Agronomy Research **11** (1), 81–88, 2013

Rational application of mobile machinery for slurry transportation and distribution

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Abstract. The article describes the most important versions of slurry transportation and distribution using mobile machinery. Calculation methods of organisation of work, including formulae calculation and description of work planning procedures are given. The principles of mathematical model development that are used for calculation and analysis of slurry transportation and distribution technological parameters are discussed.

Key words: slurry transportation, slurry distribution, planning of work, mathematical model.

INTRODUCTION

Production and application of slurry essentially facilitate the work of people in agriculture. Therefore, this technology is popular in Latvia and it is used more often (A modern dairy farm ..., 2012). But slurry can be used mainly in spring and autumn when soil is being prepared for sowing of crops (Implementation of environmental protection measures ..., 2006). Besides, the determined agrotechnical terms should be observed and therefore soil preparation is to be done in a limited period of time.

To ensure it, the existing machinery should be rationally used, but in case it is necessary the purchasing of new machinery or renting of the necessary machine should be planned. Besides, it should be considered that for this work different technological alternatives and machinery can be used, the range of which becomes larger with every year. Therefore, the aim of the present work is to develop methods and corresponding software for planning of slurry transportation and distribution using mobile machinery.

MATERIALS AND METHODS

For planning of slurry transportation and distribution the methods of design and calculation of technological lines that are discussed in special literature can be used (Priekulis, 2000). It begins with the stating of the amount of work and time consumption (period) and selection of the necessary machinery. After that the technological lines are calculated for choosing the most rational solution based on the technological and technical-economical criteria, but in the present case – mainly on the aspect of considering the agrotechnical terms.

Determination of the amount of slurry necessary for fertilising is related to the stating of definite field areas where slurry is to be distributed and definition of approximate distribution amount. For this reason the following formula is used

$$M_{iz} = \sum q \cdot S_m \quad (1)$$

where M_{iz} – amount of slurry necessary for fertilising the fields, t; q – average distribution norm in the corresponding field, t ha^{-1}; S_m – field area, ha.

Planning of work should be done in the most hectic period and in most cases it is in spring when soil is to be prepared for sowing. But the slurry distribution period depends on suitability of the definite fields for sowing (dryness) and the agrotechnical terms desirable for sowing of the corresponding crops.

Using mobile machinery two main solutions are possible.

Firstly, all work related to transportation of slurry from the main storage to the place of distribution as well as distribution of slurry can be done by one universal machine. It reduces the amount of machinery and the possible idle time that occurs with unequal work productivity of transport vehicles and machines.

Secondly, for delivery of slurry to the place of distribution, special transport machines can be used, but for distribution on the field – appropriate tractor drawn distributors. In this case roads are less damaged (muddied) along which the slurry machines are moving. In turn, slurry distribution machines can be equipped with wide wheels that improve moving along muddy fields and therefore they damage the soil structure less.

Using the first technological version when for slurry transportation and distribution a universal aggregate is used, the following formulae can be used for the planning of organisation of work.

Length of one trip

$$T_u = T_p + T_{tr.d} + T_{p\bar{a}.1} + T_d + T_{p\bar{a}..2} + T_{tr,t} = \\ = T_p + \frac{L_{tr}}{v_{tr.d}} + T_{p\bar{a}.1} + \frac{10 \cdot V_t \cdot \rho_m}{q \cdot b_d \cdot v_{ie}} + T_{p\bar{a}.2} + \frac{L_{tr}}{v_{tr.t}} \quad (2)$$

where T_u – length of universal aggregate trip, h; T_p – length of transport tank filling, h; $T_{tr.d}$ – length of aggregate moving with full tank to the place of slurry distribution, h; $T_{p\bar{a}.1}$ – aggregate rearrangement length from transport position to working position, h; T_d – aggregate working length on the field, h; $T_{p\bar{a}.2}$ – aggregate rearrangement length from the working position to transport position, h; $T_{tr.t}$ – aggregate moving length from the field to the place of tank filling (slurry storage), h; L_{tr} – slurry transportation distance to the place of distribution, km; $v_{tr.d}$ – aggregate moving average speed during slurry transportation, km h^{-1}; v_{ie} – aggregate moving speed during slurry distribution, km h^{-1}; $v_{tr.t}$ – aggregate moving speed from the field to the slurry filling place (idle), km h^{-1}; V_t – aggregate tank capacity, m^3; ρ_m – slurry density, for cattle slurry 1.01–1.02 t m^{-3}, pig – 1.05–1.07 t m^{-3} (Priekulis, 2008); b_d – aggregate working width distributing slurry, m.

