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The impact of a farm's annual cattle slurry yield on the options for moving the slurry from stable to plot: a simulation study

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Abstract. The economical efficacy is substantial on both occasions for feeding plants with nutrients and moving the manure from stables to the plots. The aim of the present research is to explain the limit values for the annual amount of slurry and average plot distance on a farm as conditions to decide in favour of a personal eco-friendly slurry distributor or custom equipment. In their previous researches, the authors have composed models to calculate slurry management costs for different technologies depending on plot distance, taking into account ammonia emissions. In the present study, simulations were made using the composed calculation models to compare slurry distribution costs for four slurry application technologies.

Calculations show that if the annual amount of slurry exceeds 4000 m^3, then for plot distance over 2 km, custom slurry distribution is cheaper than using the farm's own equipment. However, if the annual quantity of slurry exceeds 16,000 m^3, then the limit value for distance is 5 km.

If the annual amount of slurry is 4000 m^3, then full custom service is cheaper than the technology in which the farm's own slurry distributor and custom transportation is used. In the case of the annual amount of 16,000 m^3, it is less expensive to use the farm's own slurry distributor and custom transportation. In order to benefit from the use of the farm's own distributor the minimum value for annual slurry amount is 5600 m^3.

Key words: ammonia emissions, slurry application technology, plot distance, performance, operation costs, custom machines, annual slurry amount

INTRODUCTION

On the basis of environmental impacts in agricultural production, the following pollution subdivisions can be distinguished: point pollutants (animal farming, manure storages, etc) and diffuse pollution (e.g., pollution from manure distribution in the fields) (Dämmgen *et al*., 2007). Leakage of farmyard stores and runoff following slurry application to the land can lead directly to losses of organic matter, nutrients and pathogenic micro-organisms, with potential consequences for both stream ecology and human health (Naden *et al*., 2009). These diffuse losses have mainly been characterised in terms of nutrients (Vadas *et al*., 2007).

Ammonia volatilisation can be a major source of N losses from applied slurry (Lewis *et al*., 2003). Ammonia emission has been studied in several countries. The emission is magnified by higher air temperature during the spreading, wind (Misselbrook *et al*., 2005), higher pH, content of solid matter and ammonium nitrogen of the slurry (Mattila, 2006), as well as by high soil pH and temperature (Sommer *et al*., 2003; Misselbrook *et al*., 2005) and low soil moisture (Jokela & Meisinger, 2008).

Although gas emission, leaching of nutrients and odour have undesirable effects on the environment, the contribution of manure to plant nutrition and build-up of soil organic matter is considered to have a positive effect.

To utilise the nutrients contained in manure and minimise air pollution, it is essential to apply technology suppressing the gas emission from slurry distributed on the field. In the Defra (2006) project, the impact of different spreading devices on the ammonia emission was compared in the UK, Germany, Denmark and Finland. The average values of reduction of ammonia emission compared to technology where slurry was broadcast-spread and not incorporated from that research are as follows: trailing hose 32%, trailing shoe 60%, open slot injection 67%, closed slot injection 82% and deep injection 86%. By IPCC (2007) the ammonia emission factors for different application technologies are the following: 70% for broadcast spreading, without incorporation, 20% for spreading with a trailing hose, 10% for spreading with an open slot shallow injector and 1% for spreading with a closed slot. The effect of the use of slurry depends also on the time-lag between spreading and incorporation. The time-lag depends inter alia on the distance to the manure storage if incorporation is consecutive (one-man system) (Huijsmans and de Mol, 1999). Paudel *et al.* (2009) determined by a GIS-based model a least-cost dairy manure application distance for Louisiana's major dairy production area. A comparison between the dairy manure and commercial fertilizer application under three consistent rules – N, P_2O_5, and K_2O – revealed that the use of dairy manure is not economical after 30 km for N and 15 km each for P_2O_5 and K_2O.

Plant nutrient overloads can result from several forms of mismanagement, including over-fertilisation of crops (Gerber *et al.*, 2005). The objective should be to apply slurry to match the needs of the crop both in terms of amount and timing, attempting to minimise nutrient losses while maintaining adequate yields. Nutrient absorption by soil and plants is a complex of factors including soil, climate conditions, season and plant species (Lewis *et al.*, 2003).

In order to decrease excessive application of nutrients, it is not advisable to use more manure than the soil and yield properties allow. The herd size determines proportionally the area needed for distributing the manure produced by animals. However, the larger the areas, the longer are the average manure transportation distances (Tamm, 2009). The farm's annual slurry quantity and transportation distance as the selection criteria of slurry application technology should be explained. Schindler (2009) has published data for choosing the machines for the slurry delivery chain depending on those criteria in average production conditions of Germany with labour cost 16 € ha^{-1} and fuel price 1.45 € l^{-1}. In Estonia these values are 3.8 € ha^{-1} and 0.58 € l^{-1}, respectively. Thus, the German data are not applicable to Estonia and no literature is available with similar data for Estonia. The equipment for slurry application can be the farm's own or rented from a service provider. There are no data published about a farm's annual slurry quantity as a decision criterion to choose one's own or custom machinery.

