EFFICIENT MANURE UTILIZATION WITH PRECISION SIDEDRESS INJECTION

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Executive Summary

Similar to fertilizer N yield response curves, corn grain yield response to varied rates of sidedress injected manure depend on crop yield potential, and yields level off as N supply exceeds crop demand. Sidedress injection rates of liquid swine manure for 95% maximum corn yields calculated from the response curves were: 35,500 L/ha in 2000; 45,400 L/ha in 2001; and 39,200 L/ha in 2002. Optimum rates depend on grain yield potential (which ranged from 7500 to 12600 kg/ha = 120 to 200 bu/ac), and on how concentrated the manure is (which ranged from 0.4 to 0.6% N). Sidedress application method -inject vs broadcast- did not affect corn grain yields much when application was late (1999 and 2000 trials), but when corn was sidedressed earlier in dry growing seasons (2001 and 2002), injection out-yielded broadcast (by up to 3100 kg/ha). Lower and more variable yield with surface broadcast can be caused by decreased root activity near the dry soil surface, runoff losses, and N loss through volatilization if manure is applied when the canopy is small. In most situations greater broadcast sidedress manure application rates would be required to obtain yields comparable to those where manure is injected. Entering the nutrient analysis results from a representative manure sample into OMAFRA's NMAN model resulted in reliable estimates of the amount of N available to the crop where liquid swine manure was sidedress injected. With in-lay sidedress application, N availability is more difficult to predict because of seasonal variations in root activity and in volatilization and runoff losses of N. Corn grain N concentration (protein) increased with manure application rate, and was greater with injection than topdress in 2001 and 2002. Usually grain test weight increased and moisture decreased with manure application rate.

In most cases the pre-sidedress soil N test was correct in predicting whether additional N was required, so the test shows good potential for fine-tuning sidedress LHM application rates. Fall residual nitrate concentrations in the top 0.2 m of soil following harvest increased with manure rate, especially where N applied exceeded crop demand. Where N is applied in excess of crop demand, residual nitrates unused by the crop also move to surface water (via tiles) with the

fall and spring rains. To minimize contaminant movement to tile drains, manure should be applied at drier times of the year when tiles are less likely to be flowing, and rates below 56000 L/ha (6000 US gpa) should be applied. When sidedress injected, these rates supply sufficient nutrients for good corn grain yields.

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INTRODUCTION

In tiled systems, movement of contaminants into drains has been observed following manure application. Therefore the optimum time for application to corn in these systems may be sidedressing, when tiles are less likely to be flowing and roots are actively absorbing water and nutrients. Application when moisture content is lower has the additional benefit of reducing soil compaction. Furthermore, the application rates used for sidedressing can be determined more precisely than for fall or spring applications because the pre-sidedress nitrate test (PSNT) is more accurate than the pre-plant nitrate test (PPNT), and greater potential exists in the future to use tools such as on-the-go sensors and aerial images for adjusting sidedress rates on a site specific basis according to soil properties or crop response, than for adjusting pre-plant application rates. Yield response curves to sidedress manure rates in relation to PSNT values must be established however, in order to improve the prediction of sidedress rates based on the PSNT. Injection solves application-related odour problems, reduces volatilisation losses, maximizes nutrient use efficiency and reduces runoff movement of nutrients, bacteria, and other contaminants to surface waters. There is little information on how different application methods influence contaminant transport to ground- and surface waters. More information regarding nutrient and contaminant transfer and crop response, gathered using modern application equipment under realistic conditions, is needed to assist growers and policy-makers in determining the best methods and rates of application to maximize yields and minimize environmental impacts.

Objectives

Using state-of-the-art equipment for accuracy and injection: optimize the rate and application method for sidedressing corn; relate yield response to manure rate to the PSNT; and evaluate the effect of these manure application methods on the quality of tile drainage water.

METHODS

Site

The experimental site was located on silt loam soil in Perth County (43.44 lat., 81.01 long), and had not previously been manured. Eight sidedress manure treatments were arranged in a randomized strip plot design with two replicates and four subsampling points located along each plot. The four sub-sample locations per plot were flagged using Global Positioning System coordinates by A & L Laboratories Canada. Each 12-row plot (9.1 m wide x 206 m long) was centred over a different tile line. The four subsample points located in the centre of the 12 rows, approximately 40 m apart. The control treatments (0 gpa) were spaced out across the design. Manure application methods and rates used in 2000 were 0, 4000, 6000, 8000 and 10000 US gpa injected (INJ) and 0, 4000 and 6000 gpa broadcast (BC). At the time of application in 2000, manure nutrient analysis results were not known as the pit could not be agitated, due to extremely wet conditions around it. The analyses later showed that dry matter and N content levels were higher than expected, thus the injection rates used in 2001 and 2002 were reduced (0, 2000, 4000, 6000 and 8000 gpa) from those used in 2000. The treatments were repeated on the same plots as in 2000 except that in 2001 and 2002, the 2000 gpa INJ and 6000 BC treatments were switched in block 2 (plots 205 and 206). In 2002, the application rate of 2000 gpa was increased to 3000 gpa due to human error in the flow control setting calculation.

Agronomics

The experimental area was cropped with wheat in 1999. Each year the field was fall ploughed, with secondary tillage in spring. In 2000, corn (Hybrid NK3030 Bt Liberty link) was planted in 30" rows with 5 gpa 6-24-6 in furrow in late April. The south end of the experiment (sub-sample locations 3 and 4) inadvertently received 145 kg N/ac as UAN pre-plant in 2000. Herbicide (Liberty) was sprayed on 19 June 2000 to control lambsquarters. Manure sidedress treatments were imposed on 30 June (0 and 6000 gpa INJ and BC, and 8000 gpa INJ) and 1 July (4000 gpa INJ and BC, and 10,000 gpa INJ) 2000, despite the wet soil conditions, as corn height had exceeded that of the tool bar. In 2001, corn (DKC4222) was planted on 27 April and manure was applied on 19 June. In 2002, corn (DK4222 Bt) was planted on 8 May with a 6-row vacuum planter. Due to a commercial operator error, 140 lb N ac^{-1} as urea was broadcast pre-emerge on plot 208 (8000gpa INJ) and the east 6 rows of plot 207 (0 gpa BC) in 2002. Despite the cold wet spring and some soil crusting in 2002, the experimental area was not rotary hoed, due to a fair population and a timely rain on 30 May. Manure was side-dressed on 19 June, 2002.

Equipment

A six-row manure injection unit with in-tank mixing (Nuhn Industries) and electronic flow control (GreenLea Ag Centre) was used to apply manure to the plots. The unit was equipped with Kongskilde Vibrashank teeth and straddled 3 rows. Modifications to the injection tool bar were made for 2001 based on results of testing different equipment in the fall of 2000 at a nearby field. Injection of rhodamine red dye showed that worm holes are an important mechanism for the transfer of contaminants to tile drains in these soils, allowing material to by-pass normal flow through soil, and that tools with increased mixing action likely reduce the risk of movement to tile drains (Interim Report). Therefore, in 2001 and 2002, disk-hillers were mounted behind and one coulter was added in front of each Vibrashank tooth. The coulter increased soil mixing, while the disk-hillers allowed for a shallower injection depth by covering over the manure with soil. Thus minimizes odour and runoff and movement to tile drains. A local producer has already adopted the disk-hiller system for sidedress manure injection.

During calibration, less than 10% flow variability was observed between injectors on the applicator tool bar. Between-row variability was further reduced by mounting boots on the outflow to increase back pressure. Constant agitation of manure in the lagoon (finishing hogs with wet/dry feeders) during loading, and constant agitation in the nurse and applicator tanks provided uniform material for all treatment plots. Two nurse tanks were used to feed the applicator in 2002 in order to minimize time required to apply all the treatments.

Teeth were approximately 0.25 m (2000) and 0.15 m (2001 and 2002) above the ground for broadcast treatments, and 0.15 m (2000), 0.10 m (2001) and 0.13 m (2002) deep for injection treatments. To simulate the compaction effect on the zero treatment plots, the manure tanker was filled to 2/3 and pulled along the respective plots using the tractor, either with teeth in the ground (0 INJ) or without (0 BC), but no manure was applied. In 2000, application maps were generated as manure was applied (Precision GPS). The electronic flow control system developed in 2000 was modified in 2001 to obtain a faster response time for rapid flow rate adjustment.

Drainage tile at the south end of the 0, 6000 and 10000 gpa INJ and 6000 gpa BC treatments (plots 102, 104, 106, 108, 202, 204, 206 and 208) were excavated and fitted with a metal trough, and Big O tile to stabilize the walls of access holes by 28 June 2000, to facilitate tile water collection. It was noted during the 2000 season that the deep grooves of the big O tile allowed mice to access and possibly contaminate tile drainage water. Therefore when tile access points for the remaining treatments (plots 101, 103, 105, 107, 201, 203, 205, 207) were excavated and fitted with troughs, they were instead stabilized using cut-off plastic barrels (on 17-19 October 2000). The open area between the tile line and the hole cut in the side of each barrel was sealed with insulation foam. The smooth plastic surface prevented mice from entering and nesting along the inside walls, while the bottom of the barrel reduced clogging by soil of the sump pump that was used to remove water from the access hole prior to sampling. Big O tile at the original eight access points was then removed and replaced with the new cut-off plastic barrel apparatus.

Two tipping buckets (TE525, Campbell Scientific Inc., Edmonton, AL) to record rain events, one air temperature probe (Model 107, Campbell Scientific Inc.) and two (2000) to four (2001 and 2002) calibrated reflectometers (CS-615, Campbell Scientific Inc.) to monitor soil water content were installed on 1 June 2000, and then again on 10 May 2001 and 11 May 2002. In 2002, a Com100 Motorolla cellular transceiver and Com200 modem were used to call the data logger remotely to determine whether rainfall events had occurred. This minimized unnecessary trips to the field for water sample collection. Upon the completion of tile water sampling in the late fall, a 4 L jug of stones was placed in each tile to reduce heaving and breakage during the winter and spring.

<u>Sampling</u>

Manure from several different tanker loads was sampled on the day of application and analyzed for dry matter, nutrients and bacteria. In 2000, manure was also tested for cryptosporidium, which were not present.

Crop: Each year grain was harvested by hand from a 6 m section of one row at each of the four subsampling locations per plot. In 2002, grain was harvested from both the east and west sides of plot 207 (for a with and without urea comparison). Grain samples were shelled using a Wintersteiger combine. Grain weight, test weight and moisture content (using electronic Dickey-John II moisture gauge) were determined on each sample, and a sub-sample was retained and dried to approximately 15% moisture for storage prior to grinding. Grain from the remainder of the field was harvested using a combine (Case IH 2 in 2000 and 2001, John Deere in 2001) equipped with a computerized yield monitor, which recorded yield and grain moisture content every 2 seconds (2000 and 2001) or 3 seconds (2002) along two six-row passes per plot. Eight stalks (6 to 14" above soil) were collected on 16 October 2002 from yield rows at each sub location. The 8" stalk sections were cleaned (all leaf debris removed) and stalk nitrate concentration determined by A & L.

Soil cores (0.02 m-dia.) were collected from each of the four subsample locations per plot for the PSNT (6 June 2000, 30 May 2001, and 7 June 2002, 0-0.3 m deep, bulk of 8 cores per location); for determination of residual N_{inorg} after harvest (14 November 2000, 12 November 2001 and 12 October 2002, 0-0.2 m deep, bulk of 10 cores per location in 2000 and 2002, bulk of 12 cores per location in 2001); and for initial nutrient analyses (6 June 2000, 0-0.2 m deep, bulk of 12 cores per location). Deep soil samples were collected from three of the sub-sample locations (subs 2-4) per plot (0 inject, 4000 inject, 8000 inject and 4000 broadcast plots only) on 27 August and 11 September 2001, and 4-5 September 2002. A Hi-boy mounted (More et al., 2001 poster) Giddings hydraulic coring machine (Giddings, Colorado) was used with a zero recess bit, 0.6 m sleeves (5.08 cm in diameter) and a casing to allow multiple cores without contamination. In 2001, soil was sampled to 1.8 m deep and the cores were divided into seven depth increments (0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.9, 0.9-1.2, 1.2-1.5, and 1.5-1.8 m). In 2002, soil was sampled to 1.2 m deep and the cores were divided into five depth increments (0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.9, and 0.9-1.2 m).

On 27 September 2001 undisturbed cores 4.8-cm diam. x 2.6 cm were collected from sub-sample locations 1 and 4 from the 0 gpa INJ and BC treatments from 3 depths (0, 0.2, 0.4 m) to determine soil water retention characteristics and bulk density. These cores were equilibrated at matric potentials of -0, -2, -4, -6, -8, -12, -33, -100 and -200 kPa in a pressure plate apparatus (Soil Moisture, Santa Barbara, CA). Bulk density (BD) was calculated from oven dry (105^{o}C) weight and core volume,

To monitor bacterial persistence following manure application, soil samples (0-0.2 m) were collected from the 6000 gpa INJ and BC, and 0 gpa BC treatments; immediately (day 0) and periodically (day 1, 3, 5, 7) following manure application, and weekly thereafter. From each of three sub-sampling locations (1, 2 and 3) in 2000, a bulk of 6-12, 0.02 m-dia cores was collected from BC plots, and a bulk of 3-4, 0.06 m-dia cores was collected within the injection zone from INJ treatment plots. In 2001 and 2002, a bulk of six, 0.06 m-dia cores was collected from each of the three sub-sampling locations per plot from the same three manure treatments.

Worms were collected on 4 Oct. 2001 from 0 gpa INJ, 4000 gpa INJ and BC and 8000 gpa INJ treatments by pouring 50 ml formaldehyde in 8 L water on two 0.6m x 0.6m quadrats at each plot near sub-sample location #4. Number and weight of juvenile and mature *terrestris*, *turgida* and *rosea* were determined. Worm sampling was unsuccessful in spring 2001 due to dry conditons. On 26 April 2002, worm sampling was attempted but was again unsuccessful. Soil temperature was 6^{o}C.

Drainage **water** was collected when tiles were flowing, in sterile bottles at the eight plots equipped with troughs throughout 2000, and from all 16 plots throughout 2001 and 2002. The amount of time required to collect water samples from each tile was recorded when samples were collected manually. In 2002, automated water samplers (Nortech models 6712, 6700, 3700 or 2700) were used to collect water from all but four outlets (not 0 BC and 3000 INJ treatments). Liquid level actuators were placed in a plastic cup positioned below the tile outlet to trigger the samplers on whenever flow started. If flow was continuous, then samplers were programmed for collection every 15 minutes for the first few hours after manure application, and every hour thereafter for up to 8 hr. In 2002, automated (float-triggered) sump pumps were placed in the access barrels which were pumped out for 5-10 minutes before collecting a sample (to clean out any water that back-flows up the tile). When samplers were left unattended, the sump pumps remained connected to marine batteries. The glass sample bottles, when re-used in the field, were rinsed with ethanol and triple-rinsed with RO water. When flowing, water was also collected from the main drainage outlet where it flowed into an adjacent ditch, as well as upstream and downstream of the header in 2001 and 2002. Samples were collected in triplicate (within 1 minute or as soon as the next 500 ml accumulated) for nutrient, bacterial and hormonal analyses. Tile water flow was estimated based on the recorded time to collect a given weight of sample when samples were collected manually, and on the trigger times recorded by the 6700 and 3700 model water samplers. Transfer amount to tile following application was estimated based on flow and concentration, and converted to an area basis using the 9.1 m systematic tile spacing.

Laboratory Analysis

Prior to total N analysis by combustion (A&L Laboratories Canada), corn grain samples were ground using a Wiley mill, and then ground finer by rolling for 24 hr on a conveyor in glass jars containing stainless steel rods. Grain N uptake (kg/ha) was estimated by multiplying yield (kg/ha) at each sub-sampling location by the grain N concentration at that location.

Soil samples were stored in plastic bags at 4 °C until determination of gravimetric water content and N_{inorg}. Soil N_{inorg} was extracted by shaking 25 g field-moist soil in 25 ml 2*N* KCl for 1 hr. Soil texture was determined using the hydrometer method for topsoil samples collected fall 2000 (Sheldrick and Wang, 1993). Tile water samples for nutrient analyses were stored frozen or filtered (0.45 microns) and then frozen until analyzed (molybdate-reactive- and total soluble P, total particulate P, nitrate, ammonium, and total soluble- and particulate N). Total coliforms and *E. coli* in drainage water were measured by membrane filtration at A & L Laboratories Canada in 2000, and by E. Topp et al. in 2001 and 2002. In 2000 and 2001, NO_3-N and NH_4-N concentrations in filtered soil extracts (Maynard and Kalyra, 1993) and in tile water were determined by continuous flow colorimetry (Tel and Rao, 198l). In 2002, NO_3-N and NH_4-N concentrations were determined by flow injection analysis (Lachat Instruments, Milwaukee, WI) colorimetry (NH_4-N: QuikChem® Method 10-107-06-1-J, Lachat Instruments, 1999; NO_3-N: QuikChem® Method 10-107-04-3-P - modified for nitrate analysis, Lachat Instruments, 2001). Concentrations in soil were corrected for soil water content determined gravimetrically from a separate sub-sample. The total N and total P in filtered and non-filtered tile water and ortho-P in filtered water were determined by flow injection analysis (total N: QuikChem® Method 10-107-04-3-P, Lachat Instruments, 2001; total P: QuikChem® Method 10-115-01-3-A, Lachat Instruments, 2001; ortho-P QuikChem® Method 10-115-01-1-A Lachat Instruments, 2000).

Data Analysis

Soil water content, soil N_{inorg}, soil chemical properties (pH, Ca, Mg, K, Bicarbonate, Bray-P, CEC, OM, Zn, Mn, Fe, Cu, B and S), stalk nitrate concentration, corn population, grain yields (corrected to 15.5% moisture content), grain test weight, grain N concentration and grain N uptake were analyzed statistically using the General Linear Models procedure for analysis of variance according to the randomized complete block design. Least Significant Difference test was used to compare treatments when the treatment effects were significant (SAS Institute, Inc. 1996).

Yield and grain moisture data obtained from the computerized yield monitor was analyzed statistically in two ways. First, the data set was analyzed as a whole after excluding yield readings during combine turnaround at the end of each pass. Instead of using the four subsample points as a blocking factor to indicate location along a plot, a 'position' variable was used, which roughly corresponded to latitude. As well, in order to compare the accuracy of the hand-harvested yield results to those obtained from the combine yield monitor, computerized yield data only from the subsampling locations was analyzed. For each of the four subsampling locations of each of the 16 plots, the yield monitor readings (6 in 2000) that were most similar in latitude to that of each subsampling location were extracted from the data set and this subset of data (n=24 per plot in 2000) was analyzed separately. In the spring of 2000, at all sixteen plots, sub-sample locations 3 and 4 (the south end of the field) as well as the west six rows of plot 101 accidentally received 145 lb N/ac as pre-plant UAN, and in 2002, the east half of plot 207 and plot 208 was accidentally broadcast with urea at 140 lb N/ac. Therefore, in 2000, data from the south end of the experiment (subsample locations 3 and 4) and in 2002 data from 207 East were removed before analysis of fall residual soil N_{inorg} and hand-sampled corn crop characteristics (grain moisture content, grain test weight, grain N concentration, grain N uptake, corn population and percent broken stalks). Soil N_{inorg} data from plot 208 and the east side of plot 207 in 2002 were also not included in the statistical analyses of the PSNT data. To adjust yield for amount of NO_3-N present in the soil prior to the start of the experiment, the hand-sampled and combine monitor yield data from the north-end were also analyzed using the General Linear Models procedure for analysis of covariance, with spring 2000 soil NO_3-N (the PSNT) as the covariate. Yield data collected along the length of the field could not be adjusted for initial soil NO_3-N because NO_3-N was only measured at the four subsampling locations per plot.

Data from the deep core samples were ln transformed and analyzed in two ways, as the data set was unbalanced. In the first model, data from the 4000 gpa BC plots was excluded to examine the effect of injection rate (0 vs 4000 vs 8000 gpa). In the second model, data from the

0 and 8000 gpa INJ plots was excluded to examine the effect of method (BC vs INJ at 4000 gpa). The data for the two methods was thus balanced and was analyzed statistically using the General Linear Models procedure for analysis of variance according to the randomized complete block design. Least Significant Difference test was used to compare treatments when the rate or method effects were significant (SAS Institute, Inc. 1996).

RESULTS

Manure

Results from nutrient analysis of manure samples collected from the applicator on the day of application (Table 1) were fairly uniform between tank loads, probably due to constant agitation of the lagoon, nurse and applicator tanks. Nitrogen and DM concentrations of load 14 were lower than the other loads in 2000 because most of the manure had been drawn out of the pit by this point, and so more manure had to be flushed out of the barn into the pit to complete the experiment. Conductivity measured in-tank at the time of application in 2002 ranged 26-28 mS (portable YSI meter). Available nutrients supplied by each of the manure application treatments were estimated using the program NMAN using the in-season injection option for INJ treatments, and the 'not incorporated-standing crop' option for BC treatments (Table 2).

