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THE DEPENDENCE ON THE STRUCTURE OF MACHINERY AND THE LOCALITY OF PLOTS ON CEREAL FARM WORK ACTIVITIES

TERAVILJAKASVATUSE ETTEVÕTTE TÖÖTULEMUSTE SÕLTUVUS MASINAPARGI KOOSSEISUST JA PÕLDUDE ASUKOHAST

KALVI TAMM

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II Möller, H., Asi, M., Soonets, K. and **Tamm, K.** 1998 Optimum yearly operation time of machinery in a grain growing farm/ Proceedings Informational Conference of Science: Machinery, Soil, Harvest. Kaunas, p 12.

III Möller, H., Soonets, K., Asi, M., Vettik, R. ja Tamm, K. 2000. Keskmisest veokaugusest ringi ja ellipsi sisepiirkonna kujulistes taludes. APS Toimetised 12, Tartu, lk 39-42

IV Asi, M.,Möller, H., Soonets, K. **Tamm, K**. and Vettik, R. 1999. Optimization of crop-growing farm and its machinery park parameters/ Actual tasks on agricultural engineering. Proceedings.// 27. Inernational Symposium on Agricultural Engineering// Opatija, Croatia, p 21-27.

V Möller, H., Asi, M., Soonets, K., **Tamm, K**. ja Vettik, R. 2000. Suviteravilja saagikuse sõltuvus külviajast. Põllumajandustehnika, -ehitus ja -energeetika. EPMÜ teadustööde kogumik, nr 206. Tartu, , lk 108-12.

VI Möller, H., Asi, M., Soonets, K., **Tamm, K**. ja Vettik, R. 2001. Teraviljandustalu masinapargi koormamisest, APS Toimetised nr 15, lk 49-50

VII Möller, H., Asi, M., **Tamm, K**. ja Vettik, R. 2001. Teraviljandustalu ja selle masinapargi töökoormuse optimeerimisest. Põllumajandustehnika, -ehitus ja -energeetika. EPMÜ teadustööde kogumik, nr 214. Tartu, lk 176-183.

VIII **Tamm, K**.. 2001. Optimization of operation time of a cereal-growing farm machinery according to the farm's profit and profitability. Research for rural development. International Scientific conference proceedings, Jelgava, LUA, , p 89-92.

IX **Tamm, K**.. 2002. Optimisation of a cereal growing farm's machinery operating time. Actual tasks on agricultural engineering. Proceedings of the 30. International symposium on agricultural engineering. Faculty of Agricultural University of Zagreb,Croatia, p 67-76.

X **Tamm**, **K.** and Loko. V. 2004. Economic aspects of grain growing technology. Agronomy 2004. Transactions of EAU 219, Tartu. 34-36 pp.

XI Loko, V, Koik, E and **Tamm, K.** 2005. Profitability of grain and oilseed production in Estonia: future prospects. Agronomy Research 3. 81-90 pp.

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XIII **Tamm, K**.., 2006. Travel distance and and field costs. Actual tasks on agricultural engineering. Proceedings of the 34. International symposium on agricultural engineering. Faculty of Agricultural University of Zagreb,Croatia, 415-425 pp.

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XV **Tamm, K.** and Vettik, R. 2008. Influence of field distance to the choice of fertilising options: Case study of spring feeding of winter cereals. Proceedings of 13th International Conference „Biosystems Engineering And Processes In Agriculture“ . Institute of Agricultural Engineering Lithuanian University of Agriculture (Raudondvaris, Kaunas r., LITHUANIA). September 25-26, 2008. 176-180 pp.

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SYMBOLS AND ABBREVIATIONS

Latin script

a, a_1, a_2, a_3, a_4, b, b_1, b_2, b_3, b_4, c_1, c_4, d_4 - regression coefficients;

a_e - length of longer half-axis of ellipse, km;

A_h - housing area needed for a machine, m^2;

a_p - length of loan period, years;

B - farm's income, EEK/ha;

b_g - average value of regression coefficient b for spring cereals;

b_w - average value of regression coefficient b for winter cereals;

C - number of days deviating from the best sowing day;

C_1, C_2 - deviation of starting and completion day of sowing period from the best sowing day, days;

c_a - depreciation allowance of a machine, EEK/h;

C_d - sum of travelling durations affecting sowing period, days;

$C_{d,k}$ - travelling duration of sowing unit, days;

$C_{d,r}$ - sum of travelling durations affecting sowing time, if all work is done sequentially, days;

c_f - fuel cost of a tractor, EEK/h;

c_g - cost for housing of a machine, EEK/h;

c_h - maintenance cost of a machine, EEK/h;

c_i - interest, EEK/h;

c_j - labour cost, EEK/h;

c_k - insurance of a machine, EEK/h;

C_k - sowing period without considering travelling time, days;

c_m - lubrication cost of a machine, EEK/h;

d - travelling distance between farm centre and the plot, km;

d_i - travelling distance, used in calculation cycle i, km;

D_j - time that FOUs need, starting with departure to the plot until accomplishing the operation on the plot, in the case of remaining day, h;

d_k - average travelling distance in the farm, km;

d_s - travelling distance, if travelling costs are larger than a limit value, km;

D_t - length of a work day, h/day;

$D_{t,k}$ - length of a work day of sowing unit, h/day;

d_v - travelling distance, if travelling costs are smaller than a limit value, km;

e - eccentricity of elliptical farm;

$E(e)$ elliptic integral of the second kind, which value can be found from the table of elliptic integrals according to the value of eccentricity of an ellipse;
f - number of sectors of a round;
F - area of a plot, ha;
F_a - daily performance of an FOU, ha/day;
F_e - area of arable land in a farm, ha;
F_j - area, processed during residual day, ha;
F_{opt} - the optimal value of arable farm land, ha;
FOU - field-operation unit: it is tractor-implement unit or self-propelled machine;
g - payload of a transporter, kg;
G - fuel consumption, kg/h;
g_k - payload of a transporter with the corrected number of full loads, kg;
G_k - fuel consumption if the payload of a transporter is fully utilized, l/h;
G_t - fuel consumption of a transporter if idle travel, l/h;
h - average yield in a farm, kg/ha;
H - purchase price of a machine, EEK;
h_1 - average yield on a farm considering sowing time without travelling duration, kg/ha;
h_2 - average yield in a farm considering sowing time with travelling duration, kg/ha;
H_h - cost for housing unit, EEK/m^2;
h_{max} - yield from farm area, seeded in the best day (yield is the highest), kg/ha;
H_r - remaining value of machine, EEK;
h_t - yield from farm area, seeded in a day C, kg/ha;
i_{hk} - interest of housing % of price;
I_k - traffic insurance and technical inspection charge, EEK/year;
i_p - rate of interest, %/year;
i_{vk} - rate of property insurance, %/year;
J_{ag} - remaining amount of material, transported by one transporter, kg;
J_{min} - minimum transported amount, kg;
J_s - sum of remaining amounts for all transporters, kg;
j_z - relative length of remaining day;
K - sum of production costs per unit of area, EEK/ha;
K_h - costs depending on travelling distance, EEK/ha;
$K_{h,max}$ - maximum value of costs depending on travelling distance, EEK/ha;

K_i - sum of travelling costs, calculated in cycle i, EEK/ha;

K_m - costs, not depending on travelling distance, EEK/ha;

l - ratio between radius of the round and a (distance between the centre of transport and the centre of the round);

$L(e, a, \beta)$ - function, characterizing position of transportation centre in relation to the centre of ellipse;

M - travelling cost of service vehicles for one production year, EEK/ha;

M_1 - travelling cost of service vehicles for one plot visit, EEK/ha;

m_h - health insurance rate, %;

m_p - vacation fee rate, %;

m_s - social tax rate, % ;

m_t - unemployment insurance rate, %;

n - number of working FOUs;

N_m - nominal effective power of the engine of a tractor or a self-propelled machine, kW;

n_t - number of travels between the farm centre and the plot in a work day;

o - number of field operations, performed per crop;

O_f - rate of personal financing, % of loan sum;

p - operator's hourly fee , EEK/h;

P - hourly cost of travelling of an FOU, EEK/h;

P_a - hourly cost of idle travel of a transporter, EEK/h;

P_f - fuel and lubricant cost for one work hour, EEK/ha;

p_h - rate of additional compensation for maintenance, % of operator's hourly fee;

P_h - price of work hour of a trailer belonging to the transporter, EEK/h;

