

Case study: Economics of spring feeding in grassland

K. Tamm and R. Vettik

Estonian Research Institute of Agriculture, Teaduse 13, Saku, Estonia;
e-mail: Kalvi.Tamm@neti.ee

Abstract. Change in world energy prices influences the price of mineral fertilisers. To meet the globally growing need for food farmers are extending the production of milk and meat, facilitating thereby an increase in manure production. The distance of the grassland from the farm centre and fertiliser prices influences farmers' choices regarding the art and logistics of fertilising. The aim of this study is to compose a calculation model to compare the economic aspects of different fertilising options considering the grassland distance and the art of fertilising. The model contains components from the method applied to evaluate the rationality of exploitation of a field, considering the costs pertaining to field distance. Spring N feeding of grassland was simulated and five technologies were compared with the model.

In calculations it was presumed that manure comes from a farm's own production and the costs arise only from hauling and distribution. In comparison with mineral fertiliser, these costs increase with driving distance; therefore it is economical to use only manure near the farm compound. In average Estonian forage production conditions, the N rate 75 kg ha⁻¹ minimum value using cattle slurry distribution with a shallow injection system is more economical than using mineral fertiliser.

It can be also concluded that compared to a distributor, using a tank truck for hauling slurry is beneficial on farther parcels (under the conditions in the simulation, farther than 4.2–5 km), as in those cases the hourly operation cost of the slurry distributor is very high.

Key words: grassland distance, fertilizing, mineral fertiliser, slurry, transportation cost

INTRODUCTION

Prices of important inputs – energy, labour and mineral fertilisers - of agricultural production went up significantly last year. It is critical for the farmer to find ways to limit the increase of production costs. One possibility would be to find cheaper ways to feed crops. If a farm has its own slurry, it is useful to know under what conditions it is rational to use slurry instead of mineral fertiliser. In farming, dairy manure can be treated as a free good to everyone except the dairy farmer, who needs to dispose of this natural by-product of milk production. Using the manure as a source of plant nutrients in place of commercial fertilizers can offset manure disposal costs. The cost of commercial fertilizers versus the combined costs of manure loading, transportation, and application to land are economic variables influencing the level at which dairy manure could substitute for commercial fertilizer. The transportation and use of surplus dairy manure in deficit areas may result in overall improved water quality in the study region. Also, dairy manure, as a substitute for current, commercial fertilizer, could help farmers economically. Manure redistribution can reduce nutrient leaching and runoff

into water bodies (Adhikari et al., 2005). Additionally, the slow release of nitrogen in manure may reduce N leaching and thereby protect water quality (Bosch & Napit, 1992). The majority of research work related to the economics of dairy manure as a substitute for chemical fertilizers and the associated economics of its loading, transportation and land application is generally of more recent origin (Somda et al., 2003; Osei et al., 2003a,b; Ribaud & Agapoff, 2004).

By recommendation, the fertilisers containing nitrogen are distributed onto the grasslands within a week after grasses have started to grow in spring. According to the 'Integrated pollution prevention and control act', farms with intensive animal production should establish the best available technique for handling manure (Saastuse ..., 2001). Accordingly, in spring the slurry should be distributed onto the grassland only with a distributor outfitted with a trailing hose or injection system. The initial capital investment for these techniques is greater than for conventional broadcast spreading with a splash plate (Rodhe & Rammer, 2002). Therefore farmers should consider the possibility of using custom operators for this work.

The technologies and economics of spring feeding of cereals are being studied in several locations around the world (Mattila, 2006; Hiltbrunner et al., 2005; Huijsmans et al., 2003; Leick, 2003). It is possible to establish the same technologies for the grasslands. Animal slurry is transported in tankers, which is both laborious and technically demanding. For all countries within the European Union, manure transport incurs considerable operating costs (Sørensen et al., 2003). Despite the higher cost when compared to manure, it is more beneficial to use mineral fertilisers in the case of long driving distances because of lower transportation costs. The aim of this study was to compose a calculation model to clarify fertilising costs of mineral fertiliser versus slurry depending on driving distance to the grassland and to compare costs of different technologies. The distance is important because various types of fertilisers have significantly different rates per hectare, resulting in drastic effects on transportation costs. The outcome of this study, which includes a calculation model to estimate fertilising costs, should assist farmers in their decision-making regarding transportation distances and fertilising options. Costs for different application techniques are computed with regard to distances between grasslands and farm centres with the help of the model.