Therefore, the present paper compares slurry distribution costs considering a farm's annual slurry quantity and average transportation distance in the case of four technological approaches for average Estonian production conditions:

1) incorporating disc device – the slurry is simultaneously distributed and mixed with soil;
2) incorporating disc device as in variant no. 1, but the slurry is transported to the

3) slurry spreading by trailing hose spreader plus a separate operation to incorporate the slurry to the soil; and
4) custom slurry distribution: slurry is transported by tank trucks to the plot and distributed with a self-propelling and incorporating slurry distributor.

The results from this study are considered to be targeted for slurry producers, to enhance their knowledge of the impact of the farm's annual slurry quantity and plot distance on the technological options.

MATERIALS AND METHODS

In calculations, it was presumed that manure comes from the farm's own production and the only costs arise from transportation and distribution. The calculation model is composed by the authors and has been previously published (Tamm & Vettik, 2008). The model contains components from the method, applied to evaluate options for exploitation of a plot considering costs depending on plot distance (Tamm, 2009). The prices of fuel and custom works used in calculations are from summer 2009. The prices of machines are collected from KTBL (2008).

Four simulated cases for slurry handling have been studied. A description of the technological sequence for slurry handling is as follows:
1) mixing – pumping from storage into the distributor tank – transporting with distributor to the plot – distribution and mixing with soil simultaneously;
2) mixing – pumping from storage into the custom truck tank – transporting with truck to the plot – pumping from the truck tank into the distributor tank – distribution and mixing with soil simultaneously;
3) mixing – pumping from storage into the distributor tank – transporting with distributor to the plot – distribution onto the soil with trailing hoses – separate operation to incorporate the slurry to the soil; and
4) mixing – pumping from storage into the custom truck tank – transporting with truck to the plot – pumping from truck tank into the custom distributor tank – the custom distributor tank distributes and mixes slurry with soil simultaneously.

Before slurry transportation and its distribution for slurry mixing and pumping 15 kW electrical device with performance 4.5 $m^3 min^{-1}$ (price is 4605 €) is applied. From the observations of ERIA researchers, the slurry should be mixed the entire time the distribution lasts. On the plot, the distributor's own pump is used for over-pumping.

In all technological variants the distributor has a tank with 15 m^3 volume, fuel price is 0.58 € l^{-1} and labour cost is 3.8 € h^{-1}. The distributor used in variants 1 and 2 is equipped with a 4.5 m wide disc device (price of distributor is 52,560 €); tractor power is 158 kW (price is 102,560 €). The distributor used in variant 3 is equipped with a 12 m wide trailing hose spreader (price for whole system is 42,200 €) and the tractor engine power is 102 kW (price is 76,730 €). In variant 4, a custom self-propelled distributor equipped with a 4.5 m wide disc device is used with the engine power of 246 kW. The price of custom work with this distributor is 2.2 € m^{-3}.

If custom work is used only for transportation of the slurry to the field (variants 2 and 4), then the tanker lorry with initial cost 1.3 € m^{-3} is rented. If the distance exceeds 7 km, then 0.07 € m^{-3} per every extra km must be added to the initial cost.

In the 3rd technological variant a field-operation-unit containing a 158 kW tractor and a 4 m wide disk harrow (price is 31,950 €) to mix slurry with soil is used. The time span between slurry distribution and mixing with soil may not exceed 4 h.

Ammonia emission factors used for technologies are as follows: 20% for spreading with a trailing hose (variant 3) and 5% for incorporating the disc device (as the average value between values for spreading with an open slot shallow injector and for spreading with a closed slot) (variants 1, 2 and 4) (IPPC, 2007).

The annual work capacity for the spreader is 4000 m^3 and 16,000 m^3. The slurry rate was 40 m^3 ha^{-1} and the plot area was 20 ha for all technological variants. The operations are considered to be performed before the cereal is sown.

RESULTS AND DISCUSSION

Simulations were made using composed calculation models to compare slurry distribution costs for four slurry application technologies considering the farm's annual slurry quantity and distance to the plot. The results for technological variant 1 (farm's own soil mixing disc device) and 4 (custom slurry distributor) are shown in Fig. 1.

Fig. 1 indicates that if the annual quantity of slurry exceeds 4000 m^3, then for a plot distance over 2 km, custom slurry distribution is cheaper than the use of the farm's own equipment. Slurry management costs for 2 km and 4000 m^3 is 3.5 € m^{-3} both in the case of variant 1 and 4. However, if the annual quantity of slurry exceeds 16,000 m^3, then the limit value for distance is 5 km. For variant 1, slurry management costs for 5 km distance are 4.7 € m^{-3} and 3.5 € m^{-3} for annual slurry amounts 4000 m^3 and 16,000 m^3, correspondingly. The greater the annual amount of slurry, the cheaper is management of the slurry per m^3; Huijsmans *et al.* (2004) got similar results. However, a greater amount of slurry needs a larger distribution area, which requires a longer distance and a greater cost for slurry transportation.

