counted as one out of twenty-five. The final count was expressed as a percent cover and subtracted from the initial percent cover to provide a percent disturbance value.

Odour Assessment

The odour assessment was performed in a separate trial, at a later date than the liquid placement and soil and crop residue disturbance assessments. The assessment was carried out over several days with consistent weather and soil conditions. Odour measurements involved applying liquid hog manure at 67,000 L/ha (6,000 gal/ac) in a randomized complete block design with 4 replications. The site consisted of 24 plots, each measuring 2 m (6 ft) in width by 10 m (33 ft) in length. Site plan and dimensions are shown in Figure 11.

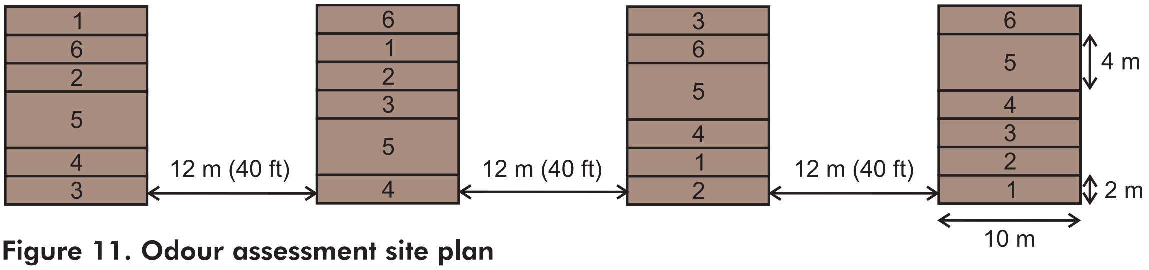

Figure 11. Odour assessment site plan

A 61 cm (24 in) diameter by 20 cm (8 in) deep vented hood (Figure 12) was used to collect odour samples from the surface of the field. The hood was placed on the surface of the injected area and pushed about 2.5 cm (1.0 in) into the ground to limit air transfer from the adjacent ground to the hood interior. An air pump was used to draw air through a carbon filter into the hood at 2 L/min (0.4 gal/min) and into two Kevlar sample bags.

Figure 12. Vented hood and air pump

The olfactometer lab at the University of Alberta was used to analyze the collected odour samples. Two odour bags, a primary sample and a backup sample, were filled at one location in each selected treatment. Samples were taken immediately following injection, and 4 h and 24 h following injection. All samples were analyzed at the olfactometer lab within 24 h of collection.

Results were provided in odour units. The numeric value of the odour concentration, expressed in odour units (E/m^3), equals the number of times that the air should be treated with odourless air to reach the odour threshold. Odour threshold is the concentration of a gaseous substance, expressed in $\mu g/m^3$, which will be discerned from odourless air by at least half of an odour panel. The odour threshold by definition has an odour concentration of 1 odour unit per cubic metre ($O.U./m^3$).

Odour panelists must be able to detect odour between 500 and 2,000 $O.U./m^3$. These individuals represent about 30% of the population.

Injector Draft Assessment

The draft force assessment was performed at a later date than all other assessments. The draft force required to pull each injector through the soil was measured using a draft cart (Figure 13). Draft was measured at 6.7 km/h (4.0 mi/h) at depths of 8 cm (3 in), 10 cm (4 in), 13 cm (5 in), and 15 cm (6 in) for each injector. The draft was not measured for the Aerway.

Figure 13. Draft cart

Results Analysis

An analysis of variance (ANOVA) was used to analyze the results, with the exception of the draft results. Duncan's multiple range tests were used to separate means that were significantly different.

RESULTS AND DISCUSSION

Liquid Placement Assessment

Due to the low moisture content of the soil at the time of the study, most liquid applied was absorbed by the soil within seconds or minutes. Liquid placement on and in the soil was therefore easily observed.

Cross-section. Furrow cross sections showed liquid distribution patterns around each furrow, regardless of the injector used. The distribution pattern typically followed the profile of the furrow, radiating outward from the furrow walls, into the surrounding soil (Figure 14). In some cases, liquid extended between adjacent furrows, across the width of the injected area. The Yetter, at the highest rate, produced a uniform pattern between the furrows, starting about 5 cm (2 in) below the soil surface and ending at injection depth. In the case of the Aerway, an inverted cone distribution pattern was observed around each spike hole. Evidence of liquid was also observed along the soil surface to a shallow depth between the holes.

Figure 14. In soil liquid distribution

Ratings. Table 2 shows the mean liquid placement rating results.