In the given study, the following five technologies have been compared: 1) spreading of mineral fertiliser with disc distributor and using a vehicle to haul fertiliser to the field; 2) spreading of mineral fertiliser with custom disc distributor, using a farm vehicle to haul fertiliser to the field; 3) hauling and distribution of liquid manure with the same implement; 4) hauling of liquid manure to the field with custom tank truck and distributed with slurry distributor; and 5) hauling of liquid manure to the field with custom tank truck, distributed with custom slurry distributor.

MATERIALS AND METHODS

Data used in simulation

It is presumed in calculations that the farm has 400 ha of arable land with 100 ha of grassland. Spring feeding on this land is done to meet the nitrogen requirement. In simulation the calculations are made for fertilisation rates 100 and 75 kg N ha⁻¹ (Table 1). Slurry features nitrogen both in the inorganic (mineral) as well as in the

organic formula. The mineral nitrogen, mainly as ammonium ions (NH_4^+), is easily obtainable by plants but is volatile to the atmosphere (Leick 2003). The hectare rate of slurry is determined taking into account the average total ammoniacal nitrogen (TAN) content in cattle's slurry (2 kg t^{-1}) (Rodhe & Rammer, 2002). Presuming that the average ammonia volatilisation after shallow injection is assessed to be 5% of TAN applied by the manure (Rodhe & Rammer, 2002), then the average nitrogen amount in soil available for plants is 1.9 kg t^{-1} thus the rate of slurry distributed to the grassland is calculated (Table 1). Price of ammonium nitrate (34% N) is 355.82 € t^{-1} .

Table 1. Fertiliser distribution rates corresponding to the need of nitrogen.

N rate, kg ha^{-1}	Ammonium nitrate rate, kg ha^{-1}	Slurry rate, t ha^{-1}
75	220	40
100	294	53

Technologies and machines

To calculate total cost of a technology per hectare, the following costs are summed up:

- in technology No. 1: the spreading and hauling cost as well as transportation cost of the mineral fertiliser and distributor;
- in technology No. 2: the spreading and hauling cost of fertiliser and cost of the mineral fertiliser;
- in technology No. 3: the spreading and hauling cost of the slurry using farm machines;
- in technology No. 4: the spreading (farm applicator) and hauling (custom vehicle) cost of slurry as well as transportation cost of the distributor ;
- in technology No. 5: the spreading and hauling cost of the slurry using custom machines,

For spreading of the mineral fertiliser, a 75 kW tractor and rotating disc distributor are used. Field work cost for a particular machine is estimated with algorithms of machinery hourly cost (Edwards 2005). The mineral fertiliser is hauled to the field by a 150 kW tractor and a 10 t wagon. For distribution of a 150 kW tractor and liquid manure distributor with shallow injection system is used (tanker size 15 m^3 and work width 6 m). The slurry is transported to the field by a custom truck with 29 m^3 - sized tank. The cost of the custom work for the mineral fertiliser distributor in technology No.2 is 4.80 € ha^{-1} and for the manure tank with shallow injection system in technology No.5 is 2.12 € t^{-1} .

Calculation model

Since the present paper concentrates on the influence of field distance on the choice of fertilising technology, it also includes calculations of the transportation cost of distributing machines. The model works both in the case of mineral as well as organic fertiliser spreader provided that fertiliser is transported to the field by a separate vehicle. The transportation costs are calculated by means of the model composed previously to estimate the rationality of exploiting a field, whereas the decisive criterion is the distance to the farm centre (Tamm, 2006).

The longer the distance to the field, the more time and resources are wasted to drive an aggregate (Steinsholt, 1997). Driving cost of the aggregate for a unit of area is calculated with formula

$$K_{s,1,p} = \frac{dn_t ZP}{vF} \quad (1)$$

where d is driving distance between the machine centre and the field (km), n_t number of drives between the machine centre and the field in a work day (e.g. driving to the field in the morning and back in the evening $n_t=2$), P hourly cost of idle drive of the aggregate (€ h^{-1}), v driving velocity of the aggregate (km h^{-1}), Z the number of field visiting times needed to perform the work on the field and F field area, ha. The grassland area used in the simulation was 20 ha.

Hourly cost of the idle drive of an aggregate is calculated with the following formula

$$P = P_t + P_r, \quad (2)$$

where P_t - hourly cost of driving of a tractor, (€ h^{-1}) and P_r hourly cost of transportation of an implement, (€ h^{-1}).