Number of trips (work cycles) possible in one day

$$r_u = \frac{T_s - T_s \cdot T_{atp.h} - T_{s.n}}{T_u}, \tag{3}$$

where T_s – average working day length, h; $T_{atp.h}$ – necessary time for rest calculating per one working hour, approximately 10 min, i.e., 10/60 h; $T_{s.n}$ – time for aggregate preparation and finishing work (before starting to work and at the end of work), h.

Necessary number of trips to prepare the field

$$r_{nep} = \frac{q \cdot S_m}{V_t \cdot \rho_m}. \tag{4}$$

Number of days to prepare the corresponding field if the number of aggregates used is z_u and r_{nep} is rounded to a whole number

$$n_d = \frac{r_{nep}}{r_u \cdot z_u} \tag{5}$$

Total number of days necessary for preparation of all fields with slurry

$$n_{kop} = \sum n_d \tag{6}$$

Using the second technological version when one or several slurry transport aggregates and a separate distribution aggregate are used the calculation formulae are different.

Time of one trip (excluding the possible idle work that can occur due to uncoordinated productivity of work)

$$T_{tr} = T_p + T_{tr.d} + T_{g.tr} + T_{ps} + T_{tr.t} = T_p + \frac{L_{tr}}{v_{tr.d}} + T_{ps} + \frac{L_{tr}}{v_{tr.t}} \text{ and} \tag{7}$$

$$T_{izk} = T_{ps} + T_d = T_{ps} + \frac{10 \cdot V_t \cdot \rho_m}{q \cdot b_d \cdot v_{ie}} \tag{8}$$

where T_{tr} – time of transport aggregate one trip, h; T_{ps} – length of slurry pumping from the transport aggregate tank into the distributor tank, h; T_{izk} – length of slurry distributor one working cycle excluding trips, h.

Number of transport aggregates necessary for serving one slurry distributor aggregate

$$n_{tr} \cong \frac{T_{tr}}{T_{izk}}. \tag{9}$$

After that the result is rounded to a whole number.

The possible slurry distributor idle time $T_{d.iz}$, that can occur due to delay of slurry transport can be calculated as follows.

If $n_{tr} \cdot T_{izk} \geq T_{tr}$, the slurry distributor is working without idle time, i.e., $T_{d.iz} = 0$,

If $n_{tr} \cdot T_{izk} \lhd T_{tr}$, the slurry distributor idle time calculated per one trip is

$$T_{d.iz} = T_{tr} - n_{tr} \cdot T_{izk} . \tag{10}$$

The possible rest time for the tractor driver serving the distributor calculated per one working hour is

$$T_{atp} = \frac{T_{d.iz}}{T_{izk} + T_{d.iz}} . \tag{11}$$

The necessary rest time for the distributor tractor driver in one hour that cannot be compensated with machinery idle time is

$$\Delta = T_{atp} - T_{d.iz} . \tag{12}$$

If Δ is a negative number it means that for the tractor driver's rest the idle time is enough and there is no need for special time to be planned. Therefore, in further calculations it is assumed that $\Delta = 0$.

The possible number of distributor trips per day

$$r_{izk} = \frac{T_s - T_s \cdot \Delta - T_{s.n.}}{T_{izk} + T_{d.iz}} , \tag{13}$$

where $T_{s.n}$ – time for aggregate preparation and finishing work (before starting to work and at the end of work), h.

Necessary number of distributor trips to prepare the corresponding field

$$r_{nep} = \frac{q \cdot S_m}{V_t} . \tag{14}$$

r_{nep} is rounded and the number of days necessary for preparation of the corresponding field is calculated

$$n_d = \frac{r_{nep}}{r_{izk}} . \tag{15}$$

After that similarly the number of days necessary for preparation of other fields is calculated and the total length of transporting slurry is determined

$$n_{kop} = \sum n_d . \tag{16}$$

Based on this methodology the corresponding software is developed.

