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The model to define optimum volume for slurry tanker

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Abstract. 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 the selection model of a tanker a pattern is composed to determine the optimum volume for a slurry tanker. The aim of the paper is to introduce the pattern and give an overview of the model. The optimality criterion is minimum slurry distribution cost. In the results the importance of optimum value for tank volume is discussed and the impact of a non-optimal solution is explained. The the impact of the parameters on distribution costs is also clarified.
The calculations show that the bigger the annual amount, the longer the transportation distance is and the shorter the tolerated distribution period – then the bigger the optimum value is for the tank size if slurry is transported with the distributor itself. Only for short distances (<3 km) and big slurry amounts (>4,000 m^3) is the transportation with the distributor itself a cost benefit.
However, in most of the cases it is cheapest to use a separate tanker for slurry transportation, while the distance has no effect on the optimum size of a distributor tank. There, in most cases only one set of the application equipment is required to supply the farm with sufficient distribution capacity. If an annual amount is 4,000 m^3 or less then a 5 m^3 tank is sufficient to serve a farm with the required distribution capacity. If an annual amount is 8,000 m^3 then a 10 m^3 tank is optimal.

Key words: animal slurry, tank volume, selection of tanker, field distance.

Introduction

In 2008 the organic fertilisers formed 21% from N supply in Estonia and 38% in EU-27; and 41% from P supply in Estonia and 53% in EU-27 crop production (Eurostat 2012). Amounts are correspondingly 78 and 143 kg N; and 9 and 19 kg P per hectare of utilized agricultural land. The results of the inquiry were made to explain the amounts of different kinds of manures in Estonia and revealed clearly that in 2009 slurry formed 68% (1.5 Mt) in the manure yearly handled in IPPC farms (Tamm & Vettik, 2011). Thus the equipment to handle slurry has a wide use in Estonia.

In the market of agricultural machines the amount of slurry tankers offered is diverse. It is a complex task to take into account all 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 the tool to assess the accordance between the size of the slurry tanker and the production parameters of the farm and provide decision support for the selection of a slurry distributor. In the literature, several manure management DSS-s are explained with unlike goals like nutrients, whole farm rating, manure treatment and application (Karmakar et al., 2007).

However, there is no model available in the literature supporting the selection of an appropriate slurry tanker for a farm.

The capacity of a slurry tanker is affected by different variables, such as work width and speed, transport distance, time to prepare and finish 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 16 m^3. In the Estonian market the range of tank volumes of slurry distributors varies between 3–30 m^3 (Agronic, 2011; Fliegl, 2011).

Authors composed a model to calculate the minimum required tank size of a slurry distributor for a farm (Tamm & Vettik, 2011) – this model does not limit maximum volume for the tank. Thus, in the present version of the selection model for a distributor, we composed a pattern to determine the optimum 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 optimality criterion is the minimum slurry distribution cost in a condition that ensures the limits of the model are satisfied. In the results is discussed how important it is to calculate the optimum value for tank volume and cost differences are explained if a non-optimal solution is selected. The impact of the parameters on distribution costs is also clarified.

The model and data

The model to determine the optimum slurry tanker volume for a farm is consisting of several steps:

1) selecting a set of slurry tankers with different tank volumes and defining pump capacity, distributor width as well as the required tractor power for every volume;
2) calculating the performance of an application for every slurry tanker depending on the average distance between slurry storage and fields and the average application rate;
3) calculating the cost of work depending on farm parameters (annual slurry production, average distance between slurry storage and fields, average application rate) if slurry is transported with the tanker itself;
4) calculating cost of slurry handling for every applicator if slurry is transported with separate tank vehicle(s); and
5) defining required number of tankers in farm; and
6) selecting the cheapest solution.

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 by crop areas planned to fertilise with slurry in the farm, and

5) the loading and unloading capacities are equal,

6) the transportation capacity of separate transportation tanks is sufficient to allow distribution without stops.