A rental machine has a defined rental price, thus hourly driving cost is equal to the rental price. With regard to use of the farm's own? aggregate, calculating the hourly cost of an idle drive tractor and machine should be handled separately. In that case the components of the fixed costs of the machine - depreciation, interest, housing costs and insurance - are presumably reflected in hourly costs of the field operation and thus in the prime price of a product with the intention to be compensated. Considering these fixed costs also as the hourly cost of an idle drive could result in double costing because all the costs will be reduced to hectare costs.

The driving distance also has an influence on the vehicle, primarily through "wear and tear" on vehicle wheels. Additionally the vehicle is affected by vibration due to the bumps in the road, which can affect working parts and accelerate depreciation. However, calculation of the latter factors is complex and is too insignificant to be taken into account.

The components of variable costs should be summed up to calculate the hourly cost of a tractor:

$$P_t = k_f + k_m + k_j + k_h, \quad (3)$$

where: k_f - fuel cost of tractor, (€ h^{-1});

k_m - lubrication cost of machine, (€ h^{-1});

k_j - labour cost, (€ h^{-1}) and k_h maintenance cost of machine, (€ h^{-1}).

To determine work duration including driving time to the grassland and back, we must calculate the number of days of an aggregate's work on the grassland:

$$\bar{z}_m = \frac{F}{\sum_{i=1}^n w_i \tau \left(T_{t,i} - \frac{dn_t}{v_i} \right)}, \quad (4)$$

where: w - hourly performance of an aggregate, not considering the time needed to drive to the field and back (ha h^{-1});

τ - time loss factor, not considering the drives to the field and back;

n - number of aggregates simultaneously working on the same parcel;

T_t - length of a work day (h day^{-1}).

As we are interested in the number of field visiting times Z related to integer of the number of working days z_m , an integer of any digit will be marked by square brackets.

If $z_m > [z_m]$ i.e. fractional number of work days is bigger than integer of that, then

$$Z = [z_m] + 1, \quad (5)$$

where Z - number of times an aggregate should visit the field to perform an operation.

If $z_m = [z_m]$, then $Z = z_m$.

The cost of mineral fertiliser transportation to the grassland is calculated by applying the following formula:

$$K_{v,s} = \frac{d (2P_m + P_f \mu_0)([Y] + 1) + P_f (\mu_t [Y] + \mu_j)}{F v}, \quad (6)$$

where: P_f - the cost of fuel and lubricants per one work hour if whole payload of vehicle is utilised (€ h^{-1});

P_m - the sum of other costs of tractor plus hourly cost of wagon (€ h^{-1});

μ - the factor considering fuel consumption depending on the usage rate of payload (μ_0 - idle drive, μ_0 - fully loaded ja μ_j - partially loaded);

Y - the number of trips needed to haul one type of material.

The transportation aggregate is usually loaded only for a part of the hauling cycle and is idle during the remainder of the cycle, which causes differences in fuel and lubricant consumption due to varying loads of an aggregate. Therefore when hauling materials (incl. fertilisers) for calculating P_m , all fixed and variable costs are considered except the expenses for fuel and lubricants.

The amount of material related to the field is often so large that several hauling cycles are needed. Thus, the hauling costs for one material depend on the number of trips to the field. If the amount of material is smaller than the payload of a transporter, nevertheless a trip will be needed unless there is another option for a haul (e.g. hauling the seed in the box of driller). If one type of material is hauled, the number of hauling cycles of a transporter will be calculated with the formula:

$$Y = \frac{pF\lambda}{\times g}, \quad (7)$$

where: g - payload of a transporter (kg);
 p - amount of material (kg ha⁻¹);
 λ - share factor of a transporter hauling one type of material (if whole material is hauled by one transporter, then $\lambda = 1$).

The hourly application cost of slurry distribution aggregate is calculated with the formula

$$K_{ov,l} = K_t + W_{v,ha} K_l, \quad (8)$$

where: $K_{ov,l}$ - hourly work cost of slurry distribution aggregate, (€ h⁻¹);
 K_t - hourly cost of tractor, (€ h⁻¹);
 K_l - hectarecost of slurry distributor, (€ ha⁻¹);
 $W_{v,ha}$ - operation performance of aggregate (ha h⁻¹).

