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A model for defining minimum volume for slurry tanker

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Abstract. In the market of agricultural machines the supply of slurry tankers is diverse. It is a complex task to consider all parameters intuitively while selecting a tanker suitable for a farm. The capacity of a slurry tanker is affected by different variables. According to previous studies, the most significant influence is the tank volume. In the present version of selection model of a tanker, we composed a pattern to determine the minimum volume for a slurry tanker. The aim of the paper is to introduce the calculation pattern and to give an overview of the model. The results of model experiments and sensitivity of key factors are discussed.

Calculations show that, the larger is slurry amount and the shorter is the time span within which it should be distributed, the greater must be tank volume. In the case of 20 days, 3m^3 of tank volume is satisfying the needs of a farm which has 2,000m^3 slurry; the transportation distance is 1km and uses a 12m spreader with application rate of 40m^3 ha^{-1}. If slurry amount is 5,000m^3, the minimum volume should be 11m^3 in the same conditions.

Sensitivity analysis shows that in the frames of reference situation the average difference of tank volume is 1) 7.5m^3 per 1,000m^3 slurry amount, 2) -0.1m^3 per 1m^3 h^{-1} unloading capacity, and 3) 4.4m^3 per 1km distance.

The study is continued to improve the selection model to define the optimum value of tanker volume regarding economical and technical constraints.

Key words: Animal slurry, tank volume, selection of tanker, field distance, sensitivity analysis.

INTRODUCTION

One of the key factors for effective agricultural production is to use energy staked on fertilisers, including slurry, with maximum efficiency. This is particularly important from the point of view of minimising environmental load of fertilisers which are one of the greatest agricultural pollutants (Ongley, 1996; EPA, 2005). The efficiency of slurry is heavily influenced by the way and the time of management, which depend largely on the appropriate selection and adequate usage of technologies and equipment (Rammer & Rodhe, 2002; Huijsmans & de Mol, 1999).

The results of the inquiry made to explain the amounts of different kinds of manures in Estonia revealed clearly that in 2009 slurry formed 68% (1.5 Mt) of the manure yearly handled by IPPC farms (Tamm & Vettik, 2011). Thus the equipment to handle slurry has a wide use in Estonia. Karmakar et al. (2007) say that appropriate decision support systems (DSS) in the area of manure management are becoming increasingly important, firstly because of the increasing population of livestock animals and the growth of the livestock industry, and, secondly, as a result of the implementation of environmental regulations and protocols.

In the market of agricultural machines the supply of slurry tankers is diverse. It is a complex task to take into account all the factors intuitively to define the tanker suitable for farm conditions. There is a need for a more systematic approach, which can be assisted by the use of DSS. The model will serve as a tool to assess the accordance between the slurry tanker and the production structure of the farm and provide information support for manure management. In the literature, several manure management DSS-s have been explained with unlike goals like nutrients, whole farm rating, manure treatment, and application (Karmakar et al., 2007). However, the relevant models available in the literature supporting the selection of slurry tanker are scarce.

The capacity of a slurry tanker is affected by different variables, such as work width and speed, transport distance, time for preparing and finishing loading, loading capacity, and tank volume. According to Sørensen (2003), the most important influence is the tank volume. He found that by changing the tank volume of a tractor-pulled distributor ±50%, the capacity would be reduced by 34.5% or increased by 20.7% as compared to the reference volume 16m^3. In the Estonian market the range of tank volumes of slurry distributors varies between 3–30m^3 (Agronic, 2011; Fliegl, 2011).

Thus, in the present version of selection model of distributor, we composed a pattern to determine the minimum slurry tanker volume for a farm. The aim of the given paper is to introduce that calculation pattern and give an overview of the parameters, constraints and relations used in the model. The results of model experiments and sensitivity of key factors are discussed in the paper.

