# Soil Nutrient Levels and Crop Performance at Various Lateral Positions Following Liquid Manure Injection

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## ABSTRACT

A three-year field experiment was conducted to investigate soil nutrient distribution and crop response at different lateral positions relative to center lines of injected manure bands in soil. Liquid swine manure was injected using coulter- and furrower-type tools at three rates (1.2, 2.4, and 3.6 litter per one meter of manure band). Levels of available soil nutrients ($NO_3$-N, $NH_4$-N, and $P_2O_5$), soil EC, and soil pH were measured at various lateral positions across the manure band. Plant characteristics (number of tillers, number of heads, and length of main stem), plant biomass, and total N and P in plant biomass were measured for crop rows at different lateral positions. The soil $NO_3$-N, $NH_4$-N, and $P_2O_5$ concentrations and soil EC were significantly lower at a farther position from center lines of manure band, especially at the highest rate. The variations of the soil pH with the positions were inconsistent. Plants in the crop row further from a manure band had 25% fewer tillers, 20% fewer seed heads, 10% shorter main stem, 60% less plant biomass, and 25% lower total N in the plant biomass, compared to those in the crop row close to the band.

**Keywords:** Soil, crop, manure, nutrient, lateral position, injection

## 1. INTRODUCTION

Injection is a recommended method of liquid manure application although the field capacity of injection is lower than that of surface application (Sørensen, 2003). This is due to the advantages of injection for reducing odour emissions and ammonia volatilization (Chen *et al*., 2001; Meisinger and Jokela, 2000; Schmitt *et al.*, 1995). Manure is injected in bands which contain variable volumes of manure, depending on the tool spacing of the injector and the manure application rate. A manure band may be defined as the manure that has been placed into a slot in the soil formed by an injection tool along the direction of travel. The volume of manure per meter of band was defined as "micro-rate" of manure application by Rahman *et al*. (2004). Very large tool spacing and high micro-rate may result in excessive manure within the manure bands and insufficient amount of nutrients between the manure bands, referred as banding effect. This uneven nutrient distribution in soil may cause uneven crop responses (Sawyer *et al*., 1990, 1991; Warner and Godwin, 1988).

Although injection is known to conserve nitrogen for plant growth, there are previous reports of production problems, particularly with corn, due to the banding effect. Poor corn root distribution in manure bands (Schmitt and Hoeft, 1986) and plant stunting and yellowing where manure was injected (Schmitt and Hoeft, 1986; Westerman *et al*., 1983) have been described in the literature. Based on their observations of soil chemical properties and nutrient distribution with knife- and sweep-injected liquid cattle manure, Sawyer *et al*. (1990) concluded that conditions inhibitory to corn root growth existed for 7-8 weeks after knife-injection of manure. Their observations have implications for cereal production on the Canadian Prairies where knife or coulter injection is frequently used to reduce soil disturbance and prevent soil erosion.

To avoid banding effects, one wishes that manure nutrient spread far in the lateral direction that is defined as the direction perpendicular to the travel direction of the injector. Lateral spread of manure nutrients in soil is affected by the width of the manure bands initially placed into the soil. Wider bands favor a more uniform nutrient distribution in the soil. The width of manure band varies with the type of injection tool. Winged tools, such as sweeps and furrowers, place manure in wider bands compared to non-winged tools, such as discs and knives (Rahman *et al*., 2004). Following the injection, manure nutrients in a manure band will move both laterally and vertically within the soil, changing their lateral distribution in the soil over time. This process is affected by the nutrient concentrations in the manure bands initially placed in the soil, i.e. micro-rate.

There have been limited numbers of studies on lateral distributions of manure nutrients in soil following manure injection. Petersen *et al*. (2003) studied the distribution of dissolved compounds in slurry applied to soil. They reported strong gradients of Br- with distance from the injection slit in the lateral direction, indicating redistribution of Br- following the liquid phase of the slurry. Sawyer *et al*. (1990) observed highest concentrations of inorganic nitrogen at the center of manure band and lower concentrations at lateral distances of 12.7 cm or greater, with knife injection of liquid beef manure. McCormick *et al*. (1983) also reported similar N distribution after injecting liquid swine manure. Sawyer *et al*. (1991) reported decreased N concentrations and lower yield in corn plants at 25.4, 50.8, and 76.2 cm distances from knife injected manure band compared to plants growing in the center of the manure band.

There is little documentation in the literature to address banding effects of different micro-rates of manure application under different injector types. The objectives of this study were to investigate (1) soil nutrient levels (mainly nitrogen and phosphorous) and (2) crop performance (plant development characteristics and biomass) at different lateral positions relative to the center line of an injected manure band, under different micro-rates and different injector types.

## 2. MATERIALS AND METHODS

### 2.1 Site and Field Equipment Description

Experiments were conducted in two different fields in the growing seasons of 2002, 2003, and 2004 at Brandon Research Centre, Agriculture and Agri-Food Canada in Brandon, Manitoba, Canada. The site (49°51'N, 99°58'W) did not have a previous history of manure application. The site was tilled using a field cultivator before the manure injection operation in spring. The experiment was moved to a different field in the second year due to the availability of the field. However, those two fields were very close within the research center, and both fields had a clay loam surface texture.

## 2.2 Field Equipment

Liquid swine manure was injected using an injector system that included a 4.5 $m^3$ tanker equipped with a positive displacement pump and bypass to continually mix the manure in the tank. Tanker-mounted load cells were used to calibrate the application rate and to monitor the weight of manure applied to the plot. A 2.1 m wide implement mounted on a three-point hitch behind the tank supported gangs of injection tools. A non-winged and a winged tool were used to create contrasting manure band widths (narrow and wide). These two tools are best described as coulter and furrower, respectively, according to ASAE Standards (2004). The coulter had a diameter of 46 cm and was set to a gang angle of 14º. The furrower was 12 cm wide, had a sweep angle of 52º, and a rake angle of 11º. A hoe-type seeder was used for seeding the field at a row spacing of 30 cm.

## 2.3 Experimental Design

Six combinations of two injection tool types (coulter and furrower) and three micro-rates (referred to as rates hereafter) ($r_1$ = 1.2, $r_2$ = 2.4, and $r_3$ = 3.6 L $m^{-1}$) were set up in a completely randomized block design, replicated four times, forming a total of 24 plots in four blocks.
To compare soil nutrient levels and crop performance following manure injection, all plots received the same gross manure application rate, 34,000 L $ha^{-1}$. The different treatment rates were achieved by using different tool spacings, while the manure flow rate from the tank and the forward speed of the injector were kept constant during the injection. The injection tools were spaced 30 cm apart for the $r_1$ plots, 60 cm apart for the $r_2$ plots, and 90 cm apart for the $r_3$ plots.