P_l - price of working hour of a transporter, EEK/h;

P_m - sum of other components of hourly cost of transporter, EEK/h;

$P_{m,t}$ - sum of other components of hourly cost of a tractor belonging to transporter, EEK/h;

P_r - hourly cost of transportation of an implement, EEK/h;

P_t - hourly cost of travelling by tractor, EEK/h;

P_{te} - hourly cost of travelling by service vehicle, EEK/h;

q - specific fuel consumption, kg/kWh;

Q - amount of material, kg/ha;

r - sale price of cereal, EEK/t;

R - radius of area of a round-shaped farm, km;

r_k - price of fuel, EEK/l;

r_m - price of lubricant, EEK/l;

s - cost of maintenance, % of replacement price of machine;
S - total yield of a farm, kg;
T_a - lifespan of a machine, years;
TAN - total ammoniacal nitrogen;
t_b - the time an FOU spends on plot visits, h;
T_h - lifespan of housing, years;
t_{ml} - unloading time, h;
t_{mp} - time that FOU needs to move between the plot and the farm centre, h;
t_{ot} - duration of the work not concerning time consumption for travelling to the plot and back, h;
t_{pl} - loading time, h;
t_s - travelling duration of a transporter, h;
t_t - time that an FOU needs to process the share of the plot F_a, h;
u - rate of lubricant consumption, % from fuel consumption;
U - travelling cost of an FOU for one production year, EEK/ha;
U_1 - travelling cost of an FOU for one work day, EEK;
$U_{1,v}$ - travelling cost of an FOU considering the number of days for the certain operation, EEK/ha;
U_{hs} - travelling cost of an FOU for unit of area, EEK/ha;
v - travelling speed of the FOU, km/h;
V - transportation cost of the materials to the plot or from the plot, EEK/ha;
V_1 - cost of one cycle of transport of a material, EEK/ha;
$V_{1,a}$ - cost for idle travel, EEK/h;
$V_{1,l}$ - cost for loaded travel, EEK/h;
v_k - travelling speed of the sowing unit, km/h;
V_s - cost of transporting one material, EEK/ha;
v_{te} - travelling speed of the service vehicle, km/h;
w - hourly performance of an FOU not considering the times needed to travel to the plot and back, ha/h;
W - annual work capacity, h/year;
w_h - hourly performance of FOU, ha/h;
w_{ml} - unloading performance, t/h;
w_{pl} - loading performance, t/h;
w_v - performance of transporter, t/h;
x - factor of the payload usage of a transporter considering a specific material;
x_j - usage of payload of FOU transporting remaining load;
Y - number of travels to transport of one type of material;
Y_j - relative rate of remaining load;

$Y_{j,k}$ - relative rate of remaining load for a transporter that was not fully loaded with the remaining amount of a material;

Y_k - corrected number of transport cycles for transporters;

Z - number of days an FOU should visit the plot to perform a specified operation;

Z_k - the number of days a sowing unit should visit a plot to seed it; and

z_m - a period within which an FOU needs to perform a certain operation on the plot, days.

Greek script

α - distance between farm centre and centre of a round, km;

Γ, Φ - rise and initial ordinate of graph of equation;

γ_i - distance between the centre of circle and longer edge of belt *i* in circular shaped farm, km;

δ - tolerance of solution, EEK/ha;

ΔB - income loss, caused by travelling duration, EEK/ha;

Δh - yield loss, caused by travelling duration, kg/ha;

ΔS_e - total yield loss in the farm, caused by travels to the plot, t;

ε_i - distance between x-axis in polar co-ordinates and further edge of sector *j* on a circular shaped farm;

θ - factor showing the portion of the tillage area of spring cereals that is not seeded before seeding the observed plot, %;

$\varkappa$ number of belts in the circle;

λ - share factor of a transporter, transporting one type of material;

μ, μ_0 - factors representing fuel consumption according to use of payload of a transporter;

ξ - factor considering daily diesel consumption depending on work type;

ϱ - density of fuel, kg/l;

τ - time loss factor, not considering travel to the plot and back;

τ_v - time loss factor of a transporter of transporting one type of material;

φ - number of calculation cycles;

ψ_{ij} - weight factor, characterizing transport works in particular farm area *ij* and

ω - the number of service travels to a plot within a production year.

INTRODUCTION

Cereals have significant importance by distribution and quantity among field crops in most countries of the world. And the main reason is that cereals are one of the most important foodstuffs, valuable feeds for animals and industrial raw material. In comparison with other crops the cultivation of cereals is relatively easy, well mechanized and not labour-intensive (PIKK 2003).

Cereals cultivated in Estonia are mainly spring and winter wheat *(Triticum aestivum)*, spring barley *(Hordeum vulgare)*, winter rye *(Secale cereale)* and oat *(Avena sativa)*, and less triticale *(Triticisecale)* and buckwheat *(Fagopyrum esculentum)*. In recent years some producers have tried to establish winter barley.

According to Statistics Estonia (2009a) from the year 2007 there was 907 thousand hectares of agricultural land in Estonia. 627 thousand hectares of that was arable land comprising 136 thousand hectares of barley, 100 thousand hectares of wheat, 35 thousand hectares of oat, 17 thousand hectares of rye and 5 thousand hectares of other cereals (Fig. 1). There were 293 thousand hectares of arable land under cereals in Estonia as a whole.

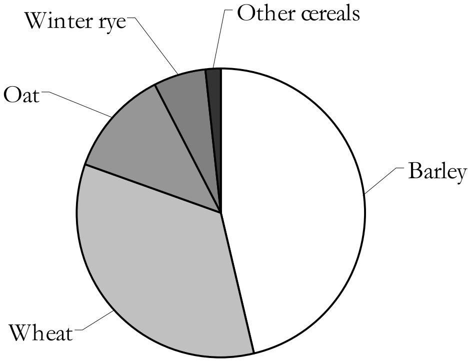


Figure. 1. Distribution of the area of cereal production in Estonia in 2007

From these data we can say that half of the arable land is under cereals, and grain production is one of the most important agricultural branches in Estonia.

Because of liberal market politics in the Republic of Estonia the market prices of grain persist at a low level (EKI 2009), but production resources are expensive and some of them, like prices of labour, fuel and electricity, are growing steadily. These are the reasons that push farmers to search for possibilities to increase productivity. It is also important from a public position to use imported resources like fuel and most agricultural machinery in the most effective way. This is why prediction and the planning of an action programme is needed. Under steadily changing living conditions only a short-term future prediction can be accurate enough, so plans should be corrected almost constantly.

Profitability is mostly an estimation criterion for a production plan of a farm. Profitability depends on many reasons - essentially on local conditions and the market prices of inputs and outputs. In grain production most of the operations are done by machines today and machine costs make a significant part of the prime cost of a product (Nix 1988) (Fig.2).

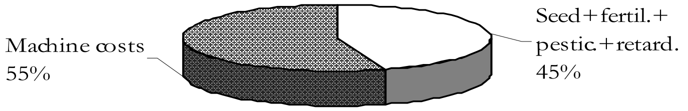


Figure 2. Portion of machine costs in prime price of grain by a calculation example where yield is 3,5 t/ha (Older,1999)

Maximizing the profitability of production is supported by minimizing the prime price of the product concerning the quality of a product, because this has an influence on the sale price of a product. There are several possibilities to minimize the prime price of a product, and this applies also to the portion of machine costs.

Lots of grain producers are trying to enlarge their own arable land, as it is generally known that use of a larger tillage area enables the farmer to minimize the prime price of grain (Suomi *et al.* 2003, Gwyer et al. 2005) and maximize capacity for profit. In addition, milk producers are trying to enlarge production capacities and new cowsheds are built which are often larger than previously. This means that there are more animals in a cowshed, but also more manure that needs to be transported to the plots. According to the requirements of environmental protection the amount of manure per unit of arable land is limited, so larger areas are needed to distribute increased amounts of manure (Kärblane 1996). However, there is no possibility to enlarge these areas endlessly, otherwise it will result in longer travelling distances to plots, which cause a higher and higher proportion of travelling costs in production costs.

During the years 2001-2007, the proportion of farms of less than 50 ha decreased; those of over 100 ha increased in the total area of agricultural land in Estonia (Statistics Estonia 2009b). In the case of small farms the land area is decreasing in Estonia due to the following reasons: 1) plant production is ceasing and land is being taken over by other producers or 2) more land is put to use and therefore the farm is moving into another statistical class, i.e. turning into a bigger farm. We can observe similar trends elsewhere in the world, for example, in the USA (Schnitkey 2005), Finland (Suomi *et al.* 2003), England (Burton and Walford 2005), and Hungary (Burger 2001).