Distributor performance w_t is calculated with formulas presented by authors in the previous paper (Tamm & Vettik, 2011). Distribution cost is calculated with formulas presented in another previous paper (Tamm & Vettik, 2008). The required number of tankers is calculated with the formula

$$z = \left[\frac{A_{\min}}{w_t} \right] + 1, \qquad (1)$$

where A_{min} – minimum slurry distribution capacity to serve maximum annual time span for slurry distribution, m^3 h^{-1};
w_t – slurry distributor performance, m^3 h^{-1}.

Cheapest solution is selected from all calculations made for both cases – if slurry is transported from storage to fields with 1) tanker itself and 2) separate tank vehicle(s).

Data used in model experiments

Slurry amount in the farm is 2,000, 4,000, 8,000 or 16,000 m^3 and average transportation distance to the field is 1, 3, 5, 10, 15 or 20 km. The average distance between field access and work pass is 0.1 km and length of the pass is 0.35 km. The number of days is 20 or 40. In all experiments, the length of the work day is 10 h and the probability of the workday is 0.7 (it means that probably 70% of planned work time can actually be used). It has been assumed in calculations that a tractor-pulled tanker is used. Loading and unloading capacities (120–300 m^3 h^{-1}) are both selected by tank size (5, 10, 15, 20, 24 m^3) and distributor width (7.5–18 m trailing hoses distributor, 5–12 m shallow disc distributor) (Table 1).

Table 1. Parameters of slurry applicators selected in present model experiments (KTBL 2008)

Tank			Tractor		Trailing hose device		Shallow disc device	
Volume, m^3	Pump, l min^{-1}	Price, €	Power, kW	Price, €	Width, m	Price, €	Width, m	Price, €
5	2,000	12,000	75	54,000	7.5	8,800	5	12,500
10	3,000	22,000	102	70,000	9	1,000	6	15,000
15	4,000	31,500	145	92,800	12	12,000	7.5	17,500
20	4,500	49,000	175	119,700	15	13,000	9	26,000
24	5,000	53,000	205	134,600	18	14,500	12	33,000

The average slurry application rate is 20 m^3 ha^{-1} in the case of the shallow disc slurry injector and 30 in the case of the trailing hose spreader. The average speed is

25 km h^{-1} on the road and 6 km h^{-1} for idle travel on the plot. Working speed v_w is calculated with formula

$$v_w = \frac{10 W_u}{b h}, \quad (2)$$

where W_u – unloading capacity, m^3 h^{-1};
b – effective working width of tanker, m and
h – slurry application rate, m^3 ha^{-1}.

Time for turns in the end of passes per one unloading cycle of tank is calculated with formula

$$t_t = \frac{3.14 Q}{100 h l v_t}, \quad (3)$$

where Q – tank volume, m^3;
l – pass length, km; and
v_t – average turning speed in end of passes, km h^{-1}.

The time for handling and turning before and after the loading is 1.93 min (Sørensen, 2003). The factor of use of nominal width of distributor φ is 100%. The life time of a distributor is 10 years.

The values in reference scenario used for sensitivity analysis are as follows: amount 4,000 m^3, 20 days, distance 3 km.

Results and discussion

As the model experiments show, the farm paramateres have a significant impact on the optimum solution. The bigger the annual amount, the longer the transportation distance and the shorter the tolerated distribution period then the bigger optimum value is for the tank size (Table 2) if slurry is transported with the distributor itself. Only for shorter distances (<3 km) and bigger slurry amounts (>4,000 m^3) has the transportation with the distributor itself come with a cost benefit.

In most cases it is cheaper to use a separate tanker for slurry transportation, where the distance has no effect on the optimum solution. And in most cases only one set of application equipment is required to supply the farm with sufficient distribution capacity.

To evaluate the effect of cost minimisation, the comparative calculations were made in the condition where slurry is transported by a distributor, number of workdays is 20, field distance is 3 km, and annual slurry amount is 4,000 m^3 for both types of distribution equipment (Table 3). The difference of distribution costs per cubic meter of slurry is small. However, if the costs are calculated per hectare, the difference is bigger. The divergence of costs calculated per year or per lifetime of distributor is particularly notable.

