Evaluation methods on manure exposure from liquid manure injection tools

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Rahman, S., Chen, Y., Zhang, Q. and Lobb, D. 2005. **Evaluation methods on manure exposure from liquid manure injection tools.** Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **47**: 6.9 - 6.16. Laboratory and field studies were conducted to explore evaluation methods on manure exposure (refer as to manure being not covered by soil, but exposed to the air) for liquid manure injection tools. The laboratory study was conducted in an indoor soil bin with three sweeps (small, medium, and large) at three injection depths (50, 100, and 150 mm), two tool forward speeds (0.6 and 1.4 m/s), and two soil moisture contents (14 and 18%). Soil surface profiles measured with a laser profiling system were used to define two parameters, risk and beneficial factors, as well as manure exposure and soil cover indices, to assess the risk for manure exposure following liquid manure injection. These parameters indicated that a larger sweep operating at greater injection depth and lower forward speed resulted in low risk for manure exposure on the soil surface. Soil moisture content did not significantly affect the manure exposure. The field study was conducted with a commercial injector consisting of 13 sweep injection tools in a clay soil at three manure application rates (28, 56, and 112 m^3/ha) and an injection depth of 100 mm. Following the manure injection, line-transect and image analysis methods were used to quantify the percentage of the surface area covered with manure (manure cover), and the odour concentration and emission rate were determined by a wind tunnel and a dynamic dilution olfactometer. The results showed that manure cover increased at an increased manure application rate. No statistically significant effect of manure application rate on odour concentration was observed, and the odour data were not correlated to the manure cover data. **Keywords:** manure, injection, exposure, rate, depth, speed, moisture, profile, odour.

Des essais en laboratoire et en plein champs ont été réalisés afin d'explorer diverses techniques aptes à déterminer le taux d'exposition du lisier après application (le taux d'exposition du lisier indique la présence de lisier non-enfouis et exposé à l'air libre). L'étude en laboratoire a été effectuée à même un bac de sol instrumenté, à l'intérieur duquel trois soc en "V" (de petite, moyenne et grande dimensions) ont été utilisés à trois profondeurs d'enfouissement ou injection (50, 100 et 150 mm) et deux vitesses d'opération (0.6 et 1.4 m/s), et ce pour deux teneurs en eau du sol (14 et 18%). Le profil de la surface du sol mesuré avec un profilographe laser ont permis d'identifier les paramètres suivants: le facteur de risques et bénéfices, ainsi que les indices d'exposition du lisier et de recouvrement par le sol, pour juger du risque d'exposition du lisier en surface suite à l'enfouissement direct (injection) du lisier. Ces paramètres indiquent que les socs en "V" de grande envergure travaillant à des profondeurs importantes et une vitesse d'opération limitée minimisent le risque d'exposition du lisier en surface après application. La teneur en eau du sol n'influence pas l'exposition du lisier. Les essais dans un champ argileux ont été réalisés avec une rampe à lisier comportant treize étançons munis de socs en "V" pour l'application de trois taux d'épandage (28, 56 et 112 m^3/ha) à une profondeur d'enfouissement de 100 mm. Après l'application du lisier, la méthode de décompte sur une ligne ainsi que l'analyse d'images digitales furent employées pour quantifier la proportion de la surface de sol couverte par le lisier (couverture de lisier), alors que la concentration et le taux d'émissions d'odeurs étaient déterminées par analyses olfactométriques d'échantillons recueillis sous une enceinte fermée. Les résultats suggèrent que la couverture de lisier augmente avec l'augmentation du taux d'application du lisier. Cependant, l'influence du taux d'application sur la concentration d'odeur n'est pas statistiquement appréciable, alors que les données sur les odeurs ne montrent aucune corrélation avec la couverture de lisier au sol. **Mot clés:** lisier, enfouissement, injection, exposition, taux, profondeur, vitesse, teneur en eau, rugosité, odeurs.

INTRODUCTION

With the expansion of the swine industry across North America, there is a growing concern in regard to odour and nutrient losses from land application of manure. Although manure injection is considered the most effective mitigation approach to minimise the nuisance caused by odour (Pain et al. 1991), significant odour emissions can still occur following liquid manure injection operations (Moseley et al. 1998; Chen et al. 2001). This occurrence is the result of the injected manure being not covered by soil and being exposed to the air (hereafter referred to as manure exposure) (Chen and Tessier 2001). Manure exposure may contribute to nutrient losses through ammonia volatilization and surface runoff (Huijsmans et al. 2003). Minimal manure exposure should be the ideal result of liquid manure injection, since the primary objective of injection is to place manure into the soil and cover it with a layer of soil.

There are different kinds of injection tools, such as knife, chisel, sweep, and disc. Among these, sweeps are widely used for manure injection because they provide a more even distribution of manure (Chen 2002). Manure exposure following injection likely depends on injection depth, manure application rate, tool operating parameter, and soil conditions as well as the combined effects of any of these. Soil profile also affects manure exposure. For example, a smoother soil profile may provide a better soil cover for the injected manure, minimising manure exposure.

