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FIELD PERFORMANCE OF A LOW-DISTURBANCE ROLLING-TINE SLURRY INJECTOR

By

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ABSTRACT

FIELD PERFORMANCE OF A LOW-DISTURBANCE ROLLING-TINE SLURRY INJECTOR

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A low-disturbance rolling-tine manure slurry injector was evaluated for effects on soil infiltration, residue cover, slurry placement uniformity, and soil electrical conductivity. Initial water infiltration rates were found to be greater for more aggressively tilled plots. Aggressively tilled plots had a lower residue cover. Soil electrical conductivity (EC) and phosphorous (P) concentrations were measured in untilled, lightly tilled and aggressively tilled plots with manure applied at 49100 L ha^{-1} (5,250 gpa). P concentrations were analyzed with and without soil EC as a covariate. P concentrations in the 0-7.6 cm (0-3 in) layer were greatest at the points of greatest soil disturbance. Using soil EC as a covariate in the analysis of soil P improved the accuracy of the analysis. Soil EC values were not affected by tillage at the 91 cm (3 ft) depth. Soil EC levels were increased by tillage at the 30 cm (1 ft) depth, with light and no tillage showing the largest increase.

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CHAPTER 1.

1. INTRODUCTION

1.1 Justification

Since the adoption of the 1972 Water Pollution Control Act, billions of dollars have been spent to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (Novotny and Olem, 1994). Initially, efforts were focused on collection and treatment of point source pollution. Point source pollution includes municipal, industrial, and some agricultural wastewaters. Point source pollution legislation made pollution discharge improvements mandatory. Overall, the programs targeting the effects of point source pollution were successful. However, point source pollution is only part of the problem. Non-point source pollution (NPSP) is detrimental to the integrity of the nations waters and land. NPSP varies with time, space, geography, weather and land management. Land management practices are often used to prevent NPSP.

The 1987 Water Quality Act was passed to prevent NPSP by voluntary improvement of land management practices. Specifically, section 319 required states to assess NPSP and develop Best Management Practices (BMP). The goal of a BMP is to prevent loss of pollutants to the environment. A BMP is developed with the goal of not exceeding the assimilative capacity for a given land or water body. The assimilative capacity is the concentration at which the pollutant begins to significantly alter the integrity of a land or water mass. Areas where land use is expected to significantly contribute to NPSP are targeted for BMP implementation. These areas include construction sites, mining areas, military grounds, silvicultural lands and agricultural lands (Novotny and Olem, 1994). Applying manure slurry to agricultural land is a practice of particular interest for NPSP. There are benefits and risks of applying manure to soil.

1.1.1 Benefits of Manure Application

Land application of manure is an established practice used to dispose of animal waste and amend soils. Manure can improve physical and chemical properties of soil. Mathers and Stewert (1984) reported that manure application increased soil organic matter, decreased bulk density and increased hydraulic conductivity. Wilkins and Rasmussen (1993) reported that adding manure to soil reduced the draft of tillage tools. Manure increases nitrogen, phosphorous and potassium concentrations in the soil (Motavalli et al 1985). Land application of slurry is an acceptable practice because of the high assimilative capacity of soil.

1.1.2 Risks of Manure Application

The risks of manure application are:

1. Nutrients can be lost to air or water where they act as pollutants.
2. The application rate may not match crop needs.

Consider surface applied liquid manure with organic and inorganic nutrients. Availability of nutrients from manure to crops may be highly variable depending on interactions between manure and soil (Schell and Alder, 1997). Soluble inorganic nutrients are distributed through the soil profile as liquid manure infiltrates the soil. Soluble nutrients are available for crop use. Soil biota break down organic nutrients and make the nutrients available to crops. Nutrients distributed through the soil by infiltration may or may not meet the crop needs due either to availability or distribution.

Manure nitrogen consists of inorganic and organic nitrogen. Organic nitrogen is not available to the crop until it is mineralized by soil biota. Nitrogen mineralization converts organic nitrogen to ammonium (NH_4^+). In this form nitrogen is available for crop use. Ammonium is not very mobile as it may be held in the soil cation exchange. Additionally, NH_4^+ can undergo immobilization or nitrification. Immobilization occurs when soil biota consume NH_4^+ and return it to an organic form. Nitrification converts ammonium (NH_4^+) to nitrite (NO_2^-) to nitrate (NO_3^-). Nitrate is also available for plant uptake. Under anaerobic conditions NO_3^- can undergo denitrification whereby N_2 is released to the atmosphere. NO_2^- and NO_3^- are easily dissolved in water and, therefore, are highly mobile. These dissolved pollutants are transferred by runoff and infiltration. Nitrogen leached to ground water can lead to high subsoil NO_3^- concentrations (Mathers and Stewart, 1984; Chen and Tessier, 2001). Excess leached NO_3^- in ground water used for drinking is a health risk.

Methemoglobinemia is caused when nitrates react with hemoglobin and impair oxygen transport in blood (Humenik et al., 1982a). Surface waters receiving runoff containing inorganic nitrogen are susceptible to increased aquatic plant growth and, subsequent eutrophication.

Inorganic phosphorous (P) added to soil is fixed and held by a number of processes. Phosphorous that infiltrates into the soil is easily fixed by sorption to clays (aluminum and iron oxides). Phosphorous becomes available for plant uptake as it desorbs from clay. Phosphorous may also be precipitated by binding with calcium. The effects of precipitation can be reversed by dissolution. Immobilization of soil solution P occurs when it is consumed by soil biota and held as organic P. Organic P can be mineralized and release inorganic P for plant uptake. Phosphorous fixation and release may occur simultaneously over time at different rates. Phosphorous build up is a problem when P is applied at rates that exceed removal (Motavalli et al., 1985). Phosphorous may also be lost from the soil through leaching and surface water runoff. Runoff can remove P fixed to soil particles in sediment. The sediment accumulates in lakes and streams. The phosphorus is released over time and perpetuates eutrophication. Phosphorous leaching generally occurs in sandy soils with excessively high soil test levels.

Poor infiltration of manure into soil may result in non-uniform distribution of nutrients and nutrient loss. Overland flow and pooling are more likely to occur when the liquid manure is slow to infiltrate into the soil profile. Pooling of nutrients in lower areas of the field causes non-uniform distribution. Volatilization of NH_4^+ to NH_3 occurs when manure is left exposed to air and NH_3 dissipates into the atmosphere. Soil nitrogen is decreased and odors increased by ammonia volatilization. Nitrogen losses from volatilization vary greatly with the manure applied and the atmospheric and soil conditions (Jokela and Cote, 1994). As much as 80 percent of manure nitrogen may be lost to volatilization when manure is not incorporated (Jokela and Cote, 1994; Humenik et al 1982a).

The application method determines manure distribution within the soil profile. Surface applications result in nutrient stratification where greater concentration of nutrients are near the soil surface. Large nutrient concentration in the surface soil present a higher risk of nutrient loss to the environment.

Tillage can be used to incorporate manure into the soil. Incorporating slurry into the soil increases the soil/slurry interface so soil biota can break down organic nutrients. Tillage also places the nutrients in the root zone where they can be used. Tillage can stimulate nitrification and increase soil temperature (Cavigelli et al., 1998). Aggressive tillage lifts, fractures, and alters the soil structure. Increased soil disturbance increases permeability, surface water storage capability and reduces runoff volume. Dunn and Phillips (1991) compared no-till and conventional tillage infiltration rates using a double ring infiltrometer. Conventional tillage infiltration rates were greater than no-till infiltration rates.

Incorporating slurry into the soil with tillage brings additional challenges. Tillage disturbs the soil structure making it susceptible to erosion. The most predominant pollutant in surface waters is eroded soil sediments. Sediment can change water column depth, temperature and habitat for aquatic life. Limiting tillage can reduce erosion by 60 to 99 percent by preserving residue cover (Humenik et al., 1982b). Aggressive tillage can reduce the soil residue cover and increase the risk of erosion. Residue can absorb some of the kinetic energy of wind and rain before it reaches the soil particles. Many studies comparing no-till and minimal tillage systems with conventional tillage showed that reduced tillage yielded less runoff sediment and volume, but the runoff from no-till fields had increased nutrient dissolved concentrations (Humenik et al., 1982b). The greater concentrations were caused by more nutrients remaining near the surface when there was little or no incorporation of nutrients.

Implementing BMPs that control placement and retention of nutrients to meet crop needs can reduce the risk of pollution. These practices include precision application and slurry incorporation. Precision application is used to distribute slurry nutrients to meet crop needs on a field scale. Tillage helps to retain nutrients in the root zone thereby reducing the risk of nutrient loss to the environment. At the same time tillage can increase the risk of erosion. Finding an appropriate method to uniformly distribute and retain nutrients in soil may require new application methods. There is a need to evaluate the ability of new manure slurry injection tools to place the slurry uniformly throughout the soil profile and prevent overland flow.

1.2 Literature Review

1.2.1 Precision Application

Precision agriculture allows producers to track slurry application and match application rates with crop needs. An aim of precision agriculture is to manage variability to enhance economic return and diminish environmental impacts (Morgan et al., 1997). Geographic referencing of agricultural data is done with a Global Positioning System (GPS). Site-specific information such as soil nutrients are geo-referenced with a GPS and stored, managed and displayed using a Geographical Information System (GIS). GIS software allows spatial analysis of geo-referenced information.

Variable rate application (VRA) of manure allows application of slurry to match crop needs. There is a need to use precision agriculture for animal waste application (Fleming et al., 2001). The challenges of slurry VRA include configuring equipment for uniform application, real time measurement of soil and manure nutrients and variable rate control.

Lague (1991) evaluated the application uniformity of a manure injection system. Due to the difficulty in evaluating the subsurface application uniformity, the experiment was performed above ground using collection pans. The length distribution proved to be highly variable due to the hydraulic head loss as the tank emptied. Of the four injectors on the distribution manifold, the two in the center always injected more manure. Thus, equipment should be configured to distribute slurry uniformly for the width and length of application.

Sensor based systems use real-time sensors for VRA feedback control (Morgan et al., 1997). An example of an electronic soil sensor is the Veris™ electrical conductivity (EC) cart. Soil EC can be used to predict soil chemical and physical properties. Ehrhardt et al (2001) found that EC can be used to predict draft. Kravchenko et al. (2002) created soil drainage maps using soil sampling and found that geo-referenced topographical and EC data could be used to increase map accuracy. Johnson et al., (2001) classified soil on a field scale basis using Veris™ EC values. Johnson et al (2001) reported correlations between EC and other soil properties such that EC could be used as a predictor of field soil properties. Electrical conductivity effectively predicted soils of varying soil texture, moisture, bulk density (BD) , phosphorous (P), pH, cation exchange capacity (CEC) and organic matter (OM; Johnson et al., 2001). Measurement of EC using Veris™ allows large areas to be sampled quickly and inexpensively. These measurements may be used to predict soil nutrient content and manure application rates changed in real time to provide suitable precision application control.

Variable rate application of manure has been limited. Precision application require precision metering and control. The application rate is a function of the slurry flow rate, slurry nutrients, soil nutrients, crop needs and the speed of the implement. Glancey et al., (1997) developed a solid manure box spreader which was equipped with two screw conveyors to deliver manure to rear-mounted spinning plates. The screws were driven by a hydrostatic motor. Strain gauges were attached to the axles and hitch to determine the mass flow rate of the manure. The averaged strain gauge values were used to reduce noise from bumpy off road conditions. An onboard ultrasonic speed sensor and DGPS system were used to measure ground speed. The mass flow rate and ground speed were used to control the hydrostatic motor on the conveyor. The system was capable of VRA from 2,300 to 11,400 kg /ha (2050 to 10180 lb/acre).

Chenard et al. (1992) designed a 28.2 meter wide, hose fed, liquid manure applicator. Two-stage flow control yielded precision control across the width of application. Precision liquid manure application requires suitable and adaptive control. The sensors and controls must also respond quickly to avoid spills. Munack et al., (2001) developed adaptive predictive control for liquid manure. They used a magnetic inductive flow meter which measured the travel time difference in magnetic pulses. The signal from their magnetic inductive flow meter suffered from lags and delays which greatly reduced the controller stability margin. The controller was improved with a Kalman filter and a Smith Predictor. These improvements increased the speed and stability of the controller for adequate precision control.

1.2.2 Slurry Incorporation Methods

When manure slurry is left on the soil surface nutrients can be lost to volatilization and runoff or redistributed by overland flow. Slurry incorporation creates soil voids to hold slurry in place after application and mix slurry with soil for increased soil/slurry interface. Nutrients are available for crop use because they are held in the root zone by the soil. Finding the appropriate amount of tillage is a challenge. Insufficient tillage can result in inadequate slurry incorporation. But increased incorporation of slurry with tillage can result in increased soil erosion. The purpose of the tillage is to incorporate the slurry into the soil by disturbing the soil, injecting the slurry and in some cases covering the slurry.

Disturbing the soil creates a void to receive the manure. Methods used are knife or chisel, concave disk coulter, s-tine cultivator, sweep, aerator and the combination of shank and coulter (Jokela and Cote, 1994; Chen et al., 2001; Schell and Alder, 1997). A knife injector opens a deep, narrow cavity in the soil. A concave disk injector has two opposing disks that cover manure that has been applied on undisturbed soil. A coulter is used to cut through crop residue. It is also suitable for opening grassland soil with low disturbance. An s-tine cultivator is similar to a knife. The difference is that the s-tine has small winged tips. This allows for greater soil disturbance at a more shallow depth resulting is less required draft than with a knife (Negi et al 1978). Sweep type injectors have even larger wings than s-tines. Sweep injectors result in a more horizontal distribution compared with concentrated vertical bands resulting from knife injection. A rolling-tine harrow perforates the soil making voids for the manure to flow into. It is suitable for grassland due to low disturbance and a reduced banding effect.

An injector draft requirement is the sum of the soil cutting forces and the frictional forces on the tool (Huijsmans et al., 1998). The soil frictional forces are a function of soil conditions and the surface area of the tool. Soil cutting for manure injection is accomplished horizontally (wing and sweep tools) and vertically (disc or knife type tools). Koolen and Kuipers (1983) and Chen and Tessier, (2001) considered a winged tool to be a two dimensional plane separating a soil beam from the furrow bottom. The separation resulted in a short-lived cavity that was filled by the soil beam.

Disc and knife tools simply open a furrow. The soil cutting forces are a function of soil conditions, the depth of injection and the effective cross-sectional area being moved through the soil. The effective cross-sectional area is dependent on the rake angle for wing and sweep tools. Reducing the depth or the cross-sectional area reduces the draft but also reduces the manure void volume. Reduced power requirements are achieved for a given application rate with shallow wing or sweep type injectors. Sweep and wing injectors increase the allowable application rate at shallow depths by providing sufficient voids to receive manure (Negi et al., 1978).

An objective of manure injection is to cover the manure with soil or place the manure below the soil surface. Wing and sweep manure injection implements are designed to allow the disturbed soil to fall down on top of the injected manure. In some cases cover disks are used to ensure that injected manure is well covered. Insufficient coverage occurs two ways, "overflow manure" and "in-furrow manure" (Chen and Tessier, 2001). "Overflow manure" results when the liquid manure flow exceeds the injection capacity of the tool (Chen and Tessier, 2001). "In-furrow manure" results from a tool soil configuration with insufficient backfill to cover the manure in the furrow. (Chen and Tessier, 2001). For example, backfill will inevitably occur with a winged tine in sandy soil. However, backfill is not likely to occur with a coulter in clay or grass. Pooling occurs when the volume of the manure exceeds the volume of the cavity formed to receive it. Pooling is undesirable because of increased volatilization and runoff risk.