Dr. Schindler (2009) has published data for a slurry distributor with a16 m^3 tank and a 6 m wide slot injector. If the distance to the plot is 2 km, the plot area is 10 ha, and the farm's annual quantity of slurry is 4,800 m^3, then the slurry distribution cost is 4.85 € m^{-3}. For 5 km, this cost is 6.43 € m^{-3}. The higher costs brought out by Schindler compared to our figures are probably induced by a more expensive distributor (it is wider and has a somewhat bigger tank, requiring a more powerful tractor), higher labour cost and fuel price.

The calculations show that distribution is cheaper (ca 0.64 € m^{-3}) in the case of the trailing hose spreader (variant No. 3), because of the greater work width and cheaper machine price; Huijsmans *et al.* (2004) and Schindler (2009) had analogous results. Considering the impact of the art of distribution of slurry on the loss of nitrogen by ammonia emission it is essential to incorporate slurry into the soil on arable land. The slurry incorporation performed for diminishing the ammonia emission is a separate operation with a cost of ca 25.6 € ha^{-1}. This result is the same as by using an incorporating spreader and, therefore, the results are not presented separately in the figure.

If the slurry distributor is used for slurry distribution only, then the custom tank lorry is used for transporting the slurry to the plot (variants 2 and 4); results are presented in Fig. 2. The eco-friendly slurry application equipment is expensive; therefore, it is most effective to use these machines for distribution, rather than for the transportation of slurry (Tamm, 2009). Thus, the separate vehicles with slurry tanks should be used to transport the slurry to the plot especially for longer distances. In Estonian conditions the maximum distance for transporting the slurry by distributor itself to the plot is about 4 km (Tamm & Vettik, 2008).

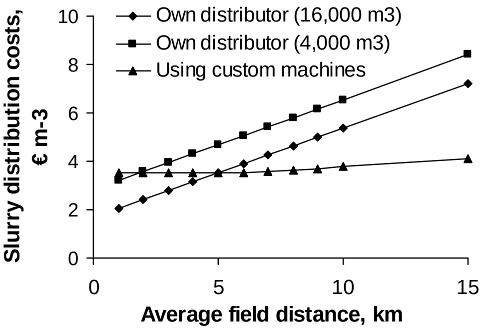

Figure 1. Slurry distribution costs in the case of farm's own distributor and using custom machines.

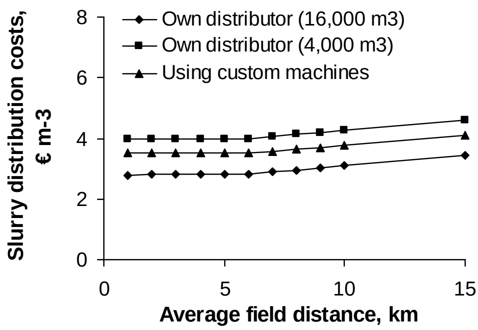

Figure 2. Slurry distribution costs if custom tank lorry is used for transportation and spreading is performed by farm's own distributor or custom distributor.

Figure 2 demonstrates that full custom service (variant 4) will be cheaper than the farms' own slurry distributor and custom transportation (variant 2), if the annual amount of slurry is 4000 m^3. If the annual amount is 16,000 m^3, then it will be less expensive to use the farm's own slurry distributor and custom transportation. For variant 2, slurry management costs for 5 km distance are 4.0 € m^{-3} and 2.8 € m^{-3} for annual slurry amounts of 4000 m^3 and 16,000 m^3, correspondingly. In order to benefit from the use of the farm's own distributor the minimum value for annual slurry amount is 5600 m^3 by our calculations. Sørensen *et al.* (2003) report that use of distributors with a large tank volume is rational when the annual slurry amount exceeds 9000 t. If that amount remains under 3000 t, it is not at all profitable to own a distributor; the custom distribution is cheaper.

CONCLUSIONS

Before investing in eco-friendly but expensive slurry distribution technology, the farmer has to calculate whether his farm has enough slurry to ensure a lower work price than custom service. The calculations show that, in the conditions used in our simulations, the minimum value for annual slurry amount is 5600 m^3 to own a distributor. We also found that the distribution cost in the case of a trailing hose spreader with an extra operation for soil mixing is equal to the distribution cost of incorporating a disc distributor. In the first case the additional time and labour should be taken into account for the soil-mixing operation. The ammonium emission is also somewhat higher than for other technologies compared in the present study. For longer distances to the plot, the farmer should consider hiring a custom tank lorry for slurry transportation, and the farm's own distributor should be used only for distribution on the plot.

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