THE MODEL AND DATA

The model to determine minimum slurry tanker volume for a farm consists of several steps: 1) defining the minimum required capacity to distribute the annual yield of slurry in the farm, 2) defining the suitable working width for the tanker; and 3) calculating the minimum volume for the tanker.

The limits used in the present study are the following: 1) first, the distributor is selected and afterwards the tractor is selected by distribution equipment; thus, the power requirement is not limited; 2) traffic conditions permitting, the tractor has enough power to apply maximum speed; 3) work method is the method of interrupted passes (by Hujsmans & de Mol,1999), application continues till the tank is empty and after reloading, the pass will be continued at the same place where it stopped; 4) application rate is the average rate weighted with crop areas planned to fertilise with slurry in the farm, and 5) the loading and unloading capacities are equal.

The minimum capacity required to distribute the annual amount of slurry in the farm is by the ASAE Standard (2003) calculated by estimating the number of days yearly within which the operation should be accomplished, and by determining the probability of working days in this time span:

$$A_{\min} = \frac{Y}{DT\tau} \qquad (1)$$

where: $A_{\min}$ is the minimum capacity required to distribute the amount of slurry in the farm, m^3 h^{-1};

D – number of days which are available for slurry distribution, days;
T – expected time available for work each day, h day^{-1};
τ – the probability of a working day during timespan, decimal;
Y – annual yield of slurry in the farm, m^3.

The distribution width varies for applicators with trailing hose 6-24m, with shallow disc slurry injector 3-12m and with arable land slurry injector 3-6m (KTBL, 2009). The calculated maximum nominal width of tanker is

$$b_{n,c} = \frac{W_u \varphi}{10 h v_w}, \tag{2}$$

where factors are described in Table 1. While the nominal width of tanker is a periodic value, the nearest minor available nominal width b_n should be selected by the calculated values $b_{n,c}$. In our study we presume that the working width is fixed and cannot be adjusted to the work conditions. The pump capacity and thus the unloading capacity are adjustable. The unloading capacity depends largely on pump capacity, resistance of distribution system, and viscosity of slurry.

Today in Estonia generally the slurry application rate is about 30–40m^3 ha^{-1} but in some cases the rate can be in the range 10-60m^3 ha^{-1} depending on field and slurry properties. If grassland injectors are used, the average application rate should be lower than by arable land systems to avoid the contamination of fodder plants (Sørensen, 2003; IPPC, 2007). Average application speed also depends on the distribution system. In the case of the broadcast systems and trailing hoses, the average speed can be lower than by arable land injection systems, in which the work speed is an important presumption for mixing the slurry with soil (Hujsmans & de Mol, 1999).

According to Sørensen (2003), the use of nominal width of injector is on average 99.6% and 99.3% for fallow soil and grassland, respectively.

Determining the tank volume. To calculate the tank volume that would satisfy the minimum required capacity $A_{\min}$ to distribute the annual amount of slurry, the cycle time for handling one tank-full should be found (Bogun & Jõgeva, 2005):

$$t_c = t_d + t_w + t_t + t_m + t_r \tag{3}$$

where: t_c is cycle time, needed to bring the tank-full of slurry from storage to the soil, min;
t_d – travel time from the reloading point to the work pass and back, min;
t_w – distribution time on the pass, min; t_t – time for turns in the end of passes, min;
t_m – time for handling and turning before and after the loading, min;
t_r – loading time, min. Most of the values of these elements can be calculated with formulas given in Table 1.

Table 1. Formulas to calculate values of elements of cycle t_c (Bogun & Jõgeva, 2005).

