TECHNICAL NOTE

A protocol for soil nutrient sampling after liquid manure injection

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Assefa, B. and Chen, Y . 2007. **A protocol for soil nutrient sampling after liquid manure injection.** Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **49**: 2.7 - 2.13. A soil sampling protocol that enables accounting for banding effects of manure injection was developed based on soil nutrient data from field trials of liquid manure injection at three tool spacings: 0.3, 0.6, and 0.9 m. The data were taken at several lateral positions (0, 0.15, 0.30, and 0.45 m) relative to the centre lines of the manure bands. Levels of soil NO_3-N, NH_4-N, and P were considered in the development of the sampling protocol. The data showed that soil NO_3-N, NH_4-N, and P concentrations were lower at the position farthest away from the centre of the manure band. A *directed paired-sampling* approach, i.e. sampling at two positions along a transect perpendicular to the injector travel direction was developed to address the position effect on soil nutrient concentrations. This approach allows for obtaining a more accurate estimate of the average NO_3-N and P concentrations in soil when compared to the traditional random sampling method provided that information on injector travel direction and tool spacing is available. **Keywords**: sampling, protocol, manure, injection, position, tool spacing, soil, nutrient.

Un protocole d'échantillonnage des sols qui prend en compte les effets de l'injection en bandes du lisier a été développé en considérant les contenus en éléments fertilisants dans le sol provenant d'essais d'injection de lisier pour trois écartements d'injecteurs: 0,3, 0,6 et 0,9 m. Les données étaient prises à différentes positions latérales (0, 0,15, 0,30 et 0,45 m) par rapport au centre des bandes de lisier. Les niveaux de NO_3-N du sol, de NH_4-N et de P étaient considérés dans le développement du protocole d'échantillonnage. Les données montraient que les concentrations en NO_3-N, NH_4-N et P étaient plus faibles à une position plus éloignée du centre de la bande de lisier. Une approche d'échantillonnage en paire dirigée, soit un échantillonnage à deux positions le long d'une ligne transversale perpendiculaire à la direction d'injection a été développé pour tenir compte de l'effet de la position sur les concentrations en éléments fertilisants du sol. Cette approche permet d'obtenir une estimation plus précise des concentrations moyennes de NO_3-N et de P dans le sol lorsque comparées à la méthode d'échantillonnage aléatoire traditionnelle, en autant que les informations sur la direction d'injection et la distance entre les injecteurs sont disponibles. **Mots clés**: échantillonnage, protocole, lisier, injection, position, espacement des injecteurs, sol, éléments fertilisants.

INTRODUCTION

Soil sampling is carried out to obtain relevant information about a given soil based on fundamental objectives such as chemical analysis, soil survey, soil fertility status, and environmental concerns (Crépin and Johnson 1993). According to De Gruijter (2002) the decision on how many, where, how, and when samples are to be collected often depends on the purpose of a given study, the budget, and logistical constraints.

Soil sampling techniques may be broadly categorized as judgmental, random, or systematic (Petersen and Calvin 1998) with none of them being universal. Judgmental sampling is a technique in which samples are collected from the most typical sites or locations (based on a researcher's judgement) representing a population. Those locations within a field can be repeatedly sampled year to year (referred as to benchmark soil sampling). Random sampling is a technique in which a given number of samples are obtained from a population, each with an equal chance of being selected. Systematic sampling technique is a method in which samples are collected at regular distances from each other in one or two dimensions. One example of two dimensional systematic sampling is grid sampling (precision sampling). According to Mohamed et al. (1996) and Thompson et al. (2004), grid soil sampling enables assessment of field-scale soil nutrient variability. However, they reported that such sampling is costly. Grid sampling may take the form of rectangular or triangular grids (McBratney et al. 1981; Petersen and Calvin 1998). Grid size depends on the desired precision and the spatial variability of the soil (McBratney et al. 1981).

Results of soil nutrient analysis depend on the soil sampling (Donohue 2002; Anderson et al. 1992). This is because soils are characterized by high degree of spatial variability in their nutrient status (Penney et al. 1996; Mallarino 1996). Donohue (2002) emphasized the importance of getting a good soil sample by indicating how small the sample size is relative to the mass of the soil in the sampled area. Mallarino (1996) related high lateral variability to soil types and management practices such as tillage and fertilizer or manure application. Schnug et al. (1998) pointed out that even uniform addition of inputs in crop production results in over and under supply of resources. McBratney et al. (1981) described a method for designing optimal sampling schemes for the purpose of earth's surface survey. This method was based on the assumption that spatial dependence is expressed quantitatively in a certain form.