RESULTS AND DISCUSSION

The advisable planning procedure using the developed software is as follows.

1. Information is summarised on the machinery available on the farm as well as on the rented slurry transporting and distribution machinery. The most suitable working technology is chosen.
2. Information is summarised on every field planned for fertilising (Table 1).

Table 1. Characterisation of slurry distribution situation

No or name of field	Crop grown	Desirable distribution norm, t ha^{-1}	Average slurry transportation distance, km	Field area, ha
Field 1				
Field 2				
...				
Field n				

1. The slurry distribution norms are specified for the total fertiliser not to exceed the amount of slurry accumulated on the farm Mk, i.e., if $M_k \geq M_{iz}$.
2. The necessary input data are inserted in the program and the results are obtained.

As it can be seen in Fig. 1 the procedure of slurry transportation and distribution has to be planned for every separate field. Besides, this calculation depends on the chosen technology. If, for instance, technology 2 is used, when one or more transport aggregates and a separate slurry distributor are applied, the program has to use the calculation scheme given in Fig. 2.

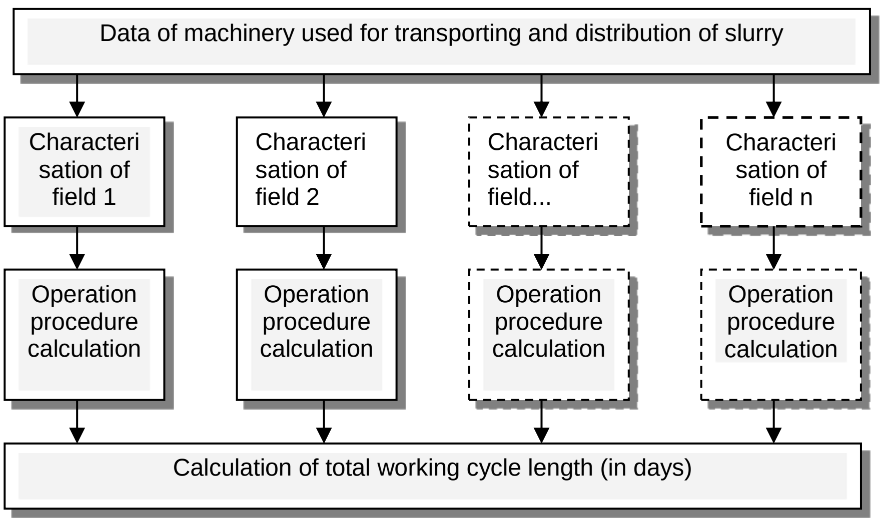

Figure 1. Program blocksheme for slurry transportation and distribution planning.

