Uniformity of liquid manure application from existing land application systems

G.J. WALL[1], D.J. KING[1], B.A. GRANT[1], N.B. McLAUGHLIN[2] and P.H. CLARKE[1]

[1]Land Resource Unit, Greenhouse and Processing Crops Research Centre, Agriculture and Agri-Food Canada, Guelph, ON, Canada N1H 3N6; and [2]Eastern Cereal and Oilseed Research Centre, Research Branch, Agriculture and Agri-Food Canada, Ottawa, ON, Canada K1A 0C6. *Received 3 April 1998; accepted 21 August 1998.*

Wall, G.J., King, D.J., Grant, B.A., McLaughlin, N.B. and Clarke, P.H. 1998. **Uniformity of liquid manure application from existing land application systems**. Can. Agric. Eng. **40**:179-183. Land application of liquid manure is currently creating significant environmental issues related to air and water quality. To reduce environmental impacts and to meet crop nutrient requirements, liquid manure must be applied at uniform controlled rates. The objective of this study was to evaluate the uniformity of current liquid manure application systems used in Southern Ontario. Existing single and multiple splash plate systems were evaluated at the field scale using three replicated continuous rows of sampling trays (0.126 m^2) placed perpendicular to the direction of travel. Application rates, coefficients of variation (CV) and uniformity coefficients (U_C) were calculated from the masses of manure in the sample trays. The manure application equipment tested had CV values ranging from 30 to 68% with a mean value of 50%. Large CV values for uniformity are inadequate for crop production purposes when the manure is the primary nutrient source. The implications are significant for soil fertility management, crop productivity, and potential environmental impact to sensitive areas due to high hydraulic conductivity to subsurface waters.

L'épandage de purin sur les sols est à l'origine de problèmes environnementaux qui affectent la qualité de l'air et de l'eau. Afin de diminuer ces impacts tout en satisfaisant les besoins des plantes en éléments nutritifs, les applications de purin doivent se faire de façon contrôlée et à des taux uniformes, L'objectif de cette étude était d'évaluer l'uniformité des épandeurs de purin actuellement utilisés dans le sud de l'Ontario. Des épandeurs à déflecteur unique et à déflecteurs multiples existants ont été évalués à l'échelle du champ, à l'aide de 3 séries de plateaux d'échantillonnage (0.126 m^2) disposés sur des rangées adjacentes, et perpendiculairement à la direction du déplacement. A partir des masses de purin recueillies dans les plateaux, on a calculé les taux d'application ainsi que les coefficients de variation (CV) et d'uniformité (U_C). Les équipements testés avaient des CV allant de 30 à 68%, et une moyenne de 50%. Des valeurs élevées de CV dans l'uniformité d'application sont inacceptables si le purin est la principale source de fertilisation des cultures. Les répercussions sont également importantes sur la gestion de la fertilité des sols, la productivité et les impacts environnementaux sur les eaux souterraines dans les zones sensibles où la conductivité hydraulique est élevée.

INTRODUCTION

Liquid manure storage systems are used by the majority of larger livestock producers in Ontario and the numbers are increasing as livestock production units expand. As the size of livestock production systems continue to increase, the availability of land for waste application becomes a concern for environmentally safe management of the nutrients. Land application of liquid wastes is creating significant environmental issues related to air and water quality (Hilborn 1992). Odour and greenhouse gases are the two main air quality issues, while bacteria and nutrient contamination of ground and surface water are the major water quality issues (King et al. 1994) causing a threat to both human and wildlife habitats. Nutrient management plans are becoming important requirements for sustainable crop production systems. Land application of agricultural liquid wastes is part of a nutrient management plan and the technology must provide for reliable and uniform application rates to meet crop nutrient requirements without leading to environmental contamination. For precision farming application it is a further requirement to be able to change the manure application rate to reflect changes in field nutrient availability.

To achieve maximum benefit, the application rate of manure should match the nutrient requirement of the crop as closely as possible (Klausner 1992). Over-application is wasteful and increases the potential for contamination, while under-application supplies too few nutrients, possibly limiting the yield. Many farmers have an overabundance of manure and do not have the facilities to store a 365-day supply (Martin and Brown 1994). Ideally, liquid manure should be applied as close as possible to the period of maximum nutrient uptake by the crop.