The performance is calculated with formula

$$W_{v,ha} = \frac{0.8 Q}{l(T_{hl} + T_{k1} + T_{k2} + T_{ik})}, \quad (9)$$

where: Q - tanker size (m³);
 l - amount of slurry, (m³ ha⁻¹);
 T_{hl} - the amount of time spent for loading of slurry (h);
 T_{k1} - the amount of time spent for travelling from manure pit to the grassland (h);
 T_{k2} - the amount of time spent for spreading of slurry (h);
 T_{ik} - the amount of time spent for idle drive back to storage (h).

If custom work for transportation of slurry to the grassland is used, then tanker lorry with initial cost 1.22 € m⁻³ is rented. If the distance is longer than 7 km, then 0.06 € m⁻³ per every additional km must be added to the initial cost, and the price of custom work is calculated with formula:

$$K_{v,e} = a + b(d_v - d_t), \quad (10)$$

where: a - the initial cost of slurry transportation (€ m⁻³);
 b - the appended cost for additional distance, (€ km⁻¹);
 d_v - field distance from slurry pit (km);
 d_t - the value of distance triggering additional cost (km).

Hourly cost for slurry spreading is calculated also with formula (8), the difference is in formula (9) where amounts of time spent for travelling between the manure pit and the field are not considered.

RESULTS AND DISCUSSION

A mathematical model was composed to analyse the economical aspects of different fertilisation technologies depending on the driving distance to the grassland. Average representative data for agricultural plant production conditions in Estonia was chosen for performing the simulation calculations and a comparison of five fertiliser application technologies. The research method is an analytical one making use of simulations without any actual experiments and the results have a functional correlation with initial data. Therefore, as the statistical analysis of the results would not provide any additional crucial information, it has not been included in the paper.

The calculation model considers the cost of fertiliser itself, cost of distribution, and cost of transportation of technological material and machines in regard to the distance of grassland. The model enables simulating different fertilising options and performing economical comparison between different opportunities in the defined situation. The costs of fertiliser application were calculated for the selected range of grassland distance and manure application techniques (Figs 1 and 2). If custom work was used in the case of the slurry (technologies No. 4 and 5) then the fertilisation cost per hectare was constant until 7 km, at which point the additional transportation cost triggered from increased distance to the grassland was calculated. Compared to slurry, in the case of the mineral fertiliser the fertilising costs (technologies No. 1 and 2) were less influenced by field distance, because the amount and thus transportation cost of slurry were much higher.

If 75 kg N ha^{-1} is given to the parcel with fertilisers, then the lowest costs appeared in technology no. 2, where the custom applicator for mineral fertiliser was used (Fig. 1) The high cost of ammonium nitrate (355.82 € t^{-1}) was compensated by low cost of distributing (4.80 € ha^{-1}). Using the farm's own distributor (technology no 1) was more expensive, because the cost of application was 9 € ha^{-1} plus transportation cost of the applicator.

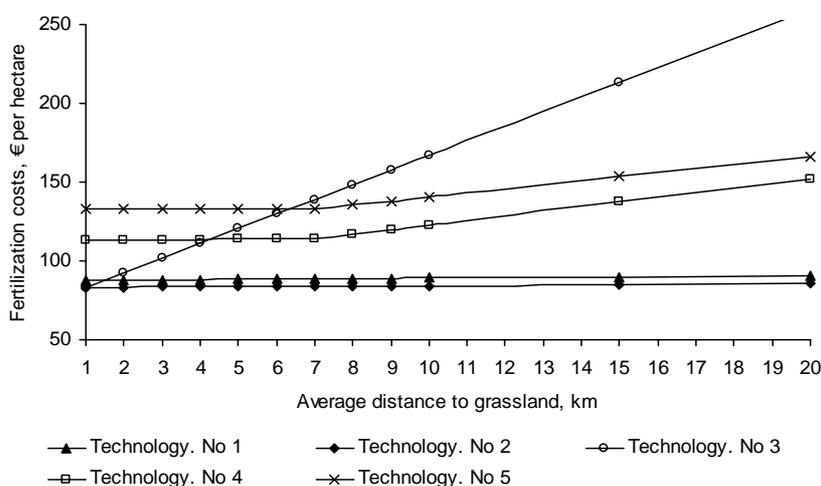


Fig. 1. The fertilisation cost depending on field distance in the five technology variants, when 75 kg ha^{-1} nitrogen with fertiliser is given.