Little research has been done in the past in terms of measuring manure exposure on the soil surface. Chen (2002) measured the manure exposure of open soil furrows only, and Hultgreen and Stock (1999) performed only visual inspections of the manure exposed on soil surface. Line-transect methods have been widely used to estimate residue cover on soil surface (Sloneker and Moldenhauer 1977) and they may be used to

(a) (b) (c)

Fig. 1. Sweep injection tools: (a) small, (b) medium, and (c) large sweeps.

estimate manure exposure on the soil surface. Image analysis has also been used to estimate percent residue cover with less human error (Han and Hayes 1990; Chen et al. 2004). As microcomputer-based imaging systems have become widely available at low cost, this method may also be applied for estimating manure exposure.

In the past, most of the soil profile studies (McKyes and Maswaure 1997; Raper and Grift 2002) have been conducted on tillage tools. The importance of soil profile associated with manure injection has been ignored or overlooked. Most of the studies on performance evaluations of manure injection have focused on manure distribution in soil (Rahman et al. 2004), crop response to different injection methods (Hanna et al. 2000; Chen and Samson 2002), and draft of tools (Rahman et al. 2001; Laguë 1991). Little research has been done on measuring and quantifying manure exposure following liquid manure injection. Past research (Hanna et al. 2000; Chen et al. 2001; Rahman et al. 2001; Oh et al. 2004) showed that odour measurements were costly and time consuming and that the data were highly variable. Chen et al. (2001) indicated that ammonia volatilization and odour emission from the soil surface following manure application seemed proportional to the amount of manure exposed on the soil surface. Therefore, it is rational and necessary to establish the relationship between manure exposure and the odour emission.

The objective of this study was to develop methods that can be used to evaluate the performance of liquid manure injection tools in terms of manure exposure. The specific objectives were: i) to use soil profile characteristics to quantify the risk of manure exposure as affected by injection depths, tool forward speeds, and soil moisture content; ii) to quantify surface manure exposure following liquid manure injection as influenced by manure application rate; iii) to explore the correlations between manure exposure and the corresponding odour level; and iv) to adopt the line-transect and image analysis methods to measure manure exposure following injection.

MATERIALS and METHODS

Laboratory study

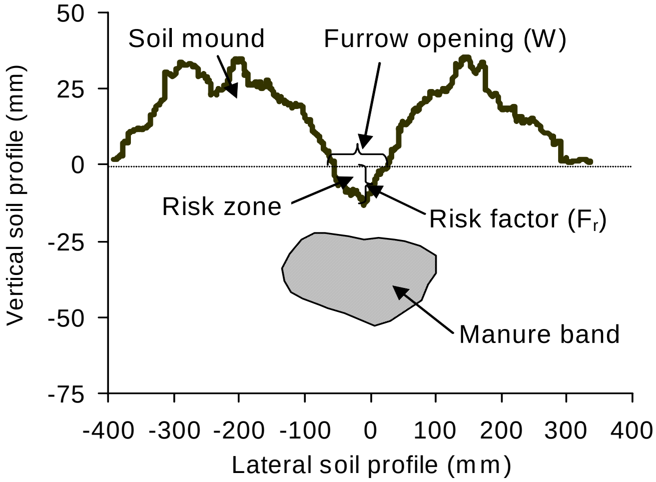
Description of the test facility and injection tools Laboratory tests of liquid manure injection tools were conducted in an indoor soil bin (1.5 m wide, 15 m long, and 0.6 m deep) with a loamy sand soil, located in the Department of Biosystems Engineering at the University of Manitoba, Winnipeg, Canada. To obtain the desired soil moisture contents, water was sprayed over the soil and left to infiltrate for 24 h throughout the tests. Then the soil was roto-tilled at a greater depth than the maximum experimental design depth. The last step for soil preparation was to level and compact the soil with a 162 kg smooth flat roller. After soil preparation, the soil dry bulk density was approximately 1.2 Mg/m^3. The same procedures for the soil preparation were used between tests. Three commercially available sweep injection tools (small, medium, and large sweeps) (Fig. 1a, 1b, 1c) were tested. The widths of the small, medium, and large sweeps were 225, 255, and 330 mm, respectively. The length of all the sweeps was 220 mm and the rake angle of the small, medium, and large sweep were 16, 18, and 20º, respectively.

Experimental design The sweeps were tested in the soil bin using a completely randomised factorial (3 × 3 × 2 × 2) experiment (three replications). The treatments included all combinations of three sweeps, three injection depths (50, 100, and 150 mm), two tool forward speeds (0.6 and 1.4 m/s), and two soil moisture contents (14 and 18%).