## 2.4 Selection of Lateral Positions for Comparisons in Soil Nutrient and Crop Performance

Following injection operation, paths of the injection tools or center of manure bands were marked with flags on the plots to be used as references for subsequent seeding operations and soil sampling. During seeding, seed rows were positioned 15 cm away from, but parallel to adjacent manure bands to create the desired positions of crop rows relative to the manure band (Figure 1).

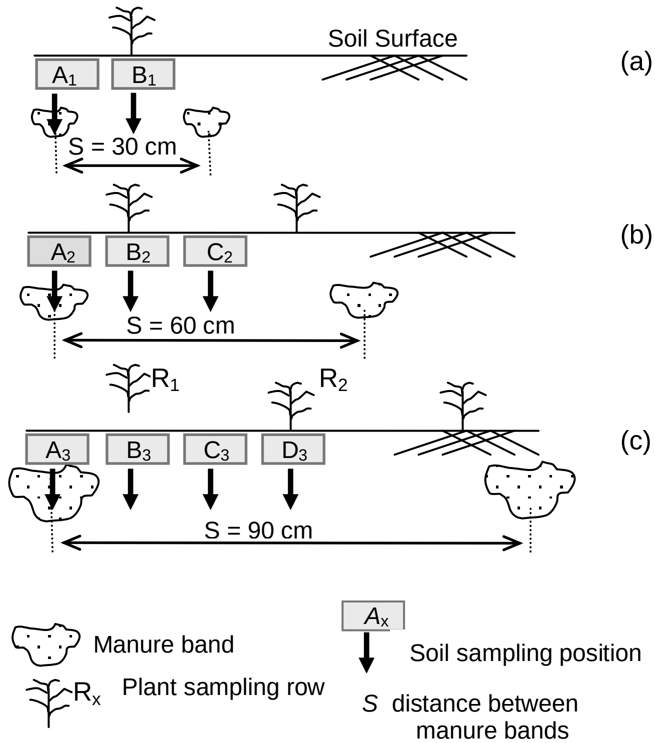



Figure 1. A schematic diagram of manure band, soil sampling position, and plant rows: (a) rate $r_1$=1.2 L m$^{-1}$, (b) rate $r_2$=2.4 L m$^{-1}$, and (c) rate $r_3$=3.6 L m$^{-1}$.

The experimental design created three different patterns of manure bands in soil, as shown in Figure 1. With increasing rate, a band contained more manure, but bands were positioned farther apart. Under each injection tool, lateral positions studied were $A_1$ and $B_1$ in the $r_1$ treatment, $A_2$, $B_2$, and $C_2$ in the $r_2$ treatment, and $A_3$, $B_3$, $C_3$, and $D_3$ in the $r_3$ treatment (Figure 1). The position A's were located on the center line of manure band. The position B's, C's, and D's were 15, 30, and 45 cm away from the center line of manure band, respectively. For the $r_1$ and $r_2$ plots, all crop rows were 15 cm away from the center line of a manure band, which could not be used for comparison of crop performance. For the $r_3$ plots, there were two distinct crop rows: $R_1$ and $R_2$ laid at 15 and 45 cm distances from the center line of a manure band, respectively. The treatments and positions are summarized in Table 1.

Table 1. Symbolic designations for manure application rate and soil and plant sampling positions

| Rate | | Lateral position | | | |
|---|---|---|---|---|---|
| | | Soil sampling | | Plant sampling | |
| Symbol | Value | Symbol | Distance from manure band | Symbol | Distance from manure band |
| | $L\ m^{-1}$ | | cm | | cm |
| $r_1$ | 1.2 | $A_1$ | 0 | | |
| | | $B_1$ | 15 | | |
| $r_2$ | 2.4 | $A_2$ | 0 | | |
| | | $B_2$ | 15 | | |
| | | $C_2$ | 30 | | |
| $r_3$ | 3.6 | $A_3$ | 0 | | |
| | | $B_3$ | 15 | $R_1$ | 15 |
| | | $C_3$ | 30 | $R_2$ | 45 |
| | | $D_3$ | 45 | | |

**2.5 Measurements**

**2.5.1 Soil Nutrients**

Following manure injection, soil samples were taken for nutrient analyses in each plot at each of the soil sampling positions shown in Figure 1. Soil core samplers with a 1.9 cm diameter were used to take soil cores. In 2002, the sampling was done in one depth range (0-30 cm), while in 2003 and 2004 it was done in an additional depth range (30-60 cm). For each position, samples were collected from three random locations in each plot. The soil cores collected from those three locations were pooled according to depth to form a composite sample of the respective position. Samples were then sent to the laboratory for nutrient analysis.
The first soil sampling was carried out three weeks after the manure application. By then the crop had reached a state of full emergence. During the first sampling in each year, the sampling locations were flag-marked for use as references in subsequent samplings. Then sampling was carried out every two to three weeks, depending on the weather conditions. The samples were analyzed in the interest of knowing soil nitrogen and phosphorus concentrations. Additional analysis was also performed on soil electrical conductivity and soil pH.

**2.5.2 Plant Development Characteristics**

Plant samples were collected at the soft dough stage for comparing plant development characteristics between the two different crop rows ($R_1$ and $R_2$) in the $r_3$ treatment (Figure 1). Whole plants were collected by randomly uprooting 40 plants per plot, 20 from each of $R_1$ and $R_2$ rows between any two random but consecutive manure bands. The number of heads and tillers per plant were counted and the length of main stem was measured using a ruler.

**2.5.3 Biomass, and Total N and P in the Biomass**

Plant samples for biomass measurement were taken also at the soft dough stage. Crop rows of 50-cm length were cut 7 cm above ground level at three random locations from each of two crop rows ($R_1$ and $R_2$ shown in Figure 1) to determine plant biomass, and total N and P in the biomass. The samples for each row from the three locations were combined to form a composite sample. Samples were weighed to determine the mass per unit length of crop row. Then, plant samples were digested using the standard acid ($H_2SO_4$-$H_2O_2$) digestion method described in Thomas *et al*. (1967). A Technicon Autoanalyzer was used to colorimetrically determine total N and P in the digest.