Pooling may be reduced by increasing the injection depth or decreasing the application rate (Chen et al., 2001).

Negi et al. (1978) evaluated cover performance and application uniformity of a sweep tine manure injector prototype using empirical excavation. The prototype was used to inject manure at 5 application rates. Twenty-four hours after injection, 30 cm (12 in) sections of the disturbed profile were excavated and measured. The depth of the cover, depth of injection and the depth of the slurry soil mixture were measured. The measured placement and uniformity were compared with the intended application distribution. In this manner the effectiveness of the application was measured. Wide injectors at shallow depths were observed to minimize draft while sufficiently distributing and covering slurry for agronomic requirements

Aeration tillage tools perforate the soil creating voids in the soil surface for manure placement. One such tool is the Aerway™ Sub-surface Deposition (SSD) Slurry Manure Applicator (Appendix C, Figures C2-C5). The Aerway™ uses ground-driven tines on a rolling shaft to perforate the soil surface requiring less power and resulting in less soil disturbance than traditional injectors (Bittman et al., 2000). The shatter tines are 20 cm (8 in) long and mounted with a small tilt on two 8.9 cm (3.5 in) diameter shafts (Appendix C, Figure C2). Figure C1 shows the shatter tine helical mount configuration for two sets of shatter tines. A set of tines consists of four tines fixed perpendicular to the rotating gang shaft. Sequential soil penetration is accomplished with helical mounting of tines. Each adjacent row of tines is mounted 22.5 degrees ahead of the last row along the shaft. The rolling-tine shaft gangs pivot with respect to the frame from zero to ten degrees (zero being normal to direction of travel) in two and one half degree increments

(Appendix C, Figure C3). When the gangs are set at zero degrees the tines roll parallel to the direction of travel and disturb little soil (Appendix C, Figure C16). The ten degree tine gang angle setting results in more aggressive tillage (Appendix C, Figure C17). Manure injection nozzles are mounted behind each set of tines. The nozzles are connected to a distribution manifold which chops and distributes manure to the nozzles.

At the zero degree gang angle setting the tines made voids in the soil that were 19 cm (7.5 in) long, 2.25 cm (0.89 in) wide and up to 11.5 cm (4.5 in) deep (Fuchs and Zumwinkle, 2002). The void capacity was 0.14 L (0.036 gallons). The tool made about 72,600 holes per acre resulting in an overall void capacity of 24,000 Lha^{-1} (2,600 gpa).

1.2.2.1 Environmental Benefits

Manure incorporation reduces nutrient loss in sediment, runoff, and by volatilization. Pollutants such as phosphorous which are bound to soil particles and transported with sediment can be controlled by limiting tillage.

Placing manure under the soil can reduce concentrations of nutrients in runoff and leachate. Runoff characteristics of agricultural practices are often compared using a rainfall simulator. A simulator is used to create comparable hydrologic events to generate runoff from test plots. Thompson et al (2001) used a rainfall simulator to evaluate the effect of raindrop energy on sediment load and soluble chemical transport. Sediment loss, soluble chemical leaching and soluble chemical in runoff were found to be functions of raindrop energy. Ross et al. (1979) treated Bluegrass sod and tilled soil (silt loam texture) with surface applied manure and spring tooth bar injected manure at two depths. Runoff was collected from simulated rainfall generated by a sprinkler irrigation system. The chemical oxygen demand (COD), total solids, pH, dissolved oxygen, and fecal coliform of runoff were measured. Manure injection was found to substantially reduce pollutants in runoff. The first 100 L (26 gallons) of runoff from the surface applied plots had COD 17 times greater than the runoff from injected plots.

Fuchs and Zumwinkle (2002) used a rainfall simulator to collect runoff from alfalfa plots treated with a broadcast manure with Aerway™ tillage, no manure with Aerway™ tillage, manure without tillage and no tillage or manure. The tool was configured so that manure was applied ahead of the rolling-tines. They measured runoff for total solids, particulate phosphorous, soluble phosphorous, bioavailable phosphorous, total phosphorous, BOD and COD. The Aerway™ tillage reduced the runoff flow rate. However the total volume of runoff and concentration of pollutants in runoff were not reduced.

Schell and Alder (1997) investigated liquid manure in reduced tillage cropping systems. With the cooperation of producers, they incorporated manure into reduced tillage cropland. After measuring nitrate movement they concluded that the risk of nitrate leaching into ground water was not greater by applying manure compared to inorganic fertilizers using similar nutrient levels.

When manure is left exposed to the air, nitrogen is lost to the atmosphere. Properly covering manure with soil retains the nutrients. Manure injection reduced ammonia volatilization by over 90% (Jokela and Cote, 1994) when injection was used. Volatilization was shown to be proportional to pooling of manure on the soil surface (Chen et al., 2001). Also, odor was reduced with injection (Jokela and Cote, 1994).

Bittman et al., (2000) measured ammonia volatilization resulting from broadcast, Aerway™ and dribble bar band slurry applications. The average ammonia emissions resulting from dribble bar application was 41% lower than emissions from broadcast applications. And the average ammonia emissions resulting from Aerway™ applications were 57% lower than the ammonia emissions compared with broadcast application. The average ammonia loss for broadcast applied manure was 40% of total applied. Petkau and May (2001) compared ammonia emissions of sleight foot, dribble bar and Aerway™ applicators during and after application. Overall, the average ammonia emissions were not different. However, the Aerway™ had the greatest ammonia emissions during application but lower after application emissions than the dribble bar once the manure was on the ground.

1.2.2.2 Crop Response

The negative effects of manure injection on crops are related to the disturbance caused by the application, poor placement of the nutrients, and the lack of uniform application. Petkau and May (2001) monitored grass yields plots treated with of sleight foot, dribble bar and Aerway™ slurry applicators. All applications of manure resulted in greater yields despite crop disturbance. Even though the sleight foot injector resulted in the largest losses due to crop damage it also resulted in the largest yields. Dribble bar yields were similar to the sleight foot yields.

Nutrient placement with respect to the plants is important. Too much manure too close to the plant can be toxic or inhibit growth (Sawyer et al., 1990). Injection of beef manure has caused plant stunting, chlorosis, and reduced yield in corn (Sawyer et al., 1991). However, manure injection more often leads to good quality, high yielding crops (Mathers and Stewart, 1984). Variability in application explains some the problems. Sawyer et al (1990) showed that sweep injected manure resulted in a more uniform lateral distribution of manure and inorganic N as compare with knife injected manure. Crops treated with sweep injection experienced a reduction in the time it took for the above ground maladies to pass.

Buckley et al. (2001) used axle mounted load cells to apply manure with an Aerway™ SSD injector. Manure was applied at 0.5x, 1x and 2x recommended ammonia N rates for 3 oat and 3 barley varieties. Inorganic fertilizers were applied at the same rates on adjacent plots for comparison. Manure application produced yields similar to fertilizer application.

1.3 Objectives

The overall objective of this study was to evaluate the field performance of a low disturbance rolling-tine slurry manure injector. Specific objectives were to:

1. Determine how tillage with a rolling-tine harrow influences initial water infiltration rates.
2. Assess the uniformity of slurry placement throughout the injection zone.
3. Evaluate changes in soil electrical conductivity following manure slurry injection, and the stability of the electrical conductivity measurements over time.
4. Evaluate correlations between electrical conductivity and soil properties.

CHAPTER 2

2. METHODS AND MATERIALS

Infiltration rate and application uniformity are of interest for manure injection implement evaluation. Many manure injection systems are commercially available including a rolling-tine harrow (Aerway™) . The tool can be used for tillage in orchards, pastures, turf grass and cropland. Minimal and aggressive tillage are possible by making changes in the gang angle. In this study, the Aerway™ was evaluated for its effect on water infiltration rate, uniformity of application, and effect on soil electrical conductivity. Images in this thesis are presented in color.

2.1 Rolling-tine harrow

A 3.66 m (12 foot) Aerway™ rolling-tine harrow for low-disturbance slurry injector was evaluated. The implement weighed 2268 kg (5000 lbs), and 680 kg (1500 lbs) was added for full penetration of the tines. The manure injector was hitched to a Nuhn™ 13627 L (3600 gal), dual axle manure slurry spreader. The spreader's splash plate was replaced with a 15 cm (6 inch) hose from the tank to the grinder on the injector (Appendix C, Figure C5). The power take-off from the tractor was used to drive a positive displacement pump on the spreader, and a hydraulically actuated butterfly valve controlled the flow rate to the Aerway™ (Appendix C, Figure C8). The valve allowed excess flow to the tank for bypass agitation. Power take-off rpm and land speed were held constant at 2200 rpm and 4.6 kph (2.9 mph) respectively. The application rate was 49100 Lha^{-1} (5,250 gpa) for all treatments receiving manure. The application rate was calculated based on speed, time and mass of manure applied. The manure passed through a hydraulically powered grinder mounted on top of the Aerway™ (Appendix C, Figure C4-6). The grinder had two plates that rotated over 18 equicentric, radially configured outlets connected to the distribution lines (Appendix C, Figure C6). The grinder plates did not allow slurry to pass through the outlets when they were over the outlets, which increased the available pressure to the outlets that were not covered and created uniform flow to each distribution nozzle. The grinder plates also chopped larger solids that might get caught in 5 cm (2 inch) outlets. The distributor hoses had rubber nozzles on the end that were positioned close the ground. The hydraulic cylinder used to raise the Aerway™ for transport was connected to a linkage which pinched the rubber nozzles preventing flow during transport (Appendix C, Figure C7).

Manure samples were collected from the tank in the field before application. The manure was agitated in the storage tank and in the field tank to ensure uniform consistency. Frozen samples were sent to the University of Wisconsin Soil & Forage Analysis Lab for nutrient analysis (Table 1).

Table 1: Liquid dairy manure analysis

Property	Sample 1		Sample 2	
	g/L	lbs/1000 gal	g/L	lbs/1000 gal
Total Nitrogen	3.38	28.21	3.35	27.94
Total P_2O_5	1.27	10.57	1.31	10.91
Total K_2O	3.67	30.67	3.69	30.76
Sulfur	0.36	2.99	0.35	2.96
Moisture	89.70 %	89.70 %	90.10 %	90.10 %
Dry Matter	10.30 %	10.30 %	9.90 %	9.90 %

Two sets of experiments were conducted on a Capac sandy loam (fine-loamy, mixed, active, mesic Aquic Glossudalfs) soil. The first was to evaluate the effects of rolling-tine harrow tillage without manure. The second was used to evaluate the effects of rolling-tine harrow tillage with manure. Data from the experiments were analyzed using SAS™ (SAS Inc., 2002). Analysis of variance of was done using the PROC MIXED procedure in SAS™. Mean separation and pair wise comparisons were made using the Fischer's protected Least Significant Difference (LSD) procedure (Kuehl, 2000).

2.2 Tillage with the rolling-tine harrow, no manure

The first experiment was used to evaluate the effects of tillage on initial water infiltration and residue cover in a Capac soil. The experiment was arranged in a randomized complete block with four replications. The tillage treatments included: 1) no tillage, 2) light tillage (0° gang angle), and 3) aggressive tillage (10° gang angle) using the rolling-tine harrow in untilled wheat stubble. Treatment plots were 3.7 m (12 ft) wide by 30.5 m (100 ft) long. No manure was applied.

2.2.1 Initial Infiltration Rate

Infiltration rate is a measure of the permeability of the soil. Generally, increasing tillage increases the infiltration rate since tillage increases pore space and the volume of adsorption cavities. Increasing the infiltration rate in manure application is important because it reduces the chance of overland flow and pooling of manure. Pooling can result in non uniform application, increased volatilization and increased risk of nutrient loss to runoff.

A double ring infiltrometer was used to measure the water infiltration rate at two locations within each plot (Appendix C, Figure C10). The double ring infiltrometer consisted of a 46 cm (18 inch) diameter ring, 46 cm (18 inch) high, a 20 cm (8 inch) diameter ring, 46 cm (18 inch) high, 2 calibrated water storage columns, and a depth gauge. The columns and rings were plumbed in such a way as to control and measure the water flowing into each ring. Both rings were driven concentrically 10 cm (4 inches) into the ground in the plot. Water was first added to the outer ring to a depth of 2.5 cm (1 inch). Water was then added to the inner ring to the same depth at which time the timer was started (time 1). Equalizing the depth of water in each ring equalized the head. The water levels in each ring were kept at 2.5 cm (1 in) for an hour. The water level of the calibrated column connected to the inner ring was recorded every 10 minutes. The water level of the column connected to the outer ring was not recorded. The infiltration rate for a given time interval was calculated as:

$$I_r = \frac{(C_1 - C_2) * C_A}{(T_1 - T_2) * R_A} \qquad \text{(Equation 1)}$$

where I_r is the infiltration rate, C_1 is the column height at time 1, C_2 is the column height at time 2, C_A is the column area, T_1 is the time 1, T_2 is time 2 and R_A is the area of the inner ring (Appendix A, Table A1). Time 1 was the timer start time and time 2 was 10 minutes after. The PROC MIXED model used to analyze infiltration included treatments as fixed factors, blocks as a random factor, the interaction of blocks with tillage treatment and the interaction of blocks with north or south sampling positions as error terms. Least Significant Difference (LSD) pair wise comparisons were made for significant treatment effects for initial infiltration.

2.2.2 Residue Cover

Residue cover is important for soil moisture retention and erosion reduction. Residue cover was measured in the middle of the plots used for the infiltration study. The line transect method was used (Hathaway et al., 1993). A tape measure was laid diagonally across each plot. The residue presence was observed every 15 cm (6 inch).

For example, if there was residue on the soil directly below the 15 cm (6 inch) mark on the tape then it was recorded as a crop residue intersect. If the soil was bare directly beneath the mark than it was not counted. The residue cover is given as:

$$X_{100} = \frac{N_i}{T_i} * 100 \qquad \text{(Equation 2)}$$

where X_{100} is the percent residue cover, N_i is the number of crop residue intersects and T_i is the total number of intersects (Appendix A, Table A2). The PROC MIXED model used to analyze differences in residue cover included treatments as a fixed factor and blocks as a random factor. LSD pair wise comparisons were made for significant treatment effects for residue cover.

2.3 Tillage with the rolling-tine harrow, with manure

The second experiment was used to evaluate the effects of tillage with manure application on surface manure coverage, soil bulk density, nutrient placement uniformity and electrical conductivity in a Capac soil. Four tillage treatments were applied with four replications on wheat stubble in a randomized complete block design. The tillage treatments were: 1) no tillage and no manure, 2) no tillage with manure, 3) light tillage (0° gang angle) with manure and 4) aggressive tillage (10° gang angle) with manure. Treatment plots were 3.6 m (15 ft) wide by 30.5 m (100 ft) long. Manure coverage, bulk density, soil Bray 1 phosphorous (P) concentration, and soil electrical conductivity (EC) were measured to evaluate treatment effects.