Both tanker and irrigation-based systems are commonly used for land application of liquid manure. In irrigation-based systems, manure is pumped at high pressure (up to 1.0 MPa) to a single nozzle travelling irrigation gun which has a spread pattern in the order of 100 m or to a travelling boom with multiple discharge points. In tanker-based systems, manure is pumped at a relatively low pressure (100 to 200 kPa) to single or multiple splash plates which have a spread pattern ranging from 1 to 2 m each for multiple splash plates, to nearly 15 m for a single splash plate. The design of the discharge points (splash plates or nozzles) has a significant effect on the uniformity of manure application. One manufacturer used different shaped restrictors (ellipses, circles, and diamonds) placed in the flow path in front of the splash plate in an effort to improve manure application uniformity.

There are no standard methods in the literature for determining uniformity and reporting performance data on liquid manure spreading equipment. The ASAE Standard S341.2 (ASAE 1997) outlines a procedure for measuring distribution uniformity and calibrating granular broadcast

Table I. Standard deviation (SD), coefficient of variation (CV), and uniformity coefficients (U_C) for different liquid manure application systems and rates.

Application System	Mean application rate (m^3/ha)	Standard deviation (m^3/ha)	Coefficient of variation (%)	Uniformity Coefficient (%)
SINGLE DISCHARGE:				
(a) Standard Inverted[1] (Figure 1A):				
opening: 108 mm	36.0	11.73	32.6	77.9
opening: 83 mm	33.6	14.54	43.3	67.0
(b) Standard Inverted with Flow Restrictors[1]:				
elliptical (143 mm x 102 mm) (540 rpm)	17.8	10.0	56.0	57.0
elliptical (111 mm x 51 mm) (540 rpm)	11.8	8.1	68.4	47.9
elliptical (111 mm x 51 mm) (1000 rpm)	12.4	5.5	44.7	71.1
circular (127 mm dia.)	20.7	14.4	69.3	51.0
circular (76 mm dia.)	9.5	4.5	47.3	71.7
diamond (89 mm x 89 mm)	23.4	15.1	64.3	47.4
diamond (67 mm x 67 mm)	11.6	5.8	50.1	60.1
(c) Wide Mouth Inverted[1] (Figure 1B):				
opening: 203 mm	76.9	31.2	40.6	70.0
opening: 127 mm	60.4	23.8	39.3	69.1
(d) Standard[1] (Figure 1C):				
opening: 108 mm	39.2	19.5	49.8	56.7
opening: 83 mm	34.8	17.1	49.1	61.7
(e) Pit King Splash Plate[2] (not shown):				
height: 1.1 m; opening: 76 mm (dairy manure)	59.7	34.2	57.3	56.7
height: 1.1 m; opening: 76 mm (veal calf manure)	55.4	14.7	26.5	78.1
(f) Irrigation Nozzle[3] (not shown):				
height: 1.6 m; opening: 36 mm	101.2	44.1	43.7	64.4
MULTIPLE DISCHARGE:				
(a) Boom (9 flat splash plates)[1] (Figure 2a):				
height: 0.56 m; opening: 58 mm (1000 rpm)	43.2	28.3	65.7	34.0
height: 0.56 m; opening: 58 mm (680 rpm)	45.6	23.4	51.2	56.2
height: 0.56 m; opening: 58 mm (520 rpm)	37.4	25.1	67.1	57.1
(b) Boom (6 winged splash plates)[1] (Figure 2b):				
height: 0.41 m; opening: 58 mm (1000 rpm)	77.8	33.1	42.6	67.2
(c) Boom (7 vortex splash plates)[4] (Figure 2c):				
height: 1.5 m; opening: 38 mm (dairy manure)	61.5	21.7	35.3	73.3

[1] Husky Farm Equipment Limited, Alma, ON (12000 L tanker); [2] Pit King Liquid Waste Disposal Services, Drayton, ON (drag hose); [3] Bauer Stargun SR 35 (irrigation gun), Rohren-und Pumpenwerk,Voitsberg, Austria; [4] Bauer Rainstar 110-300 MH/CH AG35 Slurry Boom (irrigation boom), Rohren-und Pumpenwerk,Voitsberg, Austria

spreaders. This standard gives test conditions, test procedures including guidelines of test setup, and collection devices to determine application rates and uniformity of distribution. The coefficient of variation (CV) is used to determine and express the uniformity of distribution.

The objective of this study was to evaluate the uniformity of current liquid manure application systems used by both primary producers and commercial waste disposal operators in Southern Ontario.