Corn Crop

In **2000** yield variability was greatest for the data set obtained by hand-sampling from a 6 m section of one row at the four sub-sample locations (n=4 per plot, standard error = 280.6), decreased for the subset of combine monitor data collected from six rows near the four sub-sampling points (n=24, standard error = 121.2), and was least for the data set collected every 2 seconds from 12 rows along the length of the field by the combine monitor (n=85 per plot, standard error = 65). Despite fewer samples, the hand-harvested yield response was generally comparable to that from the combine yield monitor (Figure 1A, App. Table i), and the hand-harvested and combine monitor yield data were positively correlated ($r=0.84$, $P<0.0001$). The magnitude of the difference between hand-sampled and combine monitor yield estimates was usually greater for BC than for injection treatments. This was likely related to the more variable yield response that results from spreading manure onto the surface of the soil as compared to injecting it into the ground. Variability in corn growth was also visibly greater in BC treatment plots, and yield standard errors were always nearly twice as high for BC as for INJ treatments (data not shown), even though BC treatments encompassed a narrower range of application rates (0-6000 gpa) than INJ (0-10000 gpa) treatments. Treatment effects on yield became more apparent and significant as the number of samples in the data set increased. Application rate was the only significant factor for hand-sampled yield (P=0.0001, App. Table i), with significantly lower yields at 0 gpa than at 4000 gpa (App. Table ii). The method x rate interaction became significant (P=0.0313 or 0.045) for the combine sub-sample yield data set, with yields at 0 gpa BC < 0 INJ < all other treatments. The significance of the method x rate interaction was greater for the complete combine yield data set (P=0.0001), with yields ranked 0 BC < 0 INJ < 4000 BC, 6000 INJ, 8000 INJ < 10000 INJ (App. Table ii). Increased soil aeration may account for higher yields in 0 INJ than in 0 BC plots, especially given the wet soil conditions in 2000.

Excluding data collected at the south end of the experiment (where additional pre-plant UAN was inadvertently applied), followed by adjustment of remaining grain yields for initial soil NO_3-N levels (PSNT) using covariate analysis, had little effect on the yield results for the sub-sample data sets (hand-sampled and combined, App. Tables i and ii, n=4-70 per plot). Removal of south end data however, did change the treatment effects of the largest data set (complete combine, n=85 per plot), with yields for 0 BC < 0 INJ < 4000 BC < 6000 BC, 8000 INJ and 10000 INJ (App. Table ii). The main changes were decreases to yields from the 0 BC, 0 INJ, 4000 INJ and 6000 BC treatments, and a slight increase in yield in the 8000 INJ treatment. These changes resulted in a smoother increase in the yield response with application rate. The regression curve was thus fitted for this data set (north-end, combine monitor, collected every 2 seconds) in relation to manure application rate (Tables 3 and 4). The relationship between grain yield (kg ha^{-1}) and injection rate (L ha^{-1}) was quadratic (linear and quadratic terms P=0.0001). Due to saturated soil conditions throughout most of 2000, the corn grain yield potential was limited (Figure 1A). The 95% maximum corn yield was only 7505 kg ha^{-1}, and was achieved at a sidedress manure rate of 35450 L ha^{-1} (3800 gpa) (Table 4).

The method of manure application had little effect on most of the other crop response variables (corn population, percent broken stalks, grain N concentration, grain N uptake and grain test weight), however rate of application significantly influenced the percentage of broken stalks, grain N concentration, grain N uptake and grain test weight (App. Table i). There were some broken stalks with no manure (1.5%), but none at the other four rates (0%, Table 5). Grain test weight (61 kg/hL at 0 gpa to 63 kg/hL at 6000 gpa), grain N concentration (1.1% at 0 gpa to 1.37% at 6000 gpa) and the amount of N taken up by grain (62 kg N ha^{-1} at 0 gpa to 107 kg N ha^{-1} at 4000 gpa to 129 kg N ha^{-1} at 10000 gpa) increased with manure application rate (Table 5).

Grain moisture of north-end hand-harvested samples was not affected by application method or application rate, but both factors as well as their interaction were significant for grain moisture of combine samples collected every 2 seconds along the length of the field (App. Table i), although trends were not consistent (Table 5). Grain moisture readings from the combine monitor were lower (~21%) than those measured on hand-sampled grain (~25%), likely because hand-samples were collected on 24 October 2000, over two weeks prior to combining (11 November 2000). Grain moisture of hand samples were negatively correlated with hand-sampled yield (r=-0.35, P=0.049), and positively correlated with grain moisture from the combine (r=0.60, P=0.0003).

In **2001**, more favourable growing conditions resulted in more dramatic differences in corn size and colour early in the growing season for the different rates and methods of manure application (Interim Report). Grain yields increased with manure injection rate (Fig. 1B) up to 236 kg available N/ha in manure, and injection rate for 95% of maximum yield was about 45,400 L/ha (4900 gpa) (Tables 3 and 4). Corn grain yields increased by up to 2260 kg/ha (36 bu/ac) when sidedressed manure was injected rather than broadcast. Many points were lost from the combine yield monitor data set due failure of the GPS signal. Monitor yields followed the same trends as the hand-harvested data none-the-less, and were usually lower than with hand-harvesting (Fig. 1B).

Grain N concentration in 2001 increased with manure rate and was greater with INJ than BC (Table 6). Grain moisture was less with injected manure than no manure or BC manure. Test weights were highest with 6000 and 8000 gpa injected. There were fewer broken stalks with manure than without (Table 6). Grain N uptake with injected manure was greater in 2001 than the other years.

In **2002** grain yield (hand-harvested) increased with injection rate to 4000 gpa and was greater with injection than BC (Fig. 1C). As was also observed with combine monitor data in 2000 and 2001, there was a ‘tillage response’ to injection with no manure was applied (App. Table ii). Sidedress injection rate for 95% maximum corn yields calculated from the 2002 response curve was 4190 gal/acre (Table 3). Yields were over-estimated by the combine monitor (likely due to poor monitor calibration), and the relation between monitor data and hand-harvest data was poorer than in other years, possibly due to greater variation in population in 2002.

Population was not affected by manure treatment and was lower in 2002 (47,000 /ha) than previous years (App. Table i). Low population was mainly due to poor emergence in the several weeks of cold weather after planting followed by soil crusting. There were fewer broken stalks with (1.4%) than without (6%) manure application. Grain moisture was again higher in samples collected by hand than measured by the yield monitor, but unlike previous years grain moisture was greater with INJ than BC (Table 7). Grain test weight increased with manure application rate and was not affected by method (Table 7). Grain N concentration was greater with INJ (1.15%N) than BC (0.98%), which was greater than without any manure (0.82%). The reduction in N uptake by grain with BC vs INJ averaged 44 kg N/ha over 2001 and 2002, 4000 and 6000 gpa, which is similar to the reduction in N availability estimated by NMAN with the not incorporated standing crop option (49 kg/ha less with 4000 gpa and 66 kg/ha less with 6000 gpa, Table 2).

Stalk nitrates increased with manure rate for INJ but not BC application (Table 8). Average stalk nitrate concentrations for treatments 0 and 3000 gpa INJ and 4000 and 6000 gpa BC fell within Iowa State University’s low (<250 ppm) category, which indicates a high probability that greater N availability would have resulted in higher yields. Stalk nitrate concentration with 4000 gpa INJ was in the marginal category (250 - 700 ppm), which indicates that N availability was very close to the minimal amounts needed. Stalk nitrate concentration with 6000 gpa INJ was in the optimal category (700-2000 ppm), which indicates high probability that N availability was within the range needed to maximize profits for the producer. Stalk nitrate concentration with 8000 gpa INJ was in the excess category (>2000 ppm), which indicates high probability that N availability was greater than if fertilizer N had been applied at rates that maximize profits for producers.

Soil Physical, Biological and Chemical Properties

Topsoil **texture** (fall 2000) samples averaged 20.4 % (± 3.8) sand, 55.6% (±3.0) silt and 24.1% clay. This gives a silt loam classification. There was a significant positive correlation ($r=0.36$, $p=0.0039$) between the amount of clay in soil and soil CEC (measured in the spring of 2000), and a significant negative correlation ($r= -0.48$, $p<0.0001$) between the amount of silt in soil and soil CEC.

Worm population on 4 October 2001 was 72 worms per m^2 (±35), and was comprised of 36% terrestris, 61% turgida and 3% rosea. Worm weight was 21 g/m^2 (16 ±), and comprised of 57% terrestris, 41% turgida and 2% rosea by weight. There was no effect of rate or method of manure application on worm number or weight. It was initially hypothesised that worm population would be a good indicator for extent of macropore flow. However, the method was too impractical to be used as an indicator. Worms cannot be collected under so many conditions - too cold, too dry, too soon after tillage - that the measure is not convenient for site characterisation or indexing. Pressure infiltrometer readings were instead used to characterize 'megaporosity' at the site (Ball-Coelho, Roy, Lapin and Topp, 2003).

Available nutrients and some other chemical properties of soil collected in June 2000 are listed in Table 9. Spatial trends in soil P, K, organic matter and pH in 2000 were mapped by A & L Laboratories Canada using the GPS locations of the four subsampling locations in each of the 16 plots (Interim Report). Low initial (background) variability for most constituents made the site ideal for experimentation. Some chemical properties were measured from samples collected in the fall of 2001, representing the cumulative effects of 2 years of treatments. The main trends after 2 years, were increased K, bicarb-P, and Bray-P1 with rate; and decreased pH and Ca as rate increases (Table 10). Soil OM or CEC did not change with time (2000 vs 2001) or after 2 or 3 years of treatments (App. Table iv and v). After 3 years of manure application (in the fall of 2002), potassium, phosphorus (Bicarb and Bray), and sulfur increased with manure application rate (Table 10). A reduction in pH with manure application rate (Table 10), particularly with injection of more than 4000 gpa (Table 11) is likely due to hydrogen ion release during nitrification of manure NH_4. Similar soil P concentration with BC and INJ suggests that much of the apparent N loss (as illustrated by lower grain yield and protein, and lower soil nitrates) with the BC application method was likely associated with volatilization rather than runoff.

In **deep cores** collected to 1.8 m after 2 years (in 2001), soil N_{inorg} in the top 0.2 m increased with injection rate (8000 > 4000 > 0 gpa), but below 0.2 m was not affected by rate significantly (Fig 3A). Method of application affected soil N_{inorg}, also only in the top 0.2 m of soil where INJ > BC (Fig. 3B). Application method did not affect soil NH_4 concentration (App. Table vi). After 3 years (in 2002), application rate affected soil NO_3 and N_{inorg}, but not NH_4 concentration (Table vi). Soil N_{inorg} increased with injection rate in the top 0.9 m (ie 8000 > 4000 > 0 gpa). At 0.9 to 1.2 m soil N_{inorg} was greater with manure than without (Fig. 4A). Soil N_{inorg} was greater with INJ than BC to 1.2 m deep (Fig. 4B), and again method had no effect on soil NH_4. On an area basis, the increase in nitrate in the 0.4 to 1.2 m subsoil layer after 3 years of manure application (as compared to non-manured plots) amounted to 12.7 kg NO_3-N/ha with 4000 gpa INJ and 38.3 kg NO_3-N/ha with 8000 gpa INJ. These results indicate some partitioning of N movement to groundwater in tiled soils. From extensive experimentation at the long-term Rothamsted plots (clay loam), it was determined that 20% of drainage moves rapidly through cracks and channels to tile and the rest percolates slowly through the soil matrix (Goulding et al., 2000).

Bicarbonate- and Bray-extractable P, exchangeable K, and available zinc in deep cores were also affected by application rate after 3 years (App. Table vi), but there was little evidence of downward movement of P from manure in the bulk soil. Below 0.2 m (to 1.2 m deep) bicarbonate- and Bray-extractable P were the same with no manure as with 8000 INJ. Comparing application methods, extractable P at 4000 gpa was greater with INJ than BC in the top 0.4 m, but did not differ with method below 0.4 m.

Prior to imposing the manure treatments in the spring of 2000, there were no significant treatment effects on **soil N_{inorg}** in the top 0.3 m (Table 12, App. Table iii) again indicating acceptable inherent site variability for experimentation. There was variability in soil N_{inorg}, however, due to application of 145 lb N/ac as pre-plant UAN on the south end of the experimental area (all plots). Average NO_3 concentration at the north end (sub-sample locations # 1 and 2) was 9.2 mg/kg vs 25.7 mg/kg at the south end (sub-sample locations # 3 and 4). Soil

NH_4 concentration was low (0.8 mg/kg) indicating that NH_4 from the pre-plant applied UAN had already converted to NO_3 .

Variability in the **PSNT** provided an opportunity to examine the relation between relative yield (where 1 = 95% of maximum yield that year) and the PSNT. Yield (hand-harvested) was positively correlated with the PSNT (R=0.311, p=0.0123) in 2000. With no N applied, the cut-off PSNT value where relative yield equalled one (ie no more N needed) was about 80 kg NO_3-N/ha (Fig. 5). Since maximum yield was limited (to only 120 bu/ac) by wet conditions, the 4000 gpa rate already provided sufficient N for the crop, so there were few cases within the manure-treated plots where yield could be related to the PSNT in 2000. Of the cases where the amount of N applied as manure did not exceed the PSNT-recommended amount, the PSNT correctly indicated whether additional N was required in 93% of cases.

On 30 May 2001, soil NH_4 concentration in the top 0.3 m was not altered by treatment history. Pre-sidedress NO_3 concentrations in the top 0.3 m were less in 2001 than in 2000. The PSNT was greater (6.2 mg/kg) where 6000 gpa or more was applied the previous year, than where 4000 gpa or no manure (4.8 mg/kg) were applied in 2000 (according to contrast analysis). This trend and spatial variability in the PSNT are illustrated in Fig. 6. Soil N_{inorg} increased with rate, particularly above 4000 gpa (Table 12). With 4000 gpa BC there was a trend of increased yield with the PSNT, but with 4000 gpa INJ, which already supplied sufficient N for crop requirements there was no relation (Fig. 7). In all 32 cases where N applied was less than the PSNT-based recommendation, relative yield was < 1, indicating that the PSNT was correct in predicting an additional requirement for N.

On 7 June 2002, soil NH_4 concentration was low and did not vary with treatment (Table 12, App. Table iv). The PSNT was greater with 8000 INJ than all other treatments, indicating a small cumulative carry-over of N with the high application rate (Table 12). Of 52 cases (where N recommended > N applied), the PSNT was correct 76% of the time in predicting that more N was required (since relative yield was < 1) (Fig. 8). Most of the cases (10 out of 12) where the PSNT-based recommendation was incorrect (additional N recommended but relative yield equalled one), were in the 3000 and 4000 gpa INJ treatments. This may have been due to underestimation by NMAN of available N supplied by the manure in these treatments. There were no cases in

2001 or 2002 where relative yield was ≥ 1 with no manure applied, so PSNT values were not high enough to identify a cut-off where no more N is required (Fig. 7 and 8).

Residual (fall) topsoil N_{inorg} concentrations in 2000 were high overall (5-37 mg kg^{-1}) mainly due to high NO_3-N (4-36 mg kg^{-1}) concentrations (Fig. 9). Concentration of NH_4-N remaining in topsoil after harvest was low, and not affected by manure application rate in 2000 or 2001 (App. Tables iii, iv). In 2002, soil NH_4 was greater in 4000 gpa INJ than the other treatments (Table 13), but concentrations were low. Each year topsoil NO_3-N increased with rate depending on method (App. Table iii, iv, v), increasing to a greater extent with rate for INJ than BC (Fig. 9). In 2000, there was more residual NO_3-N left in INJ (17.8 mg kg^{-1}) than in BC (9.0 mg kg^{-1}) plots at 6000 gpa. In 2001 and 2002, topsoil NO_3 was greater with INJ than BC at both 4000 and 6000 gpa. Soil NO_3 increased with BC rate in 2000 and 2001 but not in 2002 (Fig. 9).

Gravimetric **soil water** content did not differ between manure application treatments in any of the three years when measured in pre-sidedress (0-0.3 m) or in fall (0-0.2 m) soil samples (App. Tables ii, iii and iv). At the time of manure application in 2000, gravimetric soil water content averaged 30% on 30 June, and 29% on 1 July. Assuming a bulk density of 1.4 g/cm^3, this is equivalent to 42 and 40% volumetric soil water content, the same as the average topsoil water content recorded by the reflectometers (41% volumetric) (Fig. 10). Despite the wet topsoil in 2000, not all of the eight tiles fitted with sampling access were flowing at the time of manure application. During application in 2001, however, topsoil water content was similar (41% volumetric), and all 16 tiles were flowing (Fig 11). At the time of application in 2002, both measures of soil water content were less (38.4% volumetric - average of 4 reflectometers ± 1.9%; 29.2% gravimetric - average of topsoil samples collected from 6000 INJ and BC treatments, sub locations 2, 3 and 4) than the previous two years, yet all tile were flowing. Generally, topsoil volumetric soil water content (obtained using reflectometers) did not correlate well with tile flow (Fig. 10-12). Tile type alternated between plastic and clay across the site. There was no relation between flow rate and type of tile, or depth from the soil surface to tile which ranged from 55 to 79 cm.

Tile Drainage Water Quality

On 30 June 2000, prior to manure application the accessible tiles under plots to receive

6000 gpa INJ and 6000 gpa BC treatments were flowing. On 1 July 2000, tiles were not flowing under plots to be injected with 10,000 gpa, flowed for about 3 hours after application and then stopped flowing. *E. coli* exceeded 20,000 CFU/100 ml during this brief flow period. Bacteria numbers seemed to indicate rapid *E. coli* movement into tiles immediately following application in the injection treatments, whereas movement was delayed until 4 days after application (3 July) for BC treatments. This could be due to rainfall, although only 1.6 cm fell between July 1 and 3, whereas the 62 mm rain event on 9 July did not raise the *E. coli* concentrations in the tile water (possibly due to death of bacteria in soil by that time). Bacteria in tile water and bacterial persistence in soil in 2000 is reported in more detail in Lazarovits et al. (2000).

Tile water NH_4-N concentrations were low to undetectable for all treatments on all sampling events prior to the application of manure each year (Fig. 13A-C). The nature and magnitude of the change in the concentration of NH_4-N in tile drainage water depended on both the method and rate of manure application. NH_4-N concentrations increased with manure application rate, especially for injection treatments. In 2001, a small increase was noted following injection of 2000 gpa (1.91 mg L^{-1}) in rep 1, but no increase (0 mg L^{-1}) in rep 2. The increase in rep 1 may have been due to a breakdown of the injector unit and accidental application of manure at the highest rate to one section of this plot. Incrementally larger increases were observed for the 4000 gpa (1-3 mg L^{-1}), 6000 gpa (0.6-5.7 mg L^{-1} rep 2) and 8000 gpa (37-178 mg L^{-1}) injected plots (Fig. 13B). NH_4-N increases were larger with injection (0.05-26 mg L^{-1} in 2000, 0.07-179 mg L^{-1} in 2001, 11-650 mg L^{-1} in 2002) than BC (0.3-2 mg L^{-1} in 2000, 0.05-0.9 mg L^{-1} in 2001, 0.6-4 mg L^{-1} in 2002) treatment plots.

The NH_4-N increases also occurred much more rapidly under INJ than BC. Within 40 (2000 and 2002) or 9 (2001) minutes of application a dramatic increase in the concentration of NH_4-N in tile water was noted, whereas NH_4-N increases under BC were usually not observed for several days after manure was applied, and were likely related to rain events in the days following application. Some NH_4-N movement under BC treatments may not have been measured in 2000 because tiles were sampled one and three but not two days after manure application. Tile were flooded on 2 Aug. 2000, but no NH_4 movement was observed as soon thereafter as the tile could be sampled. The NH_4-N response generally appeared to be shortlived overall, as NH_4-N levels for all manure treatments returned to pre-application levels within one (2001 and 2002) or two (2000) weeks of application. From statistical analysis of the NH_4 concentration data for all 2001 samples, application method had no significant effect on tile water NH_4 concentration, and the average annual concentration was greater with 8000 gpa INJ (0.56 mg/L) than all other treatments which were equal and averaged 0.05 mg NH_4-N /L.

NH_4-N concentrations at the main drainage outlet (header) did not increase following manure application in 2000 or 2001. In 2001, NH_4-N concentrations in samples collected upstream and downstream from this header were equal. In 2002, NH_4 concentration at the header rose above detectable levels the day after application (0.3 mg/L on 20 June) and 5 days after application (1.7 mg/L on 24 June) - likely as result of flooding which occurred on the weekend of 21 June (day 172). However, no increase in NH_4 concentration was measured downstream of the header on 24 June.

Similarly to NH_4, phosphate concentrations increased right after manure injection, especially at high application rates (Fig 14A-C). With BC application, phosphate concentration increased by 3 July 2000 (at 6000 gpa), 22 June 2001 (6000 gpa) and 21 June 2002 (at 6000 gpa). The elevated phosphate concentration in the 3000 gpa INJ treatment (on 10 May) prior to manure application in 2002 (Fig. 14C) was likely contamination, since the increase only occurred in one of the two tiles.