2.3.1 Surface Manure Coverage

Digital images of the soil surface were taken immediately following application for assessment of the surface coverage of the manure. The percent manure surface coverage was estimated as:

$$P_{SMC} = \frac{M_{SA}}{T_{SA}} \qquad \text{(Equation 3)}$$

where P_{SMC} is the percent manure surface coverage, M_{SA} is the manure surface area and T_{SA} is the total surface area. The area of the manure cover was calculated by drawing polygons over the manure in *Arcview*™ and finding the total area of the polygons (Appendix A, Table A3). The PROC MIXED model for the analysis of surface manure coverage included treatments as a fixed factor and blocks as a random factor.

2.3.2 Bulk Density

Tillage affects bulk density by increasing pore space. The bulk density samples were taken using a slide hammer core sampler (Appendix A, Table A4). The samples were taken 1 day after application on light and aggressively tilled plots with manure. The cores were taken on the north and south end of each plot to a depth of 23 cm (9 inch) with three 7.6 cm (3 inch) incremental samples. The samples were oven dried at 105 °C (221 °F) until constant weight was reached (Blake and Hartge, 1986). The bulk density was calculated as:

$$\rho_b = \frac{D_M}{C_V} \qquad \text{(Equation 4)}$$

where ρ_b is the bulk density, D_M is the dry mass and C_V is the core volume. The PROC MIXED model for the analysis of bulk density included treatments as a fixed factor and blocks as a random factor. Pair wise comparisons were made for significant treatment effects for bulk density.

2.3.3 Volume and surface area of tilled soil

To aid in identifying slurry placement in the soil profile, fluorescent yellow/green dye from *Kingscote Chemicals Brightdyes* was added to the manure. Liquid dye was chosen over powder for enhanced mixing with the manure. Fluorescent green/yellow dye was added to liquid manure at 250 ppm. The dye was reported to be visible in water at a concentration of 1 ppm, and with a black light at 10 ppb. The dye was used to identify manure placement in the soil. The dye improved the visibility of the manure in contrast to the soil.

The intent in excavating the injection profile 3 days after manure application was to reveal the distribution of the manure in soil cavities. Digital images of the soil profile could then be used to evaluate uniformity. However, the dye manure mixture was not clearly visible and the black light did not cause the dye to fluoresce.

Rather than recording images of the soil profile and slurry/soil mix *insitu.*, the soil / slurry mixture in the soil loosened by the tillage tines was excavated and a powdered dye was applied to the surface of the tillage cavities. Orthogonal dimension referenced digital images were taken of the cavities. Estimated dimensions from the pictures were used to make void models. The 1:1 scale models were made to have the same shape as the top view of the void. A cloth material was fastened to the cardboard profile as to hang to the depth indicated in the photos. Coordinate measurements were taken on a 6.5 cm^2 (1 in^2) grid. The coordinates were used to make 3-D views in *Arcview* (Appendix C, Figures C18-19). The tilled surface area, void volume (cm^3) and surface area of undisturbed soil in voids were calculated for the light and aggressive void models.

2.3.4 Nutrient Placement Uniformity

Nutrient distribution from manure injection can be assessed by measuring soil nutrient concentrations around the point of injection (Sawyer et al., 1990). Changes in the nutrient content of the cores reveal where the nutrients have been placed. In this way nutrient concentration can be used as a tracer of subsurface manure placement.

Phosphorous was used as the tracer to evaluate the uniformity of nutrient placement throughout the soil profile. The P transect samples were taken at incremental positions relative to tillage with a 7.6 cm (3 in) diameter Giddings probe. The samples were divided into depths of 0-7.6 cm (0-3 in), 7.6-15 cm (3-6 in) and 15-23 cm (6-9 in). The positioning scheme is represented in Figure 1.

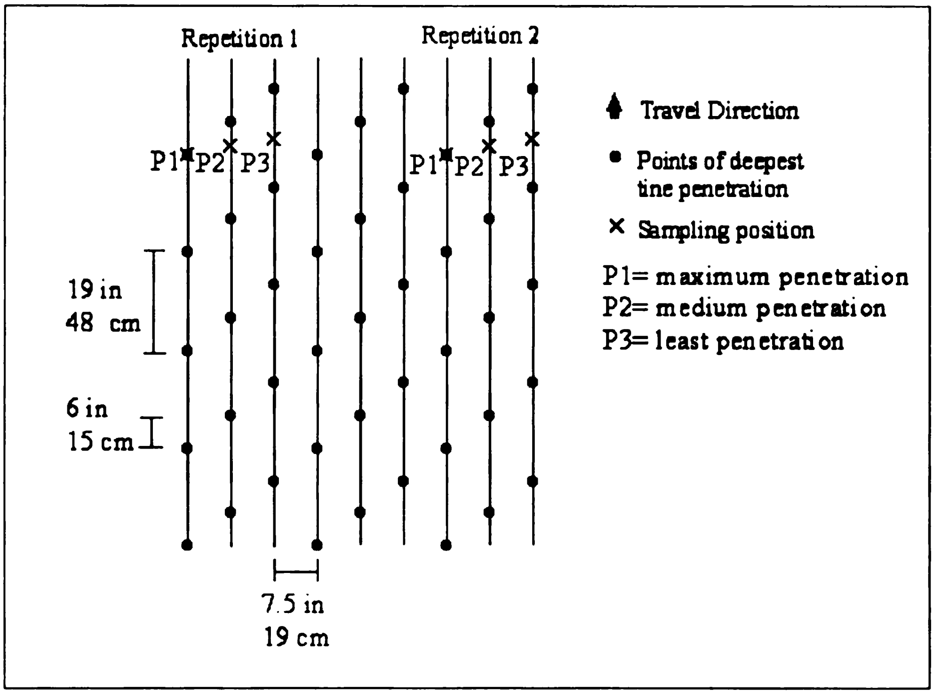

Figure 1: Position of sampling for phosphorous relative to tillage

The samples were air dried, ground and sent to the Michigan State University Soil and Plant Nutrient Laboratory where the Bray 1 – P test (Frank et al., 1998) was used to measure extractable P (Appendix A, Tables A5-8).

Treatment, position and depth were treated as fixed factors in the PROC MIXED model for the analysis of nutrient placement. In the analysis, block as a random factor and the block with treatment interaction, and the block with treatment and position interactions as error terms. Mean separations were conducted using Fishers's protected LSD. Soil EC was used as a covariate in a second analysis of the same model. A covariate is a variable that is related to the response variable of interest (Kuehl, 2000). Covariates are used to adjust the analysis to reduce experimental error.

2.3.5 Electrical Conductivity

A Veris™ 3100 (Appendix C, Figure C11) was used to measure the soil EC at depths of 30 cm (1 ft) and 91 cm (3 ft). The tool was used on the entire test site one day before, 1 day after and 1 week after application of treatments. Two coulters with an electrical potential between them penetrate the soil. The EC of the soil is measured as current induced through the volume of soil between the coulters with a voltaic potential. The Veris™ system uses six coulters. The center pair emit the electrical signal. The two that are adjacent to the center coulters measure 30 cm (1 ft) EC. The two coulters that are further apart measure EC to 91 cm (3 ft).

The EC data sets did not have the same number of readings per plot due to speed variation of the towing vehicle. Using an unequal number of values in ANOVA may bias results to plots with the highest or lowest number of readings. For this reason the values were used to make an interpolated grid so that an equal number of readings could be extracted from each plot. A grid size of 1.5x1.5 m (5x5 feet) was used to ensure that at least one actual EC value was used per grid point. Inverse distance weighting, with power of 2, was used to interpolate the EC data. An equal number of interpolated values was extracted from the interpolated grids (Appendix A, Figures A1-6) and used in the ANOVA analysis. Only the points located in the center of the plots close to the location of the original data points were extracted. Extracted interpolated grid values (EIGV) from the plot edges were undesirable because they did not reflect the values for the plot but an interpolation of the values from both plots. Absolute EIGV for one day before, one day after and one week after application (Appendix A, Table A9-14) were used in ANOVA to find differences between treatments.

Soil EC is dependent on soil properties so both were measured using a management zone approach. The initial 0.3 m (1 ft) measurements were mapped. Three management zones were established based on the 0.3 m (1 ft) EC interpolated values. A total of 17 flags were placed in 3 zones with more flags in larger zones. The flags were geo-referenced using a Trimble® AgGPS 124 reciever. The nearest neighbor method was used in *Arcview* GIS to extract soil EC values for each flag.

Soil cores were taken at the flags before treatments to a depth of 0.91 m (3 ft). The core was divided into depths of 0-0.15 m (0-0.5 ft), 0.15-0.30 m (0.5-1 ft), 0.30-0.61 m (1-2 ft) and 0.61-0.91m (2-3 ft). The samples were sent to A&L Great Lakes Laboratories for analysis. The measured soil properties were organic matter (OM; Combs and Nathan, 1998), phosphorous (P; Frank et al., 1998), potassium (K; Warnke and Brown, 1998), magnesium (Mg; Warnke and Brown, 1998), calcium (Ca; Warnke and Brown, 1998), pH (Watson and Brown, 1998), and cation exchange capacity (CEC; Warnke and Brown, 1998; Appendix A, Tables A15-18).

Sub-samples of the flag cores were taken to measure gravimetric soil moisture (Appendix A, Table 20). Samples were stored at 4° C (40° F) in air tight bags. The samples were weighed to the nearest 0.01 g before drying. The samples were air dried for a few days before being oven dried at 105° C (221° F) to constant weight (Gardener, 1986). After drying, samples were reweighed. The gravimetric soil moisture content was calculated as:

$$P_{SM} = \frac{(W_M - D_M)}{D_M} \qquad \text{(Equation 5)}$$

where P_{SM} is the percent soil moisture, W_M is the wet mass of the soil, and D_M is the dry mass of the soil.

The soil EC PROC MIXED model used tillage treatments as a fixed factor, block as a random factor and the block treatment interaction as an error term. Multiple EC measurements for each plot were treated as sub samples. Pair wise LSD comparisons were made for mean separation of significant treatment effects.

Multiple regression was performed with the PROC REG stepwise procedure in SAS ™. Soil EC was used as the dependent variable and organic matter, phosphorous, potassium, magnesium, calcium, pH, cation exchange capacity, gravimetric soil moisture, and bulk density were used as the independent variables.

CHAPTER 3

3. RESULTS AND DISCUSSION

Two sets of experiments were conducted. The first was to evaluate the effects of rolling-tine harrow tillage without manure. The second was used to evaluate the effects of rolling-tine harrow tillage with manure. Data for both sets of experiments are tabled in Appendix A. The ANOVA tables are given in Appendix B.

3.1 Tillage with the rolling-tine harrow, no manure

3.1.1 Initial Infiltration Rate

An objective of the infiltration rate study was to determine how tillage provided by the rolling tine harrow influenced the initial infiltration rate. The initial infiltration rate is important because it affects how quickly the slurry may be incorporated in the soil profile. Rapid infiltration may reduce overland flow, pooling, and minimize odor and volatile N loss. Infiltration rates over longer time intervals were not of interest. The tillage treatments had significantly different ($P<0.05$) infiltration rates during the first ten minutes of infiltration (Appendix B, Table B1). The LSD procedure was used to evaluate differences between the means of the ten minute infiltration rates for each tillage treatment (Table 2).

Table 2: Ten minute water infiltration rates for a loam soil with a rolling-tine harrow

Effect	*Ten Minute Infiltration Rate*	
	cm/hr	in/hr
No tillage	16.1 a	6.34 a
Light tillage	13.5 a	5.31 a
Aggressive tillage	22.4 b	8.82 b
LSD(0.05)	2.9	1.14

Means within each column followed by the same letter are not significantly different ($p \leq 0.05$).

The ten minute infiltration rate mean for light tillage was not different from no tillage. Light tillage was expected to increase the contact area and loosen the soil to some degree. The ten minute infiltration rates of the aggressively tilled plots were greatest and were different from plots receiving light or no tillage. The difference was likely due to the fracturing effect the aggressive tillage had on the soil. Presumably, more aggressive tillage may also speed the infiltration of manure slurry, reduce overland flow and pooling, increase soil/slurry interface, and improve the uniformity of nutrient placement.

3.1.2 Residue Cover

Residue cover is important because it can reduce erosion by absorbing rain drop kinetic energy and inhibit overland flow. Tillage resulted in significantly different ($P \leq 0.10$) residue coverage (Appendix B, Table B2). There was no difference between the residue cover of no tillage and light tillage. Aggressive tillage buried a greater amount of residue compared with light tillage or no tillage (Table 3).

Table 3: Wheat straw residue cover following tillage with a rolling-tine harrow on a loam soil.

Effect	Residue Cover (%)
No tillage	55.5 a
Light tillage	55.7 a
Aggressive tillage	41.9 b
LSD(0.10)	8.6

Means within each column followed by the same letter are not significantly different ($p \leq 0.10$).

3.2 Tillage with the rolling-tine harrow, with manure

3.2.1 Surface Manure Coverage

Surface manure coverage of the tilled plots was measured to evaluate the effect of low disturbance tillage on slurry placement (Appendix A, Table A3). The percent cover of the manure application without tillage was not calculated because tire traffic from the slurry injector interfered with the surface application (Appendix C, Figure C20). With tillage the tines were in the soil, and the tires were off the ground such that no interference occurred. No difference ($P \leq 0.10$) between manure surface coverage for light and aggressive tillage were found. This indicates plot scale uniform application for both treatments (Appendix B, Table B3). Taking the surface manure cover images immediately after treatment application did not allow time for the manure to infiltrate into the soil irrespective of tillage.

3.2.2 Bulk Density

Soil BD was measured on both ends of the light and aggressively tilled plots (Appendix A, Table A4). Tillage, depth and their interaction had significant effects ($P \leq 0.12$) on soil BD (Appendix B, Table B4). Bulk densities for light and aggressive tillage were not significantly different ($P \leq 0.12$) for 7.6-15 cm (3-6 in) depth (Table B4). Bulk densities at depths 0-7.6 cm (0-3 in) and 12-23 cm (6-9 in) were the same for light and aggressive tillage however soil bulk density at 7.6-15 cm (3-6 in) was significantly smaller in aggressive tillage. For light tillage soil bulk density at 0-7.6 cm (0-3 in) was smaller than that of the deeper soil. Aggressive tillage increased soil disturbance at a greater depth with bulk density at both 0-7.6 cm (0-3 in) and 7.6-15 cm (3-6 in) being significantly smaller than the density at the deeper depth.

Table 4: Soil bulk density (g/cm^3) following light and aggressive tillage

	Treatment	
Depth	Light tillage	Aggressive tillage
0-7.6 cm (0-3 in)	1.23 xa	1.21 xa
7.6-15 cm (3-6 in)	1.47 xb	1.28 ya
12-23 cm (6-9 in)	1.48 xb	1.42 xb

Means within each row followed by the same letter (x-y) are not significantly different ($LSD_{0.12}$=0.09)
Means within each column followed by the same letter (a-b) are not significantly different ($LSD_{0.12}$)=0.06

3.2.3 Volume and surface area of tilled soil

The fluorescent green/yellow dye was not an effective tracer for this application. The dye only fluoresced in solution. This greatly hindered empirical excavation. Orthogonal images of tine cavities were made by carefully removing the manure and back fill and highlighting the cavity with fluorescent powder (Appendix C, Figures C12-15). The images were used to make 3-D models in *Arcview* (Appendix C, Figures C18-19).

Table 5: Volume and surface area of tilled soil.