### 2.6 Statistical Analyses

The data were analyzed using SAS software (SAS Institute Inc., 2001). Analysis of Variance was carried out using the general linear model (GLM) procedure to calculate mean values of variables of interest at different positions within each treatment. Least Significant Difference (LSD) test was employed to determine mean differences within treatment at different positions under each combination of injection tool type and rate. Considering the inherently high variability in soils, all comparisons were made at a probability of 0.1 ($P < 0.1$). Data were analyzed within a year due to the great differences in precipitation between years. Due to the page limit, not all data are presented in the following sections.

## 3. RESULTS AND DISCUSSION

### 3.1 Background Information on Weather, Soil, and Manure

The weather was highly variable during the three years. Total precipitation over the growing seasons of 2002, 2003, and 2004 was 25.1, 18.5, and 36.9 cm, respectively, in contrast to a 16-year average precipitation of 29.0 cm. At the time of manure injection, the soils had a low bulk density of approximately 0.8-0.9 Mg $m^{-3}$ due to spring tillage before the injection, and the soil moisture contents were 24, 34, and 36% (dry basis) in 2002, 2003, and 2004, respectively. The average total N was 2.9 kg 1,000 $L^{-1}$ in the manure, of which approximately 90% existed in the form of $NH_4$-N. The average total P in the manure was 0.6 kg 1,000 $L^{-1}$.

### 3.2 Soil Nitrate Nitrogen ($NO_3$-N)

In 2002, a trend of decreasing soil $NO_3$-N with position farther from center line of manure band was observed (Table 2a). In the first of five sampling periods, levels of soil $NO_3$-N were significantly higher at the position $A_1$ than at the position $B_1$, regardless of injector type. Three weeks after manure injection, soil concentrations of $NO_3$-N at the position $A_2$ were two and four times higher than those at the positions $B_2$ and $C_2$, respectively, when the coulter was used for manure injection. After the last sampling, the reverse trend was observed, likely due to a combination of denitrification due to the low oxygen content of the soil close to the manure band and uptake of nitrogen by the crop. The positions $A_2$, $B_2$, and $C_2$ had similar soil $NO_3$-N when the furrower was used. Position effects were more pronounced in the $r_3$ treatments, where soil $NO_3$-N significantly decreased with the distance from the center line of manure band in four out of five sampling periods.

Table 2a. Levels of extractable soil $NO_3$-N at varying lateral positions at a soil depth of 0-30 cm, 2002

| Rate | Position[1] | Weeks after injection | | | | |
|---|---|---|---|---|---|---|
| | | 3 wk | 5 wk | 7 wk | 9 wk | 11 wk |
| L $m^{-1}$ | | μg $g^{-1}$ | μg $g^{-1}$ | μg $g^{-1}$ | μg $g^{-1}$ | μg $g^{-1}$ |
| Coulter | | | | | | |
| $r_1$=1.2 | $A_1$ | 44.0 a[2] | 20.1 a | 10.2 a | 3.7 a | 1.7 a |
| | $B_1$ | 23.8 a | 10.3 b | 5.1 a | 6.8 a | 2.7 a |
| $r_2$=2.4 | $A_2$ | 38.0 a | 5.7 a | 1.7 a | 2.3 a | 1.1 ab |
| | $B_2$ | 13.1 b | 4.2 a | 1.8 a | 2.3 a | 1.0 b |
| | $C_2$ | 7.5 b | 3.8 a | 5.3 a | 1.9 a | 1.5 a |
| $r_3$=3.6 | $A_3$ | 68.8 a | 31.7 a | 8.0 b | 3.5 ab | 1.5 a |
| | $B_3$ | 24.0 b | 14.9 b | 19.8 a | 5.8 a | 1.5 a |
| | $C_3$ | 15.0 b | 2.6 c | 4.0 c | 1.9 ab | 1.3 a |
| | $D_3$ | 12.5 b | 1.7 c | 4.5 b | 1.4 b | 1.0 a |
| Furrower | | | | | | |
| $r_1$=1.2 | $A_1$ | 42.4 a | 17.9 a | 13.9 a | 2.7 a | 1.9 a |
| | $B_1$ | 19.0 b | 5.0 a | 8.1 a | 3.1 a | 2.4 a |
| $r_2$=2.4 | $A_2$ | 18.2 a | 14.7 a | 1.8 a | 1.1 a | 1.0 a |
| | $B_2$ | 24.0 a | 13.8 a | 3.8 a | 2.1 a | 1.1 a |
| | $C_2$ | 19.9 a | 8.5 a | 2.8 a | 1.8 a | 1.1 a |
| $r_3$=3.6 | $A_3$ | 66.3 a | 35.5 a | 42.1 a | 8.4 a | 2.3 a |
| | $B_3$ | 25.9 b | 17.3 b | 5.2 ab | 3.1 b | 3.8 a |
| | $C_3$ | 14.6 bc | 5.5 c | 2.9 b | 3.1 b | 1.6 a |
| | $D_3$ | 7.5 c | 3.4 c | 2.0 b | 1.7 b | 1.5 a |

[1]A, B, C, and D refer to positions at the center of manure band, 15, 30, 45 cm away from the center of manure band, respectively.
[2]Values, within a column and the same rate, followed by the same letter are not significantly different.

In 2003, the overall trend of soil $NO_3$-N (Table 2b) was consistent with that in 2002. Using the coulter, significant differences were observed once where the position $A_3$ had higher soil $NO_3$-N than the positions $B_3$, $C_3$ and $D_3$, nine weeks after injection at the 0-30 cm depth. When the furrower was used, the position $A_2$ had significantly higher soil $NO_3$-N than the positions $B_2$ and $C_2$ at the 0-30 cm depth at all sampling periods. Similarly, in plots where manure was injected using the furrower, the position $A_3$ had significantly higher soil $NO_3$-N than the positions $B_3$, $C_3$, and $D_3$ at the 0-30 cm depth at all sampling periods. These trends were observed at the 30-60 cm depth, but they were less pronounced.