For distributing slurry up to a grassland distance of 4.2 km, the technology no. 3 (own machines) had lowest costs; for further fields, technology no. 4 (custom tank truck) proved most economical (Fig. 1). The cost of technology No. 3 is lower at short distances as compared to technologies No. 4 and 5, because there is no expense for a tank truck. If the distance to the slurry storage is short, then hauling with the distributor costs less compared to custom lorry. In case of the application rate 75 kg N ha^{-1} the hauling of slurry by custom lorry costs 48.6 € ha^{-1} until 7 km. If grassland is situated close to the manure supply, the cost of slurry transport is almost negligible. But a slurry distributor with a shallow injection system and powerful tractor are expensive, so the cost of one work hour of this application aggregate was higher than with a tank truck. The farther the parcels, the more time the distributors must spend on the road, and transportation costs per hectare grow more quickly than in technologies where a tank truck is used.

If 100 kg N ha^{-1} is applied to the parcel with fertilisers, technology no. 3 (slurry, own machines) had lowest costs until grassland distance of 2.2 km, and for more distant fields (Fig. 2).

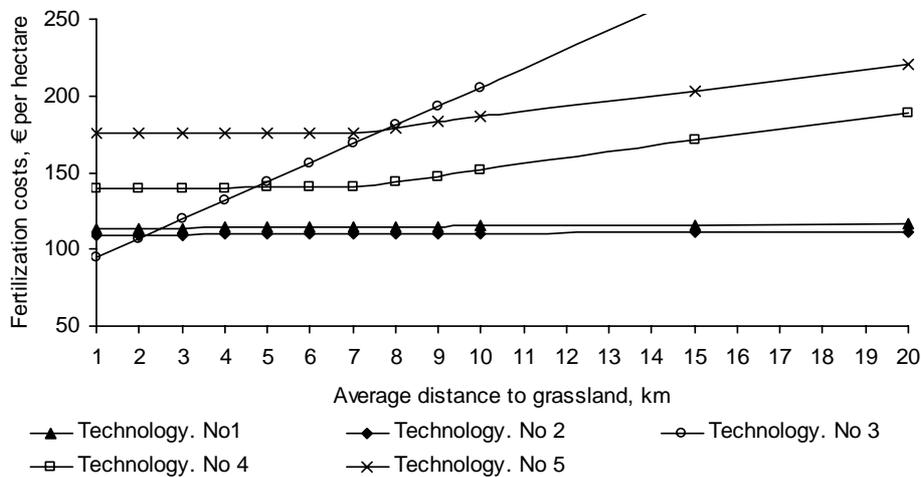


Fig. 2. The fertilisation cost depending on field distance in case of five technology variants, when 100 kg ha^{-1} nitrogen with fertiliser is given.

For distributing slurry up to grassland distance of 4.8 km, the technology no. 3 (own machines) had lowest costs and for more distant fields, no. 4 (custom tank truck) was the most economical technology (Fig. 2).

The greater the need for N per hectare, the more fertilisers must be brought to the soil. The high cost for ammonium nitrate transcends handling costs of slurry in short transportation distances. In the simulated situation, N rate 75 kg ha^{-1} is the minimum value where using the slurry is economical as compared to mineral fertiliser (Fig. 1).

Thus, the model provided examples that can be used as the presumptions for making the use of slurry more profitable than mineral fertiliser:

- high cost of mineral fertiliser – In Estonia, the price of mineral fertilisers doubled last year;
- the TAN content of slurry should be as high as possible, to obtain lower overall amounts of slurry and thus lower operation costs per hectare;
- minimum average ammonia volatilisation after slurry application;
- minimum slurry application machinery costs;
- high N application rate per hectare, and
- short distances between grassland and slurry supply.

CONCLUSIONS

1. In our calculations it was presumed that manure comes from a farm's own production and the only costs arise from for hauling and distribution. When compared to mineral fertiliser these costs grow more rapidly with the increase of driving distance, and therefore it is more economical only to use manure near the farm compound. In average Estonian plant production conditions N rate 75 kg ha⁻¹ is the minimum value at which cattle slurry distribution with shallow injection system is profitable compared to mineral fertiliser.

2. It can also be concluded that compared to a distributor, using a tank truck for hauling of slurry is beneficial on distant parcels (in the example used in our simulation the distance limit is 4.2–5 km), because the hourly operation cost of a slurry distributor is very high.

3. In this study, some cost calculations are described. Other parameter settings will often result in different outcomes. The standardised model calculations enabled a meaningful comparison of the costs of different N application options considering grassland distance to the farm centre. A further stage in the research will include a cost analysis for P and K supply to the soil, considering expenses of the fertiliser and machinery.

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