The difference of life time costs between the best and second solution is 8,800 € for trailing hoses distributor. Thereby the second equipment (with 10 m^3 tank) is

33,300 € cheaper than the first equipment (with a 15 m^3 tank). The cost benefit for the best solution comes from smaller transportation costs due to a bigger tank size. However for bigger tanks the price of equipment is so high that it cannot be covered sufficiently by smaller transportation costs in chosen production conditions. Results in table 2 show that the longer the transportation distance or the larger the annual amount of slurry then the bigger the tank size should be for optimum solution if transportation with a distributor is made.

Table 2. Minimum cost of slurry distribution K_d (€ m^{-3}), number of distribution units *z* and optimum tanker volume *V* (m^3) depending on number of days (D), slurry amount, distance *d* (km) and transportation method, if trailing hoses distributor or shallow disc distributor is used

D	d	Transportation with distributor								Transportation with separate tanker							
		2,000 m^3		4,000 m^3		8,000 m^3		16,000 m^3		2,000 m^3		4,000 m^3		8,000 m^3		16,000 m^3	
		K_d	z×V	K_d	z×V	K_d	z×V	K_d	z×V	K_d	V	K_d	V	K_d	V	K_d	V
Trailing hoses distributor																	
	0	4.1	1× 5	2.4	1× 5	1.5	1×10	1.3	2×20	-	-	-	-	-	-	-	-
	1	5.5	1×10	3.2	1×10	2.1	1×15	2.8	2×15	5.2	5	3.5	5	2.6	10	2.4	2×20
	3	7.3	1×15	4.4	1×15	3.1	1×24	4.3	2×24	5.2	5	3.5	5	2.6	10	2.4	2×20
20	5	8.8	1×15	5.4	1×15	6.5	2×15	7.9	3×24	5.2	5	3.5	5	2.6	10	2.4	2×20
	10	12.1	1×24	13.1	2×15	14.1	3×24	19.1	5×24	5.8	5	4.1	5	3.2	10	3.0	2×20
	15	14.9	1×24	16.4	2×24	18.1	3×24	30.2	6×24	6.1	5	4.4	5	3.5	10	3.3	2×20
	20	17.7	1×24	19.6	2×24	28.8	4×24	49.8	8×24	6.4	5	4.7	5	3.8	10	3.6	2×20
	0	4.1	1× 5	2.4	1× 5	1.5	1×10	1.0	1×10	-	-	-	-	-	-	-	-
	1	5.5	1×10	3.2	1×10	2.1	1×10	1.5	1×15	5.2	5	3.5	5	2.6	10	2.1	10
	3	7.3	1×15	4.4	1×15	2.9	1×15	2.3	1×24	5.2	5	3.5	5	2.6	10	2.1	10
40	5	8.8	1×15	5.4	1×15	3.7	1×15	5.3	2×15	5.2	5	3.5	5	2.6	10	2.1	10
	10	12.1	1×24	7.6	1×24	9.7	1×24	11.7	3×24	5.8	5	4.1	5	3.2	10	2.7	10
	15	14.9	1×24	9.6	1×24	12.5	1×24	15.5	3×24	6.1	5	4.4	5	3.5	10	3.0	10
	20	17.7	1×24	11.6	1×24	15.3	1×24	25.4	4×24	6.4	5	4.7	5	3.8	10	3.3	10
Shallow disc distributor																	
	0	4.6	1× 5	2.7	1× 5	1.8	1×10	3.2	1×24	-	-	-	-	-	-	-	-
	1	6.2	1×10	3.6	1×10	2.4	1×15	3.8	1×24	5.7	5	3.8	5	2.9	10	4.3	24
	3	8.1	1×15	4.9	1×15	5.8	2×15	7.1	2×24	5.7	5	3.8	5	2.9	10	4.3	24
20	5	9.7	1×15	6.4	1×15	7.7	2×20	8.6	3×24	5.7	5	3.8	5	2.9	10	4.3	24
	10	13.6	1×24	14.0	2×15	15.4	2×24	20.4	4×24	6.3	5	4.4	5	3.5	10	4.9	24
	15	16.5	1×24	18.0	2×24	25.3	3×24	36.9	6×24	6.6	5	4.7	5	3.8	10	5.2	24
	20	19.2	1×24	21.2	2×24	30.5	4×24	51.9	8×24	6.9	5	5.0	5	4.0	10	5.5	24
	0	4.6	1× 5	2.7	1× 5	1.7	1× 5	1.2	1×10		-		-		-		-
	1	6.2	1×10	3.6	1×10	2.3	1×10	1.7	1×15	5.7	5	3.8	5	2.8	10	2.3	10
	3	8.1	1×15	4.9	1×15	3.3	1×15	4.5	2×15	5.7	5	3.8	5	2.8	10	2.3	10
40	5	9.7	1×15	5.9	1×15	4.2	1×24	5.9	2×24	5.7	5	3.8	5	2.8	10	2.3	10
	10	13.6	1×15	8.5	1×24	10.6	2×15	12.5	2×24	6.3	5	4.4	5	3.4	10	2.9	10
	15	16.5	1×24	10.5	1×24	13.4	2×24	21.4	3×24	6.6	5	4.7	5	3.7	10	3.2	10
	20	19.2	1×24	12.5	1×24	16.2	2×24	26.4	4×24	6.9	5	5.0	5	4.0	10	3.5	10