Soil sampling for nutrient analysis is required by researchers and extension specialists for developing practices of manure

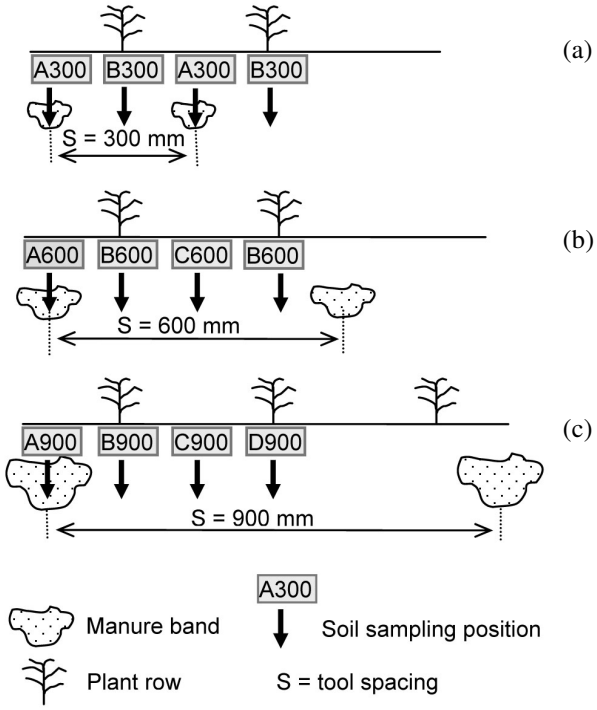

Fig. 1. A schematic diagram of soil cross-section showing manure bands, soil sampling positions, and plant rows for: (a) 0.3-m tool spacing, (b) 0.6-m tool spacing, and (c) 0.9-m tool spacing (after Assefa et al. 2005).

management and crop production. Government environmental officers also need to take soil samples when they do soil nutrient auditing following manure application. The traditional randomised soil sampling is the most common method. Soil sampling following liquid manure injection can be problematic in terms of spatial variability of soil nutrients. Liquid manure is injected into soil as bands and the centre-to-centre distance of two adjacent bands is determined by the injection tool spacing. Higher nutrient concentrations were observed at the centre of manure bands than at lateral distances away from the manure bands. Petersen et al. (2003) measured about 55 mg/kg of soil Br^- concentration (dry basis) in the centre of a pig slurry injection band as compared to about 21 mg/kg of soil Br^- at a further distance from the band. Sawyer et al. (1990) reported 60 to 80 mg/kg inorganic N on an injected beef manure band and less than10 mg/kg inorganic N at a lateral distance of 1.27 m from the band. McCormick et al. (1983) measured 491 and 87 mg/kg inorganic N concentrations at 25 and 90 mm distances, respectively, from the centre of injected swine manure bands. Similar observations were reported when inorganic fertilizers were band applied (Rehm and Lamb 2004; Zebarth et al. 1999; James and Hurst 1995).

There is limited information in the scientific literature with respect to practical soil sampling protocol such as proper sampling locations and time of sampling to address manure injection and banding of nutrients. The main goal of this study was to develop a soil sampling protocol to account for the banding effect from manure injection. This goal was achieved using existing soil nutrient data taken at different lateral positions relative to manure bands injected with different injection tool spacings. The specific objectives were to (1) examine patterns of soil nutrient variations with the lateral position and over the time after manure injection, and (2) to propose a practical soil sampling protocol with regard to where and when to take soil samples for nutrient analysis.

METHODOLOGY

The soil sampling protocol was developed based on soil nutrient data gathered through a previous field study (Assefa et al. 2005, 2006) conducted on clay loam soil in 2002, 2003, and 2004 in Manitoba. In this previous study, liquid swine manure was injected using a manure injector equipped with coulter (460-mm in diameter) and furrower (120-mm width) injection tools at three different tool spacings: 0.3, 0.6, and 0.9 m. After the manure injection, soil nutrient data (NO_3-N, NH_4-N, and P) were taken from different lateral positions: A1 and B1 for the 0.3-m tool spacing, A2, B2, and C2 for the 0.6-m tool spacing, and A3, B3, C3, and D3 for the 0.9-m tool spacing (Fig. 1). Position A's were located on the centre lines of manure bands. Position B's, C's, and D's were 0.15, 0.30, and 0.45 m away from the centre lines of manure bands, respectively.