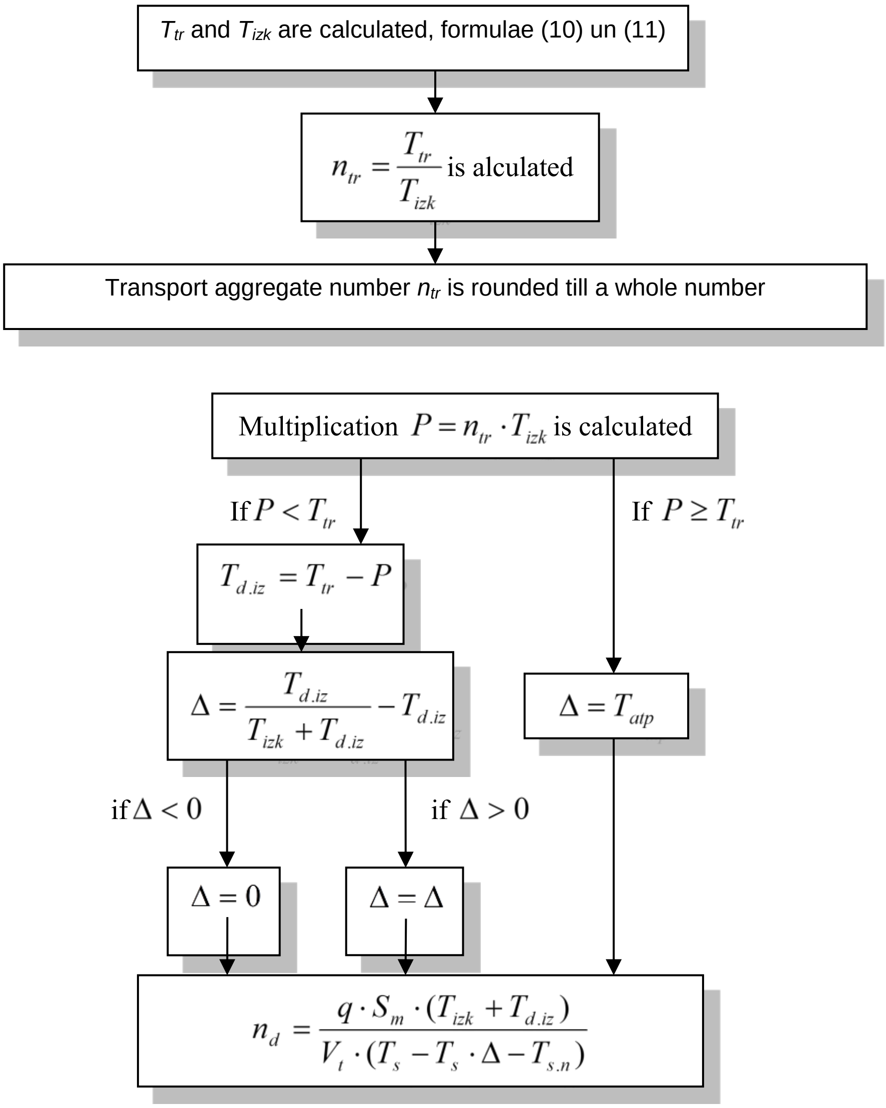

Figure 2. Slurry transportation and distribution procedure calculation scheme using a separate slurry distributor and one or several transport aggregates.

The developed program was tested inserting approximate output data and constructing corresponding graphs. One of these graphs can be seen in Fig. 3.

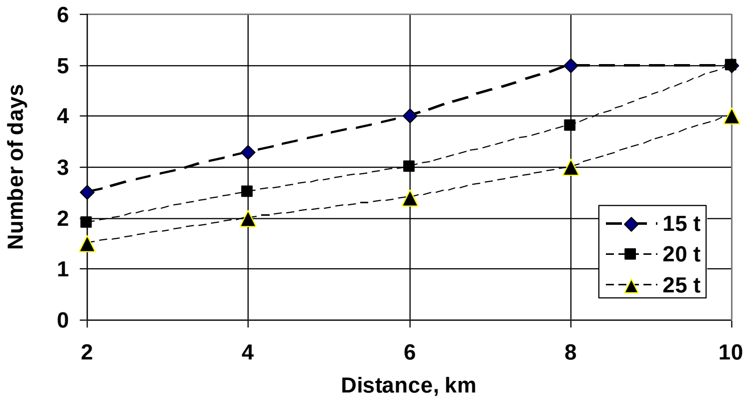

Figure 3. Number of days necessary for slurry transportation and distribution using two universal aggregates (technological version 1), depending on transportation distance and tank capacity.

According to this graph it is possible to conclude that the number of days necessary for completion of work does not increase proportionally to the transportation distance. If, for instance, the transportation distance varies from 2 to 8 km, i.e., four times, the number of days necessary for work increases 2 times. But at greater transportation distance it is still more rational to use machinery with a higher capacity tank as it decreases the time necessary for work.

CONCLUSIONS

1. If for slurry transportation and distribution on fields mobile machinery is used, two technological versions are possible: firstly, to use one or several universal aggregates, secondly, to use one slurry distributor and one or several slurry transportation aggregates, for every technological version a different planning methodology should be used.

2. Using the second technological version it is essential to coordinate the slurry distributor working cycle length with the number of transportation aggregates and the length of one trip as it influences idle time of machinery.

3. For calculation of the time (number of days) necessary for transportation of slurry the methodology described in the present article and program developed by the authors can be used.

ACKNOWLEDGEMENT. This publication has been prepared within the Baltic Sea Region Programme 2007–2013 project 'Baltic Forum for Innovative Technologies for Sustainable Manure Management' (Baltic Manure).

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