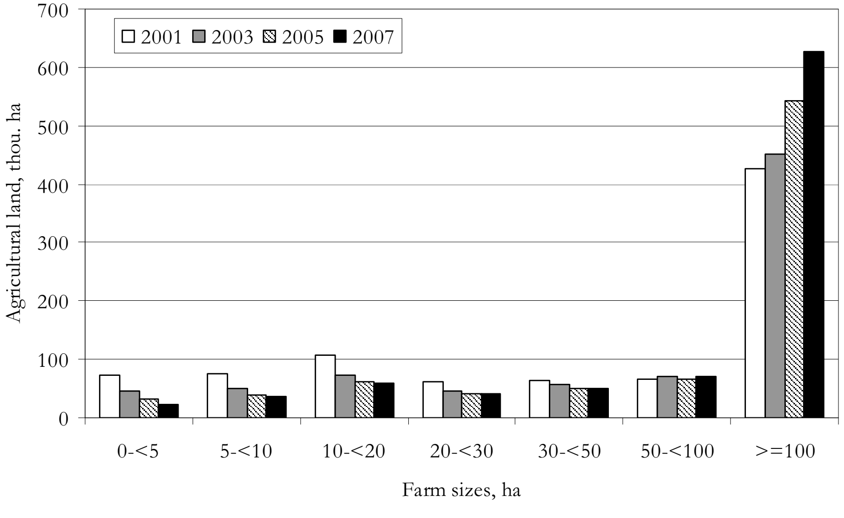


Figure 3. Division of agricultural land according to farm sizes by the year

In 2007 in Estonia there were 23 257 farms with an average agricultural area of 39 ha; of those larger than 100 ha, 1 549 farms have an average area of 405 ha. The number of plots by plot size group is given in Table 1.

Table 1. The number of plots depending on plot size group in Estonia by register of area supports of Estonian Agricultural Registers and Information Board in 2008

Plot size group	Number of declared plots	Declared area, ha	Average plot area, ha
<1 ha	46 339	24 333	0.53
1-<5 ha	61 570	160 791	2.61
5-<10 ha	23 876	173 126	7.25
10-<50 ha	23 331	447 576	19.18
50-<100 ha	951	61 840	65.03
100<	90	12 635	140.39
Total	156 157	880 301	5.64

The enlargement of the production area influences the proportion of transportation expenses in the cost price of the yield. Along with increasing distances, transportation expenses are also growing (Steinsholt 1997) and, in certain conditions, may exceed the increase of the income created by enlarging a production area; as a result, profitability of the farm begins to decline. The need for increasing the efficiency of exploitation of land and problems related to the growing costs of energy, labour and other production resources, call for the creation of decision-support systems that analyse and plan agricultural production. Several researchers have suggested (Bouma *et al.* 1998) the need to devise a method that would assist the determination of optimal farm size. Mathematical modelling is an essential method here. Several studies have been carried out and several methods devised to calculate average traveling distance on farms (**III**, **IV**, Bernhardt 1996, Kask 1997, Möller *et al.* 1994, Möller *et al.* 1997a, Möller *et al.* 1997b, Möller *et al.* 1998) and the influence of the distance to production results; the aim being to clarify the limit of how far the farm area should be extended. Kryachkov and Sharova (2005) studied the optimal area of farms in the region of Kursk (Russia), determining factors to predict the transportation costs depending on the area of the given agricultural enterprise. A mathematical model was presented to calculate the profitability of the proposed farm depending on its production capacity.

The aim of these studies was to devise a method for determining the optimal size of a farm. Nevertheless, using this parameter in real-life production management is questionable. Should the farmer exclude from production the plots located outside the critical distance, i.e., sell or lease them, and acquire plots located within the area, i.e., buy or rent them? In reality, individual plots have individual properties, different crops, and, thus, different operational capacities and production costs (Jabarin and Epplin 1994; Harasimowicz and Ostršgowska 2001). One critical factor is the size of the plot. The introduction of a small plot located far from the farm centre will probably not be economical, as the transportation costs will be so high that production will not be profitable. This may also be true for plots remaining inside the critical border. For planning of production, therefore, a method is required to analyse the costs taking into account the distance, the area and the cultivation technology used (**XVIII**) .

The aim of this thesis is to propose a calculation method enabling the estimation of the rationality of plot usage concerning the distance between the farm centre and the plot (**XVIII**).

In this paper an overview of methods related to the calculations of average transport distance of a farm is given. Since travelling distance has an influence on the working time and yield, timeliness relationships are explained. The problems needed to be solved are expressed, the aim and tasks of the research are proposed. An overview of the research on the topic is given.

The main emphasis of this paper is on the composition of a method to calculate the costs dependent on distance between farm centre and plot, in order to have a tool to estimate rationality of the use of the certain plot. On the basis of the calculation method PC software "Field distance" using development software Microsoft Visual FoxPro 8.0 for Windows was composed. Researchers, agricultural advisors and farmers can use the program "Field distance" as a DSS - Decision Support System. Results of the calculation examples presented in this paper were calculated with this program.

1. REVIEW OF THE LITERATURE

1.1. Methods of the economic estimation of farm machinery usage

Since machine costs form an essential proportion of the prime price of agricultural products and farmers are interested in producing as cheaply as possible, many researchers have searched for possibilities to minimize machine costs and have composed methods to create a mathematical model of farm machinery.

The method of load graphics is about determining the essential number of tractors and giving a graphical presentation within tractor models, operations and work terms. Load graphic is a histogram that expresses the number of necessary machines of a particular kind in the specified period of work (Fortuna 1985, Tiigimäe 1980).

The economic-mathematical method consisted of composing the mathematical model of farm machinery and solving the task arising from the model. Every model is a complex of limitations expressed by equations and inequalities and contains the criterion of optimality (Ekman 2000, Fortuna 1985, Gunnarsson and Hansson 2004, Hunt 2001, Jannot and Cairol 1994, Søgaard and Sørensen 2004, , Бадевиц 1982, Линнас 1981, Линнас 1989, Семенов *et al.* 1982).

With the method for determining optimal workload, an optimal tillage area is calculated for certain machinery, considering the profitability of production as a criterion of optimality (**V, VI**, **VIII, IX**, **XI**, Ekman 2000, Tamm 1999, Rotz and Harrigan 2004, de Toro and Hansson 2004).

All these methods enable taking travelling distances into consideration which affect the performance of field-operation units (henceforth FOU) as well as transportation costs of materials etc, but usually they only consider the transportation costs of materials.

1.2. Farm logistics studies

In an overview of studies in the field of agrologistics, Hahn (2006) reports that theory-forming contributions to the mentioned research area are still rare in the literature. Morlon and Trouche (2005) also found that there is scarce relevant scientific literature available, and the extant materials are generally based on ancient or simplistic schemes and models which are not of practical use in the present conditions.

There are, however, references to studies in which distances inside the farm are used as one of the problematic factors of plant production. One of the first contributions in this area was worked out by Johann Hermann von Thünen (1783-1850), who developed a model to describe land use practices radiating out from a central market location (Crosier, 2009). He theorized that several rings of agricultural land use practices would surround the central market place. The land within the closest ring around the market produces products that are profitable in the market, yet are perishable or difficult to transport. As the distance from the central market increases, the land use shifts to producing products that are less profitable in the market, yet are much easier to transport. The general approach of von Thünen illustrated the use of distance-based gradient analysis (e.g., the change in value for a variable such as land rent with increasing distance from the city centre).

In the late 1990s, a research team modelling agricultural production, from the Estonian University of Agriculture, devised a method to calculate the effect of the area of a circular shaped farm to the farm's profitability. This was carried out under the direction of *Professor Emeritus* Heino Möller and in cooperation with researchers from the Institute of Applied Mathematics of the University of Tartu (**IV**). The essential part of the method is a calculation of average travelling distance. There are several methods known to calculate it. The group developed methods to calculate average travelling distance on the basis of the shape of arable farm land.

1. Circular shaped farm with the centre located in the centre of the circle (Möller *et al.* 1994, Möller *et al.* 1997b).
Average travelling distance is

$$d_k = \frac{2}{3} R \tag{1.1}$$

where R - radius of the area of circular shaped farm, km; and
d_k - average travelling distance in farm, km.