	Light tillage		Aggressive tillage	
	SI	English	SI	English
Tilled surface area	46 cm^2	7.1 in^2	280 cm^2	43 in^2
Tilled soil volume	120 cm^3	7.3 in^3	1000 cm^3	61
Void side wall surface area	240 cm^2	37 in^2	500 cm^2	76 in^2

1 L = 1000 cm^3
1gallon = 3.78 L

The tilled surface area, volume and void sidewall surface area of the 3-D voids created by light tillage were estimated as 46 cm^2 (7.1 in^2), 120 cm^3 (7.3 in^3; 0.12 L, 0.03 gallons) and 240 cm^2 (37 in^2), respectively. The tilled surface area, volume and void sidewall surface area of the 3-D voids created by aggressive tillage were estimated as 280 cm^2 (43 in^2), 1000 cm^3 (61 in^3; 1.0 L, 0.27gallons) and 500 cm^2 (77 in^2), respectively. The tilled surface area was the planar area looking down at the void while standing above it. The void volume was the volume of manure the void could hold (neglecting backfill). The void sidewall surface area was the total inside surface area of the void or the area where untilled soil and slurry would meet if the void was filled with manure. The void volume and void volume and void sidewall surface area were larger for the aggressive tillage indicating that more manure may be applied with aggressive tillage.

3.2.4 Nutrient Placement Uniformity

Manure application uniformity was evaluated using soil phosphorous (P) concentration measured at three positions and three depths relative to tillage (Appendix A, Tables A5-8). Bray 1-P was used as a tracer for slurry placement. Soil P concentration measured with respect to tillage was affected (P=0.05) by depth, position, the interaction of treatment with position and depth, the interaction of depth with treatment, the interaction of depth with position (Appendix B, Table B5). Comparisons between depths and positions relative to tine penetration were made for each treatment (Tables 6).

Table 6: Bray 1-P at 3 depths and 3 positions relative to tine penetration for 4 individual tillage and manure treatments

Depth	*Bray 1-P measured at Tine Penetration**			$LSD^{Positions}$ (0.10)
	Maximum	Medium	Least	
			ppm	
No tillage / no manure				
0-7.6 cm (0-3 in)	38 xa	35 xa	36 xa	17
7.6-15 cm(3-6 in)	21 xb	29 xa	25 xa	11
15-23 cm (6-9 in)	23 xb	19 xyb	12 yb	8.8
No tillage w/ manure				
0-7.6 cm (0-3 in)	54 xa	53 xa	51 xa	17
7.6-15 cm(3-6 in)	25 xb	25 xb	27 xb	11
15-23 cm (6-9 in)	13 xc	13 xc	19 xc	8.8
Light tillage w/ manure				
0-7.6 cm (0-3 in)	73 xa	61 xya	51 ya	17
7.6-15 cm(3-6 in)	43 xb	29 yb	30 yb	11
15-23 cm (6-9 in)	24 xc	13 yc	17 xc	8.8
Aggressive tillage w/ manure				
0-7.6 cm (0-3 in)	91 xa	80 xa	59 ya	17
7.6-15 cm(3-6 in)	32 xb	29 xb	27 xb	11
15-23 cm (6-9 in)	15 xc	13 xc	13 xc	8.8

* In treatments without tillage soil samples were taken at the same relative positions and spacing as in treatments with tillage

Means within each column for a treatment followed by the same letter (a-c) are not significantly different (p=0.05).

Means within each row followed by the same letter (x-y) are not significantly different (p=0.05).

$LSD^{Depth\ 1,2}$0.10)= 8.6, $LSD^{Depth1,3}$(0.10) = 12, $LSD^{Depth2,3}$(0.10) =6.6

Soil P concentrations decreased with depth regardless of tillage or tine penetration. Soil P concentrations showed no difference between tine position without tillage. The greatest soil P concentrations were recorded at positions of greatest penetration where soil was disturbed.

The same trend of soil P decreasing with depth was observed when data from all treatments were combined (Table 7). Comparing the soil P concentration at the 0-7.6 cm (0-3 in) layer, soil P concentration at position 1 (maximum penetration) was not different from position 2 (medium penetration). Position 2 was not different from position 3 at 0-7.6 cm (0-3 in). However the means of position 1 and 3 were different (Table 7). Manure filled the tillage depressions and caused greater P concentration in the depressions and slightly lower P concentration where there was less penetration. There was no difference between the positions at depths greater than 7.6 cm (3 in).

Table 7: Bray 1-P means for the interaction of depth and position for all treatments

Depth	*Tine Penetration Position*			$LSD^{Positions}$*(0.05)*
	Maximum	Medium	Least	
		ppm		
0-7.6 cm (0-3 in)	64 ax	57 axy	49 ay	10
7.6-15 cm(3-6 in)	30 bx	28 bx	27 bx	6.6
15-23 cm (6-9 in)	19 cx	14 cx	16 cx	5.2
$LSD^{Depth\ 1,2}$0.05)	5.2	5.2	5.2	
$LSD^{Depth1,3}$(0.05)	7.4	7.4	7.4	
$LSD^{Depth2,3}$(0.05)	4.0	4.0	4.0	

Means within each column followed by the same letter (a-c) are not significantly different. (p=0.05).
Means within each row followed by the same letter (x-y) are not significantly different (p=0.05).

Effect of tillage on soil P concentration was different at different depths (p=0.05, Table B5). Comparisons between tillage treatments were made at each depth to understand the interaction of tillage with depth. There was a difference in the magnitude of the soil P concentration at 0-7.6 cm (0-3 in; Table 8) The aggressive tillage with manure had greater P concentrations than all of the other treatments at 0-7.6 cm (0-3 in;

Table 8). Greater concentrations in tilled areas indicate less overland flow and greater infiltration of manure nutrients into the soil profile. The lowest P levels were recorded where there was no tillage and no manure applied. There was no difference between soil P in the 0-3 inch layer between the surface treatment and light tillage (Table 8).

Table 8: Bray 1-P means for the interaction of depth and treatment

Depth	*Treatment*				$LSD^{Treatments}$ (0.05)
	No tillage / no manure P	No tillage / manure P	Light tillage / manure P	Aggressive Tillage / Manure P	
	ppm				
0-7.6 cm (0-3 in)	36 ax	53 ay	61 ay	77 az	15
7.6-15 cm(3-6 in)	25 bx	26 bx	34 bx	29 bx	12
15-23 cm (6-9 in)	18 cx	15 cx	18 cx	15 cx	11
$LSD^{Depth\ 1,2(0.05)}$	6.0	6.0	6.0		
$LSD^{Depth1,3}_{(0.05)}$	8.5	8.5	8.5		
$LSD^{Depth2,3}_{(0.05)}$	4.6	4.6	4.6		

Means within each column followed by the same letter (a-c) are not significantly different. (p=0.05).
Means within each row followed by the same letter (x-y) are not significantly different (p=0.05).

3.2.5 Analysis of soil P with soil EC as covariate

Natural variability in soil P concentrations between plots existed before the experiment. Using the difference between soil P values before and after application of treatments is one way of reducing this experimental error. Using a covariate is another way.

A covariate is a variable that has a relationship with the response variable and varies among the experimental units. In the analysis of experimental data a covariate can be used to help explain experimental variability. A covariate can increase the accuracy of the results of the analysis by reducing experimental error. Soil EC was used as the covariate in the analysis of nutrient placement uniformity. The ANCOVA results were compared with the ANOVA results separately for each depth. The treatment effect was significant ($p=0.05$) only at depth 0-7.6 cm (0-3 in), so only that depth was used for analyses comparison (Tables B6 and B7). However, EC had a significant ($p<0.05$) effect on soil P concentrations regardless of depth (Appendix B, Table B6). The significant effects were treatment and position. The ANCOVA resulted in lower standard errors and therefore was more accurate than ANOVA. The ANCOVA had a lower Akaike's Information Criterion (AIC) at the 0-7.6 cm (0-3 in) depth indicating a better model (Table B6 and B7).

Comparisons between positions relative to tine penetration were made with and without soil EC as a covariate (Table 9). Using the soil EC as a covariate increased the accuracy as indicated by the lower standard error of treatment mean (Table 9). Soil P concentration was higher at positions of maximum and medium tine penetration and lower at minimum tine penetration with the soil EC as a covariate (Table 9). The medium penetration soil P concentrations were not different from the soil P concentrations at the maximum or minimum when compared without using soil EC as covariate (Table 9). Using the covariate makes the distinction clear between the positions. Soil P concentration was not different at positions of medium and minimum penetration with ANOVA. Using ANCOVA soil P concentration was significantly smaller at minimum penetration than at medium penetration (Table 9).

Comparisons among P concentrations between tillage treatments were made with soil EC as a covariate (Table 11) for the 0-7.6 cm (0-3 in) depth. Linear regression slopes between soil P concentrations and EC values were significantly different for the treatments (Table 10). Figure 2 shows the graph of the regressions for each treatment.

Table 9: Mean Bray 1-P concentrations at different tine penetration positions at 0-7.6 cm (0-3 in) obtained from the data analyses with and without soil EC.

Analysis with or without the covariate	*Standard error of treatment mean*	*Tine Penetration Position*		
		Maximum	Medium	Minimum
		ppm		
ANOVA	11.0	63.4a*	57.1ab	49.1b
		0.187† 0.005‡	0.101§	
ANCOVA with EC	6.6	65.6a	59.2a	51.2b
		0.173† 0.004‡	0.091§	

* means within the same row followed by the same letter are not significantly different ($p<0.1$)

† level of significance for comparing Maximum and Medium penetration positions

‡ level of significance for comparing Maximum and Minimum penetration positions

§ level of significance for comparing Medium and Minimum penetration positions

Table 10: Relationships between soil P concentrations and soil EC at different manure-tillage treatments at 0-7.6 cm (0-3 in).

Treatment	*Linear regression equation*		
	Intercept	Slope	r^2
No tillage / no manure	83.9	-3.2ab *	0.63 †
No tillage / manure	80.4	-1.95 a	0.54
Light tillage / manure	175.6	-6.2c	0.72
Aggressive tillage / manure	143.9	-4.65 bc	0.29

* Regression slopes with the same letters are not significantly different from each other ($p<0.05$).

† Regression is significant ($p<0.01$).

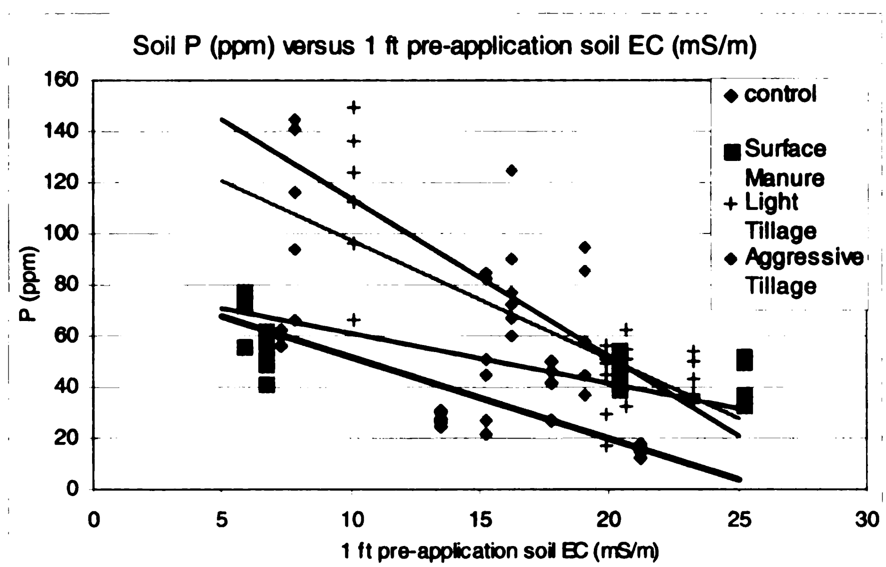

Figure 2: Soil P (ppm) verses 1 ft pre-application soil EC (mS/m)

Because the slopes of soil P concentration versus soil EC from different treatments were significantly different, the mean separation for ANCOVA was conducted at three different soil EC levels. The values used corresponded to the 25th, 50th and 75th percentile soil EC groups or EC values of 8.9, 15.6 and 20.5 (mS/m) respectively (Table 11).

Table 11. Mean soil P concentrations at different treatments at 0-7.6 cm (0-3 in) obtained from the data analyses with and without EC as a covariate. Standard errors for treatment means are shown in parenthesis.

	Treatment			
	No tillage – no manure	No tillage + manure	Light tillage + manure	Aggressive tillage + manure
		ppm		
ANOVA				
	36 (12.3) a*	52 (12.3) ab	61 (12.3) b	76 (12.3) c
	0.139† 0.033‡ 0.003§	0.393 ‖ 0.038#	0.160**	
ANCOVA				
Mean separations at				
EC=8.9	56.0 (12.2) a*	63.6 (7.7) a	121.3 (12.3) b	103.4 (10.0) b
	0.364 † 0.002‡ 0.003§	0.003 ‖ 0.005#	0.144**	
EC=15.6	34.0 (6.9) a*	50.1 (6.9) a	79.3 (7.5) b	71.6 (7.0) b
	0.029† 0.001‡ 0.001§	0.006 ‖ 0.010#	0.293**	
EC=20.5	17.9 (8.9) a*	40.3 (7.8) b	48.5 (7.2) b	48.3(10.3) b
	0.028II 0.008‡ 0.017§	0.241 ‖ 0.388#	0.984**	

* means within the same row followed by the same letter are not significantly different ($p<0.05$)
† level of significance for comparing No tillage and No tillage_Manure treatments
‡ level of significance for comparing No tillage and Light tillage_Manure treatments
§ level of significance for comparing No tillage and Aggressive tillage_Manure
‖ level of significance for comparing No tillage_Manure and Light tillage_Manure treatments
level of significance for comparing No tillage_Manure and Aggressive tillage_Manure treatments
** level of significance for comparing Light tillage_Manure and Aggressive tillage_Manure treatments

The comparisons of soil P concentrations between treatments with and without the covariate also resulted in different conclusions. Using the covariate did not indicate that aggressive tillage resulted in the greatest soil P concentrations at 0-7.6 cm (0-3 in) as was demonstrated without the covariate (Tables 11). Using the covariate lead to conclusions that light and aggressive tillage treatments had higher soil P concentrations than the control and surface applied plots for 25th and 50th percentile soil EC values. However, for the 75th percentile EC value, the soil P concentrations for the control were lower than all other treatments which were not different from each other.

3.2.6 Electrical Conductivity

Soil EC values were measured for each tillage treatment (Appendix A, Tables A9-A14). Soil EC values at the 91 cm (3 ft) depth were not significantly different ($P \leq 0.1$) between tillage treatments (Appendix B, Tables B8-10). Soil EC values at the 30 cm (1 ft) depth were different ($P \leq 0.1$) for tillage treatments (Appendix B, Tables B12-13). The combinations of tillage and manure used as treatments caused soil EC values to change differently. Plots treated with manure with no or light tillage had higher soil EC than the control and the aggressively tilled plots (Table 12). It could be that the manure application increased soil EC because treatments with manure and no or light tillage had higher soil EC. Aggressive tillage may decrease soil EC by decreasing soil continuity and thus conductivity.

Table12: Soil EC (mS/m) 30 cm (1 ft) following tillage treatments

Effect	1 day after application EC (mS/m)	1 week after application EC (mS/m)
No tillage / no manure	12.0 a	15.3 a
No tillage / manure	16.5 bc	18.9 bc
Light tillage / manure	16.9 b	20.8 b
Aggressive tillage / manure	13.0 ac	17.2 ac
LSD(0.10)	3.6	3.4

Means within each column followed by the same letter (a-c) are not significantly different ($p \leq 0.10$).