MATERIALS and METHODS

Liquid manure application systems using single or multiple splash plate/nozzle technologies were evaluated for uniformity of manure application. Swine manure was used in the uniformity tests unless otherwise stated in Table I. Details of discharge height, opening size, and associated flow restrictors for the 12 application systems evaluated are reported in Table I and illustrated in Figs. 1 and 2. The irrigation nozzle was a travelling irrigation gun to reel system with a 38 mm nozzle set at 24° to the horizontal and set to spray a 180° arc.

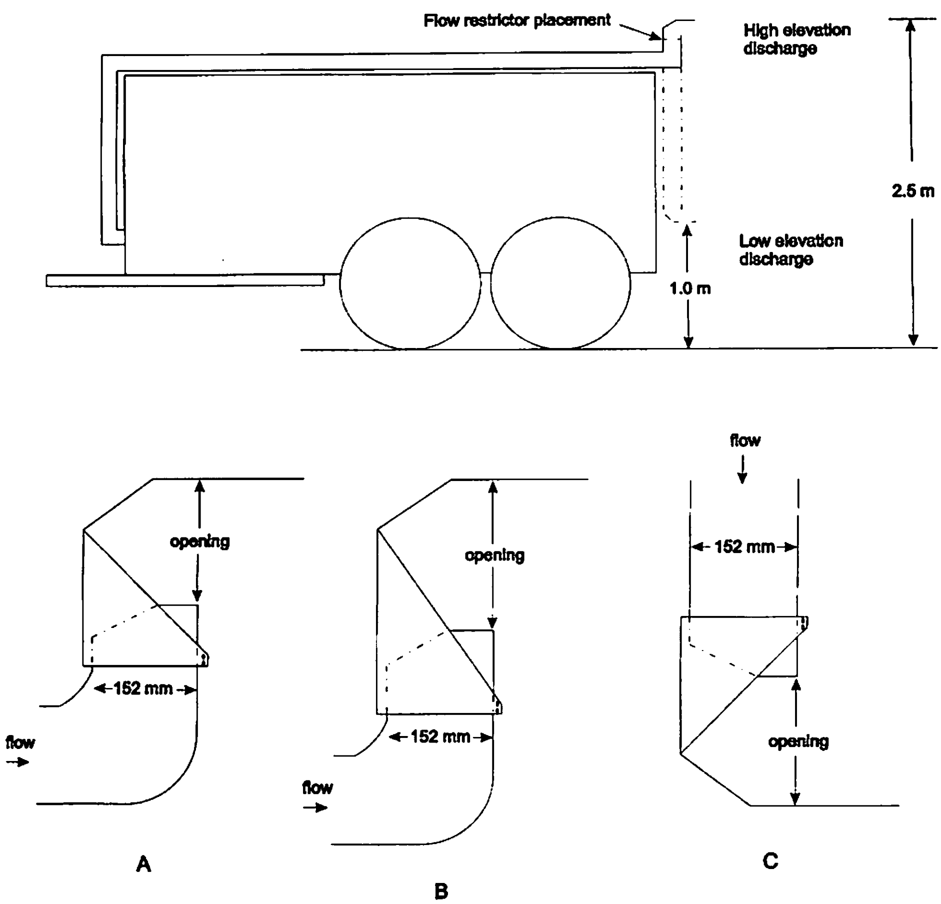

Fig. 1. Single discharge configurations: A - Standard inverted (high elevation discharge); B - Wide mouth inverted (high elevation discharge); C - standard (low elevation discharge).

The three multiple splash plate configurations evaluated are illustrated in Fig. 2. The nine splash plate system had simple flat plates while the six splash plate system utilized curved sides on the splash plates to redirect some of the higher flows at the outside of the spread pattern back towards the centre of the spread pattern. All of the splash plates were parallel to the ground and were oriented at 90° to the flow of the manure out of the vertical feeder pipes. The Bauer Rainstar system had seven vortex splash plates mounted on a travelling irrigation boom and was fed by an irrigation pump. Manure from the boom entered tangentially at the side of the vortex chamber creating a spinning vortex within the chamber. The manure exited through a central hole at the bottom of the chamber and struck a 216 mm diameter horizontal plate. The liquid was distributed in a circular spray pattern from each splash plate. The system had seven splash plates spaced 6.1 m and applied manure over a 44 m width.