Table 2b. Levels of extractable soil $NO_3$-N at varying lateral positions at two soil depths, 2003

| Rate | Position[1] | 3 wk after injection | | 6 wk after injection | | 9 wk after injection | |
|---|---|---|---|---|---|---|---|
| | | 0-30 (cm) | 30-60 (cm) | 0-30 (cm) | 30-60 (cm) | 0-30 (cm) | 30-60 (cm) |
| L $m^{-1}$ | | μg $g^{-1}$ | μg $g^{-1}$ | μg $g^{-1}$ | μg $g^{-1}$ | μg $g^{-1}$ | μg $g^{-1}$ |
| Coulter | | | | | | | |
| $r_1$=1.2 | $A_1$ | 24.8 a[2] | 12.4 a | 9.5 a | 10.0 a | 14.2 a | 9.5 a |
| | $B_1$ | 39.9 a | 13.0 a | 12.7 a | 9.4 a | 17.1 a | 8.7 a |
| $r_2$=2.4 | $A_2$ | 39.0 a | 14.8 a | 9.3 a | 8.6 a | 18.0 a | 4.9 a |
| | $B_2$ | 17.6 a | 15.9 a | 11.3 a | 10.8 a | 13.3 a | 12.5 a |
| | $C_2$ | 20.6 a | 14.8 a | 6.0 a | 11.9 a | 11.6 a | 8.3 a |
| $r_3$=3.6 | $A_3$ | 33.2 a | 15.8 a | 9.9 a | 12.8 a | 41.0 a | 10.4 a |
| | $B_3$ | 21.5 a | 14.2 a | 11.1 a | 9.4 a | 16.4 b | 10.4 a |
| | $C_3$ | 13.8 a | 15.3 a | 15.0 a | 11.7 a | 13.1 b | 11.4 a |
| | $D_3$ | 13.2 a | 11.6 a | 14.9 a | 17.3 a | 8.8 b | 6.0 a |
| Furrower | | | | | | | |
| $r_1$=1.2 | $A_1$ | 27.2 a | 13.5 a | 16.2 a | 13.7 a | 24.0 a | 12.4 a |
| | $B_1$ | 27.5 a | 13.4 a | 18.1 a | 13.9 a | 17.6 a | 9.6 b |
| $r_2$=2.4 | $A_2$ | 47.8 a | 12.1 a | 25.2 a | 10.0 a | 29.7 a | 9.4 a |
| | $B_2$ | 23.6 b | 12.3 a | 8.2 b | 10.0 a | 13.3 b | 7.0 a |
| | $C_2$ | 11.0 b | 10.8 a | 10.7 b | 10.2 a | 14.2 b | 9.7 a |
| $r_3$=3.6 | $A_3$ | 53.6 a | 16.6 a | 46.7 a | 16.3 ab | 42.7 a | 12.1 a |
| | $B_3$ | 28.5 b | 15.6 a | 13.7 b | 19.2 a | 20.7 b | 9.4 a |
| | $C_3$ | 24.4 b | 18.7 a | 14.1 b | 11.8 b | 15.2 b | 8.8 a |
| | $D_3$ | 15.5 b | 16.5 a | 7.6 b | 13.4 ab | 12.0 b | 7.2 a |

[1]A, B, C, and D refer to positions at the center of manure band, 15, 30, 45 cm away from the center of manure band, respectively.

[2]Values, within a column and the same rate, followed by the same letter are not significantly different.

Similarly, results in 2004 indicated that soil $NO_3$-N decreased with increasing distance from the center of manure band (Table 2c). Significant position effects were observed over the growing season and after harvest. Again this position effect was more pronounced at the 0-30 cm soil depth than 30-60 cm depth and in the $r_3$ treatment than in the $r_1$ and $r_2$ treatments.

Table 2c. Levels of extractable soil $NO_3$-N at varying lateral positions at two soil depths, 2004

| Rate | Position[1] | 3 wk after injection | | 6 wk after injection | | 19 wk after injection | |
|---|---|---|---|---|---|---|---|
| | | 0-30 (cm) | 30-60 (cm) | 0-30 (cm) | 30-60 (cm) | 0-30 (cm) | 30-60 (cm) |
| $L\ m^{-1}$ | | $\mu g\ g^{-1}$ | $\mu g\ g^{-1}$ | $\mu g\ g^{-1}$ | $\mu g\ g^{-1}$ | $\mu g\ g^{-1}$ | $\mu g\ g^{-1}$ |
| Coulter | | | | | | | |
| $r_1$=1.2 | $A_1$ | 24.3 a[2] | 15.5 a | 17.4 a | 14.2 a | 8.1 a | 2.3 b |
| | $B_1$ | 12.3 b | 20.6 a | 8.8 a | 11.7 a | 7.2 a | 3.3 a |
| $r_2$=2.4 | $A_2$ | 36.9 a | 26.6 a | 34.1 a | 16.0 a | 6.7 a | 2.5 a |
| | $B_2$ | 26.5 a | 19.1 b | 4.8 b | 11.4 ab | 1.3 a | 1.9 a |
| | $C_2$ | 13.0 b | 19.0 b | 4.4 b | 10.2 b | 0.8 a | 0.7 a |
| $r_3$=3.6 | $A_3$ | 23.1 a | 21.1 ab | 23.1 a | 15.0 a | 8.3 a | 3.2 a |
| | $B_3$ | 12.3 ab | 13.8 bc | 10.4 b | 12.2 ab | 4.0 a | 2.5 a |
| | $C_3$ | 10.3 b | 21.9 a | 4.2 c | 9.4 b | 1.8 a | 0.8 a |
| | $D_3$ | 15.0 ab | 13.2 c | 4.4 c | 11.4 b | 2.5 a | 0.9 a |
| Furrower | | | | | | | |
| $r_1$=1.2 | $A_1$ | 21.8 a | 24.3 a | 18.7 a | 15.9 a | 1.3 a | 1.0 a |
| | $B_1$ | 21.7 a | 21.6 a | 10.7 b | 16.4 a | 1.4 a | 3.6 a |
| $r_2$=2.4 | $A_2$ | 19.5 a | 17.6 a | 32.4 a | 16.3 a | 11.3 a | 0.8 a |
| | $B_2$ | 20.2 a | 15.6 a | 11.8 b | 14.0 b | 5.9 ab | 2.3 a |
| | $C_2$ | 14.2 a | 16.2 a | 7.9 b | 13.0 b | 4.8 b | 2.2 a |
| $r_3$=3.6 | $A_3$ | 15.0 a | 10.0 a | 42.5 a | 18.0 a | 13.8 a | 2.5 a |
| | $B_3$ | 20.6 a | 14.0 a | 15.7 b | 11.9 b | 5.7 b | 2.7 a |
| | $C_3$ | 8.6 a | 11.4 a | 3.9 b | 9.4 b | 3.5 b | 2.8 a |
| | $D_3$ | 8.5 a | 14.4 a | 3.3 b | 7.6 b | 5.0 b | 1.9 a |

[1]A, B, C, and D refer to positions at the center of manure band, 15, 30, 45 cm away from the center of manure band, respectively.
[2]Values, within a column and the same rate, followed by the same letter are not significantly different.