Grouping soils by soil EC measurement is a way to distinguish soils sharing similar characteristics. The geo-referenced soil EC values were mapped and the plot area was divided into 3 soil EC zones. Flags were placed in the zones and were used to mark locations for soil sampling within the zones. Figure 3 shows the zone divisions and the flag locations. The EC values ranged from 4.2 to 26.4 mS/m.

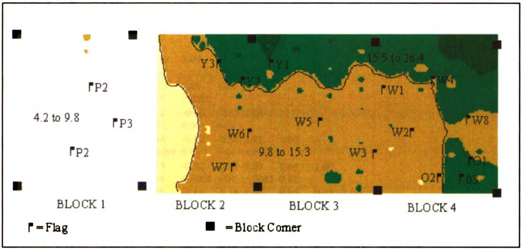

Figure 3: Pre-application 1 foot interpolated EC

Soil properties were measured at the flags (Appendix A, Tables A15-A21). Soil properties of samples at the flags were treated as independent variables. Pairwise correlations were made between the independent variables to a depth of 30 cm (12 in, Table 13)).

Stepwise regression was used to find significant ($p<0.10$) relationships between the pre-application nearest neighbor soil EC values at the flags and the pre-application soil properties measured at the flags (Table 14). Soil Mg was the most common reoccurring significant independent variable in the relationships. Magnesium and percent organic matter were positively correlated with soil EC. Percent sand was negatively correlated with soil EC. In contrast Johnson et al., (2001) found organic matter to be negatively correlated with soil EC. Johnson et al., (2001) also found percent clay to be positively correlated with soil EC. This agrees with our results of having percent sand negatively correlated with soil EC as percent sand increased percent clay decreased.

Table 13: Independent 0-30 cm (0-12 in) soil parameter Pearson correlation coefficients and p value matrix

	EC	elevation	OM	P	K	Mg	Ca	pH	CEC	sand	silt	clay	BD	SM
EC	1.00													
†														
Elevation*	-0.7	1.00												
†	0.00	0.00												
OM *	0.66	-0.77	1.00											
†	0.00	0.00												
Plppm *	-0.63	0.36	-0.25	1.00										
†	0.01	0.16	0.34											
Kppm *	-0.39	0.29	-0.28	0.81	1.00									
†	0.12	0.25	0.28	<.0001										
Mgppm *	0.91	-0.74	0.62	-0.76	-0.47	1.00								
†	<.0001	0.00	0.01	0.00	0.06									
Cappm *	0.86	-0.86	0.84	-0.62	-0.50	0.92	1.00							
†	<.0001	<.0001	<.0001	0.01	0.04	<.0001								
pH *	0.71	-0.36	0.19	-0.82	-0.51	0.84	0.64	1.00						
†	0.00	0.16	0.46	<.0001	0.04	<.0001	0.01							
CEC *	0.78	-0.93	0.88	-0.42	-0.36	0.81	0.95	0.42	1.00					
†	0.00	<.0001	<.0001	0.09	0.15	<.0001	<.0001	0.09						
sand *	-0.75	0.49	-0.73	0.46	0.37	-0.65	-0.73	-0.42	-0.63	1.00				
†	0.00	0.04	0.00	0.07	0.14	0.00	0.00	0.09	0.01					
silt *	0.14	0.26	0.16	-0.09	-0.06	0.09	0.13	0.23	-0.08	-0.49	1.00			
†	0.59	0.32	0.53	0.74	0.81	0.73	0.63	0.37	0.76	0.05				
Clay *	0.82	-0.85	0.80	-0.59	-0.54	0.82	0.88	0.47	0.89	-0.75	-0.11	1.00		
†	<.0001	<.0001	0.00	0.01	0.03	<.0001	<.0001	0.06	<.0001	0.00	0.66			
BD *	-0.30	0.31	-0.55	0.25	0.43	-0.22	-0.39	0.03	-0.37	0.52	-0.18	-0.46	1.00	
†	0.25	0.23	0.02	0.34	0.08	0.41	0.12	0.92	0.14	0.03	0.48	0.06		
SM *‡	0.68	-0.40	0.25	-0.64	-0.35	0.73	0.61	0.68	0.50	-0.47	0.21	0.48	-0.08	1.00
†	0.00	0.11	0.32	0.01	0.17	0.00	0.01	0.00	0.04	0.06	0.42	0.05	0.77	

* Pearson correlation coeffecient

† level of significance of Pearson correlation coefficient

‡ Sample from 0-6 in

Table 14: ANOVA of stepwise regression parameter estimates of soil EC

Variable	DF	Parameter Estimate	T value	Pr>t
30 cm (1 ft) EC with 0-15 cm (0-0.5 ft) soil properties at flag measurements				
Intercept	1	-4.24	-2.15	0.049
OM %	1	1.71	2.43	0.029
Mg ppm	1	0.0378	5.75	<.0001
30 cm (1 ft) EC with 15-30 cm (0.5-1 ft) soil properties at flag measurements				
Intercept	1	7.71	2.41	0.03
Mg ppm	1	0.032	5.90	<.0001
Sand %	1	-0.079	-1.83	0.088
30 cm (1 ft) EC with 0-30cm (0-1ft)* soil properties at flag measurements				
Intercept	1	10.81	2.28	0.039
Mg ppm	1	0.035	6.02	<.0001
Sand %	1	-0.16	-2.23	0.0425

* Average of 0-15 cm (0-0.5 ft) and 15-30 cm (0.5-1 ft) measured soil property values

Chapter 4

4. CONCLUSIONS

Small scale uniformity of application can be altered using tillage treatments. The uniformity of broadcast application is diminished as slurry flows overland and pools. Tillage can be used to increase the soil slurry interface and infiltration of slurry nutrients into the soil. On a field scale, this is helps to keep the application uniform. However, on a smaller scale the nutrient distribution is variable with peak concentrations where tine penetration was the greatest.

1. Aggressive tillage provided by the rolling-tine harrow increased the initial infiltration rate of a sandy loam soil compared to light tillage.
2. Aggressive tillage decreased residue cover compared to less aggressive tillage. Residue cover for light tillage and no tillage were not different.
3. The greatest P concentrations were found where the tines had the most penetration at the 0-7.6 cm (0-3 in) depth. P concentration decreased with less penetration. Increasing tillage intensity created depressions to hold manure on the soil surface. The depressions filled with manure and resulted in greater soil P levels in the 0-7.6 cm (0-3 in) layer.
4. Using soil EC as a covariate increased the accuracy of the analysis of soil P by decreasing the standard error of the treatment mean.
5. The 91 cm (3 ft) soil EC values were not different for tillage treatments.

6. The 30 cm (1 ft) soil EC values were different for tillage treatments. Light tillage with manure and no tillage with manure increased soil EC. Soil EC values for aggressively tilled plots were not different than plots receiving no tillage and no manure.

CHAPTER 5

5. RECOMMENDATIONS

1. The infiltration study could be improved in a few ways. Samples should be taken in close groups. This might alleviate effects caused by soil variability. Because the initial infiltration rate is of interest, shortening the time of measured infiltration may be helpful.
2. The problem of tracing manure in the soil after injection is still an issue. Using phosphorous as a tracer worked to a degree. The fundamental problem of using phosphorous is that it is already present and it does not move through the soil as some other nutrients do. However, the variability of background phosphorous in the application uniformity study may have contributed to insignificant differences in means at depths greater than 3 inches.
3. Potassium bromide (KBr) is a popular tracer used in many soil and water studies. It is naturally occurring only at very low concentration. It is highly soluble and moves with moisture. The challenge is to apply at a rate that is measurable yet has negligible crop response. A pilot scale manure application study with multiple KBr concentrations should be applied and measured using standard methods and procedures.
4. A rainfall simulation study was started to evaluate the effect of the tillage treatments on runoff volume and nutrient concentrations. A portable rainfall simulator was used but was damaged by weather. Although some samples were

collected there were no replications therefore the study was not presented in this thesis. There is much to gained by continuing the runoff study. The rainfall simulator needs runoff collection improvements to ensure collection of all runoff, and deter collection of non-runoff water. Other improvements could include wheels on one side of the simulator for ergonomic, one person, plot to plot transport, and retractable shielding tarps. Runoff should be collected in a way that allows tracking of runoff rates.

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APPENDIX A

Table A1: Ten Minute soil infiltration rates

Block	no tillage		light tillage		aggressive tillage	
	10 min infiltration (cm/hr)					
	North	South	North	South	North	South
	cm/hr					
1	8.8	20.8	12.8	21.0	28.8	11.3
2	17.55	16.95	7.65	13.2	18.45	29.3
3	11.7	18.45	12.45	10.05	24.75	25.2
4	17.6	16.8	16.8	14.3	19.4	21.8

1 in = 2.54 cm

Table A2: Percent residue cover

Block	No tillage	Light tillage	Aggressive Tillage
1	51.7	50.0	43.3
2	58.3	61.7	40.0
3	45.0	48.3	38.3
4	66.7	58.3	50.0

Table A3: Surface manure coverage

Block	Treatment	Manure Cover (%)
1	aggressive tillage	40.5
2	aggressive tillage	44.2
3	aggressive tillage	43.1
4	aggressive tillage	47.2
1	light tillage	41.0
2	light tillage	43.2
3	light tillage	30.0
4	light tillage	35.2

Table A4: Soil bulk density north and south ends of plots after slurry application (21 August 2002)

Block	Sample location	Treatment	0-7.6 cm depth	7.6-15 cm depth	15-23 cm depth
				g/cm^3	
1	North	light tillage	1.30	1.54	1.64
1	South	light tillage	1.20	1.45	1.58
2	North	light tillage	1.09	1.46	1.41
2	South	light tillage	1.39	1.50	1.47
3	North	light tillage	1.23	1.43	1.43
3	South	light tillage	1.05	1.34	1.36
4	North	light tillage	1.40	1.57	1.53
4	South	light tillage	1.21	1.43	1.43
1	North	aggressive tillage	1.29	1.38	1.51
1	South	aggressive tillage	1.29	1.24	1.46
2	North	aggressive tillage	1.13	1.40	1.33
2	South	aggressive tillage	1.19	1.24	1.28
3	North	aggressive tillage	1.22	1.41	1.53
3	South	aggressive tillage	1.25	1.18	1.37
4	North	aggressive tillage	1.24	1.36	1.48
4	South	aggressive tillage	1.05	1.02	1.43

Table A5: Soil P levels at 3 depths and 3 positions relative to tillage for no tillage and no manure

	No tillage and no manure soil P concentrations																							
	Block 1						Block 2						Block 3						Block 4					
Repetition	1			2			1			2			1			2			1			2		
Position	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	ppm																							
0-7.6 cm	62	64	60	60	56	56	31	25	28	30	27	26	12	16	15	18	16	15	47	50	47	42	27	42
7.6-15 cm	16	39	32	38	60	55	18	20	14	18	24	20	8	8	10	13	11	14	31	47	31	29	24	27
15-23 cm	42	20	16	32	45	16	15	17	9	14	12	14	6	9	5	8	6	7	20	25	10	43	16	20

1 lbs/acre = 2*ppm
1 in = 2.54 cm

Table A6: Soil P levels at 3 depths and 3 positions relative to tillage for no tillage with manure

	No tillage with manure soil P concentrations																							
	Block 1						Block 2						Block 3						Block 4					
Repetition	1			2			1			2			1			2			1			2		
Position	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	ppm																							
0-7.6 cm	75	78	73	56	73	75	58	49	53	62	51	42	39	40	45	55	46	48	50	52	37	33	36	34
7.6-15 cm	38	42	30	42	37	64	25	25	21	26	28	21	18	11	15	29	16	23	16	20	18	9	17	22
15-23 cm	13	14	18	14	15	58	12	20	12	13	15	12	17	14	12	20	10	20	6	9.5	7	6	6	13

1 lbs/acre = 2*ppm
1 in = 2.54 cm

Table A7: Soil P levels at 3 depths and 3 positions relative to tillage for light tillage with manure

	Light tillage with manure soil P concentrations																							
	Block 1						Block 2						Block 3						Block 4					
Repetition	1			2			1			2			1			2			1			2		
Position	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	ppm																							
0-7.6 cm	150	124	113	136	97	66	45	56	17	51	49	29	62	32	39	46	55	51	36	37	50	54	34	43
7.6-15 cm	97	70	80	97	48	40	13	15	9	37	15	25	36	17	19	23	29	34	18	19	11	25	21	25
15-23 cm	64	26	30	62	12	22	6	11	8.5	7	8	13	21	10	10	15	18	26	8.5	8	9	10	8	13

1 lbs/acre = 2*ppm
1 in = 2.54 cm

Table A8: Soil P levels at 3 depths and 3 positions relative to tillage for aggressive tillage with manure

	Aggressive tillage with manure soil P concentrations																							
	Block 1						Block 2						Block 3						Block 4					
Repetition	1			2			1			2			1			2			1			2		
Position	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	ppm																							
0-7.6 cm	116	94	94	141	145	66	51	83	45	22	85	27	90	72	77	125	67	60	86	58	45	95	37	58
7.6-15 cm	48	34	36	51	46	43	14	26	10	9.5	13	14	29	37	34	56	39	40	20	18	21	26	19	20
15-23 cm	18	11	15	23	18	20	11	9	8	5.5	5.5	9	18	15	20	15	22	22	11	16	15	21	10	14

1 lbs/acre = 2*ppm
1 in = 2.54 cm

Table A9: Interpolated pre-application soil EC to 30 cm (1 ft) depth by plot number

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
							mS/m								
7.5	5.7	9.8	8.1	6.6	13.9	15.5	19.5	21.5	20.1	21.2	16.7	17.0	17.9	24.2	25.7
7.1	5.9	10.4	7.5	6.7	13.1	14.9	20.3	20.9	21.3	19.6	15.8	18.5	20.3	22.3	24.7
6.1	6.4	8.1	6.6	6.9	11.4	14.5	19.9	20.4	17.8	18.9	15.6	17.9	18.7	20.9	23.1
5.5	6.8	7.0	5.9	7.0	10.6	13.8	17.9	17.6	16.1	16.0	14.9	15.8	13.0	18.5	21.8
5.4	6.0	6.2	5.5	7.5	10.8	14.1	17.6	15.5	14.5	15.5	14.4	15.7	15.9	16.3	21.2
5.1	5.2	4.8	5.4	7.3	9.8	13.0	15.4	15.4	14.0	16.0	15.0	14.1	15.6	15.2	17.7
4.8	5.4	4.9	5.5	6.8	9.3	12.8	14.8	15.0	16.3	14.8	14.8	11.4	16.2	16.2	18.2
4.7	5.7	4.6	4.9	7.5	9.2	10.9	14.4	14.1	13.6	14.7	13.8	13.1	12.6	17.2	18.2
4.7	6.0	7.5	5.5	6.8	8.1	11.0	15.5	13.6	12.8	13.4	14.2	13.0	12.0	17.1	16.8
5.0	5.7	8.0	5.8	6.1	7.6	10.3	13.4	13.5	13.3	13.3	13.3	13.6	11.8	15.8	14.1
5.4	5.5	7.1	5.0	6.3	7.8	10.2	12.0	13.9	13.8	13.5	13.9	15.0	10.7	15.3	12.5
5.2	6.0	7.1	6.1	6.4	8.1	9.7	12.9	14.0	12.4	14.6	14.3	12.7	11.9	15.0	11.7
5.5	6.2	7.4	7.0	5.6	7.9	11.0	12.4	14.2	13.2	15.5	14.6	14.1	11.6	15.4	13.7
5.8	6.7	7.6	7.4	6.3	9.0	10.9	11.3	14.1	14.5	12.7	14.6	9.7	11.3	15.7	15.1
6.0	6.8	9.0	7.6	7.8	9.1	10.1	13.2	13.8	13.4	14.5	14.2	11.3	11.4	15.4	14.9
7.2	6.5	9.0	8.3	7.8	8.6	12.0	13.4	13.4	13.7	14.8	14.0	13.4	10.2	15.9	15.9
6.2	6.8	7.6	7.9	7.3	8.9	12.8	13.2	13.1	12.5	16.4	15.3	14.2	10.0	15.7	15.8
6.0	6.9	6.9	6.8	7.4	9.4	12.1	12.8	13.2	12.8	16.3	14.4	14.7	9.3	15.9	15.3
6.2	6.9	6.9	6.8	7.5	9.6	13.4	13.3	13.5	11.8	14.8	15.4	12.2	12.0	16.2	18.9