Note: If slurry is transported with a separate tanker, then only 1 distributor is required in optimum solution except production condition where 16,000 m^3 should be distributed with trailing hoses distributor within 20 days

The distribution time should be under 200 h (20 days times 10 h) in the present model experiment. If one distributor is not sufficient to serve the farm within that time, then the number of distributors should be greater. In table 3 the distribution time is given as a sum for both distributors if there are 2 application units used. Results show in table 3 that the distribution period may be only 14 days instead of the required 20 days if one 15 m^3 trailing hose distributor is used. The shorter the required distribution period, the bigger the tank size or number of distributors should be. The calculation shows that the distribution cost for a 24 m^3 tank is 10% bigger than for a 15 m^3 tank, but distribution time is 30% shorter than with the smaller tank (table 3).

Table 3. The comparision of distribution costs and times for different solutions in the same work conditions if slurry is transported by a distributor. The tank 1 x 15 is reference solution (Table 2)

Number of distributors and tank size, m^3	Distribution cost, € m^{-3}	Difference of hectare cost, € ha^{-1}	Difference of annual cost, € $year^{-1}$	Difference of lifetime cost, €	Distribution time, h
		Trailing hoses distributor			
1 x 15	4.37	-	-	-	137
1 x 10	4.59	6.6	880	8,800	192
1 x 20	4.78	12.3	1,640	16,400	111
1 x 24	4.84	14.1	1,880	18,800	97
2 x 5	9.32	148.5	19,800	19,8000	350
		Shallow disc distributor			
1 x 15	4.86	-	-	-	153
1 x 20	5.51	13	2,600	26,000	122
1 x 24	5.66	16	3,200	32,000	103
2 x 10	8.05	63.8	12,760	127,600	209
2 x 5	9.83	99.4	19,880	198,800	360

In production conditions selected for the present model experiment the cheapest solution is to use a 5 m^3 distributor and separate tanker(s) from a service provider for slurry transportation (table 3 and 4). While the transportation distance between field and storage does not affect distribution costs and average transportation distances on the field are short (0.1 km) then a large tank does not have big benefits in simulated conditions.

In the present paper the calculation model for determining the optimum slurry tanker volume according to farm conditions has been introduced. The study is continued to improve the selection model as to define the optimum value for tank volume regarding the economical and technical constraints.

Table 4. The comparision of distribution costs and times for different solutions in the same work conditions if slurry is transported by a separate tanker. The tank 1 x 5 is reference solution

Number of distributors and tank size, m^3	Distribution cost, € m^{-3}	Difference of hectare cost, € ha^{-1}	Difference of annual cost, € $year^{-1}$	Difference of lifetime cost, €	Distribution time, h
Trailing hoses distributor					
1 x 5	3.49	-	-	-	102
1 x 10	3.52	0.9	120	1,200	68
1 x 15	3.81	9.6	1,280	12,800	55
1 x 20	4.50	33.3	4,040	40,400	49
1 x 24	4.71	36.6	4,880	48,800	46
Shallow disc distributor					
1 x 5	3.80	-	-	-	112
1 x 10	3.94	2.8	560	5,600	84
1 x 15	4.31	10.2	2,040	20,400	70
1 x 20	5.23	28.6	5,720	57,200	60
1 x 24	5.53	34.6	6,920	69,200	52