The commonly used sampling depth is 0 - 0.6 m for soil nitrogen analysis and shallower for soil phosphorus analysis in Manitoba. Therefore, data from a depth of 0 - 0.6 m were used for NO_3-N and NH_4-N analysis, and those from a depth of 0 - 0.3 were used for P analysis. The data used in this paper were mainly from 2004 as the year 2003 was characterised by extremely dry weather and the 2002 data were taken only at 0 - 0.3 m depth. The background soil NO_3-N (0 - 0.6 m) and P (0 - 0.3 m) levels in 2004 were 115 kg/ha and 31 kg/ha, respectively, prior to the manure injection. The nutrient contents in the manure translate into application rates of approximately 119 kg/ha of nitrogen and 18 kg/ha of P. Data from the two injection tool types were pooled together for the analysis because effects of the coulter and furrower were not significantly different in most cases (Assefa et al. 2005). Another reason for this data pooling was for simplicity. Analysis of variance was carried out using the general linear model (GLM) procedure using SAS software (SAS 2001). Considering the inherently high variability in soils, all comparisons were made at a probability of 0.1 ($P < 0.1$).

RESULTS and DISCUSSION

In the development of the sampling protocol, the spatial variations of soil properties (McBratney et al. 1981) and the effect of plant rows on nutrient use were not taken into consideration. As shown in Fig. 1, the plant rows were equally spaced 0.3 m apart for all tool-spacing treatments, while the manure bands were not. Positions B and D always had a plant row on them, while Positions A and C did not. Thus, it was expected that nutrient uptake by the plants at those positions was different, which may have contributed to the differences in nutrient concentrations between positions. This confounding effect of plant rows on spatial distribution of N was not considered in the following discussion on the spatial distributions of soil nutrients. The only spatially-dependent variable accounted for was the position effect.

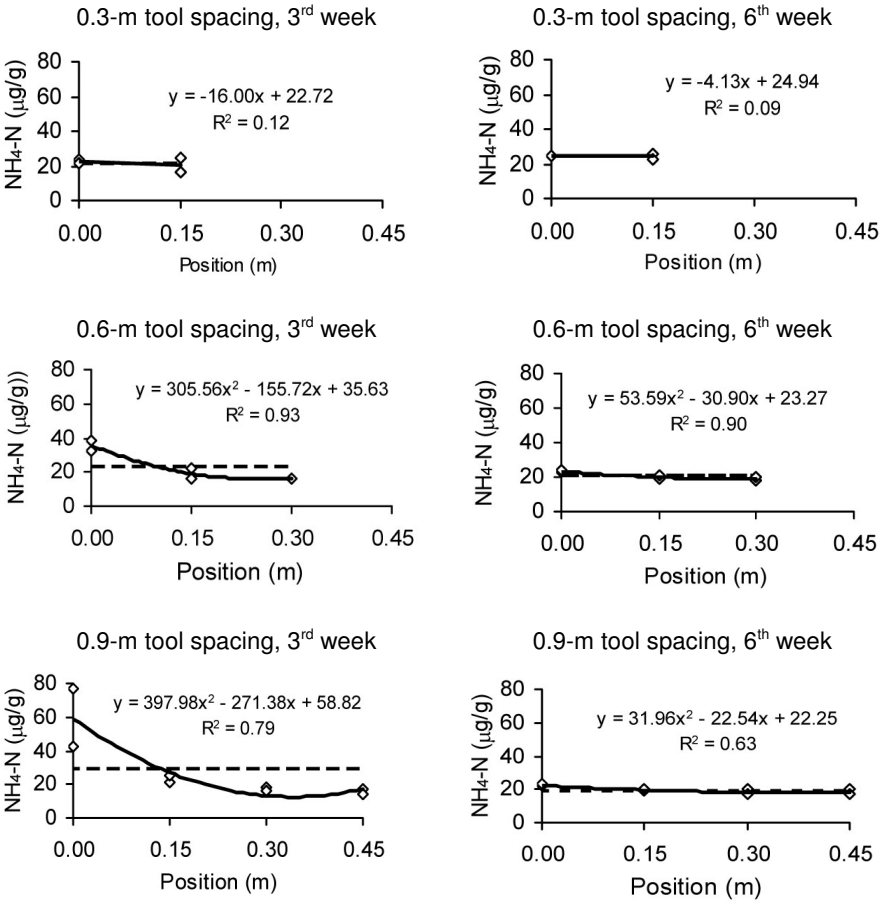

Fig. 2. Soil NH_4-N concentrations at 0-0.6 m depth at different lateral positions relative to the centre of a manure band in 2004. The two data points at each lateral position represent the average values for the coulter and furrower injection tools. Each data point is the average of four replicates. The average value over all positions is shown by a horizontal dashed line.