### 3.3 Soil Ammonium Nitrogen ($NH_4$-N)

The data of soil $NH_4$-N for 2004 are presented in Table 3. Similar to the soil $NO_3$-N, decreasing concentrations of soil $NH_4$-N were observed with increasing distance from center line of manure band. This position effect was significant for the $r_2$ and $r_3$ rates at both the 0-30 and 30-60 cm depths under both injection tools. Levels of soil $NH_4$-N (0.44-1.33 $\mu g\ g^{-1}$) in 2002 were low at all periods of sampling possibly due to nitrification. There were few significant effects of position on soil $NH_4$-N during this growing season. Therefore, the data are not presented. Soil $NH_4$-N was not measured in 2003.

Table 3. Levels of extractable soil $NH_4$-N at varying lateral positions at two soil depths, 2004

| Rate | Position[1] | 3 wk after injection | | 6 wk after injection | |
|---|---|---|---|---|---|
| | | 0-30 (cm) | 30-60 (cm) | 0-30 (cm) | 30-60 (cm) |
| L $m^{-1}$ | | µg $g^{-1}$ | µg $g^{-1}$ | µg $g^{-1}$ | µg $g^{-1}$ |
| Coulter | | | | | |
| $r_1$=1.2 | $A_1$ | 16.4 a[2] | 7.6 a | 13.9 a | 11.0 a |
| | $B_1$ | 8.5 a | 7.4 a | 14.2 a | 11.5 a |
| $r_2$=2.4 | $A_2$ | 23.2 a | 9.6 a | 13.2 a | 9.7 a |
| | $B_2$ | 10.1 b | 6.2 b | 9.7 a | 9.4 a |
| | $C_2$ | 9.4 b | 7.3 b | 8.3 a | 9.8 a |
| $r_3$=3.6 | $A_3$ | 66.0 a | 12.4 a | 12.7 a | 9.1 a |
| | $B_3$ | 10.8 b | 10.0 b | 9.6 a | 9.3 a |
| | $C_3$ | 10.8 b | 7.6 c | 9.3 a | 10.7 a |
| | $D_3$ | 9.6 b | 7.6 c | 9.4 a | 10.8 a |
| Furrower | | | | | |
| $r_1$=1.2 | $A_1$ | 11.8 a | 9.7 a | 12.6 a | 12.4 a |
| | $B_1$ | 16.0 a | 8.7 a | 11.7 a | 11.3 a |
| $r_2$=2.4 | $A_2$ | 26.9 a | 11.5 a | 14.4 a | 9.2 b |
| | $B_2$ | 12.9 ab | 9.1 a | 9.6 b | 11.0 a |
| | $C_2$ | 9.1 b | 7.0 a | 9.4 b | 10.1 ab |
| $r_3$=3.6 | $A_3$ | 31.8 a | 11.2 a | 13.2 a | 9.7 a |
| | $B_3$ | 17.6 ab | 7.5 ab | 8.6 b | 11.3 a |
| | $C_3$ | 10.3 b | 6.0 b | 7.6 b | 9.4 a |
| | $D_3$ | 8.1 b | 6.6 b | 7.2 b | 9.7 a |

[1]A, B, C, and D refer to positions at the center of manure band, 15, 30, 45 cm away from the center of manure band, respectively.
[2]Values, within a column and the same rate, followed by the same letter are not significantly different.

Position effects on soil $NO_3$-N and $NH_4$-N observed in this study are consistent with those of Sawyer *et al*. (1990), who observed that the highest concentrations of inorganic nitrogen were present at centers of manure band, with lower concentrations at lateral distances of 12.7 cm. McCormick *et al*. (1983) also reported similar N distribution effects after injecting liquid swine manure.

### 3.4 Soil Phosphate ($P_2O_5$)

Measurements in 2004 indicated that concentrations of soil $P_2O_5$ were consistently lower at all measured points distant from center line of manure band (Table 4). This was expected since manure P is relatively immobile in soil, particularly soils with high clay content. Soil $P_2O_5$ at the position A was the highest and significantly different from the positions B, C, and D at both soil depths over the growing season and after harvest. Data collected in 2003 showed the same soil response but concentration differences were lower (data not shown). The data of 2002 showed few significant differences between treatments (data not shown).

Table 4. Extractable soil $P_2O_5$ at varying lateral positions at two soil depths, 2004

| Rate | Position[1] | 3 wk after injection | | 6 wk after injection | | 19 wk after injection | |
|---|---|---|---|---|---|---|---|
| | | 0-30 (cm) | 30-60 (cm) | 0-30 (cm) | 30-60 (cm) | 0-30 (cm) | 30-60 (cm) |
| L m$^{-1}$ | | µg g$^{-1}$ | µg g$^{-1}$ | µg g$^{-1}$ | µg g$^{-1}$ | µg g$^{-1}$ | µg g$^{-1}$ |
| Coulter | | | | | | | |
| $r_1$=1.2 | $A_1$ | 73.5 a[2] | 58.2 a | 65.0 a | 52.3 a | 74.7 a | 58.2 a |
| | $B_1$ | 74.4 a | 49.4 a | 67.2 a | 59.7 a | 67.4 a | 54.8 a |
| $r_2$=2.4 | $A_2$ | 93.9 a | 62.1 a | 60.4 a | 60.9 a | 61.3 a | 45.0 a |
| | $B_2$ | 72.3 ab | 47.9 a | 50.6 a | 55.2 b | 48.3 a | 58.3 a |
| | $C_2$ | 67.4 b | 76.7 a | 49.6 a | 54.3 b | 52.6 a | 45.4 a |
| $r_3$=3.6 | $A_3$ | 123.0 a | 50.0 a | 57.6 a | 54.9 a | 92.6 a | 47.5 a |
| | $B_3$ | 68.2 b | 39.5 bc | 49.0 b | 51.4 a | 52.04 b | 44.8 a |
| | $C_3$ | 69.2 b | 47.4 ab | 51.4 b | 54.7 a | 58.4 b | 49.4 a |
| | $D_3$ | 70.7 b | 34.5 c | 51.1 b | 52.8 a | 67.9 ab | 49.0 a |
| Furrower | | | | | | | |
| $r_1$=1.2 | $A_1$ | 73.8 a | 67.1 a | 67.7 a | 65.6 a | 81.6 a | 66.5 a |
| | $B_1$ | 92.6 a | 87.6 b | 66.6 a | 63.7 a | 67.6 b | 57.8 a |
| $r_2$=2.4 | $A_2$ | 75.8 a | 48.0 a | 62.4 a | 38.3 a | 66.2 a | 44.6 a |
| | $B_2$ | 67.7 a | 43.3 ab | 51.5 b | 34.3 a | 47.8 b | 38.0 a |
| | $C_2$ | 62.9 a | 38.2 b | 49.3 b | 37.0 a | 48.8 b | 39.2 a |
| $r_3$=3.6 | $A_3$ | 93.1 a | 40.6 a | 70.2 a | 54.8 ab | 77.4 a | 56.3 a |
| | $B_3$ | 74.5 ab | 50.4 a | 60.2 ab | 57.6 a | 60.9 b | 53.9 a |
| | $C_3$ | 68.9 ab | 49.0 a | 50.9 b | 42.6 b | 58.7 b | 55.8 a |
| | $D_3$ | 63.4 b | 62.1 a | 54.2 b | 41.1 b | 59.2 b | 38.1 b |