Guidelines in ASAE Standard S341.2 (ASAE 1997) that were applicable for liquid manure spreaders were used to establish test conditions and test setup. The collection devices for the liquid manure were a continuous row of trays (173 mm wide x 730 mm long x 130 mm deep) placed end to end across the entire spread pattern perpendicular to the direction of application. Care was taken in the testing of multiple splash plates to center trays by splash plate location. In some of the initial tests with tanker systems, gaps in the trays lines were left for passage of the tractor and tanker wheels. In the later tests, the gaps were eliminated by placing the trays immediately behind the tanker wheels (and in front of the splash plates) and allowing the spread pattern to build up before initiating forward movement of the tanker. The trays were fixed to the ground with 5 mm diameter L-shaped metal pegs. When testing the uniformity of the Pit King splash plate fed by an irrigation hose, the trays that were directly in the path of the hose were buried to ground level to avoid damage from the hose. Three sets of trays separated by 5 m were used to achieve three replicates. A plastic liner was placed in each tray and then approximately 0.5 kg of liquid absorbent litter was added to prevent splashing.

After the manure applicator passed over the trays, the liners containing the litter and manure were removed from the trays and immediately weighed on a scale to a 1.0 g resolution. The mass of the manure (kg) for each tray was determined by subtracting the mass of the litter and liner. The application rate was then calculated from the mass of the manure collected in the sample tray, the manure density and the open area of the sample tray using:

$$R_m = \frac{10000 M_m}{\rho_m A_t} \tag{1}$$

where:
R_m = manure application rate (m^3/ha),
M_m = manure mass in tray (kg),
A_t = tray area (m^2), and
ρ_m = density of manure (kg/m^3)

The mean, standard deviation, coefficient of variation (Snedecor and Cochran 1989) and uniformity coefficient (Eq. 2) were calculated from the pooled data for the three replicates (Table I). The uniformity coefficient is a standard procedure for determining the overall uniformity of rainfall (Tossell et al. 1987) and was determined by:

$$U_c = \left(1 - \sum_{i=1}^{n} \frac{|x_i - \bar{x}|}{n\bar{x}}\right) * 100 \tag{2}$$

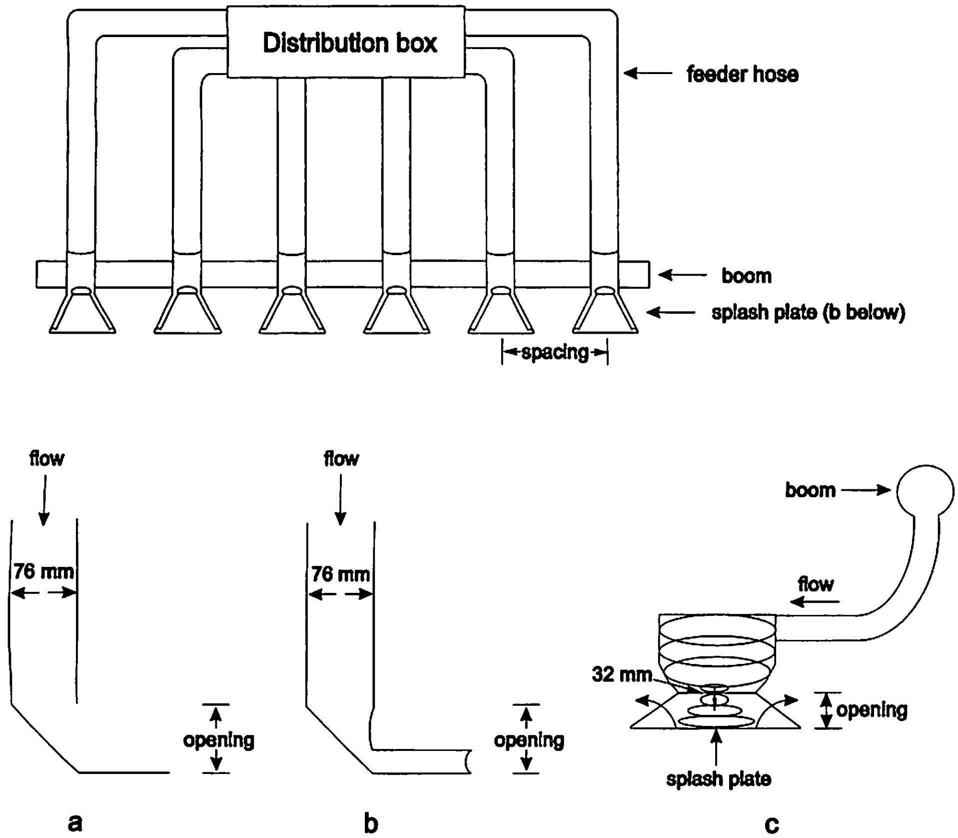

Fig. 2. Multiple discharge configurations: a - standard; b - winged; c - vortex.

where:
U_c = uniformity coefficient (%),
x_i, $\bar{x}$ = sample and mean application rate of each replication, respectively (m^3/ha), and
n = number of sample trays (Christiansen 1942).