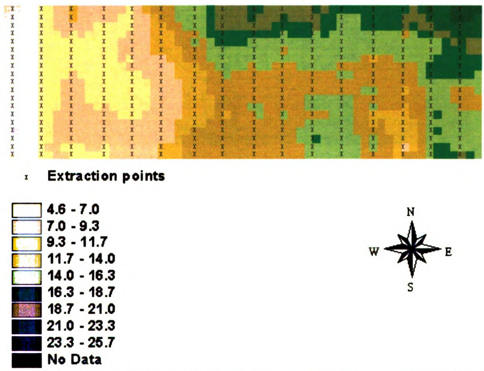

Figure A1: Interpolated Pre-application soil EC (mS/m) to 30 cm (1 ft) depth

Table A10: Pre-application soil EC to 91 cm (3 ft) depth (interpolated values) by plot number

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
							mS/m								
12.6	12.9	17.0	12.2	17.1	20.7	25.5	30.5	36.2	31.7	33.9	28.2	28.6	29.6	31.2	26.6
11.6	13.5	15.8	11.1	16.6	21.4	25.2	29.5	36.5	33.1	30.5	27.9	26.6	28.6	28.3	26.4
9.3	12.4	9.4	10.0	16.3	22.2	27.0	28.9	33.8	33.2	26.5	25.8	26.7	28.3	26.4	26.2
8.0	13.4	12.1	10.6	19.5	20.9	29.0	28.4	31.3	30.5	25.2	24.2	24.7	25.2	24.5	25.0
8.2	10.9	11.6	11.2	14.2	20.1	29.8	27.4	29.2	25.7	24.4	23.6	24.9	23.2	22.4	24.3
8.3	9.9	10.4	10.2	18.3	19.0	25.6	26.9	27.1	26.1	25.9	22.4	25.7	19.1	20.9	22.2
7.3	8.8	7.5	9.5	17.6	19.4	25.4	29.7	25.5	25.1	24.1	21.5	26.4	21.3	22.0	21.7
6.9	8.0	6.8	8.1	17.6	19.2	24.9	31.9	24.7	21.9	19.8	20.8	24.7	22.6	23.1	22.8
7.4	8.5	12.2	9.3	16.6	18.4	22.3	28.8	23.2	21.0	18.0	20.1	23.6	22.5	23.4	22.3
8.1	8.5	14.1	8.8	15.4	17.5	19.9	25.0	21.0	20.6	17.9	18.3	22.5	23.0	21.1	19.8
9.7	9.0	9.2	8.0	15.1	17.1	17.9	22.3	19.3	18.3	18.3	17.6	20.7	19.0	20.3	17.9
7.8	8.5	11.7	12.2	8.6	19.3	18.6	19.4	18.4	18.4	19.9	18.6	22.5	17.0	19.6	17.0
7.9	8.7	11.9	13.3	11.9	19.4	17.7	19.9	17.7	19.5	19.4	18.9	20.8	19.3	19.4	17.6
8.4	8.8	13.2	16.0	13.2	19.0	18.8	23.4	17.8	20.8	17.2	20.3	22.9	19.4	19.9	17.8
10.9	9.7	14.7	15.7	14.0	17.5	19.9	22.6	18.2	20.1	23.3	22.8	22.0	19.9	20.0	18.2
13.7	11.0	13.5	16.8	14.7	17.9	20.8	22.1	18.9	19.5	21.3	25.4	25.2	20.9	20.1	18.8
14.0	11.5	13.4	15.1	14.0	17.6	20.9	21.8	20.5	21.1	21.2	24.8	26.8	23.4	20.4	19.0
12.1	12.0	13.8	13.8	15.1	17.6	21.9	24.8	22.6	21.1	22.3	25.8	26.0	26.1	21.7	21.3
12.2	12.2	13.8	13.8	15.7	18.4	23.5	25.5	24.1	21.2	21.5	25.5	24.5	27.3	22.4	22.5

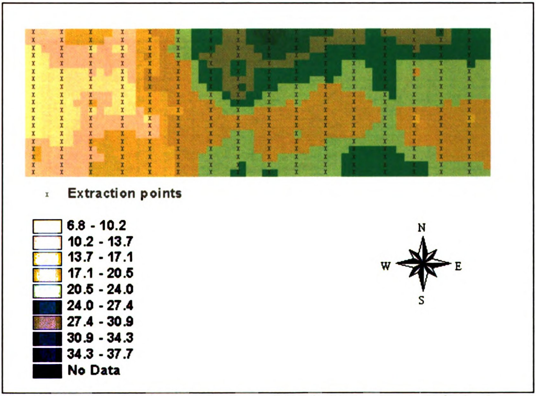

Figure A2: Interpolated pre-application soil EC (mS/m) to 91 cm (3 ft) depth

Table A11: 1 day after application interpolated soil EC to 30 cm (1 ft) depth by plot number

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
							mS/m								
9.4	10.8	11.4	7.1	10.5	12.9	14.1	20.3	22.1	22.2	28.4	13.4	17.2	14.8	23.6	28.2
9.1	11.1	14.3	7.7	10.7	11.4	15.6	22.7	20.7	22.2	29.4	13.5	17.2	12.9	23.4	28.4
8.2	11.1	13.8	7.7	10.9	11.4	13.3	20.9	18.3	20.8	25.8	15.9	17.0	14.5	22.4	30.3
7.8	10.4	12.6	6.9	11.1	11.5	12.4	19.0	17.3	20.5	26.6	17.3	17.1	16.3	21.5	29.2
7.7	9.7	12.2	6.2	11.0	9.5	12.3	17.4	16.2	18.2	24.8	16.9	16.5	13.7	20.2	25.4
7.7	9.8	10.5	5.8	11.0	9.8	14.0	18.8	16.1	18.9	23.8	17.2	13.9	16.3	19.7	25.6
7.0	8.6	9.7	6.0	11.2	10.7	14.8	19.6	15.6	18.6	22.3	18.1	14.0	14.7	19.4	23.2
6.7	8.5	9.3	6.9	11.1	9.8	14.4	17.9	13.7	16.5	23.1	18.4	13.0	15.3	19.5	24.8
6.3	7.8	9.5	6.4	10.8	9.6	13.7	17.6	14.3	17.5	21.4	18.6	14.1	12.9	19.4	23.2
5.9	8.1	10.1	6.4	10.9	9.9	14.0	17.0	14.2	17.0	21.2	18.0	14.7	12.2	18.2	20.4
6.2	8.6	11.1	6.5	10.4	10.1	13.2	17.7	14.5	17.4	19.5	16.7	13.1	10.6	17.5	19.5
6.8	8.7	10.2	5.7	9.6	10.2	12.3	16.5	14.8	18.1	19.4	17.0	14.4	10.5	17.6	18.8
6.8	9.3	10.6	6.7	9.8	10.4	12.4	16.8	15.0	17.4	20.8	17.1	13.1	10.5	16.9	18.8
7.1	10.1	12.0	7.8	10.7	10.5	14.4	16.5	14.6	16.0	20.1	18.8	12.6	11.0	18.4	19.4
7.2	11.1	11.6	9.3	11.1	10.5	14.4	16.8	14.1	16.6	20.6	18.1	11.9	11.3	19.8	20.6
7.4	10.5	11.8	10.3	10.7	10.2	14.6	16.8	14.0	16.5	20.1	18.7	11.3	11.6	19.9	18.1
8.5	11.0	12.4	10.4	10.7	10.6	16.4	16.4	14.8	15.6	20.9	19.0	11.7	12.4	20.6	20.1
8.3	11.4	12.9	10.4	10.7	11.7	15.1	16.3	15.1	15.8	22.6	18.5	12.3	13.3	24.4	18.7
8.5	11.1	12.8	11.1	10.7	11.3	13.8	16.2	16.1	13.3	21.9	17.6	10.7	11.7	20.8	19.8

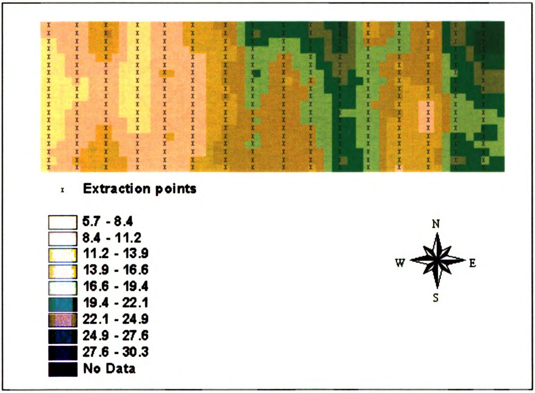

Figure A3: 1 day after application interpolated soil EC(mS/m) to 30 cm (1 ft) depth

Table A12: 1 day after application interpolated soil EC to 91 cm (3 ft) depth by plot number

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
							mS/m								
11.6	14.2	17.4	15.7	14.8	20.2	24.0	29.2	36.0	32.1	31.4	31.0	26.5	30.8	30.6	26.5
12.0	13.7	16.9	14.5	14.4	20.0	23.8	28.3	37.4	30.7	29.9	29.1	27.0	30.6	29.8	26.2
10.2	13.7	16.3	12.4	14.6	18.4	27.2	27.0	33.4	31.0	27.2	27.2	25.2	29.9	27.3	26.4
8.4	14.6	14.4	11.6	15.0	18.6	26.8	26.0	30.7	29.9	25.8	25.0	25.3	27.6	26.0	25.7
7.7	13.4	14.1	10.8	13.8	18.8	23.9	24.5	28.2	27.5	24.8	23.7	26.3	25.5	24.4	25.0
8.6	14.0	12.7	11.0	14.6	16.5	23.9	25.4	25.9	25.7	24.1	23.3	23.8	21.5	22.4	23.4
8.1	10.8	11.1	10.3	14.5	17.3	23.1	26.4	24.7	25.3	22.3	22.4	24.7	19.7	21.3	22.7
7.5	10.7	10.2	10.4	13.5	17.0	21.7	25.7	23.5	22.2	19.3	21.1	24.7	21.1	22.1	22.5
7.5	8.8	8.8	9.5	13.1	16.5	20.5	23.9	23.0	22.3	17.5	20.6	23.1	20.6	22.8	23.8
8.0	9.3	9.8	9.8	13.5	15.7	18.7	22.1	20.8	21.5	16.9	19.5	23.7	21.6	22.1	21.9
8.8	9.8	13.2	9.7	12.9	17.7	18.2	21.4	19.4	19.6	17.3	18.6	24.2	21.0	19.9	18.7
8.1	9.4	11.3	9.5	12.8	18.3	18.8	21.0	17.9	19.2	18.6	18.7	23.8	18.9	19.4	17.8
7.8	9.9	12.7	11.5	13.0	17.3	18.8	22.0	17.7	19.5	18.9	19.1	21.8	19.4	18.3	17.5
8.2	9.9	12.2	12.1	12.9	16.8	19.7	22.3	18.3	19.3	16.6	20.0	21.6	19.5	18.9	18.1
9.0	10.2	12.7	12.6	13.1	16.1	20.1	22.3	18.7	20.1	17.7	21.2	22.3	20.9	19.4	18.4
11.4	11.5	13.4	14.3	13.2	16.4	19.9	21.9	18.8	19.6	19.8	22.3	21.1	20.7	20.1	18.9
12.9	12.4	14.8	15.0	13.2	16.7	20.9	23.2	19.5	19.9	20.4	23.4	22.9	21.1	20.3	19.1
12.2	11.9	12.6	14.6	13.2	18.1	24.4	24.3	20.6	20.5	21.4	23.1	25.9	24.4	22.9	19.4
12.0	12.2	15.1	13.0	13.3	18.4	25.7	24.3	22.2	20.8	21.5	24.0	25.1	26.1	22.4	21.3

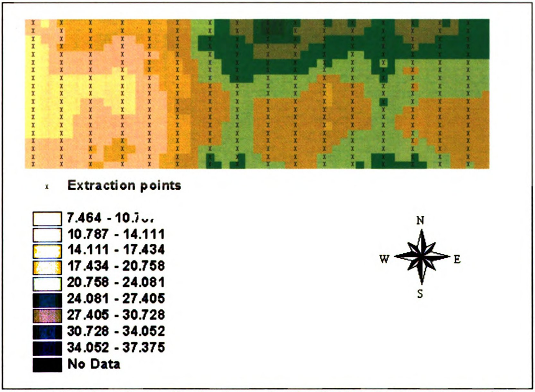

Figure A4: 1 day after application interpolated soil EC (mS/m) to 91 cm (3 ft) depth

Table A13: 1 week after application interpolated soil EC to 30 cm (1 ft) depth by plot number

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
							mS/m								
10.1	12.7	17.5	17.4	13.4	14.3	19.4	25.3	23.8	29.0	33.0	22.4	21.7	19.7	23.5	27.8
10.6	12.2	19.1	16.5	13.7	14.7	18.7	23.4	21.9	28.8	29.2	21.2	21.6	22.3	23.3	27.8
9.8	12.0	18.4	13.6	14.0	13.6	19.1	21.7	22.7	25.1	27.8	18.8	19.6	19.2	23.7	28.0
9.5	13.2	17.3	14.6	13.7	12.4	19.1	19.8	22.4	25.3	27.3	19.5	18.8	19.4	24.3	26.4
9.8	11.8	14.0	11.5	12.8	12.4	16.4	18.9	20.7	24.1	26.3	19.5	18.8	19.9	24.7	26.0
9.0	10.0	11.4	10.2	12.1	12.6	13.8	20.1	19.9	24.5	27.2	20.6	18.7	18.1	22.5	22.6
8.4	9.7	11.6	9.4	12.5	13.1	13.5	19.5	20.0	22.6	26.0	19.0	16.6	18.5	21.5	21.9
8.0	9.7	12.7	10.0	12.4	12.3	13.7	18.3	20.2	22.8	26.6	20.0	18.1	18.4	21.6	21.8
8.2	10.5	13.8	11.3	12.4	12.3	12.5	17.5	20.7	22.3	25.3	19.9	17.8	17.0	22.0	21.2
8.6	9.8	13.5	10.7	12.2	13.2	13.5	17.0	21.2	22.5	25.2	20.4	16.6	16.1	22.3	22.1
8.3	9.5	13.4	9.6	11.6	13.4	15.9	17.2	21.3	22.3	24.9	20.7	17.0	14.8	23.1	22.2
8.7	11.1	13.6	11.1	11.7	12.6	14.6	17.7	21.2	21.8	24.8	22.8	16.4	15.5	24.1	21.9
9.1	10.8	14.3	13.8	13.0	12.6	16.6	17.1	20.3	21.3	23.3	23.1	15.7	16.0	25.0	21.5
9.1	11.6	13.8	14.6	13.9	12.7	17.5	16.7	20.4	21.4	23.1	21.0	15.6	16.7	30.0	21.8
9.7	12.3	16.3	15.3	13.2	12.5	18.5	16.8	20.6	19.7	23.7	21.5	15.0	16.6	45.8	19.9
10.3	13.0	15.5	14.4	12.5	13.5	19.8	17.2	20.1	19.1	25.5	20.5	15.8	15.6	36.5	23.0
10.0	13.7	14.4	13.5	12.9	13.8	19.2	18.7	21.3	19.3	26.9	20.1	14.9	16.6	31.1	24.8
9.9	14.0	15.0	12.4	12.7	13.3	22.7	19.5	23.3	20.1	28.5	21.7	15.8	20.1	30.9	32.7
10.9	14.4	14.9	12.9	13.1	14.8	21.5	19.6	23.6	20.7	27.6	24.9	16.1	21.3	31.5	31.4