2. Circular shaped farm with the centre located at a random location in the circle (Möller *et al.* 1997b). Average travelling distance is

$$d_k = \mathrm{R}\left(0{,}067 - 0{,}021l + 0{,}571l^2 - 0{,}085l^3\right) \quad (1.2)$$

where l - ratio between radius of the circle and a (distance between the centre of transport and the centre of the circle), $l=a/\mathrm{R}$.

3. Average travelling distance, when transportation capacity into the different areas of circle-shaped farm varies (Möller *et al.* 1997b). The circle is divided into shares by $\varkappa$ belts and f sectors. The ratio of transportations to the different parts of the area is expressed with a weight factor ψ_{ij}

$$\frac{d_k}{\mathrm{R}} = \frac{1}{3\pi}\sum_{i=1}^{\kappa}\sum_{j=1}^{f}\psi_{ij}\left(\gamma_i^3 - \gamma_{i-1}^3\right)\left(\varepsilon_j - \varepsilon_{j-1}\right) \quad (1.3)$$

Where γ_i - distance between the centre of the circle and longer edge of belt i in circle-shaped farm, km; and

ε_j - distance between x-axe in polar co-ordinates and further edge of sector j in circle-shaped farm (centre of polar co-ordinates located in the centre of the circle).

4. Elliptic farm with the centre located in the centre of figure and the ratio of transportations to the different surface elements is equal (**III**, Möller *et al.* 1998)

$$\frac{d_k}{a_e} = \frac{4}{3\pi}E(e), \quad (1.4)$$

where a_e - length of longer half-axis of ellipse, km; and

$E(e)$ - elliptic integral of the second kind, which value can be found from the table of elliptic integrals according to the value of eccentricity of the ellipse.

5. Average traveling distance, when transportation centre is located at the random location in the ellipse

$$d_k = \frac{a_e}{2\pi}L(e,\alpha,\beta), \quad (1.5)$$

where L(e, a, β) - function characterizing position of transportation centre in relation to the centre of ellipse.

It is possible to find in the literature methods for calculating average travelling distance of a rectangular farm depending on the perimeter of the farm (Kask 1977). The curvature of the roads, the distance between the centre and centre of gravity of the farm area, as well as concentration of transportations (the number of transportations per plot), are also taken into consideration.

Contrarily to the methods presented above, Heinloo (1998) has devised a method to calculate an optimal transportation location for a farm where the farm has the shape of curved trapezium or sector.

De Garis De Lisle (1978, 1982) has studied the effects of intra-farm distance on farm income and on internal cropping patterns. The research was based on the data of farms situated in Manitoba (Canada) collected by crop insurance agents. The following conclusions were drawn: 1) the distribution of crops is affected both by the distance of the plot to the farm centre and the soil productivity; 2) adjustments to the management and intensity of farming compensate the effects of distance on the net income.

Myyrä and Pietola (2002) estimated, with the help of a switching-type Probit-model, the shadow prices for land parcel characteristics in Finland, such as size and distance from the centre, by adding these characteristics to the conditional profit maximization model. Their research concludes that plot size and distances from the farm centre significantly affect the farmer's choice of allocating most of the land either to grass or to grain. Small plot size was found to increase costs significantly by hindering Finnish farmers from adopting the most efficient production technologies and practices.

Fechner *et al.* (2002) has composed a simulation about agricultural transportation process through the example of cereal production. The simulation model enables to analyses of different transport chains for technological materials and selection of the best solution for a specified situation.

Heikkilä and Salo (2002) and Kapuinen (2001) have also studied logistical systems of farms. The aim of the research was to clarify bottlenecks of transportation systems in different production branches, and give suggestions how to develop a rational transportation system for technological materials. Researchers at the same institute have also studied costs depending on travelling distance and found that the average costs were 0.1 EEK/kg in 1999. Most plots had a radius of less than 6.6 km, but in the EU this value was 3.7 km (Aaltonen *et al.* 1999). About Estonia, there is no such data.

Lötjönen *et al.* (2003) analysed the production costs of grain harvesting considering, amongst other factors, the influence of parcel size and distance. A dynamic model which covered grain harvesting, grain transport from field to farm and grain drying (or some other storage treatment) was planned, constructed and tested.

Many other studies are also available, handling farm's transportation costs for fertilizers, yield and other technological materials, where costs are presented depending on area and travelling distance of the plot (Kilima and Kenkel 2004, Bogun 2005, Berruto *et al.* 2003, Buckmaster and Hilton 2003, Singh and Abeygoonawardana 1982, Pfister *et al.* 2005, Kapuinen 2003, Delchev and Trendafilov 2002, Harrigan 2003, Kübler *et al.* 2004, Iannoni and Morabito 2006).

Several software packages have been developed, helping to analyze rationality of the use of the plots proceeding from a general algorithm comparing the income and expenses of crop production (Agrar-Office 2009, Peltotuki Pro 2009). Some programs also help to calculate machine costs (Peart and Shoup 2002, Recio *et al.* 2003, Recio and Rubio 2004).

Agronomists are developing methods and computer-based decision support systems to help farmers to decide about the rationality of the use of a plot (Collentine *et al.* 2002, Myyrä *et al.* 2004, Astover *et al.* 2006). Decision criteria are usually agronomical – soil properties, economical optimality of fertilizing, and other parameters related to plant growth on the observed plot. Harasimowicz (1997) describes an evaluation system, where plot distance to the centre is one factor affecting land value in points characterising the profitability potential of land: a plot situated further away is assessed to be less valuable than a closer one.

This literature overview indicates that there is no research available containing a method to estimate rationality for the exploitation of a plot based on the distance between the plot and the farm centre; considering costs depending on this distance; such as transportation costs of FOUs, transportation costs of materials, income loss and the cost of management travel. As a result of this the aim of the paper has been proposed (**XVIII**).

2. AIM AND OBJECTIVES OF THE STUDY

The crop farming entrepreneur has always the following question, from the perspective of profitability: which of the plots is profitable to use? An important factor affecting profitability is the travelling distance between the plot and the farm centre. The more arable land a farm has, the more used the machinery is and the less the proportion the fixed costs have in the prime price of a product. Enlarging the arable farm land, the demand for the introduction of plots located further and further is necessary. Therefore the knowledge of the limit value of plot area or travelling distance applying specified technology, and assuming that use of the plot is profitable, is a must.

<u>The aim of this thesis is</u>:
1) to study the dependency of the costs on cereal farm plot distance;
2) to propose a method and software, which would help to calculate the costs on a cereal production farm depending on the distance between the plot and the centre;
3) to propose a method for assessing the rationality of maintenance of the specified plot applying specified machinery and a specified distance between farm centre and the plot; and
4) to analyse the sensitivity of different parameters to the economical effect of maintenance of the plot according to the distance.

The software composed of a calculation model should be a practical tool for the farmer, advisor, student or researcher, enabling comparisons of the influences of different technological solutions on the costs depending on the plot distance.

List of the tasks to be solved to reach the aim:.
1. Overview about the machines used for travel on a crop production farm between the plot and the farm centre will be given.
2. Overview about the costs, depending on the distance between the plot and the farm centre, will be given.
3. Devise a method for calculating the costs related to the travels on the FOUs between the farm centre and the plot.
4. Devise a method for calculating the costs related to transportation of technological materials between the farm centre and the plot.
5. Devise a method for calculating the loss of income related to travel between the farm centre and the plot is .

6. Method for calculating the cost of all management travel to the plot within one production year.
7. Devise a method for calculating the maximum travelling distance to the plot considering the area and the technology applied in the plot.
8. Project and program the software “Field distance” on the basis of devised methods related to the plot distance.
9. Test and edit the calculation methods with the help of the software “Field distance”.
10. Propose the simulations and sensitivity analysis with the help of the software “Field distance”.

3. THE MODEL: PROFITABILITY AND TRAVELLING DISTANCE OF A PLOT

3.1. The problem

While planning production the farmer often has to make essential decisions about the farmland. While deciding to buy or sell or lease or rent the land out, changing technology or crop rotation, it is always good to estimate the effects of the decision on the profitability of production. This means that he should calculate an income, and the costs of production on the plot, considering also the effect of travelling distance between the farm centre and the plot.

Usually when calculating the production costs the transportation costs of technological materials are taken into account, but the costs for transporting the FOUs to the plot, and the costs for management travels, are generally not taken into account or are considered approximately, while there is no method to calculate them.