While test conditions and setup guidelines were identical to ASAE S341.2 specifications (ASAE 1997), the collection devices were different in size and baffling. The ASAE Standard for granular fertilizer spreaders recommends that the width of the collection tray shall not exceed 10% of the anticipated swath width and the length shall be equal to or greater than the width with a minimum length of 0.3 m. Our collection tray width (0.73 m perpendicular to the direction of travel) approximated the ASAE standard but the tray length (0.17 m in the direction of travel) was less than the standard for granular spreaders. The ASAE standard recommends that each tray be divided into compartments to reduce the possibility of particles ricocheting out of the trays. In this study, we used approximately 0.5 kg of absorbent litter preweighed into each tray to reduce splash loss. There was no visual evidence of splash losses from the trays for any of the application methods evaluated. In most cases the manure and litter masses were approximately equal and thus the effect of errors in weighing litter did not have large effects on calculation of manure mass. All manure uniformity testing was conducted under climatic conditions that livestock producers or commercial waste applicators would apply liquid manures to land.

RESULTS and DISCUSSION

Standard deviation (SD) and CV, as recommended by ASAE Standard S341.2 (ASAE 1997) and the uniformity coefficient (Eq. 2) for the application systems tested are reported in Table I. A CV of 50% means that at a mean rate of 100 kg/ha the actual application rate would be expected to be within the range from 50 to 150 kg/ha on 68% of the area and lower than 50 kg/ha or higher than 150 kg/ha on 32% of the area. The same amount of manure in each collection tray would yield a CV of 0% and a U_c of 100%. All of the manure in one tray and none in the others would yield the maximum CV and minimum U_c. In many cases the CV and U_C values were approximately complementary but because the CV value is more influenced by outlying values than the U_C, large differences in these two uniformity statistics do occur.

The standard, standard inverted, and wide mouth inverted splash plates commonly used on manure tankers had CV values of about 50, 30-40, and 40%, respectively. Restrictor plates did not improve the uniformity distribution. The CV for the Pit King splash plate was about 25% for the low (1%) dry matter veal manure but was elevated to near 60% when dairy manure with high (4.3%) dry matter content was used. The irrigation gun measurement was not replicated but the CV for the single row of 125 sampling trays was 44%. A cross wind of 11.5 km/h at the time of testing contributed to the skewed application pattern. The CV values for multiple discharge application systems were similar to the single discharge systems ranging with values from 35 to 67%. Tractor PTO speed which affects manure flow rate from the pump affected the CV values of the application boom (a) from 50 to 67% with lowest CV values measured for the 680 PTO pump speed (Table I). The CV for granular fertilizer application over similar widths of spreading is usually < 10%. The UC values for all manure application systems tested ranged from 34 to 78%.

Poor uniformity values result from a combination of uneven delivery of manure from the distribution system (distributor) to the discharge points (splash plates or nozzles) and/or non uniform distribution across the spread pattern from the discharge point (splash plate or nozzle). While no attempt was made to partition these potential errors in the current study, it was observed that improved distributor and discharge point (splash plate or nozzle) technology is required to achieve uniform manure nutrient application.

CONCLUSIONS

The uniformity of application of liquid animal waste was evaluated for a number of the tanker and irrigation-based systems used by farmers and commercial operators in Ontario. The CV values for the single discharge application systems ranged from 30 to 69%. The multiple discharge systems had CV values in a similar range of 35 to 67%. Tractor PTO speed and orifice size, both of which affect the manure flow rate and manure type, all affected the application uniformity. ASAE Standard for granular fertilizers application suggest that CV values of < 10% are satisfactory for application widths similar to those used for manure application in this study. The manure application techniques used in this study do not apply liquid manure to land as uniformly as a granular fertilizer spreader. If liquid manure is being used on cropland as the primary source of crop nutrients, liquid manure application equipment with improved uniformity would be required. The poor performance of the manure application equipment tested suggests that uniformity testing should be routinely adopted.

Further research is required to develop manure application systems where: a) the distribution system delivers uniform volumes of manure to each discharge point and b) the discharge points (splash plate or nozzle) delivers the manure uniformly to the land surface.

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