Tile water NO_3-N concentrations were high in spring prior to manure application in 2000 (15-20 mg L^{-1}), 2001 (7-24 mg L^{-1}) and 2002 (7-20 mg L^{-1}), but unlike NH_4 and phosphate, NO_3 did not increase immediately following manure application (Fig. 15). Higher initial nitrates in the spring of 2000 over all plots may have been a reflection of the pre-plant UAN application over half of the experimental area. Approximately one month after manure application in 2000, NO_3-N levels increased with the highest application rate (from 22 to 35 mg L^{-1} in 10000 gpa). By the last sampling date in 2000 (14 November) and throughout the following spring prior to the second manure application event, NO_3-N concentrations were lowest with no manure applied (12 mg L^{-1} for 0 gpa) and increased with application rate (15 mg L^{-1} for 4000 gpa, 20 mg L^{-1} for 6000 gpa, 23 mg L^{-1} for 8000 gpa, and 26 mg L^{-1} for 10000 gpa). This is likely a reflection of N applied in excess of crop demand, and increasing quantities of N left unused. There were no fall

2002 water samples for comparison, due to the dry conditions and no flow. Correlation between inorganic N species and the assay (YES) for endocrine disrupting compounds in tile water samples collected in 2001 was greater between NH_4-N and YES (r = 0.60, $P < 0.0001$) than NO_3-N and YES (r = 0.23, $P = 0.0112$) (Pearson coefficients from Proc Corr, N=126).

Prior to manure application in 2001, NO_3-N concentrations in samples collected from the header were 11 and 28 mg NO_3/L on 10 and 30 May, respectively, greater than those in the ditch (2 and 11 mg NO_3/L average of upstream and downstream on 10 and 30 May). There was little change in response to manure application in 2001, and header and ditch NO_3 concentrations were similar in June. That fall, header NO_3 concentrations were less than in the ditch by 11, 8, 6, and 5 mg NO_3/L on 17 Oct., 29 Oct., 12 Nov. and 23 Nov., respectively. NO_3 concentrations were slightly higher at the downstream (by 2-3 mg/L) than at the upstream location on three of fourteen sampling events in 2001 (June 20-22). There was not much difference between NO_3 concentration in the header vs the ditch in 2002 other than on 23 July when NO_3 concentration was greater from the header (10.5 mg/L) than in the ditch (2.3 mg/L).

Amounts of NH_4 -N and phosphate-P transferred to surface water via tile drainage water the week following application were estimated based on flow rate of the tile (Table 14). Despite the high concentrations, total transfer amounts were small on a ha basis, with maximums of 0.07 kg PO_4/ha (at 6000 gpa BC in 2001) and 0.2 kg NH_4 /ha (at 6000 gpa INJ) in 2001. Amounts were greater in 2001 due to more rains and hence more tile flow the week after application. Greater PO_4 transfer with 4000 INJ than with higher injection rates as observed in 2001 was due to the higher water flow rate in rep 1 of this treatment (than all other tile). In 2002, when the most complete collection of water samples was obtained (using automated samplers), ortho-phosphate and NH_4 transfer to tile totalled over the week following application was greatest with 8000 INJ (Table 14).

When manure was applied (6700 gpa) in November just 1 month after new tile drains were installed, Hodgkinson et al. (2002) observed movement of LHM into tile, 4 to 6 wk after application when rains first initiated drainage. Ortho-P concentrations increased up to 10 mg PO_4/L and total movement amounted to 0.4 kg PO_4/ha, greater than what we observed. In subsequent years however (after tile had settled), following application of 6400 to 11,400 gpa in

September they observed much less P movement to drainage waters averaging 0.06 kg PO_4 /ha, an amount similar to the maximum P transfer the week following application of 0.07 kg/ha that we estimated in 2001 with 6000 gpa BC.

DISCUSSION

Good corn yields were achieved by sidedress injection of crop nutrient requirements as liquid manure over 4 years of testing. Yield potential in 2000 was low due to saturated soil conditions, but the distinctive visual differences in corn growth observed early in the 2001 and 2002 growing seasons was carried through to final yield differences.

Incidental pre-plant application of 145 lb N/ac as UAN in the spring of 2000 resulted in a wide range of **PSNT** values in 2000, variability which illustrated a PSNT cut-off beyond which no more N is required of about 80 kg NO_3-N/ha. To further assess the PSNT-yield relationship, relative yield was compared to the PSNT-based N recommendations considering the actual amount of manure N applied. In most cases the PSNT was correct in predicting whether additional N was required, indicating that in systems fertilized with liquid hog manure, it can be a useful tool to help fine tune sidedress N requirements.

Residual **(fall) soil nitrates** were excessive where manure was applied at rates above that required for 95% maximum yield, and lower where manure application rates were more in line with crop demand. Lower residual soil N_{inorg} in BC plots was likely due to greater volatilization N losses with BC than with INJ. Yield and soil nitrate data were usually consistent with the NMAN estimates of available N. Stalk nitrates (measured in 2002 only), indicating excess N available to the crop at 8000 gpa INJ, and not enough N supply with BC application, also corroborated the yield response and residual topsoil nitrate data.

Nitrate concentrations in tile water also provided an indication of residual nitrogen unused by the corn crop in the fall and following spring. Nitrates were not useful for tracing short-term manure movement from soil to tile drainage water. Nitrate concentrations were high prior to manure application, and did not change following the application. Tile water NH_4-N concentration however, was a good indicator of manure contamination, because initial pre-application levels were low to undetectable, and dramatic increases that corresponded to the manure application methods and rates were noted almost immediately following manure application. Tile water NH_4-N contamination patterns were also similar to those noted for bacteria. The unexpected poor correlation between topsoil water content and tile flow indicates that it will likely be difficult to model tile flow events, and emphasizes the need for experimental field data to accompany modelling exercises. Ortho-phosphate was also a good indicator of manure movement to tile, with low background concentrations, and rapid increases in response to manure application. The main drainage outlet and downstream collection point had low concentrations of NH_4-N and phosphate, even following manure application, demonstrating low impact on nutrient loading to adjacent surface waters.

Rate of manure application was extremely important to the transfer of contaminants to tile drains. Results indicate that with the proper rate and equipment, at acceptable soil water contents for injection, significant transfer of manure constituents to drainage tiles can be avoided. Contamination was noted at the highest rates (8000-10000 gpa injected), but was considerably less at the lower application rates, which were sufficient to supply corn nutrient requirements. These results should provide incentive to producers to minimize water content in the manure (perhaps by reduced flushing of water into lagoons), so that the volume of manure applied is low enough to minimize the transfer of contaminants to the environment, while still meeting crop requirements. When the application rate was too high, not only did manure contaminate tile water at the time of application; because N applied exceeded crop demand, residual nitrates accumulated in topsoil after harvest, movement of nitrates to surface water via tile drains increased, and eventually (after 3 years) nitrate concentrations in subsoil layers (to 1.2 m deep) increased. Our preliminary results provide no evidence of P movement to depth in the bulk soil at any application rate.

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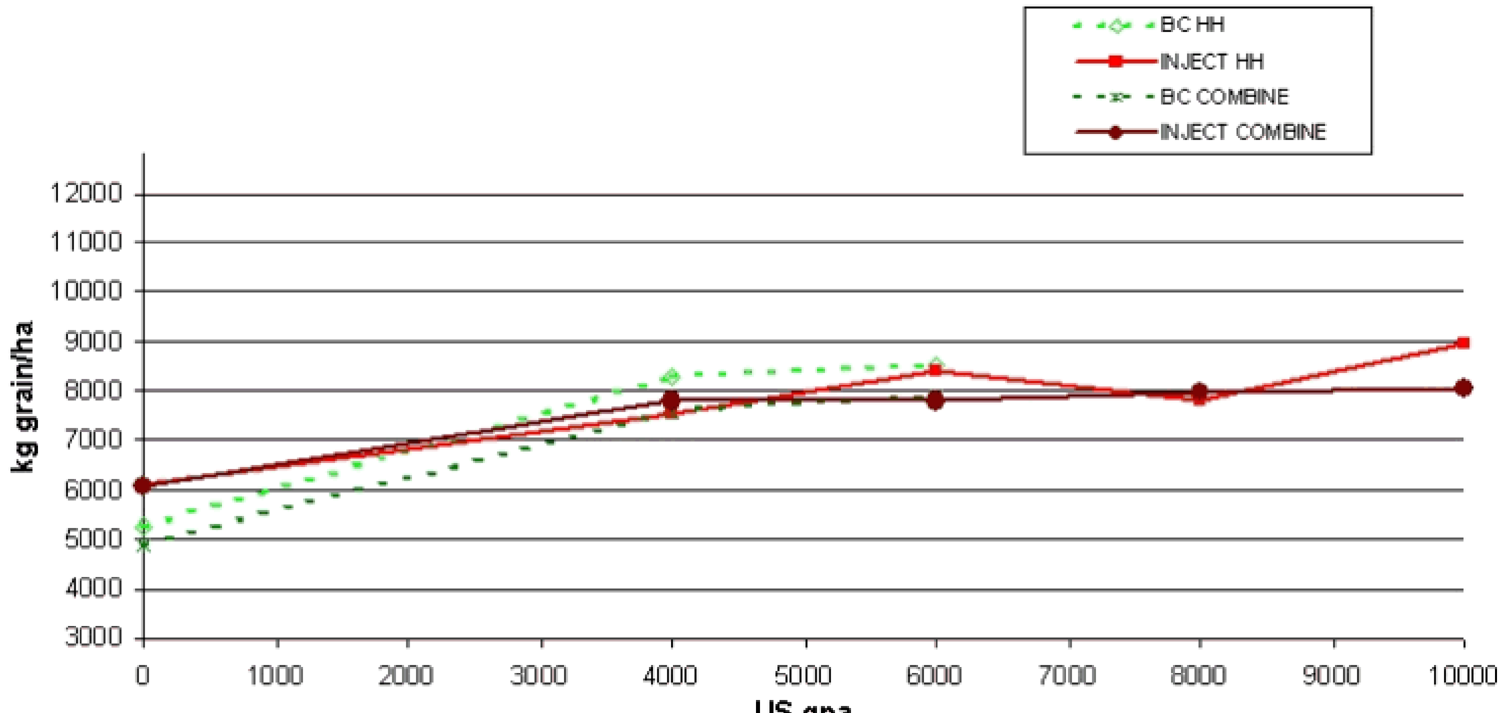


Figure 1A - Corn grain yield (15.5%) from hand-harvested samples (HH) and combine monitor with different rates and methods of manure application (2000 north end - no pre-plant fertilizer N, Case IH)

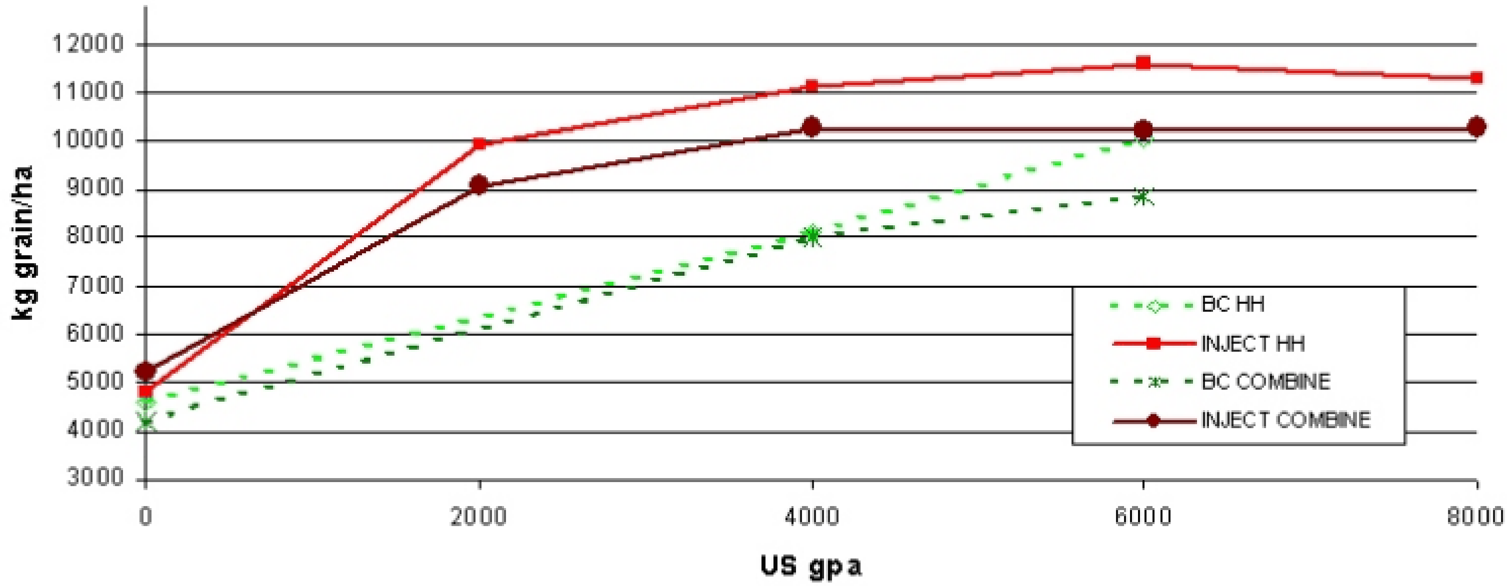


Figure 1B - Corn grain yield (15.5%) from hand-harvested samples (HH) and combine monitor with different rates and methods of manure application (2001 - whole field, John Deere)

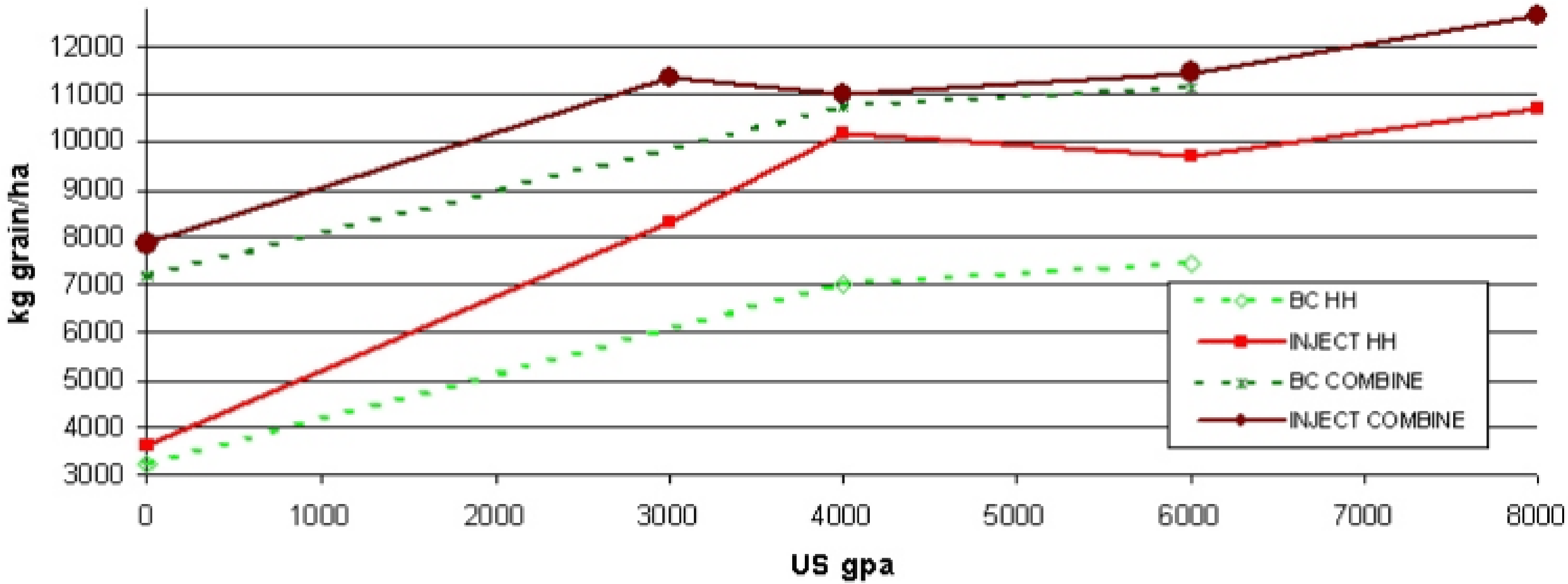


Figure 1C - Corn grain yield (15.5%) from hand-harvested samples (HH) and combine monitor with different rates and methods of manure application (2002 - 207E omitted, Case IH)

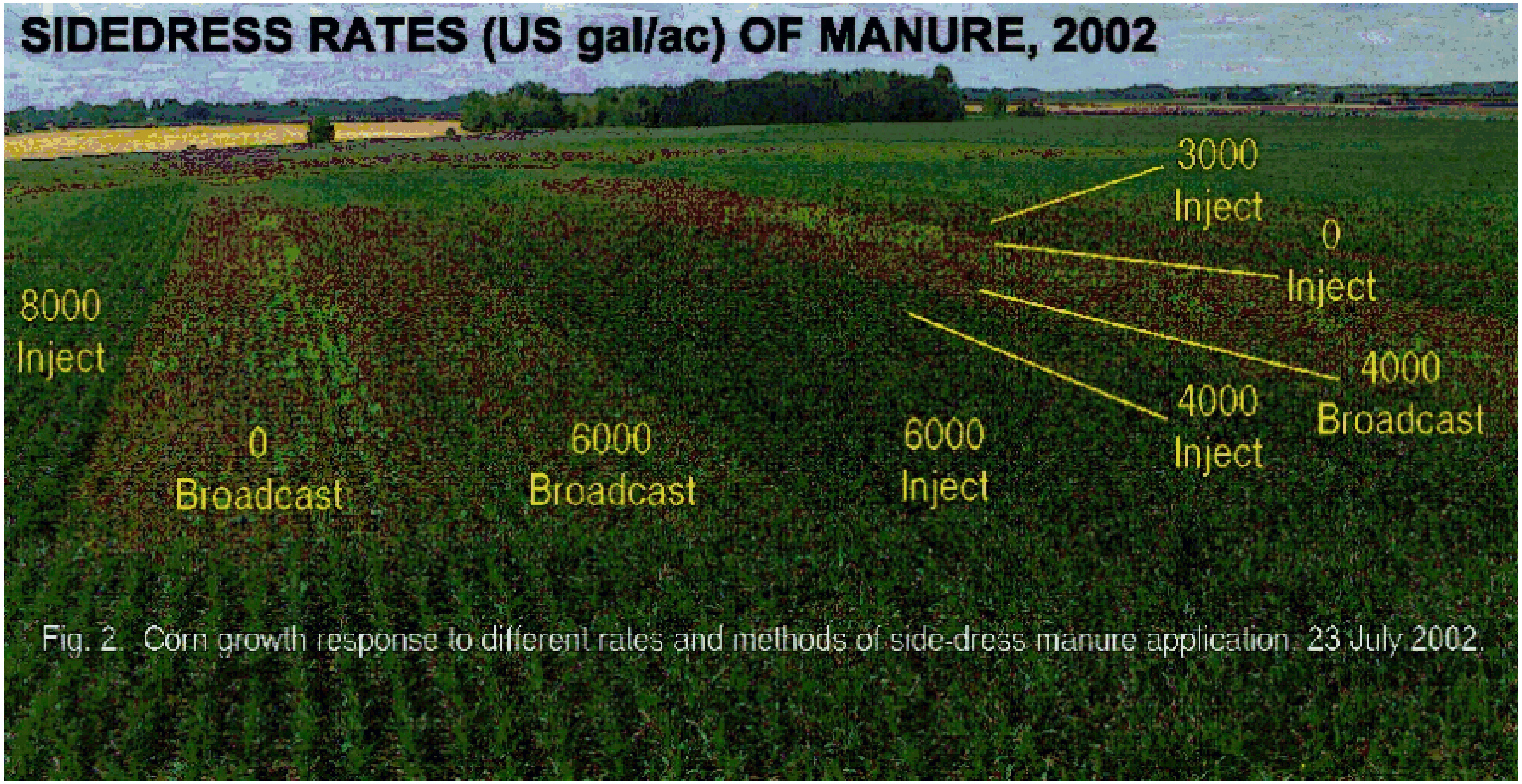


Fig. 2. Corn growth response to different rates and methods of side-dress manure application. 23 July 2002.