Parameter	Calculation formula	Definitions
Transportation time	$t_d = 120\left(\frac{d_{road}}{v_{road}} + \frac{d_p}{v_p}\right)$	b – effective working width of tanker, m; b_n – nominal width of distributor, m; d_p – distance from field access to the pass, km;
Distribution time on the pass	$t_w = \frac{600Q}{bhv_w}$	d_{road} – distance between storage and field, km; h – slurry application rate, $m^3\ ha^{-1}$; l – length of pass, km;
Effective width	$b = 0.01 b_n \varphi$	Q – volume of tanker, m^3;
Work speed	$v_w = \frac{10W_u}{bh}$	t_{1t} – average time for one turn, h. v_p – average idle speed on the plot, km h^{-1};
Time for turns in the end of passes	$t_t = \left(\frac{t_w v_w}{60l}\right) t_{1t}$	v_{road} – average road speed, km h^{-1} v_w – average work speed, km h^{-1} W – loading capacity, $m^3\ h^{-1}$;
Reloading time	$t_r = 60\frac{Q}{W}$	W_u – unloading capacity, $m^3\ h^{-1}$; φ – factor of use of nominal width, %.

The relation between capacity $A_{\min}$, cycle time t_c and minimum tank volume Q is

$$Q = \frac{t_c A_{\min}}{60} \tag{4}$$

and thus

$$Q = \frac{t_d + \frac{t_m}{60}}{\frac{1}{A_{\min}} - \frac{10}{bhv_w} - \frac{t_{1t}}{6bhl} - \frac{1}{W}} \tag{5}$$

Data used in model experiments. Slurry amount in the farm is 2,000, 3,000, 4,000 or 5,000m^3 and average transportation distance to the field is 1, 3 or 5km. Average distance between field access and work pass as well as length of pass is 0.2km. Number of days is 20 or 40. In all experiments, the length of working day is 10h and the probability of workday is 0.7 (it means that probably 70% of planned work time can actually be used). It is assumed in calculations that tractor-pulled tanker is used. Loading and unloading capacities both are 180$m^3\ h^{-1}$. The average slurry application rate is 20$m^3\ ha^{-1}$ in the case of a 8.4m shallow disc slurry injector and 40 in the case of a 12m trailing hose spreader. Average speed is 20km h^{-1} on the road and 10km h^{-1} for idle travel on the plot. Working speed v_w is calculated with formula given in Table 1. The average turning time for tractor-pulled distributor is 0.47 min per turn; and time for handling and turning before and after the loading is 1.93min (Sørensen 2003). The factor of use of nominal width of distributor φ is 100%.

Values in reference scenario used to make sensitivity analysis are: amount 4000m^3, 20 days, distance 3km, application rate 20$m^3\ ha^{-1}$, pass length 0.4km, width 8.4m, un-/loading capacities 180$m^3\ h^{-1}$ and transportation speed 20km ha^{-1}.

RESULTS AND DISCUSSION

Model experiments with formula 5 show that, the larger is annual amount of manure and the shorter is the time span, the higher is the capacity requirement and thus the bigger tank is needed (Table 2). In the case of 20 days, the 3m^3 of tank volume is satisfying the needs of a farm which has 2,000m^3 slurry annually, average distance 1km and uses a 12m trailing hose spreader with application rate of 40m^3 ha^{-1}. If slurry amount is 5,000m^3, then the tank volume should be 11m^3 at least in the same conditions. Doubling of time span allows to choose a smaller tanker: 2m^3 instead of 3 and 4 instead of 11 regarding the slurry amount.

Table 2. Minimum tanker volume, m^3 depending on number of days, slurry amount, distance, tanker width and application rate.

Distance to storage, km	Number of days and annual yield of slurry in the farm, m^3							
	20 days				40 days			
	2,000	3,000	4,000	5,000	2,000	3,000	4,000	5,000
12m trailing hose spreader, 40m^3 ha^{-1}								
1	3	5	8	11	2	3	3	4
3	7	11	17	24	3	5	7	9
5	10	17	25	36	5	8	10	13
8.4m shallow disc slurry injector, 20m^3 ha^{-1}								
1	4	6	8	12	2	3	4	5
3	7	12	18	26	3	5	7	9
5	11	18	27	40	5	8	11	14

The average distance has proportional impact on the required tank volume. The longer is the distance, the more essential is large tank volume to improve transportation capacity and overall manure application capacity. Economic calculations have shown (Vettik & Tamm, 2010) that if a 12m trailing hose spreader has tank volume 15m^3 and the amount is 4,000m^3, the use of own distributor for slurry transportation is cheaper just until 2km compared to custom lorry. The present calculations show that in similar conditions the interpolated value for minimum tank volume is 12.5m^3 for time span 20 days. The technological accordance between the variability of the production conditions (within reasonable time span) and capacity of distributor were not analysed in those economical calculations. Present calculation shows that until 2km the tank volume 15m^3 is sufficient to serve farm needs in that case.