Table 2. Mean liquid placement ratings

Rate L/ha (gal/ac)	34,000 (3,000)	56,000 (5,000)	79,000 (7,000)	101,000 (9,000)	124,000 (11,000)	146,000 (13,000)
Yetter	1.25[y]ab[z]	1a	1.5a	1.5a	1.25a	1.75a
Sweep	1a	1.5ab	1.5a	1.75ab	2b	2a
Spike	1.5b	1.5ab	1.5a	1.75ab	1.75ab	1.75a
K-Hart	2c	2b	2a	2.5bc	2.75c	3b
Aerway	3d	3c	3b	3c	na[x]	na

[x] Not Available.
[y] Rating scale: 1 = no evidence, 2 = evidence in furrow only, 3 = evidence outside of furrow.
[z] Means within a column followed by the same letter are not significantly different ($P<0.05$).

34,000 L/ha (3,000 gal/ac)
The best performer was the Sweep, although there was no significant difference between the Sweep and the Yetter and between the Yetter and the Spike. There were significant differences among the Sweep, Spike, K-Hart, and Aerway.

56,000 L/ha (5,000 gal/ac)
The best performer was the Yetter, although there were no significant differences among the Yetter, Sweep, and Spike. There were also no significant differences among the Sweep, Spike, and K-Hart. The Aerway produced a significantly higher rating than the other injectors.

79,000 L/ha (7,000 gal/ac)
The best performers were the Sweep and Spike. There were no significant differences among the Yetter, Sweep, Spike, and K-Hart. The Aerway produced a significantly higher rating than the other systems.

101,000 L/ha (9,000 gal/ac)
The best performer was the Yetter, although there were no significant differences among the Yetter, Sweep, and Spike as well as between the Sweep, Spike, and K-Hart. Also, there was no significant difference between the K-Hart and Aerway.

124,000 L/ha (11,000 gal/ac)
The best performer was the Yetter. There was no significant difference between the Yetter and Spike as well as between the Sweep and Spike. The K-Hart was significantly different from the other injectors. No data was collected for the Aerway due to ground speed and flow rate constraints.

146,000 L/ha (13,000 gal/ac)
The best performers were the Yetter and the Spike. There were no significant differences among the Yetter, Sweep, and Spike. The K-Hart was significantly different from the other injectors. The Aerway was not tested at this rate.

In some cases, liquid placement outside the furrows was the result of splashing as liquid contacted the furrow. Liquid placement outside the furrows was also caused when the injector encountered obstructions such as rocks or hard soil conditions. Such obstructions caused injector tripping, reduced injection depth, or drop hose interference. In the case of the Aerway, splashing on the soil surface was caused by the high flow rates of liquid release from the drop hoses.

Soil Disturbance Assessment

The actual injection depth varied from the intended tillage depth of 15 cm (6 in) due to the varying opener designs, soil conditions, and ground speeds. The higher the ground speed the shallower the injection depth. The soil disturbance results are shown in Table 3.

Table 3. Mean soil disturbance and crop residue disturbance

	Soil Disturbance (%)		Crop Residue Disturbance (%)	
Injector	**2.6 km/h (1.6 mi/h)**	**10.6 km/h (6.6 mi/h)**	**2.6 km/h (1.6 mi/h)**	**10.6 km/h (6.6 mi/h)**
K-Hart	26a[z]	29a	11a	15a
Sweep	54b	68b	38b	54a
Spike	46b	66b	53b	65b
Yetter	15a	27a	12a	17a
Aerway	20a[y]	22a[x]	18a[y]	23a[x]

[x] Ground speed of 7.2 km/h (4.5 mi/h).
[y] Ground speed of 2.7 km/h (1.7 mi/h).
[z] Means within a column followed by the same letter are not significantly different ($P<0.05$).

At low ground speed, the Yetter produced the least amount of soil disturbance. There were no significant differences, however, among the Yetter, Aerway, and K-Hart as well as between the Spike and Sweep. There were, however, significant differences between the shank injectors (Sweep and Spike) and the other injectors.

At high ground speed, the Aerway produced the least amount of soil disturbance. There were no significant differences, however, among the Yetter, Aerway, and K-Hart as well as between the Spike and Sweep. There were, however, significant differences between the shank injectors and the other injectors.