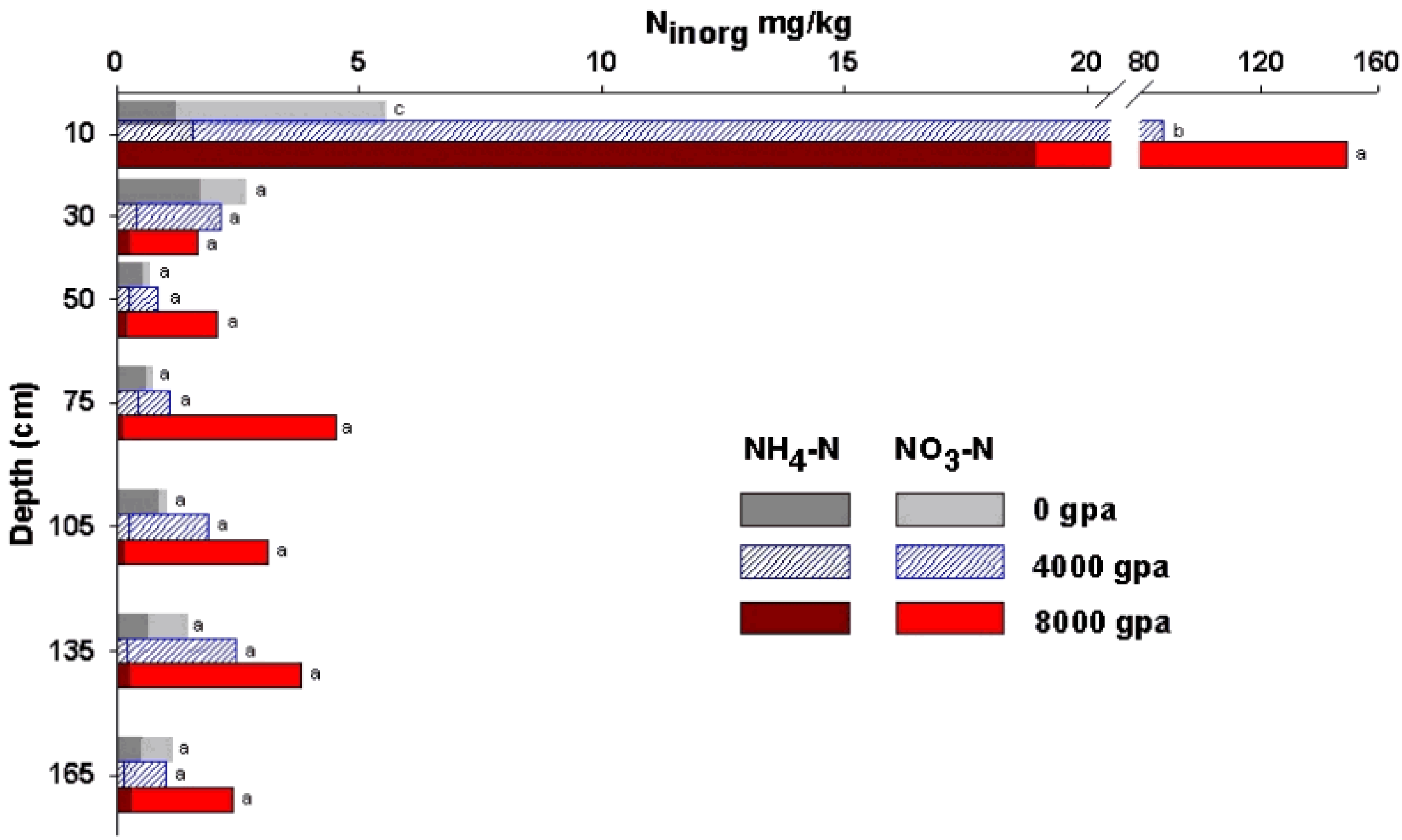


Figure 3A - Soil inorganic nitrogen to 1.8 m deep as affected by injection rate of manure after 2 years, Sept. 2001.
Means within a layer followed by the same letter are not different.

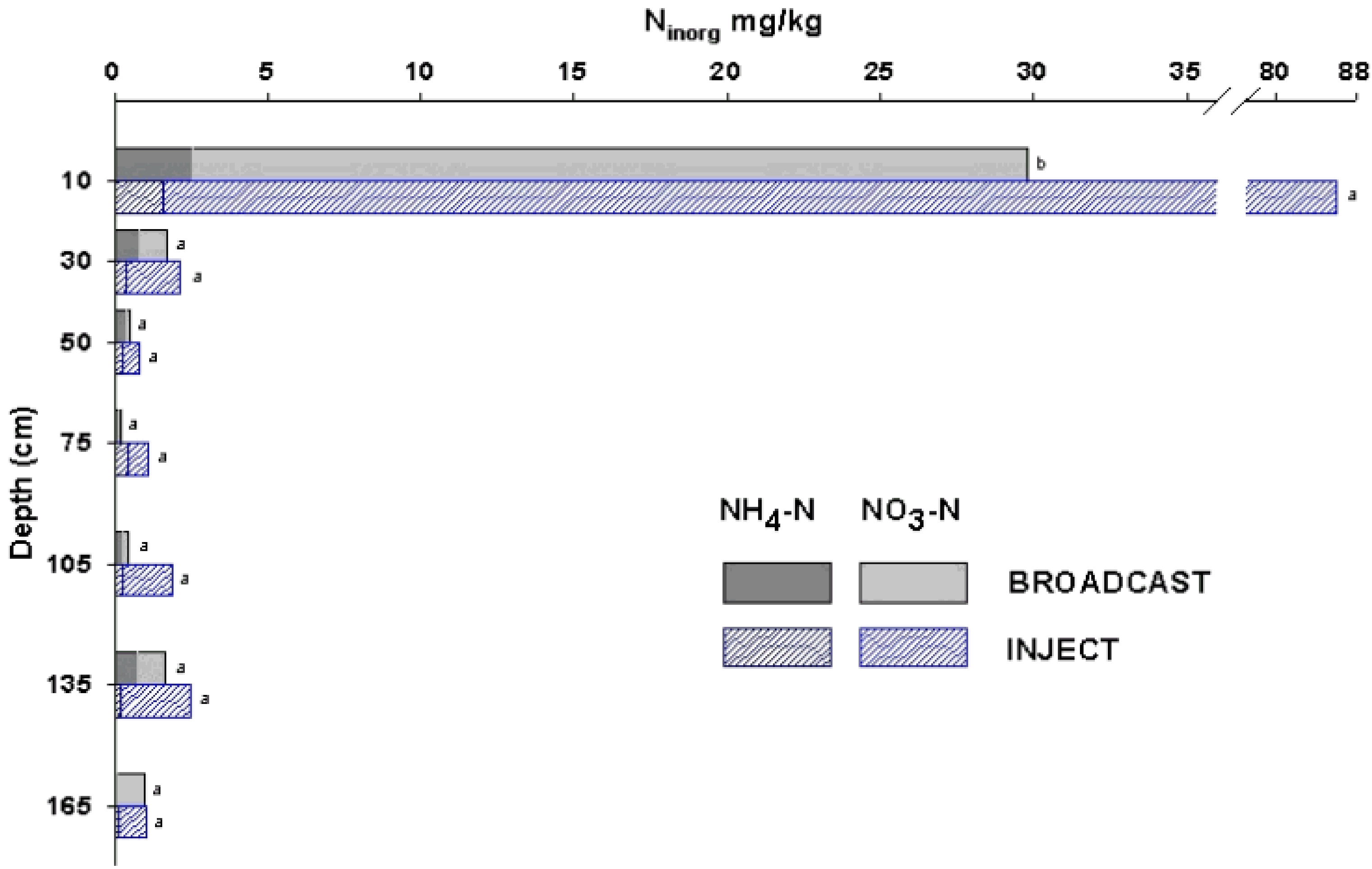


Figure 3B - Soil inorganic nitrogen to 1.8 m deep as affected by application method (at 4000 gpa) after 2 years, Sept. 2001. Means within a layer followed by the same letter are not different.

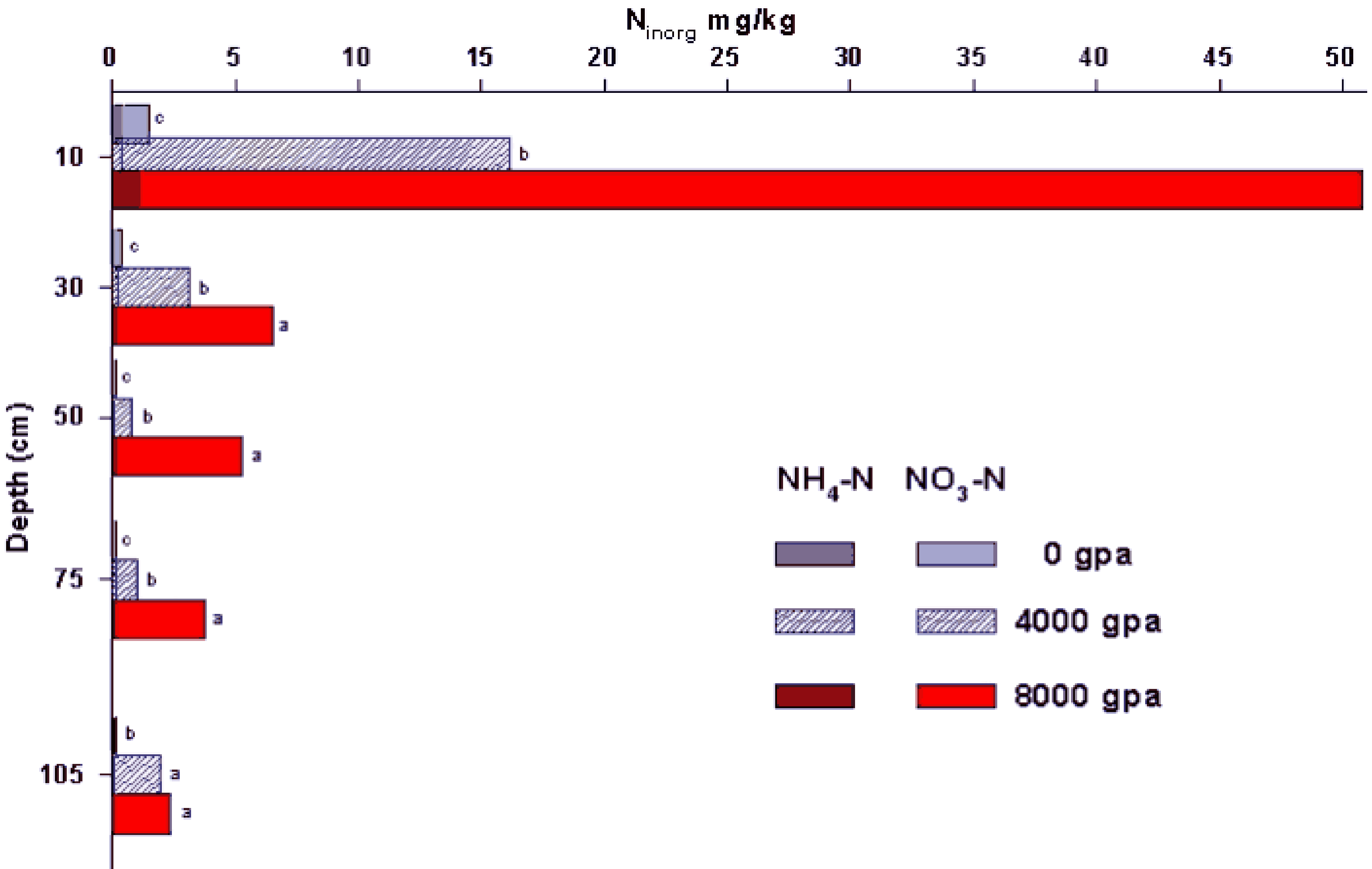


Figure 4A - Soil inorganic nitrogen to 1.2 m deep as affected by injection rate of manure after 3 years, Sept. 2002.
Means within a layer followed by the same letter are not different.

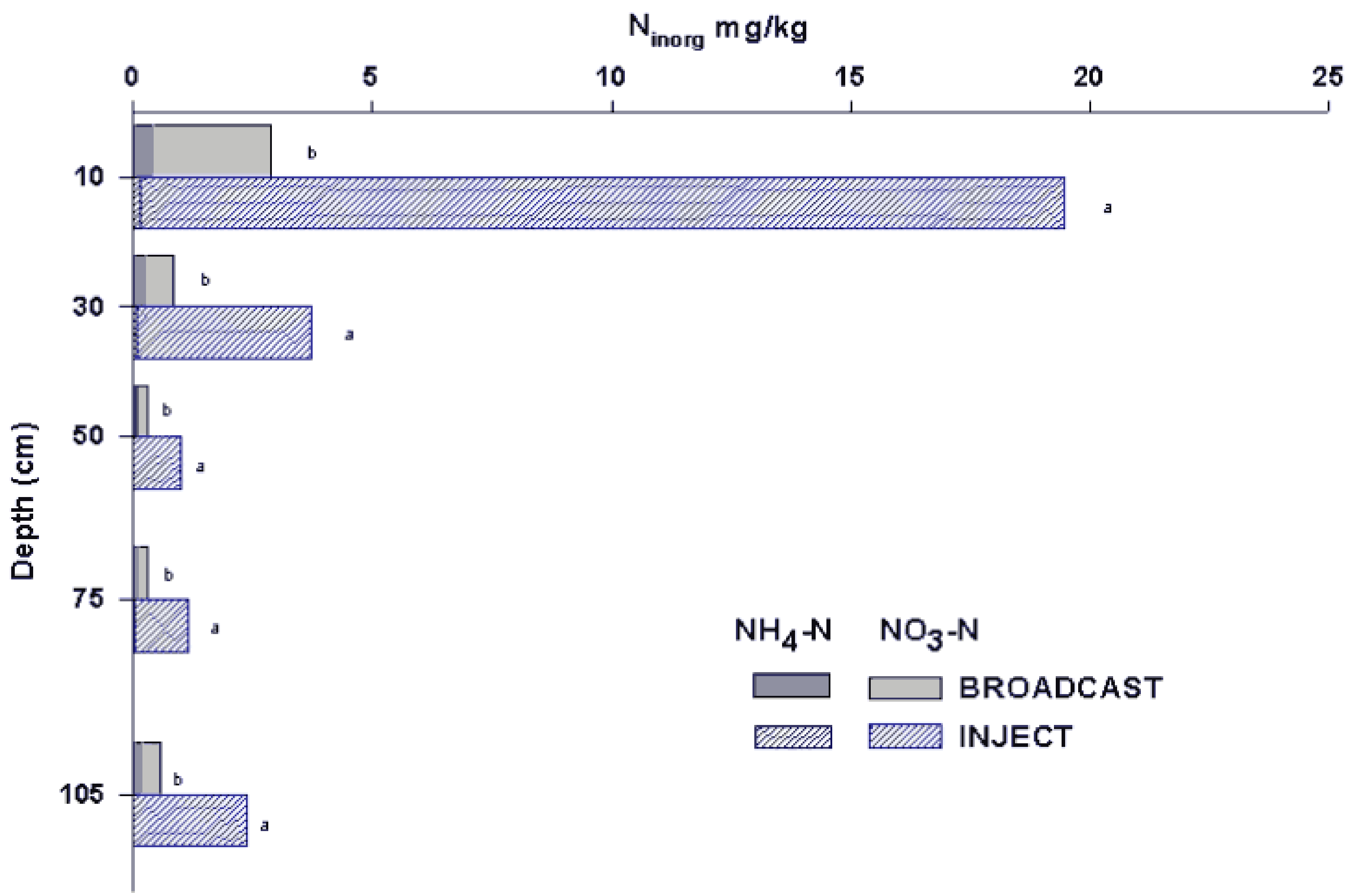


Figure 4B - Soil inorganic nitrogen to 1.2 m deep as affected by application method (at 4000 gpa) after 3 years, Sept. 2002.
Means within a layer followed by the same letter are not different.

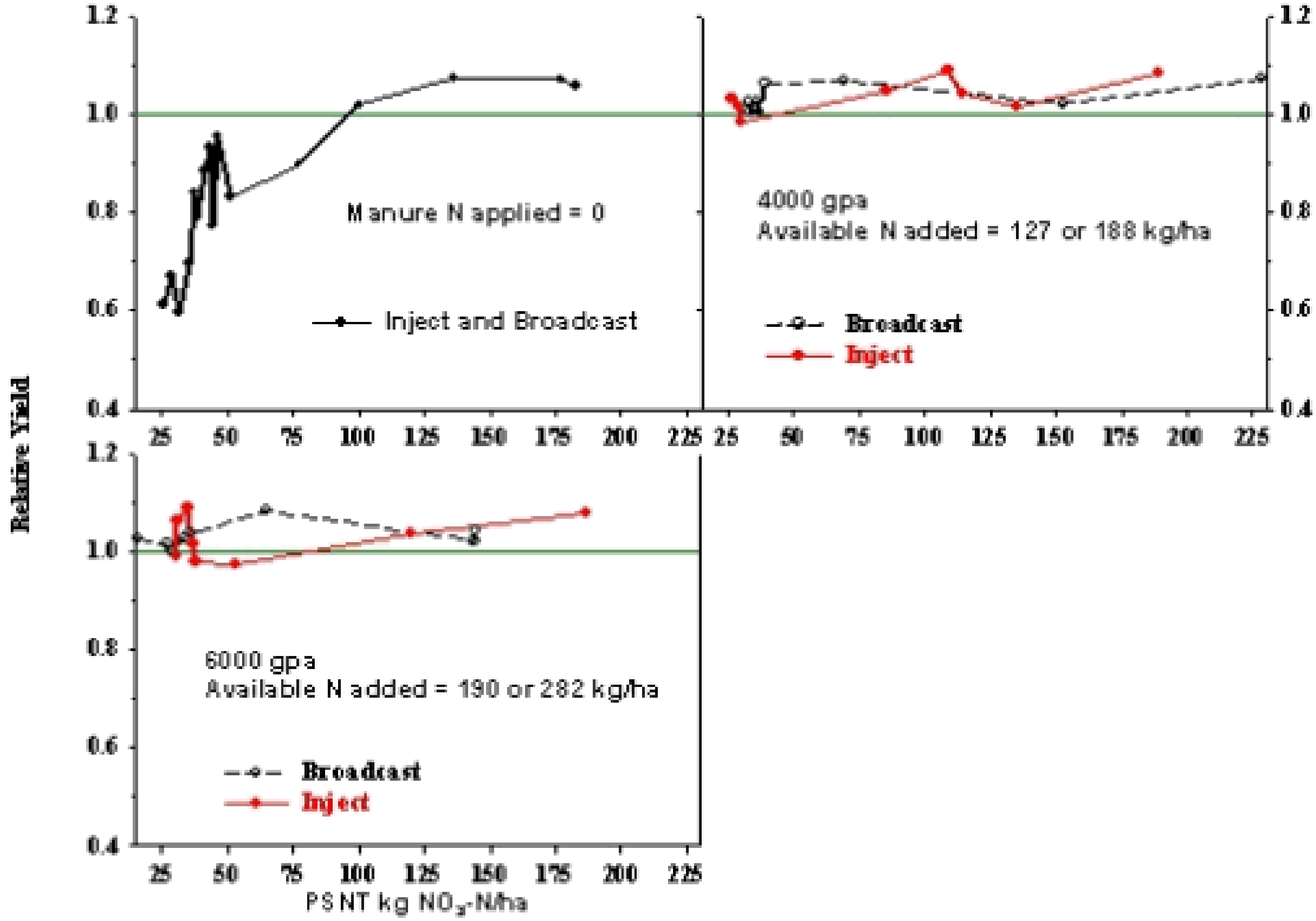
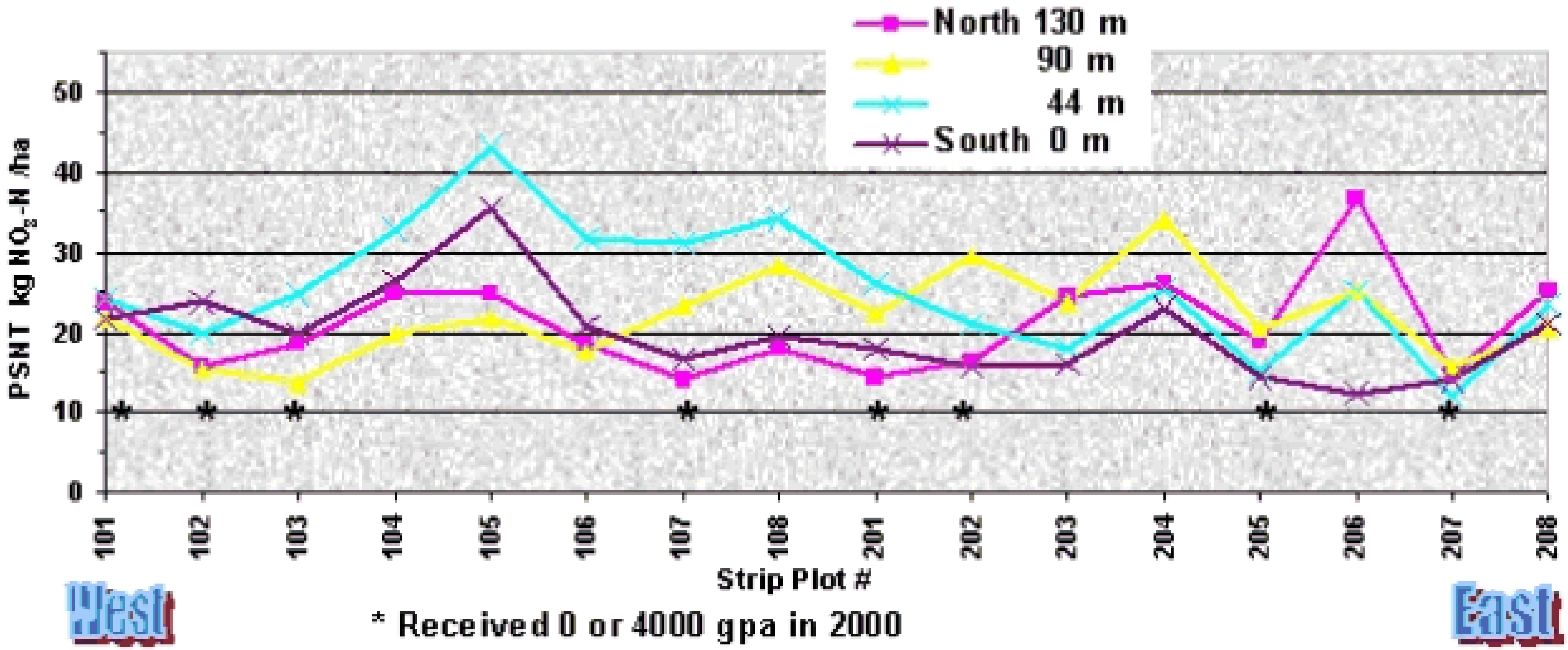


Figure 5. Relative yield (1 = 95% of maximum yield) in relation to the PSNT in 2000 for different rates of manure. Available N is according to NMAN.