In the present study, the travelling distance to the plot denotes the shortest way passable with an agricultural machine from the farm centre to the nearest entry point in the plot. The farm centre is the storage location for most of the farm's field machines and technological materials (**XVIII**).

In the process of composing a calculation model, all technology/technical equipment used during the whole yield year on the plot is taken into account (**XVIII**).

3.2. Overview of machines used for travel between the plot and the farm centre

Intra-farm travels associated with plant production occur mostly between the farm centre and the plots of the farm. Technological materials (seed, fertilizers, pesticides, water and yield), labour, FOUs and fuel as well repairing and maintenance materials have to be transported.

Usually a transportation unit, consisting of a tractor and one or several trailers, is used for transportation of the technological materials. Trucks are also used, especially for transportation of the harvest. Transportation of materials is accomplished partially by the FOUs meant for dosing material on the plot - e.g. pesticide and water could be transported in a tank of sprayer to the plot. Often only manure spreaders are used to transport manure to the plot.

Generally, FOUs move to the plot and back on their own and the operators move with them.

To transport the other staff cars are mostly used or, if there is a need to transport many people, for example for harvesting vegetables or picking the stones, then buses are used.

For transporting the fuel, as well as repairing and maintenance materials, vehicles adapted for that purpose are used.

3.3. Costs and income depending on the travelling distance

Profitability is predictable by calculating the costs and the income of production (Tamm 1999):

$$R_e = \frac{\mathrm{B}}{\mathrm{K}} - 1 \tag{3.1}$$

where K - sum of production costs per unit of area, EEK/ha;
R_e - profitability; and
B - income, EEK/ha.

Both operations are quite time consuming and should be repeated every time conditions change. Therefore it is essential to establish simplifications enabling us to concentrate only on the calculations necessary to find out how travelling distance affects income and costs.

Pertaining to travelling distance dependent and independent costs are identified, naming the later as other costs (e.g. the costs for fertilizers, pesticides, field operations etc.):

$$K = K_b + K_m \tag{3.2}$$

where K_b - costs dependent on travelling distance, EEK/ha and
K_m - costs not dependent on travelling distance, EEK/ha.

While the costs dependent on travelling distance are the matter of interest other costs are not considered here.

Knowing the average values of the market price of grain and expected yield, the income per unit of area can be predicted. According to the income it is possible to find out the maximum production costs within the limits of income

$$K_{\max} = B\,. \tag{3.3}$$

Using a plot with a specified distance is rational in cases when the cost K_h related to distance is less than the maximum value $K_{h,max}$ ($K_h \leq K_{h,\max}$). The last factor is found with formula (**XVIII**)

$$K_{h,\max} = B - K_m\,, \tag{3.4}$$

If the model user wants to take into account the profit or the production risk, these factors can be added to the costs not dependent on travelling distance K_m (**XVIII**).

So, we can concentrate henceforth on the costs dependent on travelling distance between the farm centre and the plot. These costs are the following (**XVIII**):

1) costs related to the travel of the FOUs,
2) costs related to transporting the technological materials, and
3) cost of all the management travels to the plot.

In addition to the expenses, we need to look at the effect of travelling distance on income. If the distance increases, the daily performance of the FOU will decrease and work periods will lengthen; as a result, the working time will increasingly deviate from the optimal and the average yield will decrease. The consequent income loss is considered a cost, as well (**XVIII**). Thus

$$K_h = U + V + M + \Delta B \tag{3.5}$$

where U - the travelling cost of FOU to and from the plot for one production year, EEK/ha;
V - the cost of transporting the materials to or from the plot, EEK/ha;
M - the travelling cost of service vehicles per one production year, EEK/ha; and
ΔB - the income loss caused by travelling duration, EEK/ha.

Subsequently the calculation methods of these costs will be discussed. An overview about the model is presented in Figure 3.1.

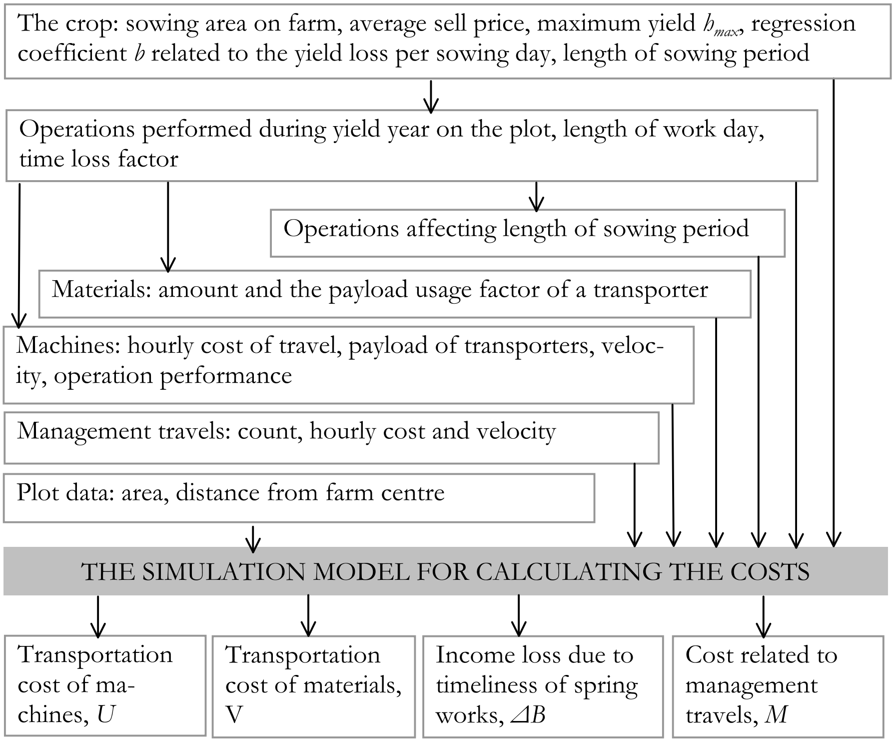


Figure 3.1. The calculation model for calculating costs depending on travelling distance, the inputs and outputs of the model (**XVIII**)

3.4. Transportation cost of FOUs

3.4.1 Need for the transportation of FOUs

Farm's plots are located at known distances from the farm centre. To operate on the plot the FOU should travel from the farm centre to the plot and at the end of the work or day it should travel back. The longer the distance to the plot is the more time and resources are wasted on FOU travel (Naef 1983, Steinsholt 1997). Thus, to make the best of the working time the further plots should either be large enough, or several small plots with the same crop should be located close together to result in a sufficient work capacity worth travelling to the plot. Summing the areas of these plots we can manage the group of plots as one, and calculate the minimum area at that distance that can be used for tillage of a crop. If the plot is too far away an additional question arises about the appropriate distance that makes it worthwhile to travel back to the farm centre for the night instead of leaving the machine near the plot. In the mathematical model we have to take into account that travelling duration must not exceed the length of the workday. In addition we should consider that all the travels of the FOUs between the plot and the farm centre are carried out during the workday, unlike the arrangement that designates the travel-back of the FOU to the farm centre at the end of the workday.

Presuming that the FOU stays on the plot until the work is completed over the whole area the total travelling cost of the FOU does not depend on the area of plot. Thus, dividing the cost by the area of the plot, the larger the plot is the lower the cost per unit area is

$$U_{ha} = \frac{U}{F} \tag{3.6}$$

where U_{hs} - travelling cost of FOU for unit of area, EEK/ha and
F - plot area, ha.

3.4.2 Calculating the travelling cost of an FOU

The travelling cost of the FOU depends on the travelling distance between the farm centre and the plot, the number of passes of the distance as well as travelling speed and hourly cost of idle travel of the FOU:

$$U_1 = \frac{dn_t P}{v} \tag{3.7}$$

where U_1 - travelling cost of the FOU for one work day, EEK;
d - travelling distance between the farm centre and the plot, km;
n_t - number of travels between the farm centre and the plot in a work day (e.g. travelling to the plot in the morning and back in the evening n_t=2);
P - hourly cost of travelling the FOU (section 3.4.3.), EEK/h; and
v - travelling velocity of the FOU, km/h (Herrmann 2000, Fröba *et al.* 2001).

The idle travel is travel when the implement is not loaded –the implement is in transportation mode.

3.4.3 Hourly cost of the travel of FOU

Information about the calculations of hourly costs can be found from different internet and paper publications (Hunt 2001, Koik *et al.* 2003, Schnitkey and Lattz 2008, Witney 1988). However, there is no direct algorithm available to calculate the hourly cost of the idle travel of the FOU.