Soil nutrient concentrations at different lateral positions

Position-nutrient curves are plotted in Figs. 2 - 4 using the 2004 data taken at the third, sixth, and nineteenth week after manure injection. Although the data were highly variable, a clearly decreasing trend in soil NH_4-N, NO_3-N, and P concentrations with farther position from the centre line of the manure band was observed, as discussed in Assefa et al. (2005). For the 0.3-m tool spacing, the curves can be represented by straight lines, as there are only two positions, A1 and B1 (Fig. 1). For the 0.6-m or 0.9-m tool spacing, the position-nutrient curves can be expressed by polynomials of second degree. As expected, position effects were more pronounced for the 0.9-m tool spacing than those for the smaller tool spacings, and more pronounced for the NO_3-N concentrations than for the P concentrations.

Forms of soil nitrogen over time

The decreasing trend in NH_4-N concentration was less pronounced at the sixth week after injection than at the third week after manure injection (Fig. 2) perhaps due to the nitrification that levelled off the NH_4-N in the soil over time. The nitrification increased the NO_3-N concentration on the manure band (Fig. 3), which made the decreasing trend in NO_3-N become more pronounced at the sixth week. At the nineteenth week (after harvest), the decreasing trend of NO_3-N diminished due to crop use.

Variations in nutrient concentration over time

The general trend was that concentrations of soil NO_3-N (Figs. 5a) and P (Fig. 5b) decreased over time, although the data were highly variable. This was attributable to the nutrient use of the plants. Denitrification and movement to the deeper soil layer could also be the reason for the decrease in NO_3-N. The trends in soil P between positions remained fairly constant over time, while significant differences in soil NO_3-N between positions were observed at the earlier weeks (at the third and sixth week). No data were taken for the following 13 weeks during which crop maturity and harvest were achieved. The position effect on the soil NO_3-N was not found at the nineteenth week. Therefore, it is unknown when the position effect vanished.

The 2002 data (Fig. 6) further confirmed the larger differences in soil NO_3-N between lateral positions earlier in the season and that the differences decreased with time. Most importantly, the 2002 data show that these differences vanished after nine weeks after manure injection for all tool spacings used. This phenomenon was possibly caused by the gradient in nutrient concentration between two successive manure bands, which resulted in lateral movement of nutrients towards the middle of those manure bands. Nutrient movement is expected to be slower for phosphorus, as phosphorus tends to bind to soil and may not disperse easily through the soil. This explains why the differences in soil P concentration between lateral positions had little changes over time (Fig. 5).

SOIL SAMPLING PROTOCOL

The aforementioned results showed that soil NO_3-N, NH_4-N, and P are not evenly distributed laterally in soil due to the banding effect following fertilizer application. The traditional randomised soil sampling protocol may result in sampling either more on manure bands or more at some distance away from the manure band, which will lead into uncertainty of the nutrient levels of a given soil.

Sampling procedure for soil nitrate-nitrogen

Time for sampling The data shown in Fig. 2 suggest that considerable amount of soil nitrogen was still in NH_4-N form up to three weeks after injection. Thus sampling within the first three weeks of application may lead to samples reflecting mainly high levels of NH_4-N. Consequently, levels of NO_3-N were not as elevated as they could be once most of the NH_4-N would have been nitrified. It is advisable to schedule field