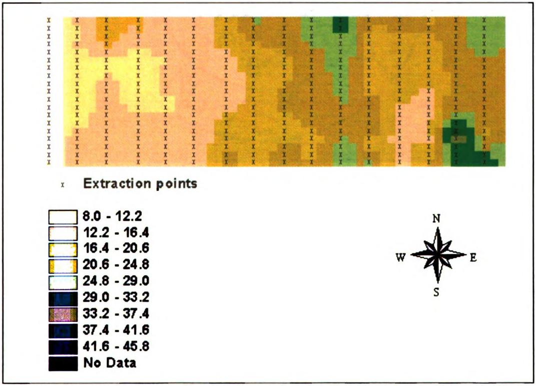

Figure A5: 1 week after application interpolated soil EC(mS/m) to 30 cm (1 ft) depth

Table A14: 1 week after application interpolated soil EC to 91 cm (3 ft) depth by plot number

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
							mS/m								
15.4	13.6	16.8	13.6	15.9	20.0	26.3	37.1	27.2	32.8	33.7	26.4	26.5	23.2	24.4	23.1
13.4	12.9	17.7	12.4	16.9	18.1	25.3	34.8	25.3	32.3	30.7	25.9	26.9	21.3	22.7	22.9
10.6	13.4	15.5	11.4	15.7	17.9	25.5	32.6	26.0	30.9	29.1	23.8	26.1	19.7	22.6	23.6
9.5	13.5	14.8	12.8	15.2	17.0	25.3	30.0	27.2	29.2	28.0	22.4	25.7	21.7	24.2	24.1
9.6	12.6	12.9	11.4	16.3	18.4	23.7	27.9	27.0	27.1	28.0	22.5	25.1	22.3	24.8	24.7
9.1	11.7	11.6	10.7	15.8	18.8	21.5	26.9	24.8	27.7	26.0	21.7	24.1	23.5	22.6	22.1
8.2	10.5	10.4	9.9	14.5	18.3	19.1	25.2	23.6	23.5	23.3	20.5	23.5	21.7	21.1	19.9
8.3	9.7	11.1	10.0	14.2	18.1	17.8	24.8	23.1	22.4	21.2	19.8	24.8	19.1	20.9	18.6
8.5	10.7	13.7	10.2	15.2	19.6	18.2	23.1	22.1	21.6	20.8	19.0	23.6	18.9	20.2	19.3
9.7	9.8	13.0	9.8	14.3	21.7	18.9	21.4	23.1	20.4	21.0	19.4	22.8	20.6	21.1	19.8
9.2	10.2	12.2	12.2	13.5	20.0	19.9	21.0	23.2	19.6	22.0	19.5	21.3	20.1	22.4	20.6
8.6	10.5	14.1	13.1	13.1	19.4	21.5	20.4	23.0	21.2	22.1	20.5	22.6	19.9	22.9	20.0
9.0	10.4	13.4	13.4	14.0	18.1	21.4	19.9	22.9	20.5	20.0	21.6	23.5	20.7	23.1	20.9
10.0	11.3	13.9	15.7	14.8	18.4	21.7	19.3	24.1	21.1	23.4	23.4	25.9	22.7	26.1	21.1
12.0	12.5	16.1	15.9	15.1	18.5	23.6	20.3	25.4	19.6	23.1	25.0	26.0	24.8	31.9	23.1
13.9	14.0	14.0	15.2	14.7	19.9	26.5	21.3	26.0	20.1	24.1	24.1	26.4	26.5	30.7	24.7
13.4	13.5	14.7	13.6	15.1	20.7	27.9	22.9	27.1	21.4	24.5	23.9	24.9	28.9	29.8	28.4
12.7	14.6	16.0	12.7	16.1	19.7	27.9	24.4	28.8	21.9	25.2	25.8	25.5	30.0	30.8	33.5
13.5	13.3	15.5	13.5	16.4	20.4	27.5	26.1	29.1	22.2	25.0	26.4	25.7	30.0	31.6	33.8

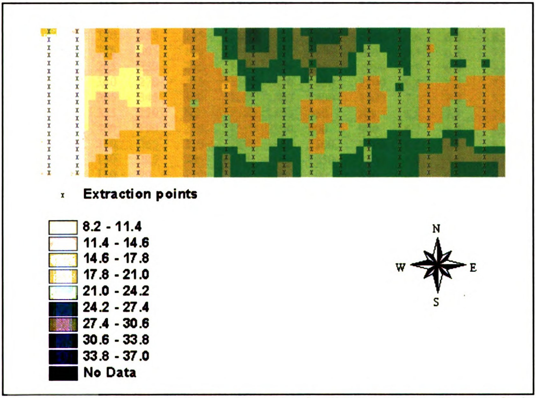

Figure A6: 1 week after application interpolated soil EC (mS/m) to 91 cm (3 ft) depth

Table A15: OM, P, and K of multiple depth soil cores taken at flags

Flag	OM				P				K			
	0-15 cm	15-30cm	30-61 cm	61-91 cm	0-15 cm	15-30cm	30-61 cm	61-91 cm	0-15 cm	15-30cm	30-61 cm	61-91 cm
	%				ppm							
W1	4.2	3.4	1.6	1.3	39	21	6	6	174	77	61	69
W2	4.4	3.6	1.2	1.1	30	21	9	11	161	72	61	49
W3	4.5	3.5	1.3	1.4	40	22	8	9	203	97	63	43
W4	3.6	3.5	0.6	1.2	15	9	2	3	122	77	43	38
W5	4.4	4.5	1.8	1	25	14	10	9	137	68	61	40
W6	3.8	4.2	1.1	1.6	17	11	4	4	112	53	52	55
W7	3.8	2.7	1.3	1.2	14	5	4	3	91	59	43	33
W8	3.7	3.4	0.9	2	24	10	3	4	165	74	55	62
O1	3.5	2	0.9	NS	24	10	5	NS	183	85	58	NS
O2	4	4.3	0.8	0.7	30	18	7	8	219	91	71	70
O3	4	2	0.8	0.8	26	6	3	2	157	74	60	46
P1	2.6	2.8	1	1.5	39	28	2	3	189	117	63	66
P2	2.8	2.3	0.8	1	54	17	10	4	209	62	37	32
P3	2.7	2.7	1	1.4	30	19	5	3	169	95	51	51
Y1	5.3	4.7	1.5	1.1	16	11	3	1	137	79	92	45
Y2	4.9	4	1.1	1.6	15	10	3	5	99	74	53	86
Y3	3.7	2.5	1.4	1.5	12	2	2	7	111	70	68	40

Table A16: Mg, Ca, and pH of multiple depth soil cores taken at flags

Flag	Mg				Ca				Acidity			
	0-15 cm	15-30cm	30-61 cm	61-91 cm	0-15 cm	15-30cm	30-61 cm	61-91 cm	0-15 cm	15-30cm	30-61 cm	61-91 cm
	ppm								ph			
W1	270	245	255	265	1700	1650	1450	1250	6.3	6	7	7.3
W2	240	235	240	185	1300	1500	1350	850	5.9	5.9	6.8	7.8
W3	270	260	240	170	1450	1550	1200	900	6.2	6.1	7.1	7.8
W4	345	370	255	245	1600	1700	3100	2950	6.6	6.8	8.2	8.2
W5	315	375	305	180	1850	2300	1750	800	6.5	6.9	7.3	7.8
W6	325	285	230	235	1750	1700	115	1050	6.7	6.9	7.3	7.5
W7	275	340	270	235	1500	1650	1650	2100	6.5	7.1	7.6	8.1
W8	360	365	345	380	1650	1600	1400	1800	7.1	7.3	7.7	7.52
O1	335	325	270	NS	1550	1450	950	NS	6.8	7.3	7.6	NS
O2	335	400	190	210	1550	2100	800	900	6.7	6.9	6.8	7.2
O3	320	310	265	210	1550	1350	2500	4300	6.8	7.1	8	8.3
P1	135	110	225	300	650	600	1050	1100	5.8	5.6	6.5	3.9
P2	155	110	90	110	800	650	500	550	6.2	6.1	6.7	7.1
P3	135	130	145	260	750	850	750	2400	5.9	6	6.9	8
Y1	380	430	500	255	2150	2300	2000	3900	6.8	6.9	7.5	8.4
Y2	365	335	330	445	2200	1700	3400	1750	6.8	7	7.9	7.7
Y3	330	400	360	260	1600	1700	1550	3200	7.2	7.5	7.8	8.1

Table A17: Clay, sand and silt of multiple depth soil cores taken at flags

Flag	Clay				Sand				Silt			
	0-15 cm	15-30cm	30-61 cm	61-91 cm	0-15 cm	15-30cm	30-61 cm	61-91 cm	0-15 cm	15-30cm	30-61 cm	61-91 cm
							%					
W1	21	21	23	23	50	52	58	52	29	27	19	25
W2	23	21	19	17	58	50	54	58	19	29	27	25
W3	19	22	18	22	52	54	60	68	29	24	22	10
W4	24	26	18	24	50	46	54	56	26	28	28	20
W5	22	24	22	12	46	48	56	68	32	28	22	20
W6	20	20	22	22	46	48	50	52	34	32	28	26
W7	20	24	18	18	48	50	56	60	32	26	26	22
W8	22	22	20	NS	50	49	59	NS	28	29	21	NS
O1	19	17	13	NS	50	60	64	NS	31	23	23	NS
O2	21	17	15	17	48	47	62	58	31	36	23	25
O3	19	17	15	17	48	54	56	54	33	29	29	29
P1	14	14	22	20	57	57	49	69	29	29	29	11
P2	12	14	14	10	57	51	61	71	31	35	25	19
P3	12	12	12	16	57	57	61	57	31	31	27	27
Y1	22	35	32	22	47	1.5	29	43	31	37	39	35
Y2	24	22	21	26	43	49	49	39	33	29	30	35
Y3	17	25	24	18	51	49	49	45	32	26	27	37

Table A18: CEC and EC of multiple depth soil cores taken at flags

	CEC (meq/100g)				EC (mS/m)	
Flag	0-15 cm	15-30 cm	30-61 cm	61-91 cm	0-30 cm	0-91 cm
W1	13.6	14.1	9.5	8.6	11.3	26.5
W2	12.5	13.2	9.2	5.9	11.6	15.9
W3	12.4	12.6	8.2	6	14.3	20.5
W4	12.4	12.1	16.9	16.9	16.6	18.8
W5	13.4	15	11.4	5.6	13.3	18.1
W6	12.9	11.2	7.8	7.3	12.8	19
W7	11.2	11.2	10.6	12.5	13.5	22.1
W8	11.7	11.2	10	12.3	13.8	19.4
01	11.4	10.2	7.1	NS	14.8	18.2
O2	12.3	14.3	5.9	6.4	15.9	19.7
O3	11.2	9.5	14.9	23.4	15.9	19.7
P1	6.1	6.6	8.5	8.3	5.2	9.9
P2	7	5.5	3.3	3.7	8.4	14.5
P3	6.5	6.8	5.2	14.3	4.8	7.6
Y1	14.7	15.5	14.4	21.7	21.5	32.4
Y2	14.7	11.5	19.9	12.7	17.4	26.7
Y3	11	12	10.9	18.3	14.4	29.3

Table A19: Soil bulk density at flags before slurry application (15 August 2002)

Flag	BD Sample 1				BD Sample 2				BD Sample 3			
	0-8 cm	8-15cm	15-23	23-30cm	0-8 cm	8-15cm	15-23	23-30cm	0-8 cm	8-15cm	15-23	23-30cm
	g/cm^3											
W1	1.32	1.44	1.42	1.72	1.43	1.42	1.51	1.52	1.28	1.36	1.62	1.52
W2	1.40	1.41	1.37	1.37	1.30	1.42	1.42	1.48	1.31	1.49	1.33	1.48
W3	1.36	1.44	1.48	1.60	1.31	1.32	1.40	1.59	1.34	1.34	1.42	1.59
W4	1.42	1.41	1.36	1.45	1.25	1.37	1.38	1.55	1.49	1.36	1.38	1.55
W5	1.37	1.34	1.37	1.46	1.68	1.39	1.42	1.17	1.26	1.26	1.26	1.17
W6	1.31	1.46	1.33	1.54	1.37	1.48	1.36	1.31	1.32	1.44	1.41	1.31
W7	1.44	1.48	1.38	1.43	1.34	1.46	1.50	1.43	1.35	1.31	1.43	1.43
W8	1.41	1.46	1.37	1.47	1.36	1.45	1.48	1.61	1.50	1.46	1.50	1.61
O1	1.50	1.51	1.33	1.61	1.38	1.44	1.57	1.56	1.36	1.36	1.57	1.56
O2	1.40	1.37	1.44	1.37	1.38	1.56	1.45	1.62	1.39	1.42	1.50	1.62
O3	1.28	1.53	1.31	1.53	1.24	1.54	1.46	1.55	1.27	1.44	1.37	1.55
P1	1.48	1.36	1.46	1.43	1.42	1.45	1.46	1.34	1.44	1.42	1.55	1.34
P2	1.35	1.81	1.42	1.55	1.39	1.09	1.50	1.46	1.41	1.43	1.42	1.46
P3	1.48	1.36	1.46	1.43	1.42	1.45	1.46	1.34	1.44	1.42	1.55	1.34
Y1	1.33	1.33	1.30	1.56	1.27	1.36	1.44	1.32	1.37	1.45	1.32	1.32
Y2	1.36	1.49	1.33	1.51	1.42	1.43	1.45	1.36	1.42	1.43	1.35	1.36
Y3	1.46	1.40	1.40	1.56	1.44	1.50	1.48	1.44	1.44	1.42	1.40	1.44

1 oz/in^3 = 1.73 g/cm^3
1 in = 2.54 cm

Table A20: Gravimetric water content at flags before application (14 August 2002)