Fig. 6. Spatial Variability in PSNT values across the field in 2001 shows some residual nitrogen in strip plots where more than 4000 gpa manure was applied the year before.



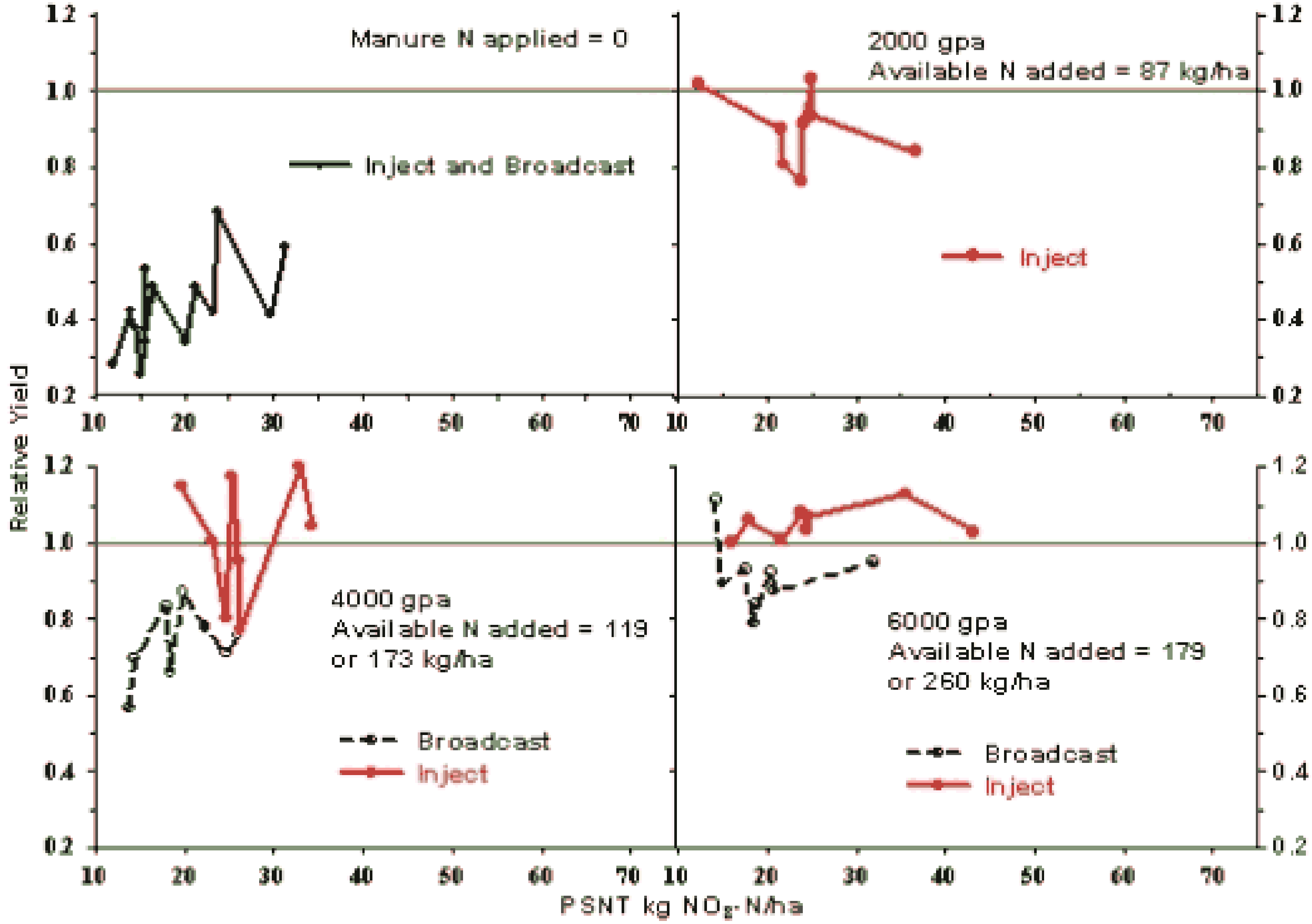


Figure 7. Relative yield (1 = 95% of maximum yield) in relation to the PSNT in 2001 for different rates of manure. Available N is according to NMAN.

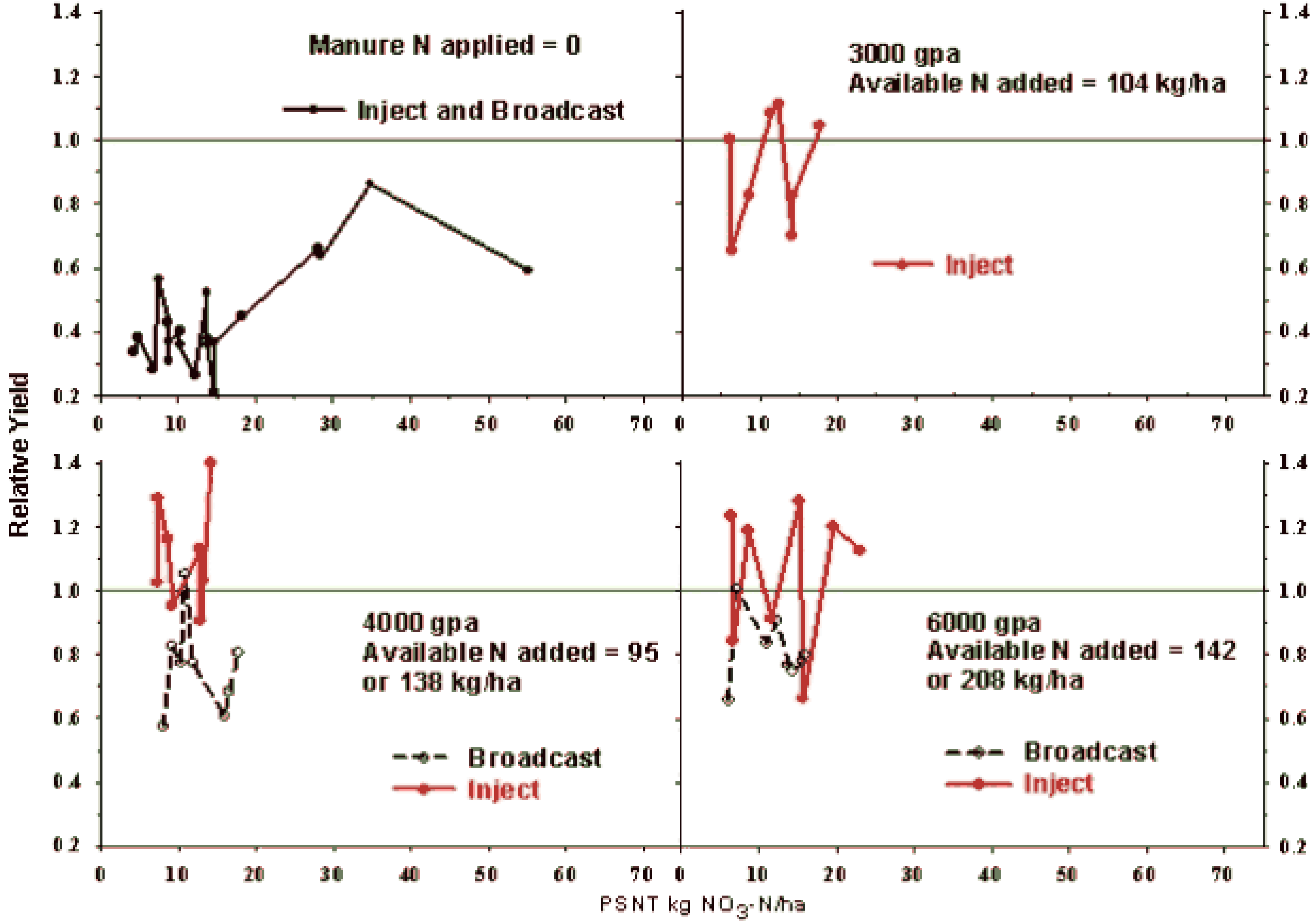


Figure 8. Relative yield (1 = 95% of maximum yield) in relation to the PSNT in 2002 for different rates of manure. Available N is according to NMAN.

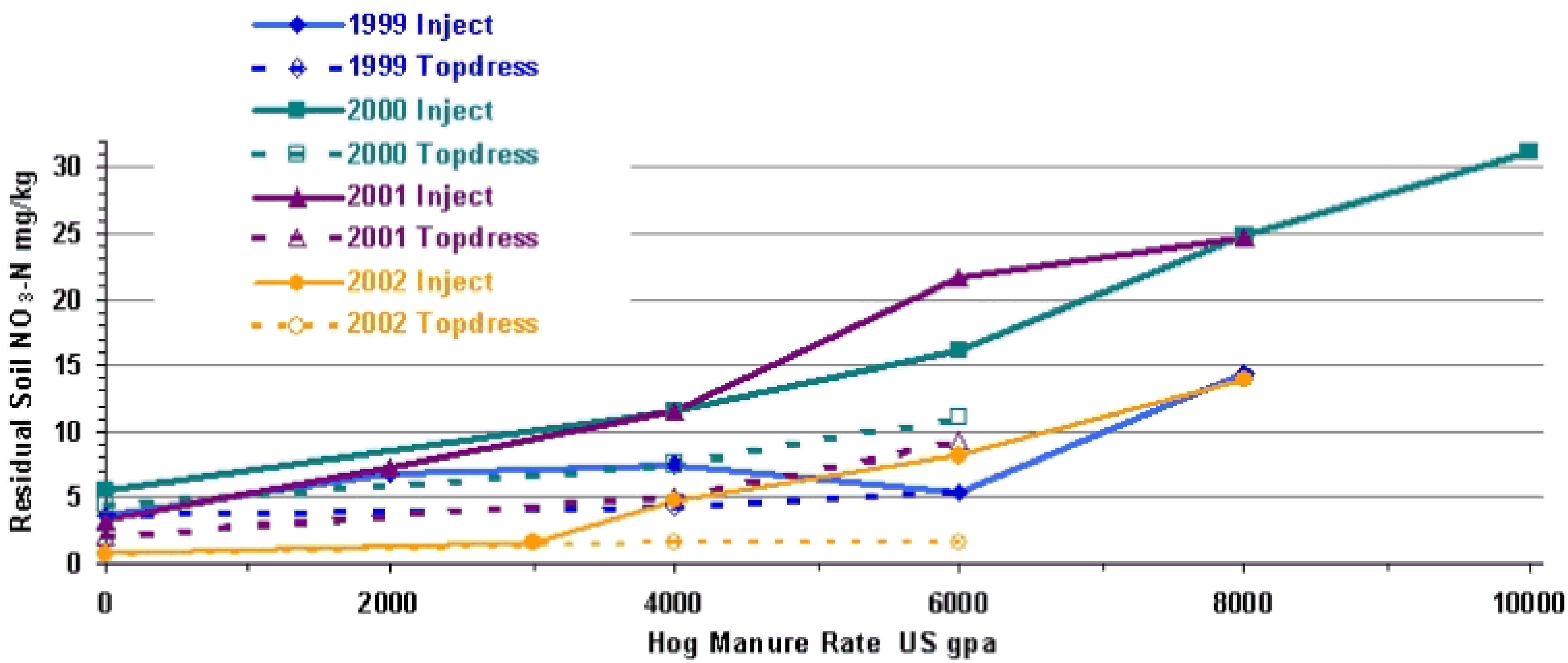


Figure 9. Residual nitrate concentrations in the topsoil after corn harvest increase with sidedress rate of hog manure. Trials were in Huron (1999) & Perth (2000-2002).

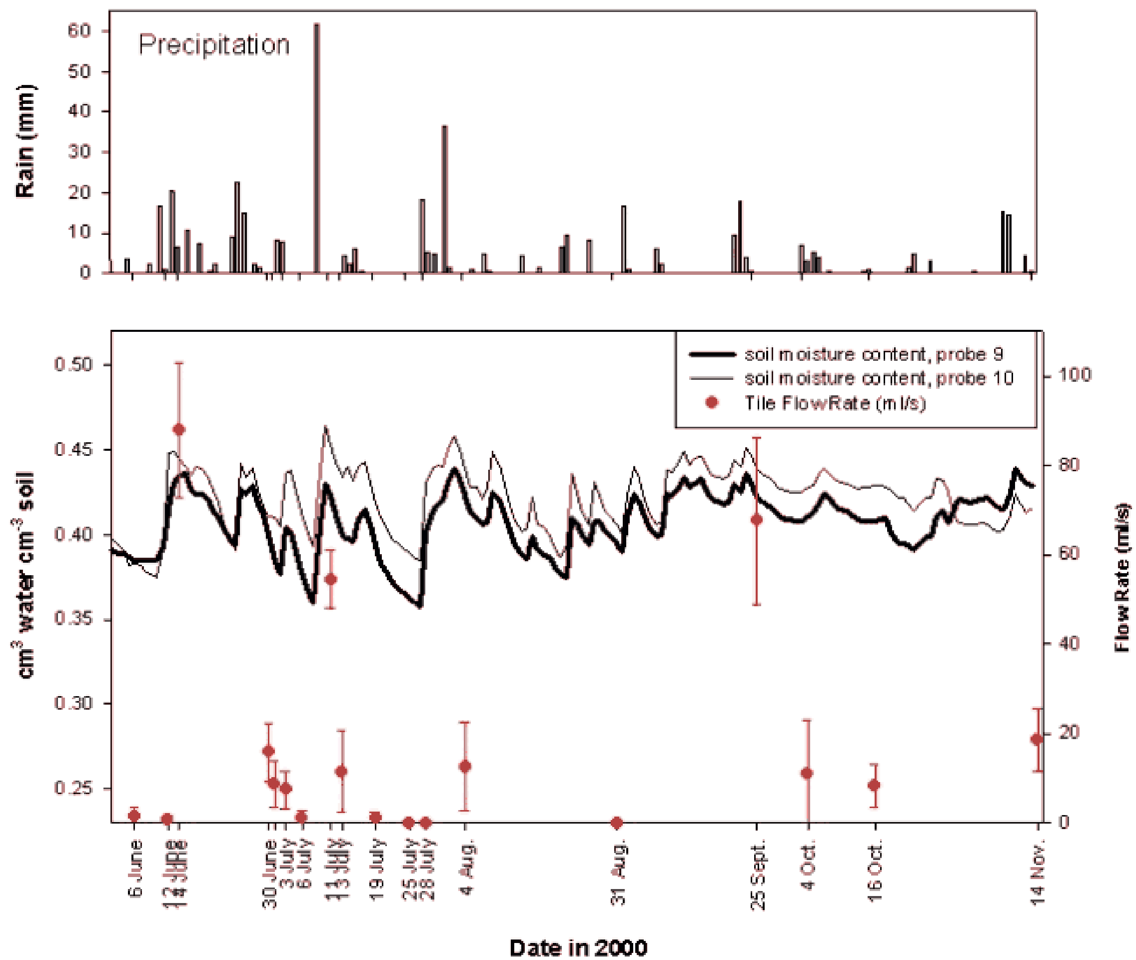


Figure 10. Rainfall, tile flow, and volumetric water content in the topsoil as measured by reflectometers, in 2000.

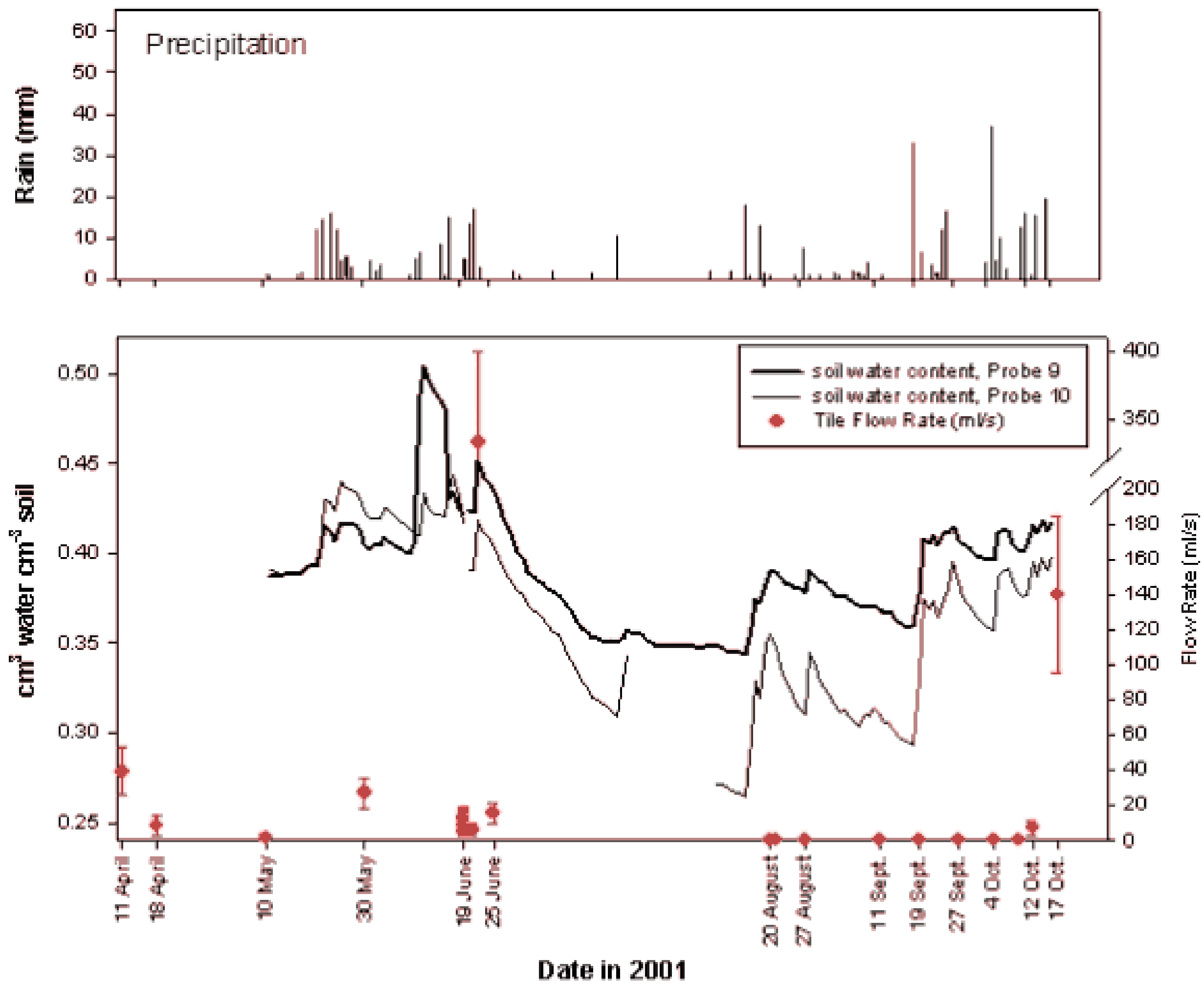


Figure 11. Rainfall, tile flow, and volumetric water content in the topsoil as measured by reflectometers, in 2001.