The only benefit from distribution time shortening taken into account in the present model is decreasing the agitation costs, because the agitation period is calculated to be proportional to the distribution period. The model does not take into account other possible benefits related to a shortening of the distribution period like minimising the loss of ammonia from storage or minimising timeliness costs. The shorter the distribution period, the less ammonia loss from manure storage, if it is not covered. It also depends on the average daily temperature and radiation period (Huijsmans, 2003; Agri-Facts, 2008). Possibilities to consider for these parameters in the optimisation model are estimated in future studies.

Conclusions

The calculation model, which can be used to determine the optimum slurry tanker volume according to farm conditions, is composed. The experiments with the model show that the bigger the annual amount, the longer the transportation distance is and the shorter the tolerated distribution period is - then the bigger the optimum value is for the tank size if slurry is transported with the distributor itself. Only for short distances (<3 km) and big slurry amounts (>4,000 m^3) has the transportation with distributor itself come with a cost benefit.

However, in most of the cases it is cheapest to use a separate tanker for slurry transportation, while the distance has no effect on the optimum size of a distributor tank. There, in most cases only one set of the application equipment is required to supply the farm with a sufficient distribution capacity. If an annual amount is 4,000 m^3 or less then a 5 m^3 tank it is sufficient to serve a farm with the required distribution capacity. If an annual amount is 8,000 m^3 then a 10 m^3 tank is optimal.

The comparision of distribution costs for different solutions in the same work conditions show that although the difference of distribution costs per cubic meter of slurry is small then the divergence of costs - calculated per year or per lifetime of distributor - is particularly notable. Over- and underestimation of distributor size can be both economically very unfavourable, in the model experiments 1,200-198,800 € per lifetime of a distributor depending on the selection of tank volume. Underestimation also results in a significant time loss which is the cause of additional possible disadvantages.

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

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References

Agri-Facts. 2008. Ammonia Volatilization from Manure Application. http://www1.agric.gov.ab.ca/department/deptdocs.nsf/all/agdex12064 (29.02.2012)

Agronic. 2011. Slurry tankers. Agronic OY. Haapavesi. Finland. http://www.agronic.fi/en/tuotteet/lietevaunut/agronic_lietevaunut.pdf (09.02.2011)

Eurostat.2012. Agri-Environmental Indicators http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database (29.02.2012).

Fliegl. 2011. Gülletechnik. Fliegl Agrartechnik GmbH. http://www.fliegl-agrartechnik.de/content/files/2010_Prospekt,Guelle%28D%29.pdf (09.02.2011).

Huijsmans, J.F.M. & de Mol, R.M. 1999. A Model for Ammonia Volatilization after Surface Application and Subsequent Incorporation of Manure on Arable Land. *J. agric. Engng Res.* **74**, 73–82.

Huijsmans, J.F.M. 2003. Manure application and ammonia volatilization. Doctoral Thesis. Wageningen University. 160 pp.

Karmakar, S, Laguë, C., Agnew, J. & Landry, H. 2007. Integrated decision support system (DSS) for manure management: A review and perspective. *Computers and Electronics in Agriculture* **57**(2), 190–201.

KTBL 2008. Betriebsplanung Landwirtschaft 2008/09. 21. Auflage, 752 s. (in German).

Sørensen, C. 2003. A Model of field Machinery Capability and Logistics: the Case of Manure Application. Agricultural Engineering International: the CIGR Journal of Scientific Research and Development.

Tamm, K. & Vettik, R. 2008. Case study: Economics of spring feeding in grassland. *Agronomy Research* **6**, 387–396.

Tamm, K. & Vettik, R. 2011. A model for defining minimum volume for slurry tanker. *Agronomy Research* Biosystem Engineering Special Issue 1, 253–259.