The K-Hart, Yetter, and Aerway produced the least amount of soil disturbance. The K-Hart had a low soil disturbance at 10.6 km/h (6.6 mi/h), but penetrated to an average depth of 8.9 cm (3.5 in) at this speed. The Yetter provided consistent penetration to a depth of 13 cm (5 in). The Yetter cutting disk is offset and creates a slightly larger opening in the soil than the straight K-Hart coulter. The Yetter had slightly lower soil disturbance than the K-Hart at the 2.6 km/h (1.6 mi/h) ground speed. The Sweep and Spike produced the most soil disturbance. The percent soil disturbance with the K-Hart did not vary with speed. The Yetter produced a similar soil disturbance as the K-Hart at 10.6 km/h (6.6 mi/h). The Yetter, however, produced only 15 % soil disturbance at 2.6 km/h (1.6 mi/h), the least of all the injectors tested.

The Aerway turned very little soil and produced minimal soil blocking. The system did create a number of spike holes across the soil surface. These were measured as the percent of soil disturbance. The average percent disturbance varied slightly with speed from 20 to 22%. This disturbance is the second lowest compared to all the other systems at the low speed and the lowest at the high speed. The Aerway's highest ground speed was, however, considerably slower than the other systems highest ground speed and is therefore difficult to compare directly.

All systems caused soil-fracturing disturbance. The fracturing was not measured for the K-Hart tests (Figure 15).

Figure 15. Example of soil fracturing and blocking

The Sweep fractured the entire width of the injected area, understandably since the sweeps were 26.7 cm (10.5 in) wide on 30 cm (12 in) spacing. Soil blocks, measuring up to 25 x 25 x 12 cm (10 x 10 x 5 in), were created at the slow speed. The clumps were smaller at the high speed, but were thrown further.

The Spike fractured the top 5 cm (2 in) of soil across the entire injected area width and a 20 cm (8 in) width at injection depth at all speeds. At times the Spike fractured the entire injection width soil profile from the surface to injection depth.

The Yetter cut a 3.8 cm (1.5 in) wide furrow at the soil surface, which tapered to a 1.9 cm (0.75 in) width at injection depth. The disks fractured the soil across the entire injection width to injection depth. Soil was broken into blocks with an average size of 15 x 14 x 10 cm (6 x 5.5 x 4 in) that were always left in place by the cleaning wheel.

The spiked holes created by the Aerway were oblong cone shaped. The holes were oval shaped at the surface and tapered to a point at depth. The Aerway spikes had inconsistent penetration at the higher ground speed in the hard, dry ground with some spikes penetrating only 5 cm (2 in). The Aerway fractured the soil in a cone shaped profile. The fractured profile was 20 cm (8 in) average in diameter at the surface and tapered to 5 cm (2 in) in diameter at the injection depth at the slow injection speed. The Aerway soil fractured profile at the 7.2 km/h (4.5 mi/h) speed was 16.5 cm (6.5 in) average in diameter at the surface and tapered to 3.8 cm (1.5 in) at the injection depth.

Due to the dry soil conditions, large blocks of soil were brought to the surface by the high disturbance injectors. In moderate soil moisture and good soil tilth conditions, it is expected that soil will fracture more completely and flow around the opener. Uncovered furrows were observed during testing with the high disturbance injectors, where soil did not flow around the Sweep or Spike and back into the furrow. These uncovered areas were not consistent, but would none the less result in odour production and nutrient loss.

Crop Residue Cover Disturbance Assessment

At low ground speed, the Yetter produced the least amount of residue disturbance. There were no significant differences among the Yetter, K-Hart, and Aerway as well as between the Sweep and Spike (Table 3). There were, however, significant differences between the shank injectors and the other injectors.

At high ground speed, the K-Hart produced the least residue disturbance. There were no significant differences among the Yetter, K-Hart, Aerway, and Sweep. The Spike, however, produced significantly higher disturbance than the other injectors.

The K-Hart and Yetter produced very similar residue disturbance. The K-Hart measured 1 to 2% better at the low and high speeds. The K-Hart measured 11 and 15% of disturbed residue after injection, the lowest disturbance numbers of all the injectors.

The Sweep and Spike produced the highest residue disturbance with the Sweep at 54% for the high ground speed. The Spike had the highest overall residue disturbance of 65% measured at the high speed.

The Aerway had 18 and 23% residue disturbance at the 2.7 km/h (1.7 mi/h) and 7.2 km/h (4.5 mi/h) ground speeds, respectively.

Odour Assessment

Odour Concentrations. Mean odour concentration results are shown in Table 4.