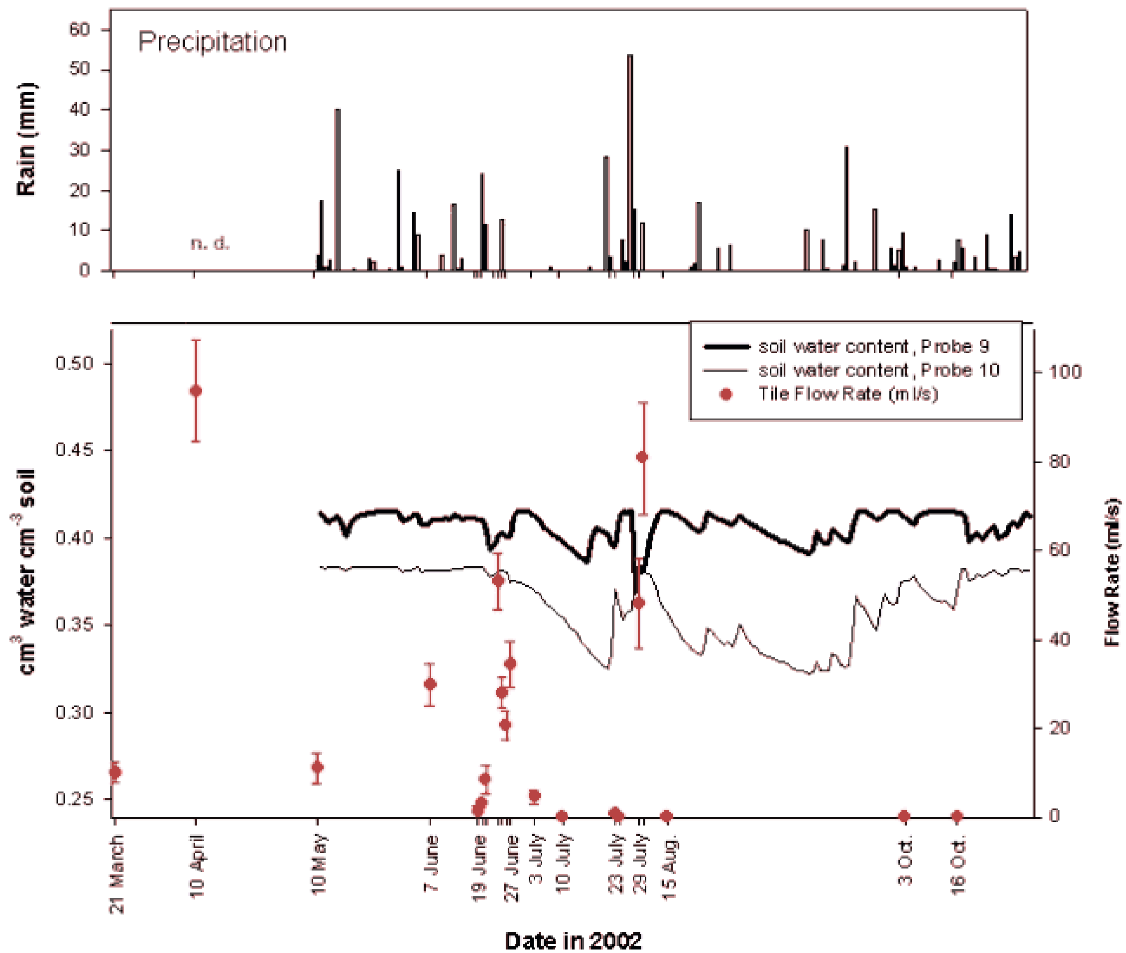


Figure 12. Tile flow, and rainfall and volumetric water content (after 10 May) in the topsoil as measured by reflectometers, in 2002.

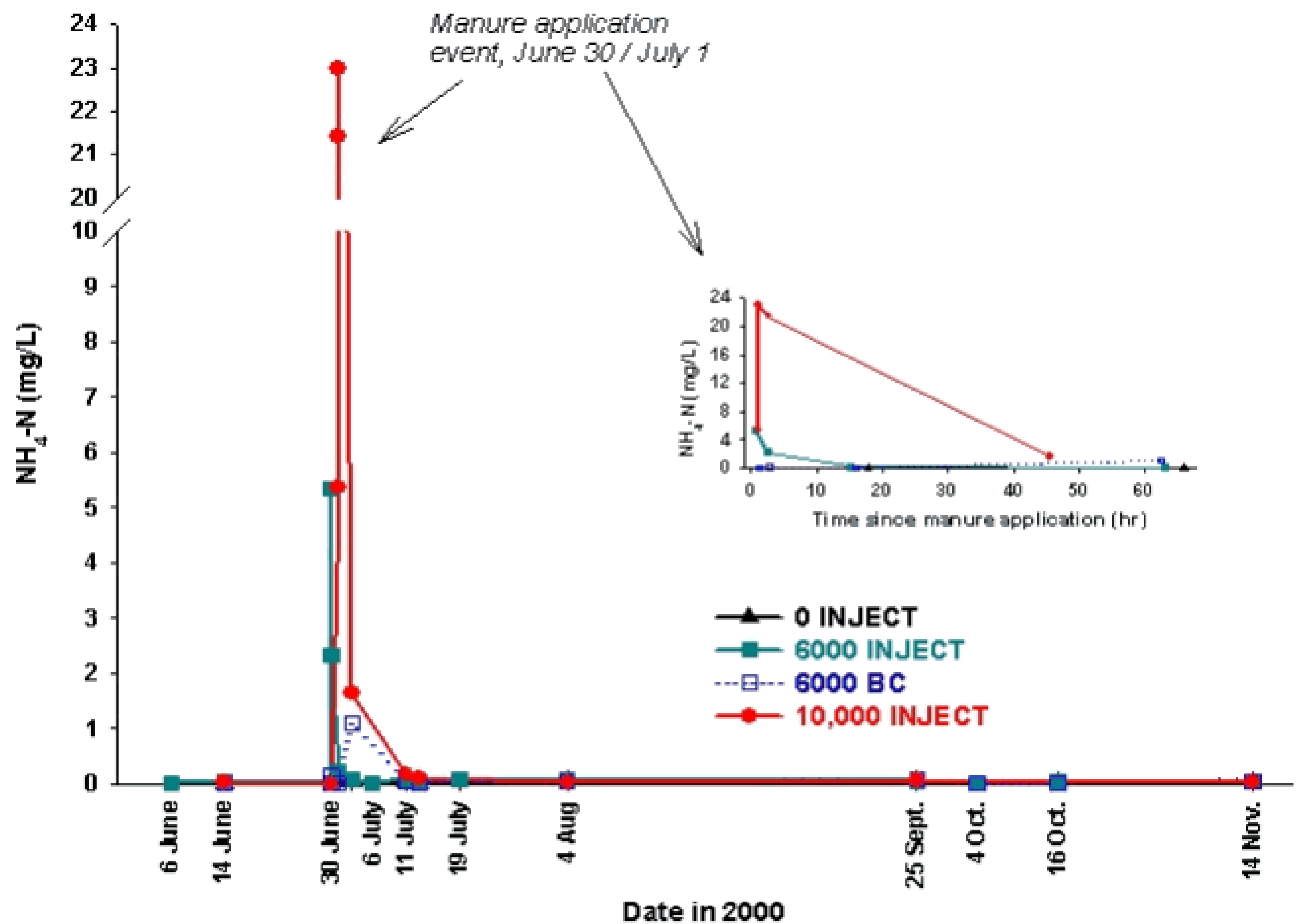


Figure 13A. NH_4-N concentrations in tile drainage water in 2000 with different rates and methods of manure application.

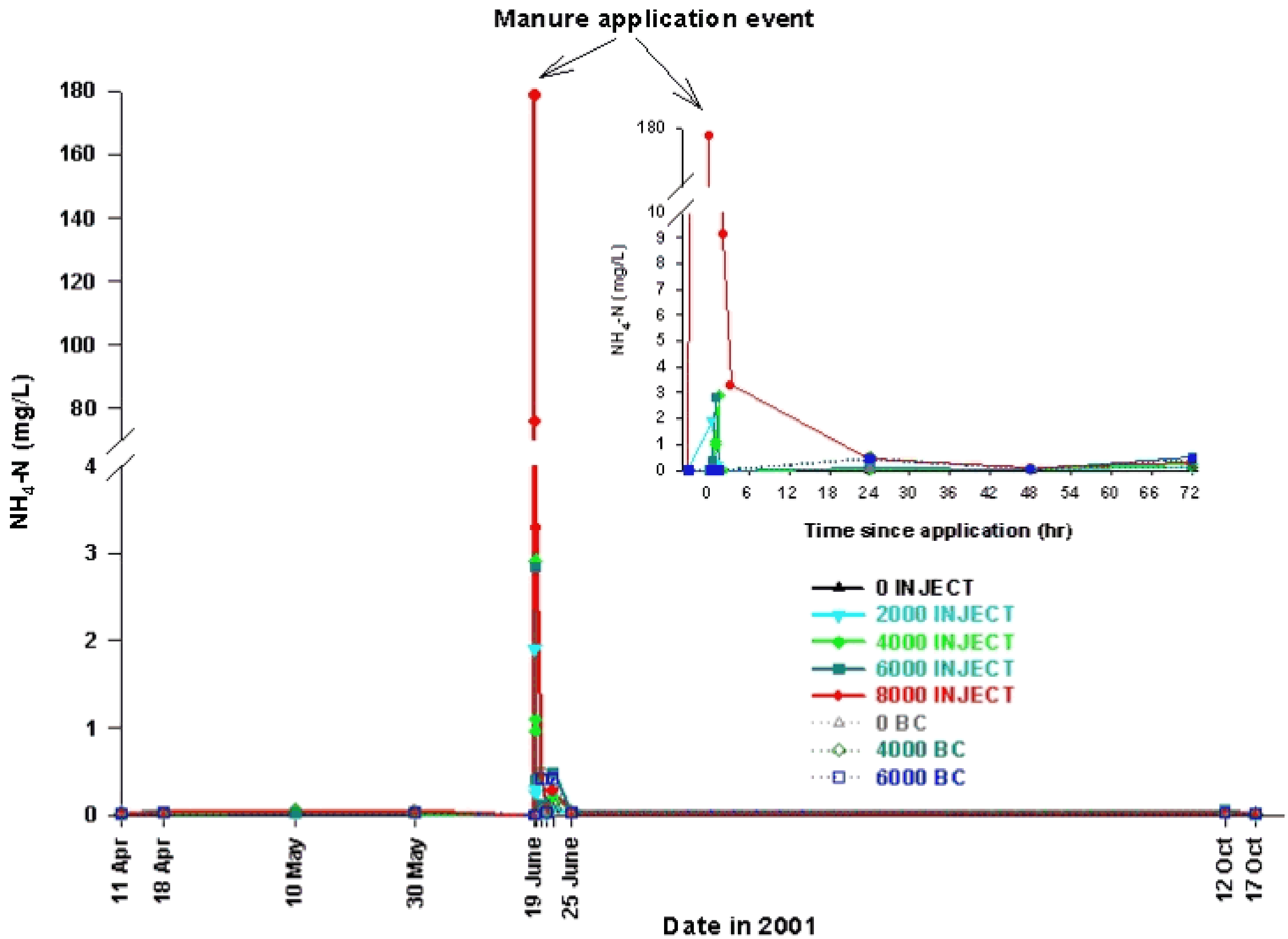


Figure 13B. NH_4-N concentrations in tile drainage water in 2001 with different rates and methods of manure application.

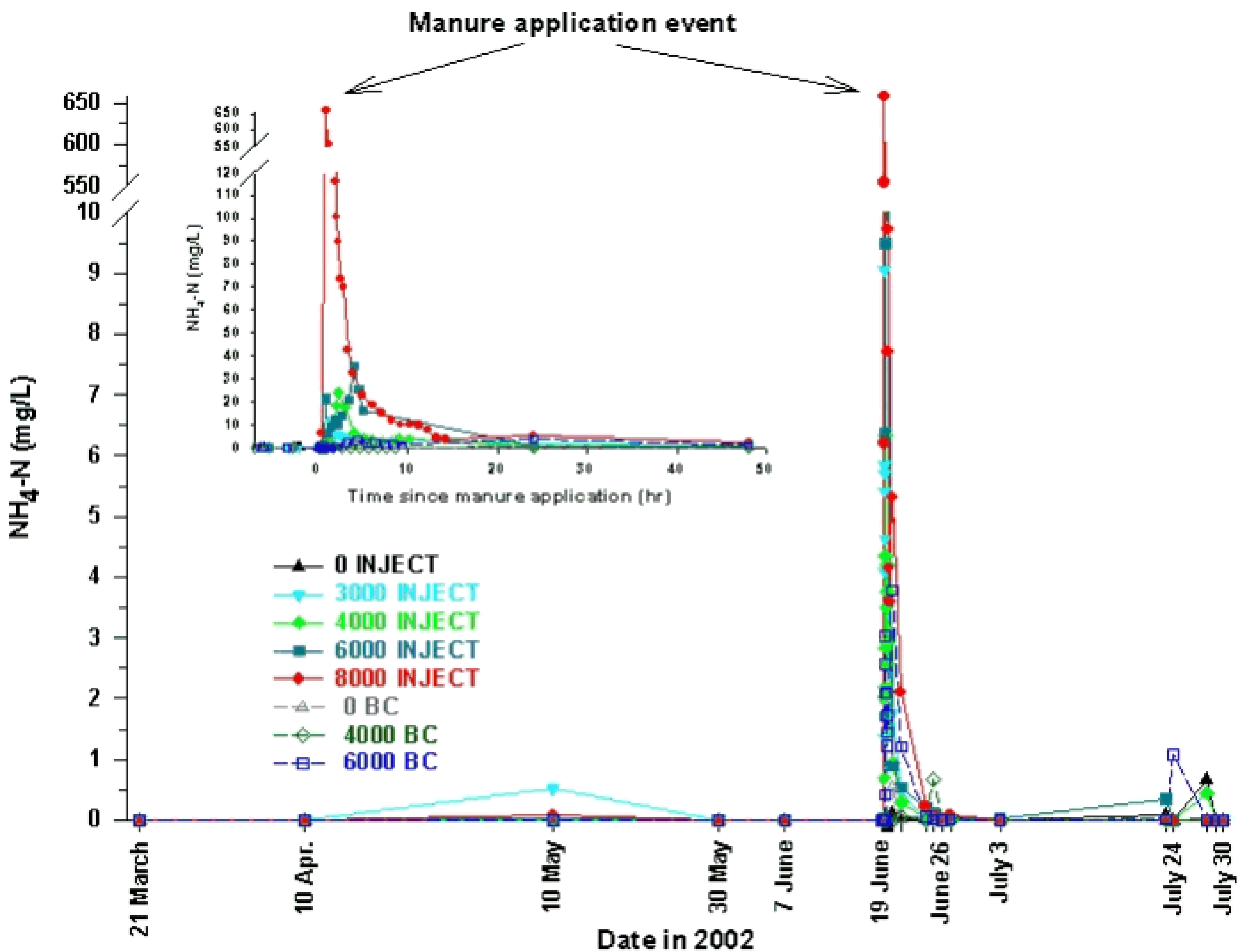


Figure 13C. NH_4-N concentrations in tile drainage water in 2002 with different rates and methods of manure application.

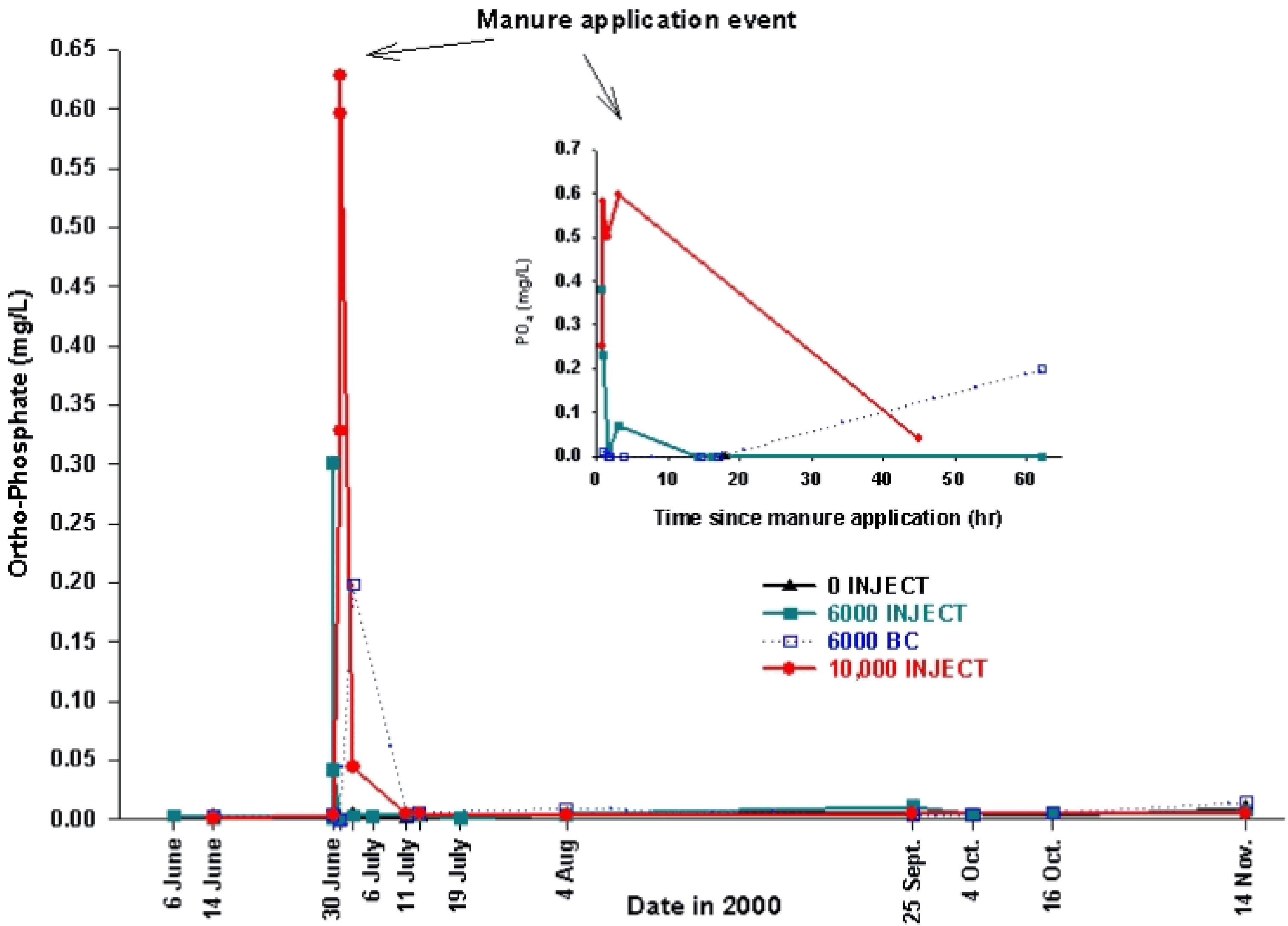


Figure 14A. Orthophosphate concentrations in tile drainage water in 2000 with different rates and methods of manure application.

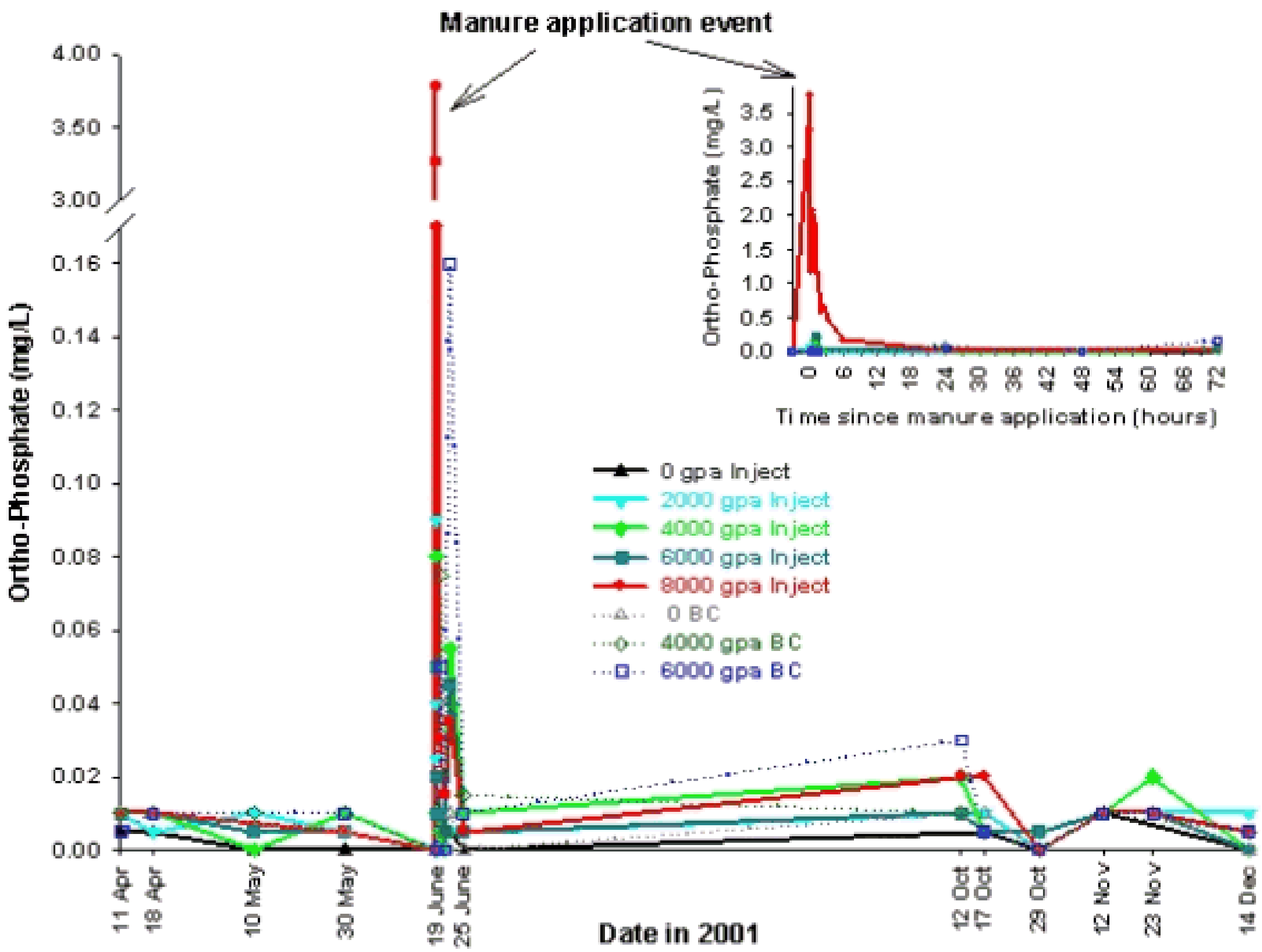


Figure 14B. Orthophosphate concentrations in tile drainage water in 2001 with different rates and methods of manure application.