Costs depend on the status of the FOU – is it owned or rented. A rental machine has a defined rental price and there is no difference whether the machine works on the plot, makes an idle travel or stands still doing nothing – the hourly cost is equal to the rent price anyway and it should be considered while calculating the travelling costs of the FOU.

With regard to personal machines, calculating the hourly cost of an idle travel the tractor and the implement should be handled separately. The components of the fixed costs of the machine - depreciation, interest, housing costs and insurance - are presumably already reflected in the hourly costs of the field operation and thus in the prime price of a product. This is because it is presumed that the transportation time of the machines is not included in the annual work capacity *W* (formula 3.10) of the machines. Considering these fixed costs also as the hourly cost of idle travel, it could result in double costing because all the costs will be reduced to hectare costs. Thus the components of the fixed costs of field machines are not considered by calculating the hourly cost of idle travel.

There is now the question of the direct influence of travelling distance on the implement as a resource. We can say that work tools do not wear while travelling. There is some wear on in the wheels of the implement while touching the surface of the road. Additionally an implement is affected by vibration due to bumps in the road, which can cause motion in the joints of the device or generate cycles of bend and twist and thus accelerate wearing of the parts . On the one hand, the calculation of these factors is complex while on the other hand the influence of the factors is too small to take these into consideration, so they are not considered.

Hourly cost of the idle travel of an FOU is calculated with the following formula:

$$P = P_t + P_r \tag{3.8}$$

where P_t - hourly cost of a tractor travelling, EEK/h; and
P_r - hourly cost of transportation of an implement, EEK/h.

To calculate the hourly cost of the idle travel of a tractor or a self–propelled field machine, we have to take fuel, lubrication, labour and maintenance costs into account. These components of variable costs should be summed up to calculate the hourly cost of a tractor:

$$P_t = c_f + c_m + c_j + c_h, \tag{3.9}$$

where c_f - fuel cost of tractor, EEK/h;
c_m - lubrication cost of machine, EEK/h;
c_j - labour cost, EEK/h; and
c_h - maintenance cost of machine, EEK/h.

The formulae for calculating these cost components are presented in section 3.3.4.

3.4.4 Calculating the components of the hourly cost of the machines

The formulae for calculating the components of hourly cost of the machines have been much used in different research concerning the economic usage of agricultural machines (**IX**, Older 1999).

A linear method is usually used in practice to calculate the depreciation allowance of machines

$$c_a = \frac{H - H_r}{T_a W}, \tag{3.10}$$

where H - purchase price of machine, EEK;
H_r - remaining value of machine, EEK;
T_a - lifespan of machine, years; and
W - annual work capacity, h/year.

Interest is calculated as an average from the life-span of a machine:

$$c_i = \frac{a_p i_p H\left(1 - \frac{O_f}{100}\right)}{2 \cdot 100 T_a W}, \tag{3.11}$$

where a_p - length of loan period, years;
i_p - rate of interest, %/year; and
O_f - rate of self financing, % from loan sum.

The 2 in formula (3.11) is used to calculate the average remaining value of the machine.

Housing costs of a machine

$$c_g = \frac{H_h A_h}{W}\left[\frac{1}{T_h} + \left(\frac{i_p + i_{hk}}{200}\right)\right], \tag{3.12}$$

where H_h - cost for housing unit, EEK/m^2;
A_h - housing area needed for the machine, m^2;
T_h - lifespan of housing room, years; and
i_{hk} - insurance rate of housing room, % from price.

Insurance

$$c_k = \frac{\frac{i_{vk} H}{200} + I_k}{W}, \tag{3.13}$$

where i_{vk} - rate of property insurance, %/year; and
I_k - traffic insurance and technical inspection charge,

EEK/year.

Fuel costs

Fuel consumption is calculated with the following formula:

$$G = \frac{q\xi N_m}{\rho}, \tag{3.14}$$

and fuel cost with the following formula:

$$c_f = r_k G, \tag{3.15}$$

where q - specific fuel consumption, kg/kWh;

ξ - factor considering daily average diesel consumption depending on work type: hard work 0.6-0.7, medium work 0.4-0.5 and easy work 0.3 (KTBL 2004/05, TTS 2001);

N_m - nominal effective power of the engine of a tractor or a self-propelled machine, kW;

ϱ - density of fuel, kg/l; for diesel fuel ϱ= 0,86 kg/l; and

r_k - price of fuel, EEK/l.

Usually, during idle travel, an engine works only at partial output power and this should be considered when calculating the consumption of fuel. According to Tiigimäe (1980) the proportion of fuel consumption of the idle travel to fuel consumption of operation is on average 68% for tractors with an engine power of over 55 kW. About 60% of engine power is used on average during the operation period Therefore, compared to a 100 % loaded engine the fuel consumption on idle travel is 68×60/100=41% on average.

Lubricant cost

$$c_m = 1{,}2\frac{ur_m G}{100}, \tag{3.16}$$

where u - rate of lubricant consumption, % of fuel consumption; and

r_m - price of lubricant, EEK/l.

The r_m is the price of engine oil. The cost k_m also includes the cost of other lubricants such as transmission oil and others. The other lubricants are estimated to be somewhat more expensive than engine oil and therefore the coefficient 1.2 is used.

Maintenance cost

Costs for periodical technical maintenance and repair are taken into account as maintenance costs:

$$c_h = \frac{sM_a}{100W}, \tag{3.17}$$

where s - costs for maintenance, % of replacement price of machine; and

M_a - replacement price of machine (for new machine at the same as purchase price), EEK.

Labour cost

$$c_j = p\left(1+\frac{p_h}{100}\right)\left(1+\frac{m_s+m_h+m_t+m_p}{100}\right), \tag{3.18}$$

where p - operator's hourly fee , EEK/h;

p_h - rate of additional compensation for maintenance, % of operator's hourly fee;

m_s - social tax rate, %;

m_h - health insurance rate, %;

m_t - unemployment insurance rate, %; and

m_p - vacation fee rate, %.

It is taken into account that the machine operator gets an additional fee for machine maintenance. The additional fee is calculated as a percentage of the operator's hourly fee.

3.4.5 Total travelling costs during the production year

Several works need to be done for the cultivation of a crop through the production year. The production year is the time beginning from the end of harvesting the previous crop to the end of harvesting the present crop. Every operation starting with stubble ploughing, or any other work done after harvesting the previous crop, is performed to benefit from the present production year, thus we have to consider all the works on the plot during the relevant period.

Considering the previous arguments the following factors need to be found out to calculate the travelling costs:

1) operational reasons for travelling to the plot,
2) FOUs performing these operations and

3) travelling costs of every FOU.

Total costs of the travels of all FOUs, presuming that an FOU visits the plot once for every operation, are as follows:

$$U = \frac{2d}{F}\sum_{j=1}^{o}\frac{P_j}{v_j} \tag{3.19}$$

where o - number of field operations performed for one crop.

3.4.6 FOUs' travelling costs if a field operation is performed over several days

If the FOUs have low performance, or the plots are large, several days may be needed to perform the work on the plot. Moreover, the further the plot is the more time from a working day is wasted travelling to the plot and back, and the less time remains for performing the work. Therefore, we have to calculate the number of working days and corresponding travelling costs.

The line of reasoning follows.

Duration of the work, not considering time consumption for travelling to the plot and back, is as follows:

$$t_{ot} = \frac{F}{w\tau} \tag{3.20}$$

where w - hourly performance of an FOU, not considering the time needed to travel to the plot and back, ha/h; and
τ - time loss factor, not considering the travels to the plot and back.

To find out work duration including the time needed to travel to the plot and back we have to calculate the number of days which an FOU works on the plot first, in the case where it is working singly:

$$z_m = \frac{F}{w\tau\left(D_t - \frac{dn_t}{v}\right)} \tag{3.21}$$

where z_m - a period within which an FOU needs to perform a certain operation on the plot, days; and

D_t - length of a work day, h/day.

As we are interested in the number of plot visiting days *Z,* related to the integer of the number of working days z_m, an integer of any digit will be marked by square brackets (Jürimäe and Velsker 1984).

If $z_m > [z_m]$ i.e. fractional number of work days is bigger than the integer of it, then (**XIII**)

$$Z = [z_m] + 1 \tag{3.22}$$

where Z - number of days an FOU should visit the plot to perform a specified operation.