Table 4. Mean odour unit results

	Mean Odour Concentrations (O.U./m^3)		
Injector	**0 h**	**4 h**	**24 h**
Aerway	2,585a[z]	168a (35%)[y]	167a (0%)
K-Hart	1,109ab	129a (31%)	64b (14%)
Spike	153	56 (20%)	169a (-)
Sweep	841b	118a (29%)	77b (9%)
Yetter	2,291ab	366 (24%)	219a (9%)

[y] Values in parentheses represent the percentage change between 0 and 4 h and 4 and 24 h, respectively.

[z] Means within a column followed by the same letter are not significantly different (P<0.01).

At 0 h after injection, the Spike treatment produced significantly less odour than the other injector treatments. The Aerway treatment produced the most odour but was not significantly more than the K-Hart and Yetter treatments. There were no significant differences among the Sweep, Yetter, and K-Hart.

At 4 h after injection, the odour from the Spike treatment was significantly less than the odour from the other treatments. Odour from the Yetter treatment was significantly higher than the odour from all the other treatments. There were no significant differences in odour among the Aerway, K-Hart, and Sweep treatments.

At 24 h after injection, there were no significant differences in odour among the Aerway, Spike, and Yetter treatments as well as between the K-Hart and Sweep treatments.

At 4 and 24 h after injection, it is difficult to assess the performance of the injectors since the soil properties at the various locations and times may also have influenced changes in the odour. However, with the exception of the Spike treatment, odour from all treatments diminished significantly from 0 to 4 h and from 4 to 24 h.

Draft Assessment

The draft assessment results are shown in Table 5.

Table 5. Draft assessment results[z]

Depth	7.6 cm (3 in)		10.2 cm (4 in)		12.7 cm (5 in)		15.2 cm (6 in)	
Injector	N (lbf)	kW (hp)	N (lbf)	kW (hp)	N (lbf)	kW (hp)	N (lbf)	kW (hp)
K-Hart	331 (70)	0.56 (0.75)	485 (109)	0.89 (1.2)	1,592 (358)	2.8 (3.8)	na	na
Spike	1,579 (355)	2.8 (3.8)	1,948 (438)	3.5 (4.7)	na[y]	na	na	na
Sweep	2,055 (462)	3.6 (4.9)	2,411 (542)	4.3 (5.8)	2,549 (573)	4.5 (6.1)	na	na
Yetter	596 (134)	1.0 (1.4)	885 (199)	1.6 (2.1)	1,450 (326)	2.6 (3.5)	2,362 (531)	4.2 (5.7)

[y] Injector did not penetrate soil to required depth.
[z] Draft measurements performed at a ground speed of 6.7 km/h (4.0 mi/h) with one injector.

The draft measurements were performed under higher soil moisture conditions. The soil was well packed. The K-Hart and the Yetter required the lowest draft. The Spike and the Sweep required the highest draft.

Although most the injection tests were done at a 15.2 cm (6 in) tillage depth, only the Yetter was able to penetrate to this depth, due to its high force trip spring and design. The Spike and Sweep were operated with a medium duty shank and trip and could have achieved deeper depths with a heavy duty shank and trip.

CONCLUSIONS

Liquid Placement

The liquid placement surrounding a given furrow is due to liquid absorption into the soil and, most predominately, movement of liquid along fracture lines created by soil-tool interaction. Liquid placement is therefore not limited to the furrow surface area only, but to the surface area created by the fracture pattern surrounding the furrow.

Ideally, manure injection must result in no evidence of liquid on the soil surface. The Yetter, Sweep, Spike, and K-Hart achieved this criterion at the 34,000, 56,000, and 79,000 L/ha (3,000, 5,000, and 7,000 gal/ac) rates, with little difference among injectors. At all other rates, the Yetter, Spike, and Sweep achieved the above criterion.

Provided manure is applied at agronomic rates (typically in the range of 34,000 L/ha (3,000 gal/ac)), all of the above mentioned injectors should provide liquid placement limited to the furrow only, with no spillage onto the soil surface between furrows. In practice, however, manure is applied at rates in the range of 79,000 L/ha (7,000 gal/ac). Based on the study results, all the above-mentioned injectors should provide acceptable liquid placement at practiced rates.

The low moisture content of the soil may have skewed the liquid placement results. Under higher soil moisture conditions, the above mentioned injection systems may not provide the same liquid placement at the higher rates.

The Aerway did not meet the above criterion and is therefore not considered an injection system based on the liquid placement results.

High-speed release of liquid from the drop hoses can result in improper liquid placement due to splashing on the soil surface and on the equipment. Soil-opener interaction, such as injector tripping due to rocks, can result in improper liquid placement.