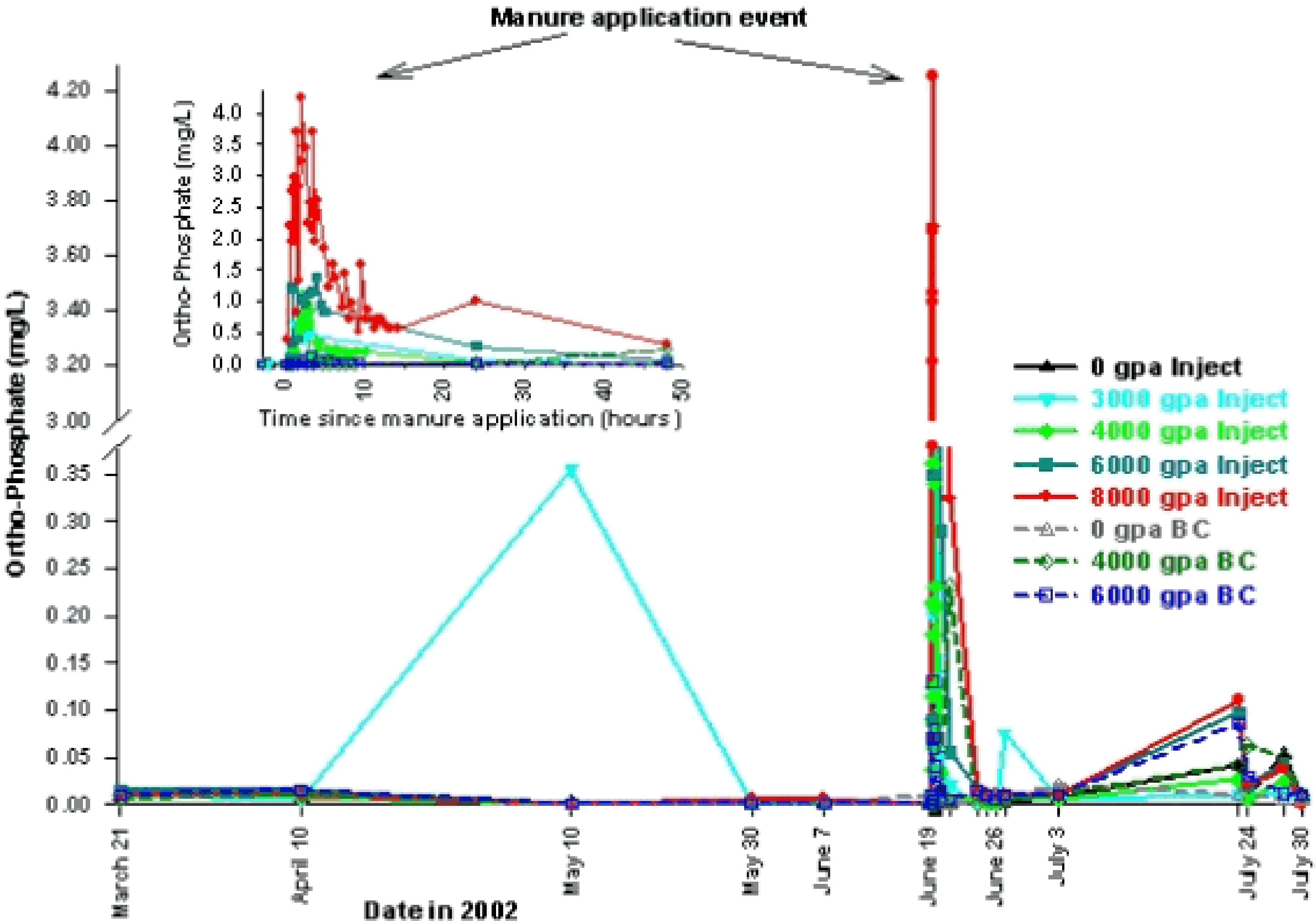


Figure 14C. Orthophosphate concentrations in tile drainage water in 2002 with different rates and methods of manure application.

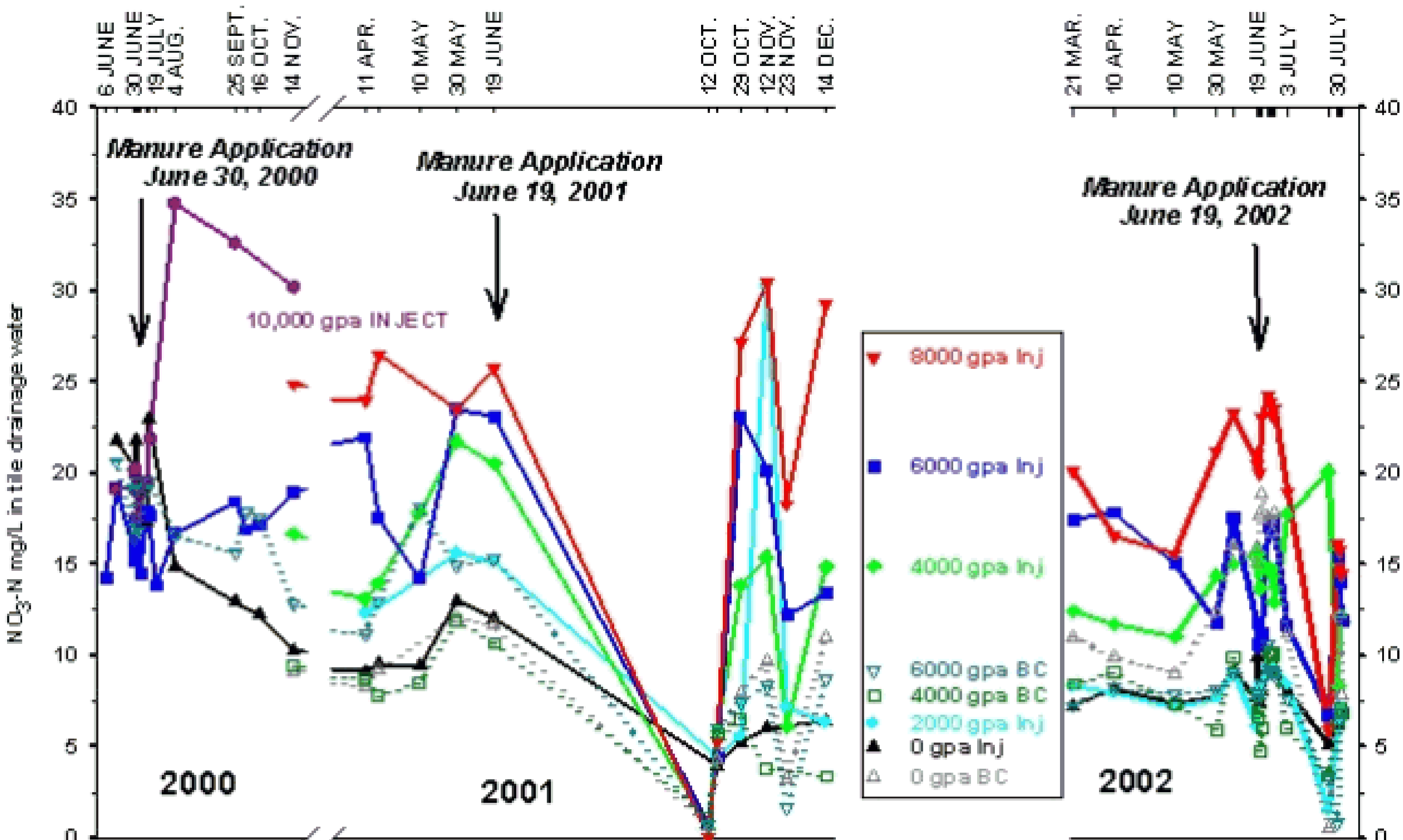


Figure 15. Nitrate concentrations in tile drainage waters increase when manure application rates exceed crop demand for N, particularly in fall and spring.

Table 1. Nutrient composition of LHM from selected tank loads, and respective plot to which the loads were applied during sidedressing experiments, 2000-02.

Load	Date	Time	Plot	Treatment (US gal/ac)	N (%)	P (%)	K (%)	NH_4-N (mg/kg)	DM (%)
2000									
1	30 June	3:07 pm	206	6000 BC	0.51	0.13	0.32	4745	3.84
8	30 June	7:55 pm	105	8000 INJ	0.53	0.17	0.3	4811	4.67
9	1 July	9:07 am	208	10000 INJ	0.54	0.18	0.31	5026	4.98
11	1 July	11:02 am	108	10000 INJ	0.54	0.17	0.28	5275	4.4
14	1 July	12:57 pm	103	4000 BC	0.46	0.16	0.27	4405	2.93
			101	4000 INJ					
	Average of loads 1, 8, 9, 11				0.53	0.16	0.30	4964	4.47
2001									
2	19 June	2 pm	206	2000 INJ	0.53	0.19	0.29	4200	3.92
			208	8000 INJ					
11	19 June	6 pm	103	4000 BC	0.71	0.22	0.39	5670	4.51
			105	6000 INJ					
Average					0.62	0.21	0.34	4935	4.22
2002									
2	19 June	12:15 pm	101	3000 INJ	0.43	0.11	0.28	3500	2.7
			108	8000 INJ					
7	19 June	2 pm	206	3000 INJ	0.43	0.1	0.28	3600	2.3
			208	8000 INJ					
Average					0.43	0.1	0.28	3550	2.5

Analyses by U of G in 2000 and 2001; by A&L in 2002

Table 2. Available nutrients supplied by manure as estimated by NMAN, Nutrient Management Program using the 'in-season injection' option for injection treatments, and the 'not incorporated-standing crop' option for broadcast treatments.

Manure Application		Available Nutrients		
Rate	Method	N	P_2O_5	K_2O
gallons/acre		-------- *lb/acre* -------		
	2000 [z]			
4000	INJECT	188	55	121
6000	INJECT	282	83	182
8000	INJECT	376	110	242
10000	INJECT	470	138	303
4000	BROADCAST	127	55	121
6000	BROADCAST	190	83	182
	2001			
2000	INJECT	87	31	62
4000	INJECT	173	63	122
6000	INJECT	260	95	184
8000	INJECT	346	126	246
4000	BROADCAST	119	63	122
6000	BROADCAST	179	95	184
	2002			
3000	INJECT	93	23	76
4000	INJECT	123	30	101
6000	INJECT	186	46	152
8000	INJECT	247	62	202
4000	BROADCAST	85	30	101
6000	BROADCAST	127	46	152

[z] average of concentrations in loads 1, 8, 9 and 11

Table 3. Summary from 2000, 2001 and 2002 of yield response to injection rate, 95% maximum yield and manure rate for 95% maximum yield calculated from the response.

	Response Equation	95% maximum yield		Rate of 95% max yield	
	y = kg grain/ha, x = L manure/ha	(kg/ha)	(bu/ac)	(L/ha)	(usgal/ac)
2000					
hand-harvest	$y = 6908.50 + 0.0256x - 0.0000001x^2$	8120	129	62630	6698
combine, subs	$y = 6760.07 + 0.0304x - 0.0000002x^2$	7520	120	31516	3371
combine, all [1]	$y = 6110.88 + 0.0535x - 0.0000004x^2$	7505	119	35451	3792
2001					
hand-harvest	$y = 5174.62 + 0.2545x - 0.000002x^2$	12607	202	45410	4856
combine, subs	$y = 5411.96 + 0.1922x - 0.000002x^2$	9528	152	32215	3445
combine, all	$y = 5412.01 + 0.1972x - 0.000002x^2$	9759	156	33274	3559
2002					
hand-harvest [2]	$y = 3689.8 + 0.2189x - 0.000002x^2$	9195	146	39174	4190
combine, subs [2]	$y = 8026.9 + 0.1122x - 0.0000007x^2$	11897	189	50235	5373
combine, all [2]	$y = 8102.8 + 0.1100x - 0.0000007x^2$	11803	188	48781	5217

[1] North end only

[2] 207 East excluded

Table 4. Summary of sidedress injection rates for 95% of maximum yield, available nutrients from manure injected at that rate, and corresponding DM and N contents, over 4 years of study.

Year	Application Rate for 95% Max Yield gpa[x]	Available Nutrients* *lb/acre*			Manure Content %	
		N	P_2O_5	K_2O	DM	N
1999[z]	5800	181	94	128	3.9	0.49
2000	3800	178	52	115	4.5	0.52
2001	4900	236	86	167	4.2	0.62
2002	4200	183	45	149	2.5	0.43

*As estimated by NMAN Nutrient Management Program

[z] Huron County

[x] based on combine monitor data north end 2000, and hand-harvest data in 2001 and 2002

Table 5. Grain (north end only) and crop characteristics in 2000 with different rates and methods of manure application.

Rate (gpa)	Grain N conc. (%)		Grain N uptake (kg/ha)	
	BC	INJECT	BC	INJECT
0	1.10 d	1.09 d	57.4 c	67.3 c
4000	1.27 c	1.38 ab	106.3 b	107.5 b
6000	1.39 ab	1.35 abc	116.7 ab	112.4 ab
8000		1.33 bc		102.9 b
10000		1.44 a		128.8 a
Std. Error	0.034		5.86	
Rate (gpa)	**Grain moisture (%), hand samples 1-2**		**Grain moisture (%), monitor whole field**	
	BC	INJECT	BC	INJECT
0	26.3 a	25.4 abc	22.2 B	21.7 DE
4000	25.3 abc	26.2 a	22.1 B	22.0 B
6000	25.6 ab	24.1 c	21.7 E	21.8 D
8000		26.4 a		22.2 A
10000		24.7 bc		21.9 C
Std. Error	0.49		0.03	
Rate (gpa)	**Broken Stalks (%)**		**Grain Test Weight (kg/hL)**	
	BC	INJECT	BC	INJECT
0	2.2 a	0.8 b	60.3 c	61.2 bc
4000	0 b	0 b	63.2 a	62.3 ab
6000	0 b	0 b	63.0 a	63.4 a
8000		0 b		63.3 a
10000		0 b		62.8 a
Std. Error	0.36		0.42	

Table 6. Grain and crop characteristics in 2001 with different rates and methods of manure application.

Rate (gpa)	Grain N conc. (%)		Grain N uptake (kg/ha)	
	BC	INJECT	BC	INJECT
0	0.96 D	0.96 D	44.1 E	46.4 E
2000		1.13 C		111.8 C
4000	1.14 C	1.28 B	91.7 D	142.1 B
6000	1.18 C	1.36 A	118.3 C	157.7 A
8000		1.33 AB		149.9 AB
Std. Error	0.021		3.99	
Rate (gpa)	Grain moisture (%), hand samples 1-4		Grain moisture (%), monitor whole field	
	BC	INJECT	BC	INJECT
0	27.3 A	27.7 A	24.6 A	24.7 A
2000		24.8 B		23.2 E
4000	26.9 A	24.5 B	24.4 B	23.3 DE
6000	26.6 A	24.7 B	24.0 C	23.4 D
8000		24.7 B		23.3 E
Std. Error	0.43		0.03-0.05	
Rate (gpa)	Broken Stalks (%)		Grain Test Weight (kg/hL)	
	BC	INJECT	BC	INJECT
0	11.7 ab	12.8 a	66.1 CD	65.9 D
2000		1.9 c		66.8 B
4000	2.2 c	3.7 c	67.3 B	67.4 B
6000	1.9 c	3.7 c	66.8 BC	68.4 A
8000		5.3 bc		68.7 A
Std. Error	2.53		0.24	

Means followed by the same letter are not significantly different

Table 7. Grain and crop characteristics in 2002 with different rates and methods of manure application.

Rate (gpa)	Grain N conc. (%)		Grain N uptake (kg/ha)	
	BC	INJECT	BC	INJECT
0	0.79 c	0.84 c	25.8 D	30.1 D
3000		1.10 a		91.7 B
4000	0.96 b	1.11 a	68.0 C	113.8 A
6000	0.99 b	1.15 a	73.1 C	111.6 A
8000		1.12 a		120.1 A
Std. Error	0.028		5.53	
Rate (gpa)	Grain moisture (%), hand samples 1-4		Grain moisture (%), monitor whole field	
	BC	INJECT	BC	INJECT
0	29.6 A	28.3 AB	21.4 DE	22.1 C
3000		28.3 AB		22.6 B
4000	26.2 C	28.4 AB	20.8 E	24.8 A
6000	27.2 BC	28.1 AB	21.1 DE	24.8 A
8000		25.4 C		21.5 CD
Std. Error	0.65		0.19-0.21	
Rate (gpa)	Broken Stalks (%)		Grain Test Weight (kg/hL)	
	BC	INJECT	BC	INJECT
0	7.9 a	4.1 ab	66.0 c	65.9 c
3000		0.6 b		68.2 b
4000	1.1 b	1.3 b	68.8 b	69.1 ab
6000	2.5 b	2.8 b	68.5 b	68.8 b
8000		0.0 b		69.8 a
Std. Error	1.7		0.36	

207 East excluded in 2002. Means followed by the same letter are not significantly different.

Table 8. End of season stalk nitrates in 2002 with different rates and methods of manure application.

Rate (gpa)	INJ		BC	
	mg NO_3 / kg			
0	40	D	11	D
3000	174	D		
4000	827	C	22	D
6000	1668	B	28	D
8000	3556	A		

Values followed by the same letter are not significantly different at the 0.05 probability level.

Table 9. Variability in soil chemical properties and available nutrients in the topsoil in 2000 (average of 64 samples) prior to imposing manure treatments.

	OM	CEC	pH	P [1]	K	Ca	Mg	Zn	Mn	Fe	Cu	B	S
	%	meq/100g		-------------	-------------	-------------	-------------	*mg/kg*	-------------	-------------	-------------	-------------	-------------
low	3.5	15.3	5.9	18	73	2190	220	2.7	11	75	1.6	0.5	15
high	5.1	20.7	7.8	43	162	3580	495	5	48	95	3.9	1.6	20
average	4.5	17.3	7.1	29	107	2622	361	3.4	22	85	2.5	0.7	17

[1] Bicarbonate extactable

Table 10. Calcium, pH, potassium, phosphorus and sulphur concentrations in the top 0.2 m of soil prior to (spring 2000) and following two (fall 2001) and three (fall 2002) years of manure application at five rates.

	Sample Date	Manure Application Rate (gpa)					
		0	2000/3000[1]	4000	6000	8000	SE
Calcium (mg/kg)	Spring 2000	2621	2419	2663	2656	2681	92.4
	Fall 2001	2696	2336	2770	2546	2649	80.3
	Fall 2002	2558	2500	2464	2442	2542	92.4
pH	Spring 2000	7.2	6.7	7.1	7.1	7.4	0.12
	Fall 2001	7.4	6.6	7.2	7.1	7	0.12
	Fall 2002	7.3	6.9	7	7	6.8	0.13
Potassium (mg/kg)	Spring 2000	105	105	110	110	98	5.7
	Fall 2001	87	108	116	137	142	4.0
	Fall 2002	82	95	108	114	128	4.1
Phosphorus (Bicarb.) (mg/kg)	Spring 2000	30	29	27	28	31	1.4
	Fall 2001	31	39	38	45	48	1.4
	Fall 2002	26	31	32	35	41	1.9
Phosphorus (Bray-P1) (mg/kg)	Spring 2000	53	50	49	48	55	2.7
	Fall 2001	57	79	80	103	115	4.6
	Fall 2002	46	54	57	66	83	3.9
Sulphur (mg/kg) [2]	Spring 2000	17.2	17.8	17.1	17.2	17.2	0.3
	Fall 2002	11.4	12.2	12.5	13.2	14.6	0.5

[1] Application rate was 2000 gpa in 2001 and 3000 gpa in 2002

[2] Sulphur not measured in 2001

Table 11. Soil pH in the top 0.2 m (fall 2002) after 3 years of manure application with different rates and methods.