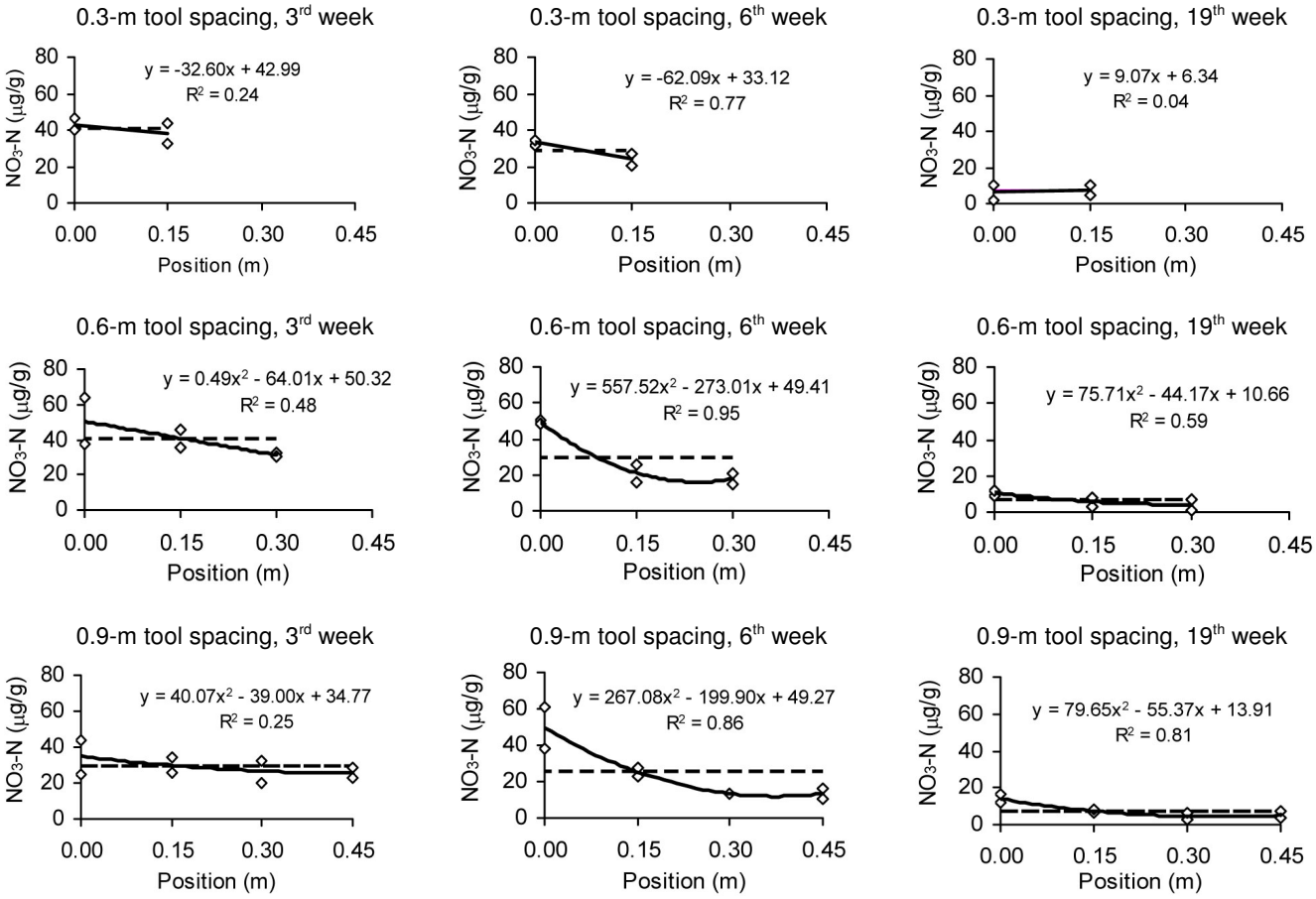

Fig. 3. Soil NO_3-N concentrations at 0-0.6 m depth at different lateral positions relative to the centre of a manure band in 2004. The two data points at each lateral position represent the average values for the coulter and furrower injection tools. Each data point is the average of four replicates. The average value over all positions is shown by a horizontal dashed line.

sampling aimed at monitoring NO_3-N to a time when more than three weeks have elapsed between manure injection and the sampling.

Situations of relatively uniform NO_3-N levels after injection
While little liquid manure injection equipment is configured with a tool spacing of 0.3 m, injection equipment that is set up in this fashion is expected to provide relatively uniform manure distribution shortly after liquid manure injection. Soil sampling after nine weeks allows for the manure NH_4-N to be nitrified and for the soil NO_3-N to be redistributed laterally. For example, fall sampling from a field injected in the spring ensures that the banding effect has greatly diminished if not vanished completely. Accordingly, the traditional randomized sampling approach can be used where either the tool spacing is of the order of 0.3 m or less, or sampling occurs nine weeks after manure injection.

Sampling protocols for NO_3-N within three to nine weeks from time of injection with a tool spacing greater than 0.3 m
If sampling for soil NO_3-N must be carried out within nine weeks of manure injection, significant variability in soil NO_3-N between manure bands may be expected. An ideal sampling protocol would be to sample at different lateral positions to account for the banding effect to ensure obtaining representative soil nutrient levels. However, this would be very tedious. The following practical approaches are proposed for different scenarios.

Information on injector travel direction and tool spacing can usually be obtained from the producer or the custom applicator. If this is the case, soil sampling should be performed along a transect which is perpendicular to the injector travel direction. Sampling along the direction of maximum variation was also suggested by McBratney et al. (1981). Two sub-samples need to be taken along the transect and the distance between these two samples should be half of the tool spacing. This approach is referred to as *directed paired-sampling* approach. This approach will increase the probability that both the zone enriched with NO_3-N near or in the liquid manure band and the zone into which manure NO_3-N has not moved yet are sampled. As compared with the traditional randomised sampling, the *directed paired-sampling* approach doubles the number of soil samples to be taken, which adds additional cost to soil sampling. If 15 random locations are sampled in a field as commonly done in Manitoba for soil nutrient auditing, the *directed paired-sampling* requires a total of 30 samples, which still appears to be practical.

If the injector travel direction and tool spacing are unknown, one has to resort to the traditional randomised sampling method.