If $z_m = [z_m]$, then $Z = z_m$ (**XIII**).

There may often arise a situation where the calculated value of the share of the plot remaining for the last work day is too small so it would be more sensible to prolong the previous working day(s), and thus the FOU is not bound to travel to the plot for the last short day of work. However, there is a question here about the limit value of the length of the remaining working day that ensures profitability of prolongation of the working day(s) before the last day. In this case other factors can also be important such as lighting conditions, need for refuelling the tractor, occupational safety of an operator etc. Providing that the other factors set no limits the minimum work capacity should be found justifying travel to the plot for the remaining working day. The costs should be subsequently compared in two cases:

1) using overtime to complete the plot; or
2) travelling to the plot for the remaining working day

and the less costly of these options should be adopted.
The calculation of length of the remaining day is shown in section 3.3.8.

The time an FOU spends for plot visits can be calculated on the basis of the number of working days in relation to the given work:

$$t_b = \frac{dn_t Z}{v} \tag{3.23}$$

In this case the travelling cost of an FOU for one operation per unit of area is:

$$U_{1,v} = \frac{t_b P}{F} = \frac{dn_t ZP}{vF} \tag{3.24}$$

where $U_{1,v}$ - travelling costs of FOU considering the number of days for the specified operation, EEK/ha;

and thus for all works within a production year:

$$U = \frac{dn_t}{F} \sum_{j=1}^{o} \frac{P_j Z_j}{v_j} \tag{3.25}$$

3.4.7 FOUs travelling costs if a field operation is performed using several FOUs

Often the performance of one FOU is not high enough to complete the work within a specified time span. Thus, several FOUs are simultaneously used on the same plot. Previously the situation was discussed where every operation on the plot was performed with a single FOU, now the question arises, how many working days are needed if several FOUs are used for same operation?

Similarly to the section 3.4.6 we should first calculate the work period on a specified plot (**XIII**):

$$z_m = \frac{F}{\sum_{i=1}^{n} w_i \tau_i \left(D_{t,i} - \frac{dn_t}{v_i} \right)} \tag{3.26}$$

where n - number of working FOUs.

The number of days an FOU should visit the plot is calculated with formula 3.22.

To calculate the number of work periods z_m we need the following information:

1) is an FOU performing the same operation together with the other FOUs at the same time on the same plot; and
2) if it does, the performance of other FOUs working simultaneously on the same plot has to be taken into account.

Travelling cost of all FOUs is computed with the following formula:

$$U = \frac{dn_t}{F} \sum_{j=1}^{o} Z_j \sum_{i=1}^{n} \frac{P_{i,j}}{v_{i,j}}. \tag{3.27}$$

3.4.8 Calculating the working time for the remaining day

There is a share of the plot to till during the remaining day, and it doesn't take the whole working day. It is necessary to know the length of the remaining day to decide whether division of working time of the remaining day between the previous working days is reasonable or not.

If there are several FOUs with different travelling speeds they will arrive at the plot and start the work at different times. Nevertheless, the FOUs work until the plot is completed and finish the work about the same time. The question is, for how long does any FOU work on the plot during the remaining day? Therefore we have to take the different performances of the FOUs into consideration.

Transforming the formula 3.26 we get an area processed during the given work period (days):

$$F = z_m \sum_{i=1}^{n} w_i \tau_i \left(D_{t,i} - \frac{dn_t}{v_i} \right) \tag{3.28}$$

In formula 3.28 we have to use the remainder of the fractional number of the working period (z_m)

$$j_z = z_m - [z_m] \tag{3.29}$$

And thus the remaining area is as follows:

$$F_j = j_z \sum_{i=1}^{n} w_i \tau_i \left(D_{t,i} - \frac{dn_t}{v_i} \right) \tag{3.30}$$

We know that the sum of areas processed during the remaining day by all working FOUs results in the total remaining area F_j.

$$F_j = \sum_{i=1}^{n} F_a \tag{3.31}$$

where F_a - daily performance of FOU, ha/day.

We also presume that the time span between departure from the farm centre and the moment the work on the plot is completed during the remaining day is equal for all FOUs:

$$D_j = t_{mp} + t_t \tag{3.32}$$

where D_j - time that FOUs need, starting with departure to the plot until accomplishing the operation on the plot in the case of the remaining day, h;

t_{mp} - time that an FOU needs to move between the plot and the farm centre, h; and

t_t - time that an FOU needs to process the share of the plot F_a, h.

Time that an FOU needs to move between the plot and the farm centre is as follows:

$$t_{mp} = \frac{d}{v}. \tag{3.33}$$

Time that an FOU needs to process the share of the plot F_a, is:

$$t_t = \frac{F_a}{w\tau}. \tag{3.34}$$

Thus, replacing t_t in the formula 3.32 we will get the following:

$$D_j = t_{mp} + \frac{F_a}{w\tau}. \tag{3.35}$$

and from that:

$$F_a = w\tau\left(D_j - t_{mp}\right). \tag{3.36}$$

Replacing F_a in formula 3.31 we will get the following:

$$\begin{aligned} F_j &= \sum_{i=1}^{n} w_i \tau_i \left(D_j - t_{mp,i}\right) = \sum_{i=1}^{n} w_i \tau_i D_j - w_i \tau_i t_{mp,i} = \\ &= D_j \sum_{i=1}^{n} w_i \tau_i - \sum_{i=1}^{n} w_i \tau_i t_{mp,i}. \end{aligned} \tag{3.37}$$

While we know the total remaining area $F_{j,}$ the only unknown, $D_{j,}$. has to be expressed:

$$D_j = \frac{F_j + \sum_{i=1}^{n} w_i \tau_i t_{mp,i}}{\sum_{i=1}^{n} w_i \tau_i} \tag{3.38}$$

and using the formula of travelling time (3.33) we get the following:

$$D_j = \frac{F_j + \sum_{i=1}^{n} \frac{d w_i \tau_i}{v_i}}{\sum_{i=1}^{n} w_i \tau_i}. \tag{3.39}$$

Replacing F_j with the formula 3.30 we get the following:

$$D_j = \frac{j_z \sum_{i=1}^{n} w_i \tau_i \left(D_{t,i} - \frac{d n_t}{v_i} \right) + \sum_{i=1}^{n} \frac{d w_i \tau_i}{v_i}}{\sum_{i=1}^{n} w_i \tau_i}, \tag{3.40}$$

and transforming that:

$$D_j = \frac{\sum_{i=1}^{n} j_z w_i \tau_i D_{t,i} - j_z w_i \tau_i \frac{d n_t}{v_i} + \sum_{i=1}^{n} \frac{d w_i \tau_i}{v_i}}{\sum_{i=1}^{n} w_i \tau_i} =$$

$$= \frac{\sum_{i=1}^{n} j_z w_i \tau_i D_{t,i} - \sum_{i=1}^{n} j_z w_i \tau_i \frac{d n_t}{v_i} + \sum_{i=1}^{n} \frac{d w_i \tau_i}{v_i}}{\sum_{i=1}^{n} w_i \tau_i}, \tag{3.41}$$

from which:

$$D_j = \frac{\sum_{i=1}^{n} j_z w_i \tau_i D_{t,i} - j_z w_i \tau_i \frac{dn_t}{v_i} + \frac{dw_i \tau_i}{v_i}}{\sum_{i=1}^{n} w_i \tau_i} =$$

$$= \frac{\sum_{i=1}^{n} w_i \tau_i \left\{ j_z D_{t,i} - j_z \frac{dn_t}{v_i} + \frac{d}{v_i} \right\}}{\sum_{i=1}^{n} w_i \tau_i} \qquad (3.42)$$

and thus:

$$D_j = \frac{\sum_{i=1}^{n} w_i \tau_i \left\{ j_z D_{t,i} + \frac{d}{v_i}\left(1 - j_z n_t\right) \right\}}{\sum_{i=1}^{n} w_i \tau_i}. \qquad (3.43)$$

On the basis of the formulas 3.32 and 3.33 the working time of an FOU during the remaining day is as follows:

$$t_t = D_j - \frac{d}{v}. \qquad (3.44)$$

3.5. Transportation cost of technological materials

3.5.1 Cost of one transportation cycle

Cost of one transportation cycle of one material is generally calculated with the following formula (**XIII**):

$$V_1 = \frac{2dP}{v}. \tag{3.45}$$

Looking closer at the charge of a transporter during a transportation cycle we will detect that the FOU is usually loaded for only a part of a transportation cycle and it makes an idle travel during the rest (**XVIII**). Moreover, if we study the costs in the different phases of the cycle, the travelling costs within one transportation cycle will be (**XIII**):

$$V_1 = K_{1,l} + K_{1,a} \tag{3.46}$$

where $V_{1,l}$ - cost for loaded travel, EEK/h; and
$V_{1,a}$ - costs for idle travel, EEK/h.

$$V_{1,l} = \frac{dP_l}{v} \text{ and} \tag{3.47}$$

$$V_{1,a} = \frac{dP_a}{v}, \tag{3.48}$$

where P_l - price of working hour of a transporter, EEK/h; and
P_a - hourly cost of idle travel of a transporter, EEK/h.