Rate	pH	
gpa	BC	INJECT
0	7.4 A	7.2 AB
3000		6.9 BC
4000	6.9 BC	7.2 AB
6000	7.3 A	6.8 C
8000		6.8 C
SE	0.13	

Table 12. Pre-sidedress soil inorganic N content in the top 0.3 m with different rates and methods of manure application in 2000, 2001 and 2002. Mean of 4 sub-sampling locations.

Rate	NO_3-N (PSNT)		NH_4-N		N_{inorg}	
	BC	INJECT	BC	INJECT	BC	INJECT
gpa	mg/kg					
*6 June **2000***						
0	14.0 a [1]	20.3 a	0.69 a	0.74 a	14.7 a	21.1 a
4000	19.7 a	22.5 a	0.98 a	1.01 a	20.6 a	23.5 a
6000	15.5 a	16.6 a	0.78 a	0.81 a	16.2 a	17.4 a
8000		15.5 a		0.95 a		16.4 a
10000		15.9 a		0.78 a		16.7 a
SE	2.21		0.123		2.24	
*30 May **2001*** [2]						
0	4.4 b	4.9 ab	0.87 b	1.2 ab	5.3 c	6.1 bc
4000	4.9 ab	5.0 ab	1.18 ab	1.21 ab	6.1 bc	6.2 bc
6000	5.9 ab	6.6 a	1.23 ab	1.27 ab	7.1 ab	7.9 a
8000		6.5 a		1.62 a		8.1 a
10000		5.9 ab		1.36 ab		7.3 ab
SE	0.6		0.235		0.58	
*7 June **2002*** [3]						
0	2.1 c	3.3 b	0.25	0.39	2.3 c	3.6 b
3000		2.8 bc		0.22		3.1 bc
4000	3.1 bc	2.7 bc	0.49	0.31	3.6 b	3.0 bc
6000	3.0 b	3.4 b	0.41	0.31	3.4 b	3.7 b
8000		4.4 a		0.69		5.1 a
SE	0.27 - 0.39		0.11 - 0.16		0.27 - 0.39	

[1] least squares means for a response variable followed by the same letter are not significantly different at the 0.05 probability level

[2] 2000 used treatments since manure not yet applied

[3] plot 208 and 207 east excluded

Table 13. Residual soil inorganic N concentration in the top 0.2 m following harvest with different rates and methods of sidedressed manure in 2000, 2001 and 2002.

Rate	NO_3-N		NH_4-N		N_{inorg}	
	BC	INJECT	BC	INJECT	BC	INJECT
gpa				mg/kg		
14 November 2000 average of subs 1 and 2						
0	4.0 E [1]	5.1 E	0.78	2.23	4.8 F	7.3 EF
4000	6.3 DE	9.0 D	1.03	1.67	7.3 EF	10.7 D
6000	9.0 D	17.8 C	1.00	1.17	10.0 DE	19.0 C
8000		28.1 B		1.98		30.1 B
10000		35.6 A		1.1		36.7 A
SE	1.08		0.383		1.13	
method mean [2]			0.94 B	1.69 A		
12 November 2001						
0	2.2 D	3.2 D	1.43 ab	0.56 b	3.6 C	3.8 C
2000		7.4 BCD		0.66 b		8.0 BC
4000	5.0 CD	11.6 B	1.49 ab	0.93 b	6.5 BC	12.5 B
6000	9.3 BC	21.7 A	1.39 ab	1.28 ab	10.7 B	22.9 A
8000		24.6 A		2.07 a		26.7 A
SE	1.97		0.394		2.18	
21 October, 2002 [3]						
0	0.6 D	0.9 D	0.09 B	0.07 B	0.7 D	0.9 D
3000		1.7 D		0.07 B		1.7 D
4000	1.7 D	4.7 C	0.09 B	0.16 A	1.8 D	4.9 C
6000	1.6 D	8.2 B	0.07 B	0.06 B	1.6 D	8.3 B
8000		14.0 A		0.08 B		14.0 A
SE	0.60		0.018		0.6	

[1] least squares means for a response variable followed by the same upper case (protected) or lower case (unprotected) letter are not significantly different at the 0.05 probability level

[2] means are arithmetic, and for injection treatments are calculated using only the three lowest application rates in order to compare to the broadcast mean

[3] excluding east half of plot 207

Table 14. Phosphate and ammonium transfer to tile the week following manure application, estimated from concentrations and flow (converted to a ha basis assuming systematic tiling).

	2000		2001		2002	
Method	INJECT	BC	INJECT	BC	INJECT	BC
Rate gpa	**g PO_4 /ha / wk**					
0	0	/	1.91	3.8	0.2	0.2
2000/ 3000 [1]	/	/	2.64		1.4	/
4000	/	/	53.75	14.78	2.0	0.2
6000	0.45	0.33	19.7	67.59	2.1	0.7
8000	/	/	17.7		4.9	/
10000	1.43	/			/	/
	g NH_4 /ha / wk					
0	0.4	/	25.6	55.2	0.5	/
2000 /3000 [1]	/	/	34.3	/	16.1	/
4000	/	/	167.8	46.8	17	0.4
6000	20.3	2.2	216.1	175	37.5	10
8000	/	/	172.2	/	78.4	/
10000	62.5	/	/	/	/	/

[1] Application rate was 2000 gpa in 2001 and 3000 gpa in 2002

APPENDIX.

Table i. P values from statistical analyses of grain and crop in 2000, 2001 and 2002

	Method	Rate	Method x Rate	Mean
2000				
Yield, hand samples 1-4	0.87	0.0001	0.063	
Yield, monitor samples 1-4	0.0575	0.0001	0.0313	
Yield, monitor, whole field	0.0003	0.0001	0.0001	
Yield, hand samples 1-2, adjusted	0.95	0.0001	0.0901	
Yield, monitor samples 1-2, adjusted	0.17	0.0001	0.045	
Yield, monitor, whole north end	0.0001	0.0001	0.0001	
N concentration [1]	0.54	0.0001	0.11	
N uptake [1]	0.64	0.0001	0.49	
Moisture, monitor, whole field	0.0001	0.0001	0.0001	
Moisture, hand samples (%) [1]	0.26	0.0612	0.0675	25.5
Test weight (g $100L^{-1}$) [1]	0.69	0.0002	0.11	
Population (plants ha^{-1}) [1]	0.19	0.15	0.5	73681
Percent Broken Stalks [1]	0.14	0.004	0.12	
2001				
Yield, hand samples 1-4	<0.0001	<0.0001	0.0007	
Yield, monitor samples 1-4	<0.0001	<0.0001	<0.0001	
Yield, monitor, whole field	<0.0001	<0.0001	<0.0001	
N concentration	<0.0001	<0.0001	0.0004	
N uptake	<0.0001	<0.0001	<0.0001	
Moisture, monitor, whole field	<0.0001	<0.0001	<0.0001	
Moisture, hand samples (%)	0.0009	0.0002	0.0056	
Test weight (g $100L^{-1}$)	0.0177	<0.0001	0.0008	
Population (plants ha^{-1})	0.371	0.439	0.9665	75000
Percent Broken Stalks	0.4775	0.0023	0.9914	
2002				
Yield, hand samples 1-4 [2]	<0.0001	<0.0001	0.067	
Yield, monitor samples 1-4 [2]	<0.0001	<0.0001	0.34	
Yield, monitor, whole field [2]	<0.0001	<0.0001	0.1166	
N concentration [2]	<0.0001	<0.0001	0.1127	
N uptake [2]	<0.0001	<0.0001	0.0015	
Moisture, monitor, whole field [2]	<0.0001	<0.0001	<0.0001	
Moisture, hand samples (%) [2]	0.8166	0.0013	0.0296	
Test weight (g $100L^{-1}$) [2]	0.0395	<0.0001	0.7849	
Stalk NO_3 concentration [2]	<0.0001	<0.0001	0.0001	
Population (plants ha^{-1}) [2]	0.0788	0.0629	0.8209	47014
Percent Broken Stalks [2]	0.1019	0.0451	0.4091	

[1] Based on data from subsampling locations 1 and 2 (north end) only.

[2] Data from 207 East excluded

Table ii. Grain yields at sub-sampling locations from hand-harvesting and from the combine monitor, and down the entire length of the plot with different rates and methods of manure application.

	Hand		Monitor Sub-samples		Monitor All	
RATE	BC	INJECT	BC	INJECT	BC	INJECT
gpa	------------------------------------- *kg ha*$^{-1}$					---
			Entire Field 2000			
0	5969 d [1]	6802 c	6151 C	6708 B	6005 E	6666 D
4000	8345 ab	8037 ab	7778 A	7811 A	7761 C	7951 AB
6000	8558 a	8148 ab	7745 A	7721 A	7985 AB	7714 C
8000		7597 bc		7707 A		7815 BC
10000		8739 a		7895 A		8022 A
Std. Error						
0					66.2	64.1
4000					67.0	63.4
6000	280.6		121.2		64.1	65.8
8000						62.8
10000						64.0
			North End 2000			
		Adjusted for PSNT			[2]	
0	5264 c	6100 c	4887 C	6019 B	4881 D	6094 C
4000	8309 ab	7538 b	7641 A	7425 A	7602 B	7790 AB
6000	8528 ab	8405 ab	7728 A	7836 A	7876 A	7778 AB
8000		7797 b		7789 A		7979 A
10000		8966 a		7898 A		8028 A
Std. Error						
0	338	337	254	254	101	91
4000	333	415	250	312	101	111
6000	348	334	262	251	94	95
8000		336		253		93
10000		333		251		94

Table ii cont'd

RATE	Hand Samples BC	Hand Samples INJECT	Monitor Sub-samples BC	Monitor Sub-samples INJECT	Monitor All BC	Monitor All INJECT
gpa			*kg ha*$^{-1}$			
			2001			
0	4604 D	4815 D	4111 E	5117 D	4194 F	5233 E
2000		9916 B		9157 B		9067 B
4000	8079 C	11143 A	7881 C	10260 A	8001 D	10255 A
6000	10054 B	11581 A	8925 B	10152 A	8874 C	10223 A
8000		11317 A		10414 A		10263 A
Std. Error						
0			166	117	85	58
2000				132		68
4000	330		113	118	58	60
6000			113	140	58	73
8000				113		59
			2002			
0	3242 D	3610 D	7314 g	7844 f	7190[3] g	7873 f
3000		8325 B		11333 bc		11382 bc
4000	6996 C	10207 A	10694 e	10945 de	10747 e	11005 d
6000	7459 BC	9702 A	11056 cd	11488 b	11139 cd	11466 b
8 000		10672 A		12644 a		12663 a
Std. Error						
0					107	89
3000						87
4000	420		130	152	88	88
6000					96	85
8 000						93

[1] to convert yield values from kg ha^{-1} to bushels per acre (56 lb bushel), multiply by 0.019

[2] 'Whole north end' data set could not be adjusted for PSNT, as soil samples were collected only at the subsampling locations.

[3] East 207 excluded

Least squares means for a response variable followed by the same upper case (protected) or lower case (unprotected) letter are not significantly different at the 0.05 probability level

Table iii. P values from statistical analyses of soil characteristics in 2000

	Method	Rate	Method x Rate	Mean
6 June 2000 (0-0.2 m depth)				
pH	0.5142	<0.0001	0.8419	
Ca (mg kg^{-1})	0.271	0.007	0.8063	
Mg (mg kg^{-1})	0.5493	0.009	0.3025	
K (mg kg^{-1})	0.4471	0.06	0.2256	
P (Bicarbonate extractable) (mg kg^{-1})	0.5662	0.0391	0.093	
P (Bray-P1) (mg kg^{-1})	0.2418	0.0328	0.1011	
CEC (meq/100g)	0.5466	0.278	0.1986	
OM (%)	0.5498	0.1859	0.6553	
Zn (mg kg^{-1})	0.1518	0.1642	0.5827	
Mn (mg kg^{-1})	0.2196	0.0123	0.27	
Fe (mg kg^{-1})	0.5744	0.2025	0.6116	
Cu (mg kg^{-1})	0.9124	0.3696	0.2277	
B (mg kg^{-1})	0.1922	0.3262	0.9351	
S (mg kg^{-1})	0.1539	0.1896	0.5031	
6 June 2000 (0-0.3 m depth)				
Water content (%)	0.92	0.44	0.3	25.3
NO_3-N (mg kg^{-1})	0.0671	0.0662	0.49	17.5
NH_4-N (mg kg^{-1})	0.72	0.2	0.99	0.84
N_{inorg} (mg kg^{-1})	0.0678	0.0611	0.5	18.3
14 November 2000 (0-0.2m depth) [1]				
Water Content (%)	0.43	0.82	0.11	31.0
NO_3-N (mg kg^{-1})	0.0002	0.0001	0.0068	
NH_4-N (mg kg^{-1})	0.0299	0.43	0.28	
N_{inorg} (mg kg^{-1})	0.0001	0.0001	0.024	

[1] Based on data from sub-sampling locations 1 and 2 (north end) only.

Table iv. P values from statistical analyses of soil characteristics in 2001

	Method	Rate	Method x Rate	Mean
30 May 2001 (0-0.3 m depth) [1]				
Water content (%)	0.9117	0.4402	0.344	25.6
NO_3-N (mg kg^{-1})	0.3683	0.0618	0.8469	
NH_4-N (mg kg^{-1})	0.4829	0.5649	0.7629	
N_{inorg} (mg kg^{-1})	0.2281	0.0145	0.7769	
12 November 2001 (0-0.2m depth)				
Water Content (%)	0.8212	0.0343	0.3039	28.1
NO_3-N (mg kg^{-1})	0.0002	<0.0001	0.0259	
NH_4-N (mg kg^{-1})	0.1218	0.0955	0.6382	
N_{inorg} (mg kg^{-1})	0.0016	<0.0001	0.0326	
pH	0.1479	0.0141	0.0015	
Ca (mg kg^{-1})	0.8359	0.032	0.0616	
Mg (mg kg^{-1})	0.6608	0.0039	0.035	
K (mg kg^{-1})	0.0002	<0.0001	0.482	
P (Bicarbonate extractable) (mg kg^{-1})	0.0617	<0.0001	0.2996	
P (Bray-P1) (mg kg^{-1})	0.008	<0.0001	0.7031	
OM (%)	0.5638	0.7221	0.1123	

[1] Used 2000 treatments since manure not yet applied

Table v. P values from statistical analyses for soil characteristics in 2002

	Method	Rate	Method x Rate	Mean
7 June 2002 (0-0.3 m depth) [1]				
Water content (%)	0.57	0.88	0.93	28.5
NO_3-N (mg kg^{-1})	0.048	0.013	0.018	3.1
NH_4-N (mg kg^{-1})	0.67	0.22	0.35	0.4
N_{inorg} (mg kg^{-1})	0.07	0.013	0.0043	3.4
12 October 2002 (0-0.2m depth) [2]				
Water Content (%)	0.7564	0.9072	0.7873	27.2
NO_3-N (mg kg^{-1})	<0.0001	<0.0001	<0.0001	
NH_4-N (mg kg^{-1})	0.8130	0.02	0.0315	
N_{inorg} (mg kg^{-1})	<0.0001	<0.0001	<0.0001	
pH	0.0191	0.0945	0.017	
Ca (mg kg^{-1})	0.9064	0.7215	0.3924	
Mg (mg kg^{-1})	0.4216	0.2408	0.3703	
K (mg kg^{-1})	0.0171	<0.0001	0.5216	
P (Bicarbonate extractable) (mg kg^{-1})	0.0182	<0.0001	0.9826	
P (Bray-P1) (mg kg^{-1})	0.0048	<0.0001	0.6675	
CEC (meq/100g)	0.258	0.6256	0.9692	
OM (%)	0.4017	0.9372	0.4387	
Zn (mg kg^{-1})	0.0770	0.0006	0.5148	
Mn (mg kg^{-1})	0.0710	0.2421	0.0026	
Fe (mg kg^{-1})	0.6536	0.1324	0.2504	
Cu (mg kg^{-1})	0.5108	0.598	0.6093	
B (mg kg^{-1})	0.7084	0.3984	0.5753	
S (mg kg^{-1})	0.2229	0.0004	0.7042	

[1] Data from 208 and East 207 excluded.
[2] Data from East 207 excluded

Table vii. P values from statistical analyses of deep core samples in 2001 and 2002

	Transformation[1]	Method	Depth	Method x Depth
Method at 4000 gpa				
2001				
Water content (%)	untransformed	0.0021	<0.0001	0.2195
NO_3-N (mg kg^{-1})	ln(NO_3-N+0.1)	<0.0001	<0.0001	0.1877
NH_4-N (mg kg^{-1})	ln(NH_4-N+0.001)	0.9169	<0.0001	0.2153
N_{inorg} (mg kg^{-1})	ln(N_{inorg}+0.1)	0.0001	<0.0001	0.0974
2002				
Water content (%)	ln(soilwat+1)	0.7697	0.212	0.8495
NO_3-N (mg kg^{-1})	ln(NO_3-N+0.1)	<0.0001	<0.0001	0.8116
NH_4-N (mg kg^{-1})	ln(NH_4-N+0.01)	<0.0001	0.0121	0.8149
N_{inorg} (mg kg^{-1})	ln(N_{inorg}+0.1)	<0.0001	<0.0001	0.306
P (Bicarbonate extractable) (mg kg^{-1})	ln(bicarb+1)	0.0011	<0.0001	0.1426
P (Bray-P1) (mg kg^{-1})	ln(bray+1)	0.0009	<0.0001	0.3185
Zn (mg kg^{-1})	ln(zinc+1)	0.0855	<0.0001	0.0929

	Transformation[1]	Rate	Depth	Rate x Depth
Rate of Manure Application (0, 4000 and 8000 gpa) for Injection Treatment				
2001				
Water content (%)	ln(soilwat+1)	<0.0001	<0.0001	0.0729
NO_3-N (mg kg^{-1})	ln(NO_3-N+0.1)	<0.0001	<0.0001	<0.0001
NH_4-N (mg kg^{-1})	ln(NH_4-N+0.01)	0.4274	<0.0001	0.021
N_{inorg} (mg kg^{-1})	ln(N_{inorg}+0.1)	<0.0001	<0.0001	<0.0001
2002				
Water content (%)	untransformed	0.3855	0.7401	0.4178
NO_3-N (mg kg^{-1})	ln(NO_3-N+0.1)	<0.0001	<0.0001	0.0229
NH_4-N (mg kg^{-1})	ln(NH_4-N+0.001)	0.081	<0.0001	0.5768
N_{inorg} (mg kg^{-1})	ln(N_{inorg}+0.1)	<0.0001	<0.0001	0.0375
P (Bicarbonate extractable) (mg kg^{-1})	ln(bicarb+1)	0.007	<0.0001	0.1732
P (Bray-P1) (mg kg^{-1})	ln(bray+1)	0.0007	<0.0001	0.0741
Zn (mg kg^{-1})	ln(zinc+1)	0.0348	<0.0001	0.0222

[1] Data transformed to normalize

Publications and Presentations of this Research

Invited presentations:

Ball-Coelho. Sources and Placement of Nitrogen: Effects on crop yield and water quality. Integrated Farming Systems, Annual Certified Crop Adviser Seminar, 30 Jan, 2002, Guelph, ON.

Ball-Coelho and R. Stone. VRT Manure Management. Ontario Agri-business Association, Crops Update 2002, Jan 17, Woodstock ON

Ball Coelho. Manure and Cropping. 22nd Annual Centralia Swine Update, Jan 29, 2003. Kirkton. Proceedings p I-16.

Ball-Coelho Minimizing the Environmental Impacts of Fertilizing Crops with Liquid Hog Manure, Perth County Pork Producers, Nov. 7, Rostock ON.

B. Ball-Coelho. Variable Rate Manure Application: Minimizing Environmental impacts of Fertilizing with Liquid Hog Manure. Growmark Precision Farming Group, Perth County Co-op, Nov. 28, Mitchell

Ball Coelho Research Results presented to Nutrient Management Plan Group (S. Sweeney-Nutrient Fate and Transport Specialist, C. Brown, D. Hilborn, J. De Bruyn) May 9, OMAFRA, Woodstock.

Practices to minimize environmental impacts of manure application. Coldstream, Sept. 26, 2000. Township of Middlesex Centre Open House & Information Session Agricultural Practices and the Environment.

Other Presentations
B. Ball Coelho, R.C. Roy, D. Lapen and E. Topp[1]. Evaluation of injection and broadcast application of liquid swine slurry for protection of tile water quality. Proceedings of the 2nd Canadian Organic Residuals Recycling Conference. April 24 and 25, 2003. [1] presenting author.

Posters
B. Ball Coelho, E. Topp, R. C. Roy. Efficient Manure Utilization with Precision Sidedress Injection. Poster, for special session hosted by the Environment Committee: On-farm Research Ontario Federation of Agriculture Annual Convention, 25 Nov. 2002, Toronto.

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