Crop Residue Cover and Soil Disturbance

Disk injectors cause considerably less residue and soil disturbance than shank injectors. This is due to the fact that disk injectors are designed to inject manure into various crop conditions while producing minimal residue disturbance. As such, disk injectors are better suited than shank injectors for situations where crop residue cover maintenance and minimal soil disturbance is desired. Disk injectors may not penetrate dry hard soil as well as shank injectors.

The disk injectors and the Aerway satisfied the low disturbance injection guideline of 30% soil disturbance at all ground speeds making them compatible with low disturbance cropping systems such as direct seeding and forage production. The shank injectors are incompatible with low disturbance cropping systems.

Odour

With the exception of the Spike, all injectors provided acceptable odour control immediately after application, and in the hours following injection.

Given that the Spike performed similar to the Sweep on all other assessments, the increase in odour emissions from the Spike treatment 24 hours after injection is likely due to a high background odour concentration or an erroneous measurement by the olfactometer.

The odour assessment was performed under dry soil conditions. Under different soil conditions, the percentage change in odour concentration may not have been as large from 0 to 4 h and from 4 to 24 h after injection. Also, any conclusions drawn from the odour assessment must be appraised with caution since the injectors were not evaluated on the same day and the possible effects of the soil on odour emissions are unknown. It was assumed that soil and weather effects on odour concentrations were negligible given that these conditions were consistent during the assessment period.

Odour diminished rapidly during the hours following injection for all treatments. This is likely due to manure absorption into the soil and along fracture lines. The odour concentrations produced at 4 and 24 h for all injector treatments were below detectable levels for the majority of the population. In a field situation, the odour produced at 4 and 24 h after injection would likely be undetectable by individuals located near the injection site.

Draft

Disk type injectors require less horsepower to than shank type injectors at various injection depths.

SUMMARY

When selecting manure injection technology, it is important to weigh the pros and cons of each system being considered. As shown in the study, high disturbance injection technology controls odour effectively but at the sacrifice of residue and soil disturbance. Low disturbance injection technology, on the other hand, provides minimal residue and soil disturbance but controls odour less effectively than high disturbance injection. All technologies provide acceptable nutrient placement.

A producer's individual situation should dictate which system to use. For example, a producer practicing direct seeding may choose low disturbance injection while a producer practicing tillage may choose high disturbance injection.

ACKNOWLEDGEMENTS

Rick Atkins, M.Sc., P.Eng., Agricultural Technology Centre, Alberta Agriculture, Food and Rural Development, Lethbridge, Alberta, Canada
Project advisor.

Barry Olson, Ph.D, Irrigation Branch, Alberta Agriculture, Food and Rural Development, Lethbridge, Alberta, Canada
Project advisor.

Troy Ormann, AScT, County of Lethbridge NO. 26, Lethbridge, Alberta, Canada
Coordinated liquid manure source.

Lawrence Papworth, P.Eng., Agricultural Technology Centre, Alberta Agriculture, Food and Rural Development, Lethbridge, Alberta, Canada
Project advisor.

All liquid hog manure used in the study was supplied by Wilson Colony, Wilson Siding, Alberta, Canada.

REFERENCES

American Society of Agricultural Engineers. 2004. Terminology and Definitions for Soil Tillage and Soil-Tool Relationships. ASAE Standards. ASAE EP291.2 FEB04.

Canada-Alberta Environmental Sustainable Agriculture (CAESA) - Soil Inventory Project Working Group. 1998. AGRASID: Agricultural Region of Alberta Soil Inventory Database (Version 1.0). [CD-ROM computer file] J.A. Brierley, B.D. Walker, P.E. Smith, and W.L. Nikiforuk (eds.). Agriculture and Agri-Food Canada, Alberta Research Council, and Alberta Agriculture, Food and Rural Development.

Hultgreen, G., and Stock, W. 1999. Injecting Swine Manure with Minimum Disturbance. [Online]. Saskatchewan Soil Conservation Association. Available at http://ssca.usask.ca/1999proceedings/Hultgreen.html (accessed January 1, 2005).

Province of Alberta. 2001. Agricultural Operation Practices Act. Alberta Queen's Printer, Edmonton, Alberta, Canada.

Province of Alberta. 2004. Agricultural Operation Practices Act and Regulations. Alberta Queen's Printer, Edmonton, Alberta, Canada.

Statistics Canada. 2001. Census of Agriculture. Ottawa, Ontario, Canada. Available at: www.statscan.ca. Accessed 8 September 2005