[1]A, B, C, and D refer to positions at the center of manure band, 15, 30, 45 cm away from the center of manure band, respectively.
[2]Values, within a column and the same rate, followed by the same letter are not significantly different.

### 3.5 Soil Electrical Conductivity (EC)

Soil EC also declined with increasing distance from the manure band (Table 5). In 2002, a decline in soil EC was observed when manure was injected using the coulter, although there was no significant difference observed between the positions $A_1$ and $B_1$ at all sampling periods (Table 5a). In contrast, when manure was injected using the furrower, the soil EC at the position $A_1$ was higher than that at $B_1$ at all sampling periods. At the highest rate, the soil EC measured in the manure band was frequently higher than the soil EC at the other sampling positions, regardless of the type of injection tool. Soil EC was not determined in 2003. The same decreasing trend was observed in 2004 (Table 5b) as in 2002. Differences among positions were also similar to those observed in 2002, but were less consistent. These observations are consistent with those reported by Peterson *et al*. (2003), who observed a horizontal gradient in soil EC after injecting swine and cattle slurries using disc injection tools, with the highest EC occurring in the injection slit. However, when using a harrow tine injection tool, they reported similar EC levels at varying positions relative to injection slit, which they attributed to horizontal distribution of slurry liquids or initial mixing of slurry into a large soil volume.

Table 5a. Soil EC at varying lateral positions at a soil depth of 0-30 cm, 2002

| Rate | Position[1] | Weeks after injection | | | | |
|---|---|---|---|---|---|---|
| | | 3 wk | 5 wk | 7 wk | 9 wk | 11 wk |
| L $m^{-1}$ | | dS $m^{-1}$ | dS $m^{-1}$ | dS $m^{-1}$ | dS $m^{-1}$ | dS $m^{-1}$ |
| Coulter | | | | | | |
| $r_1$=1.2 | $A_1$ | 0.84 a[2] | 0.71 a | 1.61 a | 0.52 a | 0.50 a |
| | $B_1$ | 0.62 a | 0.63 a | 0.60 a | 0.55 a | 0.49 a |
| $r_2$=2.4 | $A_2$ | 0.79 a | 0.63 a | 0.60 ab | 0.53 a | 0.50 a |
| | $B_2$ | 0.56 a | 0.56 a | 0.57 b | 0.49 a | 0.48 ab |
| | $C_2$ | 0.55 a | 0.61 a | 0.62 a | 0.50 a | 0.44 b |
| $r_3$=3.6 | $A_3$ | 1.20 a | 0.78 a | 0.63 a | 0.54 a | 0.48 a |
| | $B_3$ | 0.59 b | 0.64 b | 1.31 a | 0.53 a | 0.47 a |
| | $C_3$ | 0.56 b | 0.60 b | 0.66 a | 0.53 a | 0.39 a |
| | $D_3$ | 0.54 b | 0.58 b | 0.61 a | 0.51 a | 0.43 a |
| Furrower | | | | | | |
| $r_1$=1.2 | $A_1$ | 0.83 a | 0.71 a | 0.64 a | 0.53 b | 0.52 a |
| | $B_1$ | 0.63 b | 0.55 b | 0.57 b | 0.57 a | 0.48 b |
| $r_2$=2.4 | $A_2$ | 0.62 a | 0.66 a | 0.63 a | 0.55 a | 0.55 a |
| | $B_2$ | 0.66 a | 0.69 a | 0.62 a | 0.55 a | 0.53 a |
| | $C_2$ | 0.63 a | 0.60 a | 0.62 a | 0.51 a | 0.47 a |
| $r_3$=3.6 | $A_3$ | 1.12 a | 0.85 a | 0.75 a | 0.61 a | 0.50 a |
| | $B_3$ | 0.70 b | 0.68 b | 0.65 b | 0.55 ab | 0.54 a |
| | $C_3$ | 0.60 c | 0.58 c | 0.61 b | 0.50 b | 0.49 a |
| | | 0.55 c | 0.55 c | 0.61 b | 0.49 b | 0.50 a |

[1]A, B, C, and D refer to positions at the center of manure band, 15, 30, 45 cm away from the center of manure band, respectively.

[2]Values, within a column and the same rate, followed by the same letter are not significantly different.