Flag	Gravimetric Water Content			
	0-15 cm	15-30 cm	30-61 cm	61-91 cm
	g/g			
W1	0.16	0.16	0.18	0.20
W2	0.13	0.19	0.16	0.17
W3	0.11	0.19	0.17	0.18
W4	0.18	0.21	0.15	0.18
W5	0.15	0.22	0.20	0.16
W6	0.17	0.21	0.16	0.17
W7	0.17	0.20	0.18	0.16
W8	0.15	0.18	0.21	0.16
O1	0.19	0.21	0.14	0.00
O2	0.18	0.26	0.20	0.18
O3	0.18	0.13	0.15	0.14
P1	0.12	0.15	0.13	0.15
P2	0.11	0.14	0.12	0.13
P3	0.12	0.14	0.10	0.15
Y1	0.18	0.22	0.21	0.15
Y2	0.15	0.17	0.16	0.25
Y3	0.14	0.17	0.21	0.17

Table A21: Gravimetric water content (g/g) at flags after application (26 August 2002)

Flag	Sample 1	Sample 2
W1	0.30	0.25
W2	0.28	0.26
W3	0.28	0.29
W4	NS	0.27
W5	0.30	0.28
W6	0.30	0.29
W7	0.27	0.30
W8	0.24	0.27
O1	NS	NS
O2	NS	NS
O3	NS	0.27
P1	0.22	0.23
P2	0.22	0.24
P3	0.24	0.27
Y1	0.31	0.32
Y2	0.28	0.28
Y3	0.27	0.26

APPENDIX B

Table B1: Ten minute infiltration rate ANOVA

Source	DF	Sum of Squares	Mean Squares	F-value	Pr> F
Total	23	SS total			
A	2	333.0173	166.509	9.83	0.0128
B	3	1.624	0.541	0	
B*A	6	101.681	16.947	0.42	0.8464
B*C	4	46.895	11.724	0.29	0.8759
Error	8	322.348	40.297		

A=Tillage
B=Block
C=North or South subsample
DF= Degrees of freedom

Table B2: Residue cover ANOVA

Source	DF	Sum of Squares	Mean Squares	F-value	Pr> F
Tillage	2	0.030123	0.015061	5.62	0.0688
Block	3	0.027056	0.009019	3.37	
Error	4	0.010710	0.002678		

Table B3: Surface manure coverage ANOVA

Source	DF	Sum of Squares	Mean Squares	F-value	Pr> F
Tillage	1	81.92	81.92	3.21	0.1710
Block	3	52.77	17.59	0.69	0.6162
Error	3	76.51	25.50		

Table B4: ANOVA table for bulk density as a function of treatment and depth

Effect	Numerator degrees of freedom	Denominator degrees of freedom	F-value	Pr> F
Tillage	1	3	5.05	0.1101
Depth	2	28	41.59	<0.0001
Tillage*depth	2	28	5.28	0.0113

Table B5: Phosphorous application uniformity ANOVA

Effect	Num. df	Den. df	F-value	Pr>F
Treatment	3	11.8	2.47	0.1127
Position	2	29.5	2.48	0.1007
Treatment*Position	6	29.5	0.93	0.4865
Depth	2	84	195.49	<.0001
Trt*Depth	6	84	13.25	<.0001
Position*depth	4	84	2.79	0.0316
Trt*position*Depth	12	84	1.62	0.1003

Table B6: Analysis of covariance table for phosphorus concentration as a function of treatment and tine position with soil EC as a covariate separately at each depth.

Effect	Num. df	Den df	F-value (Level of significance shown in parenthesis)		
			0-7.6 cm (0-3 in)	7.6-15 cm (3-6 in)	15-23 cm (6-9 in)
AIC=			714.9	749.2	705.7
Treatment	3	5	12.1(0.010)	1.88(0.25)	0.64(0.62)
Position	2	24	5.0 (0.015)	0.04(0.96)	0.55(0.58)
Treatment*Position	6	24	1.4 (0.265)	0.96(0.48)	2.34(0.065)
EC	1	5	26.4 (0.004)	9.4(0.028)	7.53(0.041)
Treatment*EC	3	24	7.0 (0.002)	NS	NS

Table B7: ANOVA table for phosphorus concentration as a function of treatment and tine position separately at each depth.

Effect	*Numerator degrees of freedom*	*Denominator degrees of freedom*	*F-value*	*Level of significance*
Depth1 AIC=743.1				
Treatment	3	9	5.8	0.018
Position	2	24	4.7	0.019
Treatment*Position	6	24	1.3	0.300
Depth2 AIC= 758.4				
Treatment	3	9	0.40	0.76
Position	2	23	0.05	0.95
Treatment*Position	6	23	0.97	0.46
Depth3 AIC=712.6				
Treatment	3	9	0.34	0.79
Position	2	23	0.52	0.60
Treatment*Position	6	23	2.35	0.65

Table B8: Pre-application soil EC at 91 cm (3 ft) depth ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Significance p-value
Trt	3	515.82	171.94	1.79	0.2194
Blck	3	7535.99	2512.00	26.12	<.0001
Blck*trt	9	865.58	96.18	7.99	<.0001
Error	288	3468.55	12.04		

Table B9: 1 day after application soil EC at 91 cm (3 ft) depth ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Significance p-value
Trt	3	595.39	198.46	1.91	0.1990
Blck	3	6597.73	2199.24	21.13	0.0002
Blck*trt	9	936.82	104.09	9.99	<.0001
Error	288	3001.49	10.42		

Table B10: 1 week after application soil EC at 91 cm (3 ft) depth ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Significance p-value
Trt	3	408.48	136.16	1.25	0.3448
Blck	3	6993.55	2331.18	21.59	0.0002
Blck*trt	9	971.80	107.98	11.49	<.0001
Error	288	2705.43	9.39		

Table B11: Pre-application soil EC at 30 cm depth (1 ft) ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Significance p-value
Trt	3	238.75	79.58	0.97	0.4490
Blck	3	4090.80	1363.60	16.6	0.0005
Blck*trt	9	739.44	82.16	17.13	<.0001
Error	288	1381.28	4.80		

Table B12: 1 day after application soil EC at 30 cm depth (1 ft) ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Significance p-value
Trt	3	1389.66	463.22	32.0	0.0764
Blck	3	4149.15	1383.05	9.56	0.0037
Blck*trt	9	1301.50	144.61	36.11	<.0001
Error	288	1153.35	4.00		

Table B13: 1 week after application soil EC at 30 cm depth (1 ft) ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Significance p-value
Trt	3	1254.97	418.32	3.25	0.0742
Blck	3	5874.37	1958.12	15.2	0.0007
Blck*trt	9	1159.41	128.82	19.21	<.0001
Error	288	1930.90	6.7		

APPENDIX C

Figure C1: Shatter tine helical mount configuration for two sets of shatter tines (courtesy of Aerway™)

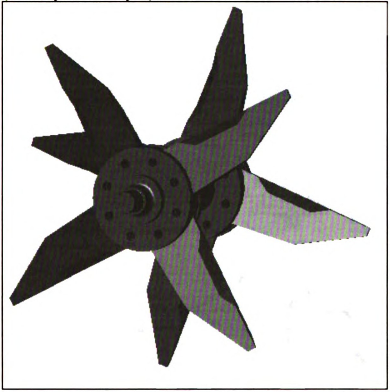

Figure C2: Rear and side views of rolling tine harrow (courtesy of Aerway™)

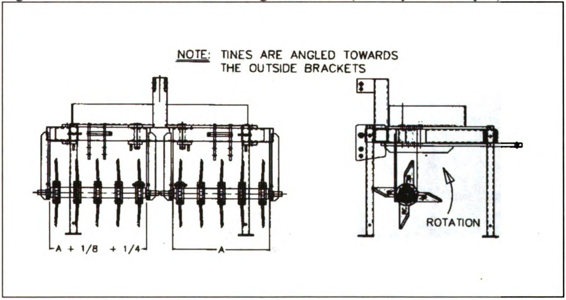

Figure C3: Top and side of 10 foot rolling tine harrow. (courtesy of Aerway™)

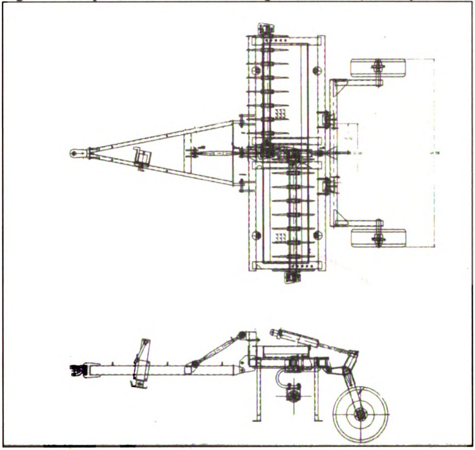

Figure C4: Aerway™ rolling tine harrow manure injector

Figure C5: Aerway™ in use on experimental plots

Figure C6: Inside the Aerway™ grinder and distribution manifold

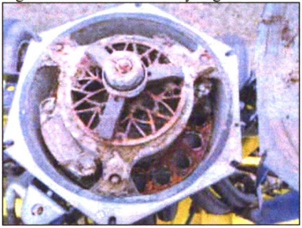

Figure C7: Aerway™ distribution nozzles with outlet shut-offs closed

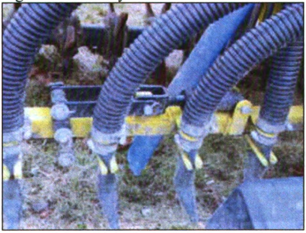

Figure C8: Valve and pump configuration on Nuhn™ tank

Figure C9: Hitch on Nuhn™ tank

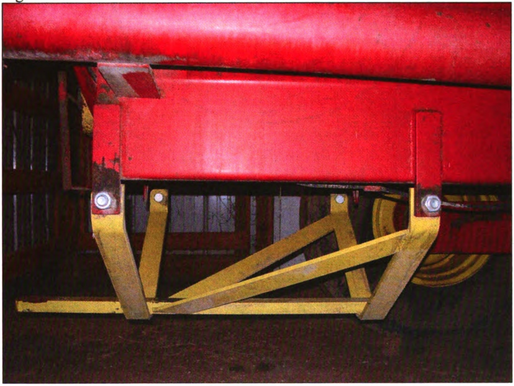

Figure C10: The double ring infiltrometer

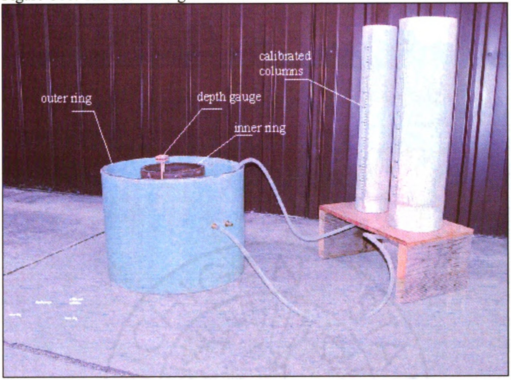

Figure C11: The Veris® 3100

Figure C12: Aerway™ light tillage void cavities (excavation normal to travel)

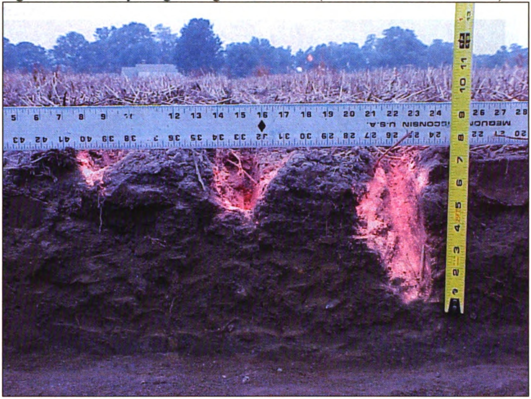

Figure C13: Aerway™ light tillage void cavities, top view (excavation normal to travel)

Figure C14: Aerway™ aggressive tillage void cavities, top view (excavation normal to travel)

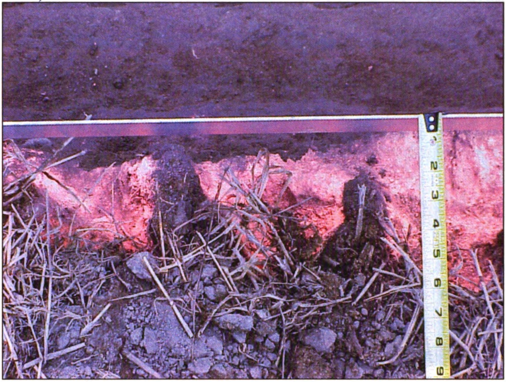

Figure C15: Aerway™ aggressive tillage void cavities, side view (excavation normal to travel)

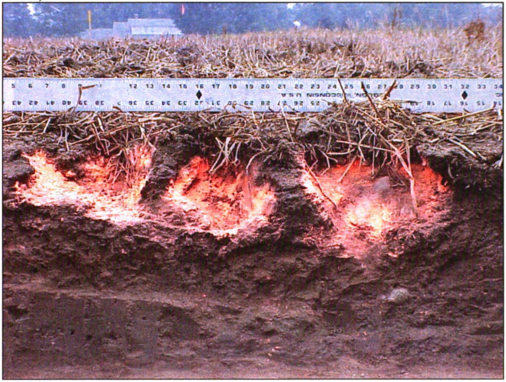

Figure C16: Aerway™ light tillage void cavity pattern

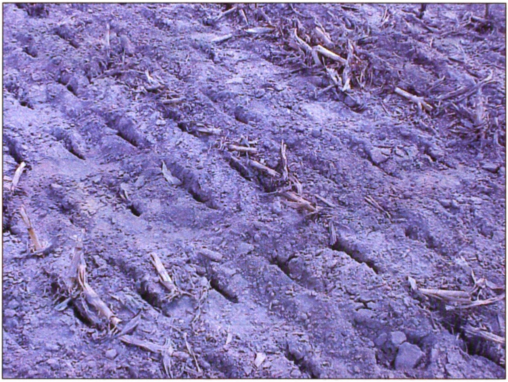

Figure C17: Aerway™ aggressive tillage void cavity pattern

Figure C18: Aerway™ aggressive tillage 3-D void cavities model

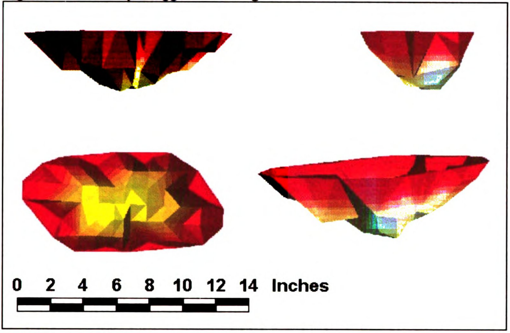

Figure C19: Aerway™ light tillage 3-D void cavities model

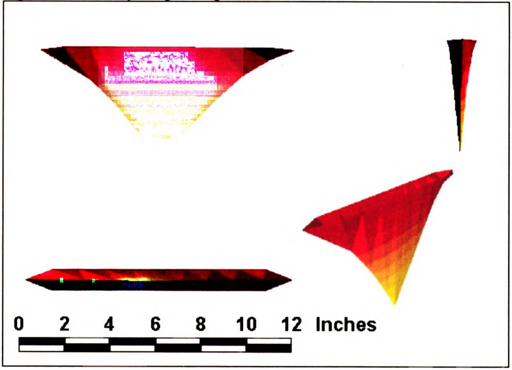

Figure C20: Aerway™ no tillage surface manure coverage with tire track