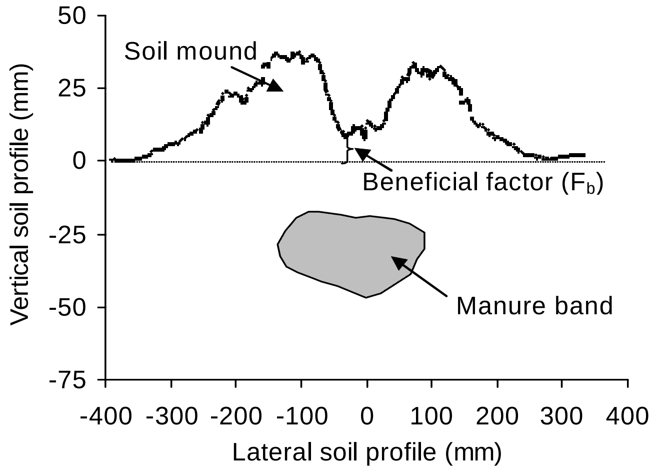
Measurements After each test run, a laser soil profiler, LPS sensor (INO, Quebec, QC) was moved over the disturbed soil surface to measure the soil surface profile on the plane perpendicular to the tool travel direction. For each test run, three measurements of the soil profile were taken at random locations along the length of the soil bin. Measurements were concentrated in the area around the centre line of tool path where manure is to be injected (Fig. 2a, 2b). This area is described as a “risk zone” for manure exposure. The distance between the lowest soil profile and the original soil surface along the centre of the tool path was measured. The lateral distance of the furrow opening along the original soil surface was also measured. These measurements were selected to assess the potential impact of soil surface profile on manure exposure, as discussed below. Due to the limitation of the indoor test facility used, no manure was applied during this laboratory study. This had little or no effect on the study of the soil surface profiles, since soil surface profile is mainly affected by the soil cutting action of the tool.

Field study

Description of the field injection unit Since none of the sweeps used for the laboratory study was available for the field study, a commercial field injection unit (Fig. 3) had to be used although its sweeps were different from those used in the laboratory study. The 13 sweeps were spaced 540 mm apart and were arranged on a 7-m tool bar in two ranks (7 sweeps in the



(a)



(b)

Fig. 2. Diagram showing a typical soil surface profile: (a) negative-type and the definitions of risk factor (F_r) and the furrow opening (W); (b) positive-type and the definition of beneficial factor (F_b).

Fig. 3. Field injection unit with 13 narrow sweeps in two ranks (seven sweeps in the first rank and six sweeps in the second rank).

first rank and 6 sweeps in the second rank). Both the sweep width and the length were 100 mm, and the rake angle was 26°. Agitated swine liquid manure (3% solid contents) was delivered from the storage to the injector through a hose system.

Site description and experimental design The field manure injection trial was conducted in a clay soil at St. Agathe, Manitoba in October 2002. Before the manure injection, the stubble field was tilled with a typical field cultivator. A completely randomised experimental design (four replicates) was used with three manure application rates: R1=28, R2=56, and R3=112 m^3/ha at an injection depth of 100 mm. Thus, a total of 12 plots was required for the field trial. One pass was made with the injection unit in each plot and the plot size was 7 m width by 10 m long.

Measurements Five soil cores (150 mm deep and 52 mm diameter) were collected from random locations within the field before the field trial was conducted. Soil samples were weighed, oven dried for 24 h at 105°C, and re-weighed to determine the gravimetric soil moisture content and soil dry bulk density. The mean ambient temperature and relative humidity of the ambient air were measured with a thermometer.

Two methods, line-transect (LT) and image analysis (IA), were used to estimate the manure cover. In the IA method, a simple quadrant (1000 mm wide by 1000 mm long) (Fig. 4a) was placed randomly over the plot immediately following the manure injection. A digital image (Fig. 4b) was quickly taken over the simple quadrant. Images were downloaded to a personal computer and were converted to 680 by 480 pixels bitmap (BMP) images. The BMP images were processed with the ASSESS (Lamari 2002). Manure cover (the percentage of the surface area covered with manure) was determined using the ASSESS program, which could separate the surface covered by manure based on hue (or saturation) (Fig. 4c), and the area of the manured surface was selected digitally using a user defined threshold. In the LT method, a mesh quadrant (700 mm wide by 800 mm long) with 110 grids (70 mm wide by 70 mm long) was used. To compare this method to the IA method, the mesh quadrant was quickly placed inside the simple quadrant (Fig. 4a) after the digital image was taken. The number of intersections that were directly over the surface covered by manure was counted. Manure cover was determined using:

$$C_m = \frac{N_m}{N_t} \times 100 \tag{1}$$

where:

C_m = manure cover (%),

N_m = number of intersections over the manured surface, and

N_t = total number of intersections in the mesh quadrant.

Immediately after the manure injection, a portable wind tunnel (Fig. 5a) was placed on the soil surface to collect odorous air samples from the soil surface. The wind tunnel consisted of a carbon filter, a fan, a main chamber, and a sampling outlet (Fig. 5b). A complete description of the wind tunnel can be found in Cicek et al. (2003). The bottom of the main chamber (0.25 m high from the ground) was open to the soil surface and