Table 5b. Soil EC at varying lateral positions at two soil depths, 2004

| Rate | Position[1] | 3 wk after injection | | 6 wk after injection | | 19 wk after injection | |
|---|---|---|---|---|---|---|---|
| | | 0-30 (cm) | 30-60 (cm) | 0-30 (cm) | 30-60 (cm) | 0-30 (cm) | 30-60 (cm) |
| L m$^{-1}$ | | dS m$^{-1}$ | dS m$^{-1}$ | dS m$^{-1}$ | dS m$^{-1}$ | dS m$^{-1}$ | dS m$^{-1}$ |
| Coulter | | | | | | | |
| $r_1$=1.2 | $A_1$ | 0.68 a[2] | 0.70 a | 0.65 a | 0.70 a | 0.51a | 0.55 a |
| | $B_1$ | 0.58 a | 0.71 a | 0.58 a | 0.68 b | 0.53a | 0.62 a |
| $r_2$=2.4 | $A_2$ | 0.69 a | 0.75 a | 0.70 a | 0.66 a | 0.52a | 0.58 a |
| | $B_2$ | 0.72 a | 0.69 b | 0.52 b | 0.65 a | 0.50a | 0.60 a |
| | $C_2$ | 0.61 a | 0.69 b | 0.52 b | 0.63 a | 0.50a | 0.59 a |
| $r_3$=3.6 | $A_3$ | 0.69 a | 0.73 a | 0.71 a | 0.71 a | 0.51a | 0.63 a |
| | $B_3$ | 0.66 a | 0.68 b | 0.60 b | 0.70 ab | 0.51a | 1.32 a |
| | $C_3$ | 0.61 a | 0.73 a | 0.52 c | 0.69 ab | 0.50a | 0.91 a |
| | $D_3$ | 0.61 a | 0.71 ab | 0.61 b | 0.68 b | 0.51a | 0.72 a |
| Furrower | | | | | | | |
| $r_1$=1.2 | $A_1$ | 0.73 a | 0.75 a | 0.66 a | 0.80 a | 0.53a | 0.71 a |
| | $B_1$ | 0.64 a | 0.76 a | 0.62 a | 0.72 a | 0.51a | 0.77 a |
| $r_2$=2.4 | $A_2$ | 0.55 a | 0.64 b | 0.63 a | 0.72 a | 0.51a | 0.61 a |
| | $B_2$ | 0.58 a | 0.70 a | 0.52 b | 0.69 ab | 0.47a | 0.61 a |
| | $C_2$ | 0.49 a | 0.64 b | 0.49 b | 0.67 b | 0.47a | 0.57 a |
| $r_3$=3.6 | $A_3$ | 0.65 a | 0.79 a | 0.77 a | 1.14 a | 0.60a | 1.03 a |
| | $B_3$ | 0.64 a | 0.75 a | 0.60 b | 1.32 a | 0.49b | 1.18 a |
| | $C_3$ | 0.51 a | 0.69 a | 0.54 b | 0.84 a | 0.46b | 1.28 a |
| | $D_3$ | 0.52 a | 0.67 a | 0.44 c | 0.67 a | 0.49b | 1.18 a |

[1]A, B, C, and D refer to positions at the center of manure band, 15, 30, 45 cm away from the center of manure band, respectively.
[2]Values, within a column and the same rate, followed by the same letter are not significantly different.

### 3.6. Soil pH

Soil pH has been shown to be an important factor, which controls the soil microbial community in general, and the community of denitrifiers in particular (Simek and Hopkins, 1999). Rate effects on soil pH in the surface layer (0-30 cm) are likely the result of proton ($H^+$) production during nitrification of ammonium (Table 6). Soil pH within manure band tended to be lower at the higher rate compared to the lower rate, although no significant differences were detected. Conversely soil pH tended to increase with increasing distance from center line of manure band applied with either the coulter or furrower, although the effect was not consistent for all combinations of tools and rates (Table 6). Soil pH was not measured in 2003. Results of the field experiment conducted in 2004 indicated little lateral variation (data not reported).

Table 6. Soil pH at varying lateral positions at the depth of 0-30 cm, 2002

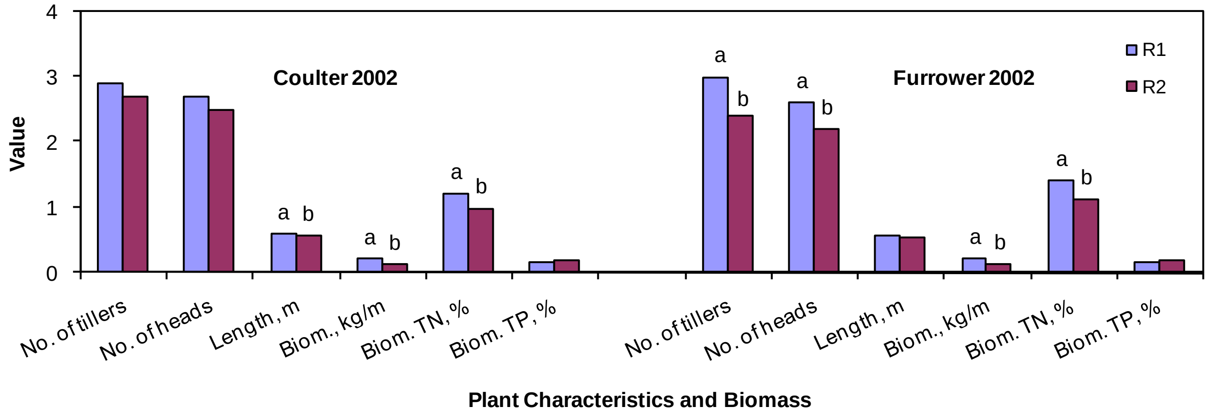
| Rate | Position[a] | Weeks after injection | | | | |
|---|---|---|---|---|---|---|
| | | 3 wk | 5 wk | 7 wk | 9 wk | 11 wk |
| L $m^{-1}$ | | | | | | |
| Coulter | | | | | | |
| $r_1$=1.2 | $A_1$ | 7.63 a[b] | 7.63 a | 7.70 b | 7.85 a | 7.75 a |
| | $B_1$ | 7.68 a | 7.68 a | 7.85 a | 7.80 a | 7.80 a |
| $r_2$=2.4 | $A_2$ | 7.43 a | 7.58 a | 7.75 a | 7.73 a | 7.83 a |
| | $B_2$ | 7.55 b | 7.63 a | 7.75 a | 7.68 a | 7.80 a |
| | $C_2$ | 7.60 b | 7.68 a | 7.75 a | 7.70 a | 7.80 a |
| $r_3$=3.6 | $A_3$ | 7.35 c | 7.53 b | 7.68 a | 7.63 a | 7.75 a |
| | $B_3$ | 7.50 b | 7.55 b | 7.60 a | 7.65 a | 7.68 b |
| | $C_3$ | 7.55 ab | 7.65 a | 7.63 a | 7.68 a | 7.65 b |
| | $D_3$ | 7.63 a | 7.65 a | 7.70 a | 7.65 a | 7.68 b |
| Furrower | | | | | | |
| $r_1$=1.2 | $A_1$ | 7.53 b | 7.58 b | 7.73 a | 7.63 a | 7.85 a |
| | $B_1$ | 7.60 a | 7.73 a | 7.78 a | 7.65 a | 7.83 a |
| $r_2$=2.4 | $A_2$ | 7.68 a | 7.70 a | 7.75 a | 7.75 b | 7.78 a |
| | $B_2$ | 7.68 a | 7.73 a | 7.75 a | 7.83 a | 7.78 a |
| | $C_2$ | 7.70 a | 7.75 a | 7.78 a | 7.83 a | 7.78 a |
| $r_3$=3.6 | $A_3$ | 7.40 c | 7.68 a | 7.60 b | 7.65 a | 7.83 a |
| | $B_3$ | 7.53 b | 7.50 a | 7.68 a | 7.65 a | 7.80 a |
| | $C_3$ | 7.58 ab | 7.58 a | 7.65 ab | 7.73 a | 7.80 a |
| | $D_3$ | 7.60 a | 7.65 a | 7.68 a | 7.70 a | 7.75a |

[1]A, B, C, and D refer to positions at the center of manure band, 15, 30, 45 cm away from the center of manure band, respectively.
[2]Values, within a column and the same rate, followed by the same letter are not significantly different.