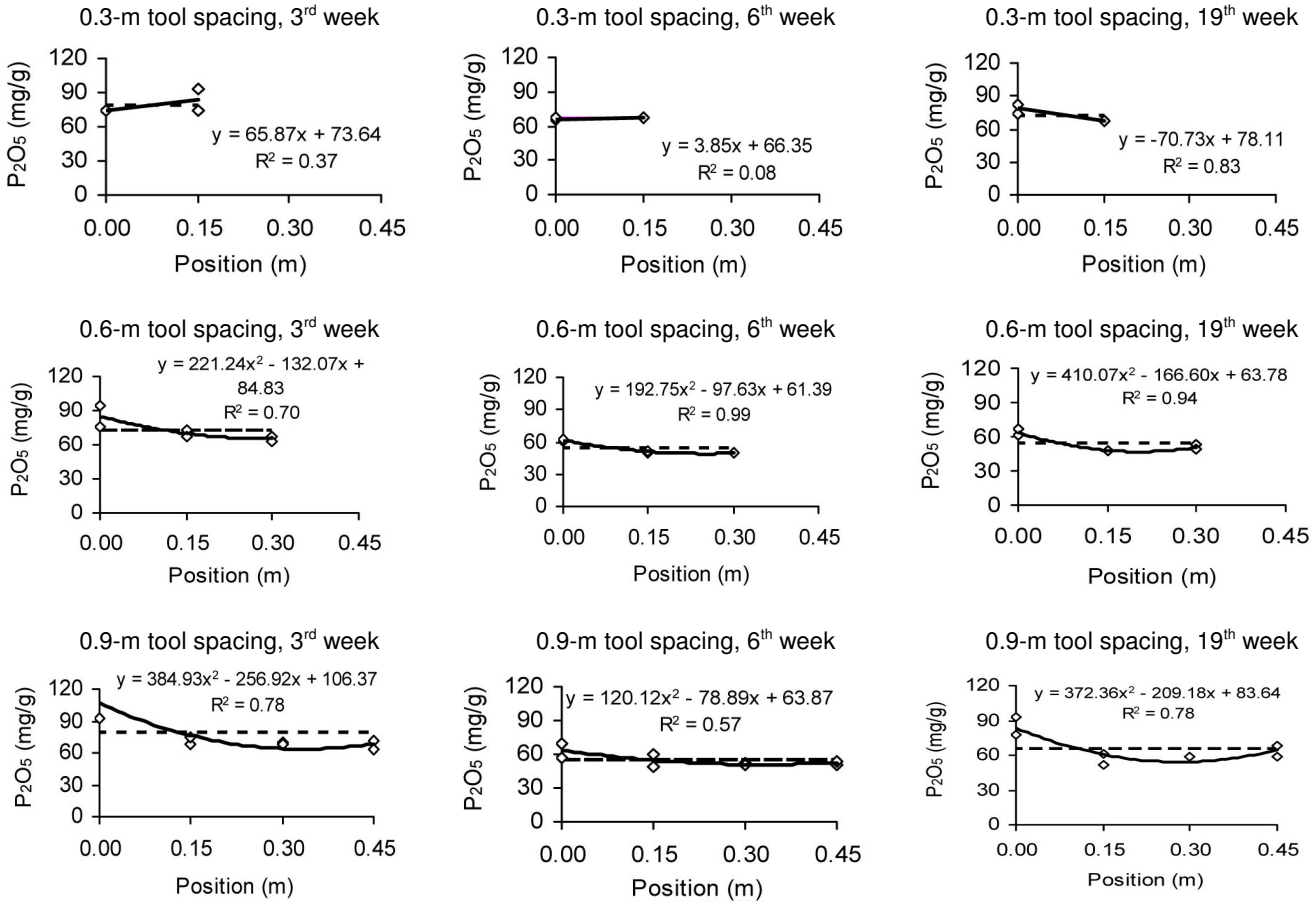

Fig. 4. Soil P_2O_5 concentrations at 0-0.3 m depth at different lateral positions relative to the centre of manure band in 2004. The two data points at each lateral position represent the average values for the coulter and furrower injection tools. Each data point is the average of four replicates. The average value over all positions is shown by a horizontal dashed line.

The nutrient level results from this case may be assessed with considerations of data variations.

Sampling procedure for soil phosphorus

Sampling approaches for phosphorus can be tailored to those proposed for nitrogen because position effects on trends of both nutrient concentrations are similar. One exception is that sampling for phosphorus analysis needs to consider banding effects at any time of the year.