Parameters have variable impact to the minimum volume of the tanker. A sensitivity analysis was made for six parameters:

The necessary tank volume is most affected by the slurry amount. By changing the amount ±50%, the necessary tank volume is either increased by 19.1m^3 (105%) or reduced by 11.1m^3 (61%). The loading and unloading capacity for tanker is the second most influential factor, but also an inverse proportional factor. The change of capacity ±50% either reduced the volume by 2.6m^3 (14%) or increased it by 17.3m^3 (95%).

Third in the range of impact factors was the field distance - varying it by ±50% either increased or reduced the tank volume by 6.5m^3 (36%).

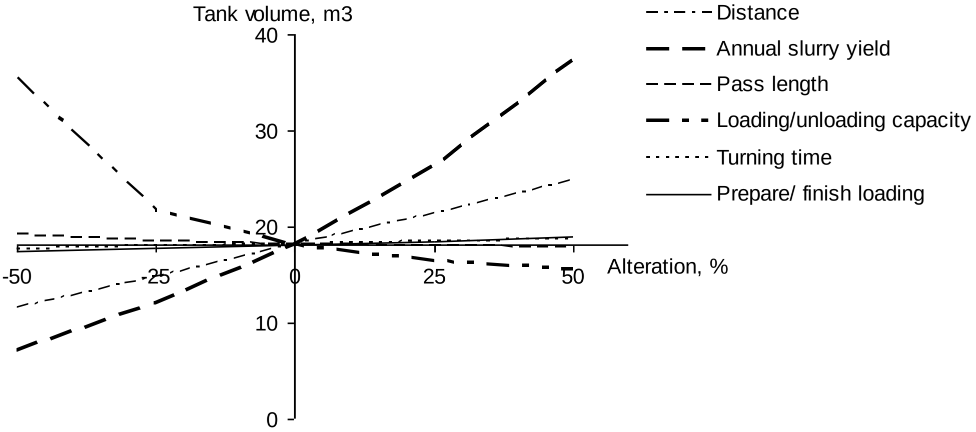

Figure 1. The tank volume of the tractor-pulled tanker with an injector as a function of selected factors varied within the range of ±50%.

Thus, in the frames of reference situation, the average difference of tank volume is: 1) 7,5m^3 per increase of 1,000m^3 of annual slurry, 2) -1m^3 per 10m^3 h^{-1} loading and unloading capacity, and 3) 4.4m^3 per 1km average distance between storage and field access. The other factors (pass length, turning time and prepare/finish loading) have minor impact on the minimum tank volume.

In the present paper the calculation model for determining the minimum slurry tanker volume according to farm conditions has been introduced. The study is continued to improve the selection model for defining the optimum value for tank volume regarding the economical constraints. The power of the tractor pulling the distributor and properties of the soil dragging the distribution equipment are additional constraints which should be taken into account when defining the tank volume.

CONCLUSIONS

The calculation model which can be used to determine the minimum slurry tanker volume according to farm conditions is composed. The calculations made by that model show that the necessary tank volume is most affected by the annual slurry yield and these parameters have a proportional relation. The loading and unloading capacity for a tanker is the second most influential factor increase which results in the decrease of minimum tank volume. The distance between storage and field is also an important factor if manure is transported by the distributor itself.

The study will be continued to improve the selection model to define optimum value for tank volume regarding the economical and technical constraints.

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