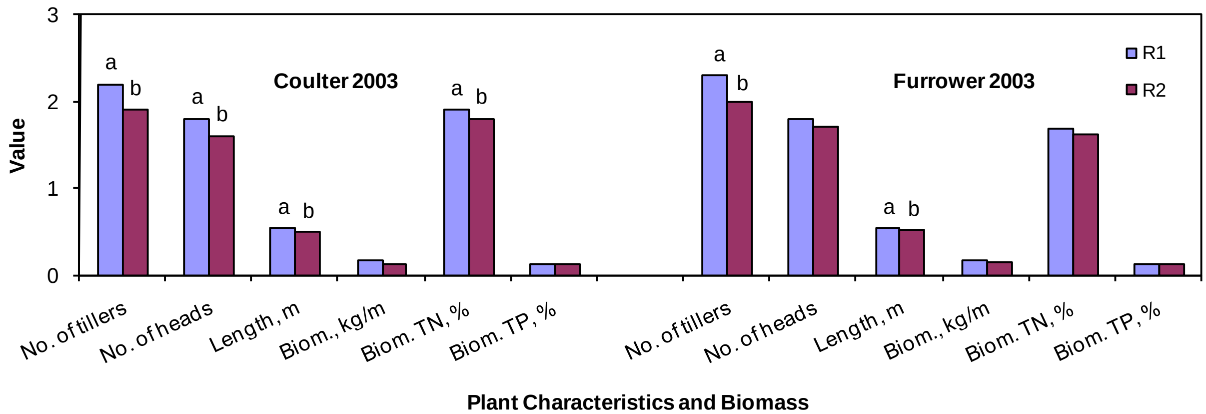
### 3.7 Plant Development Characteristics and Biomass

Better plant performance was obtained in crop rows closer to a manure bands as determined by a number of plant development characteristics (Figure 2). In 2002, a significantly higher number of tillers and heads per plant were observed for the crop row $R_1$ than for $R_2$, when manure was injected using the furrower (Figure 2a). For the length of main stem, a similar difference was observed when manure was applied using the coulter. Plant biomass of $R_1$ was significantly higher than that of $R_2$ when manure was injected using either tool. In 2003, number of tillers and stem length were significantly greater for $R_1$ than for $R_2$ when manure was applied using either tool (Figure 2b). When the coulter was used, the number of heads per plant for $R_1$ was significantly higher than that for $R_2$. In 2004, $R_1$ had greater number of tillers than $R_2$ when using the furrower, and there were no significant differences in measured crop parameters between these two crop rows for both the coulter and furrower (Figure 2c). Extremely dry soil conditions and high temperatures during crop anthesis may have masked some of the position effects.

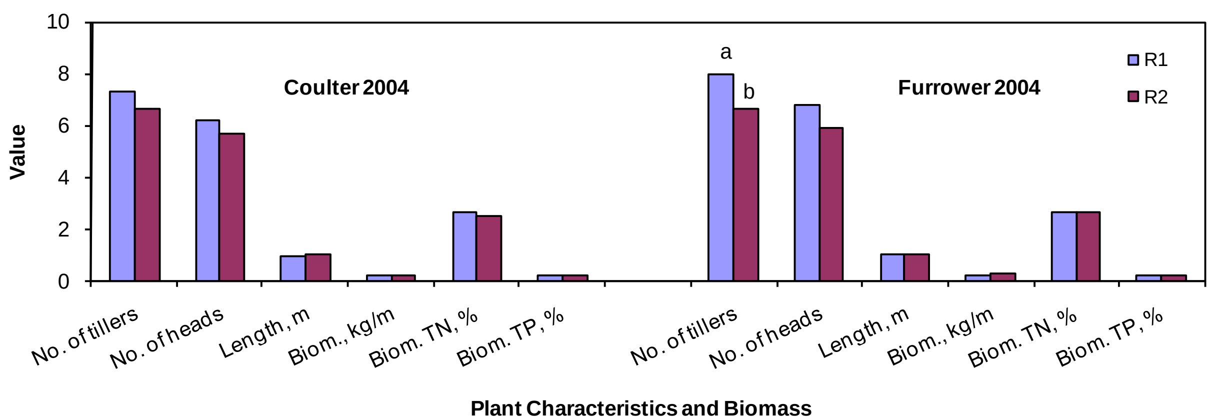
Total N in plant biomass was consistently higher for $R_1$ than for $R_2$, this difference between these rows being significant in three out of six measurements over the three-year period (Figure 2). There were no significant differences in total P in plant biomass between the two rows. The results are consistent with observations by Sawyer *et al*. (1991) who reported lower plant nitrogen concentrations in corn offset at parallel distances of 25.4, 50.8, and 76.2 cm from knife injected manure bands compared to corn planted in the centers of manure band.




(a)




(b)




(c)

Figure 2. Comparisons in plant development characteristics (number of tillers and heads, and length of main stem) and biomass per meter of crop row, total N and total P in biomass between two crop rows, R1 and R2; R1 and R2 are 15 and 45 cm from center of an injected manure band, respectively; Values within each variable followed by the same letter are not significantly different; (a) 2002; (b) in 2003; (c) 2004.

## 4. CONCLUSIONS

Availability of soil nutrients was highest at centre lines of manure bands and decreased with lateral distance from the manure bands, irrespective of the type of injection tool used. These trends were observed for all soil nitrate nitrogen ($NO_3$-N), ammonium nitrogen ($NH_4$-N), and phosphate ($P_2O_5$). The differences in soil nutrients were more pronounced at the 0-30 cm soil depth interval than at 30-60 cm depth interval and when manure was injected at the highest rate. The increased availability of nutrients in close proximity to the manure bands compared to the middle was substantiated by better plant performance and consistently higher total N in plant biomass observed at the plant row closer to a manure band. Considering the differences in lateral nutrient distribution in soil and the differences in crop performance between the two crop rows, large tool spacing such as 90 cm may be avoided in order to obtain uniform soil nutrient distribution and plant development, regardless of tool type to be used. The fact of positional differences in soil nutrient levels should also be considered when sampling for soil nutrient analysis following manure injection, so that representative soil nutrient levels can be obtained.

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