Comparison between the traditional randomized sampling and the *directed paired-sampling*

To illustrate the improvement in soil sampling accuracy by proceeding with the *directed paired-sampling* approach, a simulation of field variability was performed by randomly sampling around a liquid manure band for two situations: one sub-sample was taken at each of 15 field locations, and two sub-samples (spaced by one half of the injection tool spacing) were taken at each of the same field locations. The former represents the traditional randomised sampling approach, and the latter represents the *directed paired-sampling* approach. In the simulation, the regression equations fitted to the nutrient data (Figs. 2 - 4) were used to predict the nutrient levels at any random position relative to a manure band between two adjacent manure bands. The accuracy of each sampling approach was assessed by the differences between the values predicted using the regression equations and the measured average values that are represented by the horizontal lines in Figs. 2 - 4.

This simulation was carried out 20 times, where a random number generator was used to set the sampling location for each of the 15 sampling locations. This is equivalent to carrying out 20 different samplings in the same field. The simulation results show that at the third or nineteenth week after injection, the predicted NO_3-N values remain relatively close to the measured averages in most instances (results not shown). In such situations, either the traditional randomised sampling or the *directed paired-sampling* approach would result in NO_3-N measurements in close agreement with the averages measured at any location in the field. However, the simulation results illustrate the advantages of the *directed paired-sampling* for the data taken at the sixth week after injection. This was the stage at which a significant nitrification of NH_4-N would occur but would not allow a significant use of nutrients by the crop.

The simulation results (Fig. 7) suggest that the *directed paired-sampling* approach allows for obtaining a more accurate estimate of the average NO_3-N more than half of the time, and maintains the error well below 20% most of the time. The traditional randomised sampling approach may result in obtaining field variability ranging over the 20% of the measured

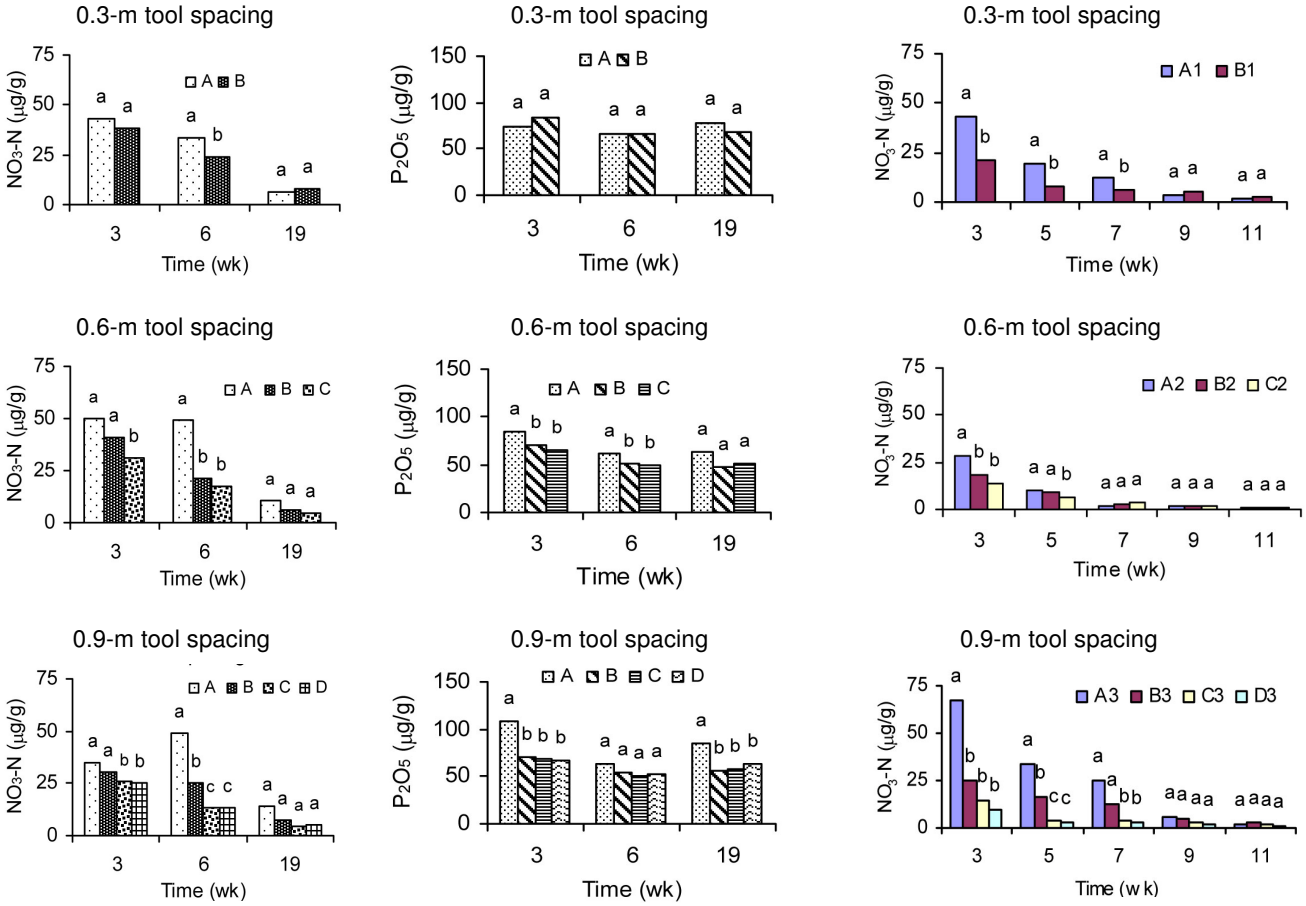

Fig. 5. Soil nutrient concentrations at different lateral positions weeks after manure injection for different injection tool spacings in 2004. Positions A's were located on the centre lines of manure bands; Position B's, C's, and D's were 0.15, 0.30, and 0.45 m away from the centre lines of manure bands, respectively; (a) soil NO_3-N at 0-0.6 m depth; (b) soil P_2O_5 at 0-0.3 m depth. Each data point represents the average value of coulter and furrower injection tools and four replicates. Mean values for each factor within a year and a column followed by same letter are not significantly different (P>0.1).

Fig.6. Soil NO_3-N concentration at 0-0.3 m depth at different lateral positions weeks after manure injection for different injection tool spacings in 2002. Positions A's were located on the centre lines of manure bands; Position B's, C's, and D's were 0.15, 0.30, and 0.45 m away from the centre lines of manure bands, respectively. Each data point represents the average value of the coulter and furrower injection tools and four replicates. Mean values for each factor within a year and a column followed by the same letter are not significantly different (P>0.1).

averages. Understandably, the benefits of taking paired samples at each sampling location are greater when the injection tool spacing is greater.

Similar simulations were also performed for the phosphorus data (results not shown). The predicted values of phosphorus were within 10 to 12% of the measured averages for injection tool spacings of 0.6 and 0.9 m, respectively.

CONCLUSIONS

Compared to the traditional randomised sampling approach, the *directed paired-sampling* approach allows obtaining a more representative estimate of the average soil NO_3-N in a field with manure injected at larger spacing than 0.3 m especially between three and nine weeks after manure injection. The *directed paired-sampling* approach decreases the risk of obtaining field variability ranging beyond 20% of the measured averages. However, additional cost is associated with the *directed paired-sampling* due to the double number of samples to be taken.

When the tool spacing of injection equipment is 0.3 m or less, or if soil sampling can be delayed until nine weeks or more after manure injection, the traditional randomised sampling approach can be used. Note that the protocol developed took no account of spatial variations in soil properties and the effect of the nutrient use by plants. The conclusions were drawn using the data from a given experimental condition. Care should be taken in application of the results.

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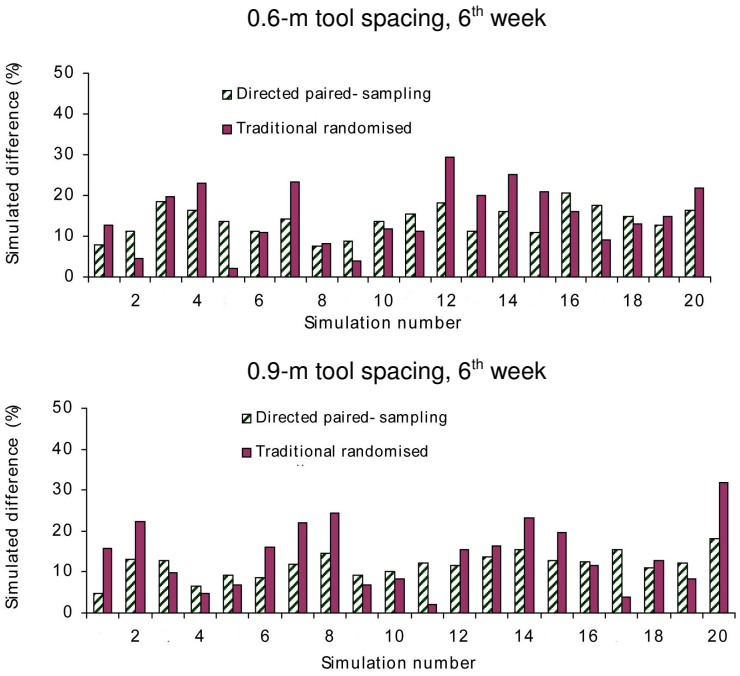

Fig. 7. Simulated differences in NO_3-N levels (in the top 0.6 m depth of soil and at the sixth week after injection) between the predicted values and the measured averages for two sampling approaches: traditional randomised sampling and directed paired-sampling at each of 15 field locations.

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