A difference in costs P_l and P_a is a result of fuel and lubricant consumption caused by the different loads of an FOU. Therefore it is apparent from the formulas 3.47 and 3.48 that the distance will not be multiplied by two, since the both phases are handled separately.

Fuel and lubricant costs should be distinguished from the hourly cost of a transporter to operate these separately:

1) fuel and lubricant cost P_f per one working hour, if the payload of transporter is totally exploited:

$$P_f = c_f + c_m \text{ and} \tag{3.49}$$

2) sum of other components of the hourly cost of a transporter consisting of other components of hourly cost of a tractor and hourly cost of trailer(s):

$$P_m = P_{m,t} + \sum_{i=1}^{n} P_{h,i} \qquad (3.50)$$

where $P_{m,t}$ - sum of the other components of the hourly cost of a tractor belonging to the transporter, EEK/h; and

P_h - price of working hour of a trailer belonging to the transporter, EEK/h.

Calculation of hourly cost of the machines belonging to the transporter has been described in paragraph 3.5.2.

Fuel consumption of a tractor under the complete use of payload of a trailer is applied in formula 3.49, since one tractor can be equipped with different trailers and the charge factor of a tractor engine can vary because of the different values of load (**XVIII**). If we would like to include fuel consumption at the nominal effective power of the engine into the calculations, we should clarify the load factor of the tractor engine considering the different transportation loads. It has been found that, from the perspective of practical use of the calculation model, it is easier to clarify the fuel consumption either by experience or by experimental measuring on the farm because newer tractors have a fuel consumption display. For older tractors, such as the ones produced in the Soviet Union, such data is available in the literature (ATK 1984) for the models of tractors. We can find such information on size classes of tractors from the German journals of the Association for Technology and Structures in Agriculture (*KTBL - Kuratorium für Technik und Bauwesen in der Landwirtschaft*) (Fröba and Funk 2005). Grisso *et al.* (2006) have developed a calculation model to predict the fuel consumption of tractors for different engine loads and speeds. However, we need the relationship between fuel consumption and usage of the payload of a transporter (paragraph 3.5.3).

Fuel and lubricant costs while transporting the material are calculated according to formulae 3.15 and 3.16.

Thus, according to our discussion (**XIII**):

$$P_l = P_m + \mu P_f \text{ and} \qquad (3.51)$$

$$P_a = P_m + \mu_0 P_f \qquad (3.52)$$

where μ - factor considering the fuel consumption according to the usage of payload of a transporter (paragraph 3.5.3); and
μ_0 - μ, if transporter makes an idle travel.

Merging the formulas 3.46, 3.47, 3.48, 3.51 and 3.52, we get

$$V_1 = \frac{d}{v}\left(P_m + \mu P_f\right) + \frac{d}{v}\left(P_m + \mu_0 P_f\right), \qquad (3.53)$$

simplifying which, we get a formula for calculating travelling costs for one transportation cycle

$$V_1 = \frac{d}{v}\left[2P_m + P_f\left(\mu + \mu_0\right)\right]. \qquad (3.54)$$

3.5.2 Cost of travelling hour of a transporter

The hourly cost of the tractor and the trailer belonging to the transportation unit should be handled separately. The components of the fixed costs of both machines - depreciation, interest, housing costs and insurance - are now considered, because it is presumed is that work time of the transportation machines is included in the annual work capacity W (formula 3.10) of the machines.

The sum of the other components of the hourly cost of a tractor belonging to the transportation unit is calculated with the following formula:

$$P_{m,t} = c_a + c_i + c_k + c_g + c_j + c_h, \qquad (3.55)$$

where c_a - depreciation costs of machine, EEK/h;
c_i - interest, EEK/h;
c_k - insurance of machine, EEK/h; and
c_g - costs of housing machine, EEK/h.

Price of work hour of a trailer belonging to the transportation unit is as follows:

$$P_h = c_a + c_i + c_k + c_g + c_h, \qquad (3.56)$$

Components of the costs in the formulae 3.49 and 3.50 are calculated separately for every machine. The formulae presented in section 3.4.4. should be used to calculate these components.

3.5.3 Relationship between fuel consumption and payload usage of a transporter

The relationship between fuel consumption and usage of the payload of a transporter is clarified with the help of data available in literature (ATK 1984), where fuel consumption of transporters is expressed with different payloads according to the weight class of freight. There are trailers with different payloads for one tractor, and fuel consumption is presented in payload and usage.

We can compare fuel consumption considering different trailers, to calculate the proportion of fuel consumption of a partially loaded trailer from the fuel consumption of a fully loaded trailer (Table 3.1).

Table 3.1. Fuel consumption as absolute amount (l/h) and as relative (Rel.) portion of fuel consumption of a transporter with a fully used payload and by trailers with different payloads, if a 57 kW tractor is used (ATK 1984)

Use of payload, %	4 t		6 t		4 + 4 t		6 + 4 t	
	l/h	Rel.	l/h	Rel.	l/h	Rel.	l/h	Rel.
0	9.8	0.649	10.6	0.601	11.6	0.703	11.9	0.68
40	10	0.662	11.3	0.646	12.8	0.776	13.3	0.76
60	12.5	0.828	13.6	0.777	14.2	0.861	15.8	0.903
80	13.7	0.907	15.7	0.897	16.5	1	16.3	0.9314
100	15.1	1	17.5	1	16.5	1	17.5	1

Relative fuel consumption of trailers with different payloads are put into the equable system of co-ordinates, resulting in a correlation plot as a basis for finding a regression model and coefficients for this. On the bases of data presented in table 3.1 a linear regression model describes the relationship between fuel consumption and use of the payload of a transporter adequately:

$$\mu = \Gamma x + \Phi \, , \tag{3.57}$$

where Γ, Φ - gradient and initial ordinate of graph (Fig. 3.2); and
x - factor of the payload use of a transporter considering a specified material, % (Table 3.2).

The values that apply to the 57 kW tractor are the following: Γ =0.3605, Φ =62.68 and coefficient of determination R^2=0.84. We can find such values for the tractors with the other engine power in the same way.

Table 3.2. Classification of agricultural materials according to the payload usage of transporters (ATK 1984)

Class of payload use	Factor x, %	Materials
1.	100	Road metal, stones, earth, clay, sand, mineral fertilisers, water, loose grains (except oats), oats and pulses in sacks, potato and forage root crops, pumpkins and fruits in boxes, baskets or containers.
2.	85	Slack lime, sawdust and shavings in sacks, packing – flax, gunny or paper sacks, peat and peat compost, machines, loose oats and pulses, concentrated fodder, oil cakes, bran and mill residues, pressed hay, straw and flax, silage, vegetables, berries and plants in baskets or boxes, loose fruits, grass flour in sacks.
3.	60	Pesticides, dry silage, silage grass, trees, bushes and plants, agricultural and garden tools
4.	45	Loose hay and straw, flaxes, not packed young plants of vegetables, flowers and berry bushes, loose vegetables, wooden boxes.

As discussed in the previous chapter we can use a linear function to express the relationship between relative fuel consumption and usage of the payload, so we only need to know fuel consumption during idle travel, and the case when the payload is fully used, to calculate the regression coefficients Γ and Φ.

In this case, if we want to transform the absolute amounts to the relative fuel consumption, the initial ordinate of the graph (Fig. 3.2) of the equation 3.57 is the following:

$$\Phi = \frac{100G_t}{G_k} \tag{3.58}$$

and the gradient:

$$\Gamma = \frac{G_k - G_t}{G_k}, \tag{3.59}$$

where G_k - fuel consumption if the payload of a transporter is totally utilized, l/h; and

G_t - fuel consumption of a transporter in idle travel, l/h.

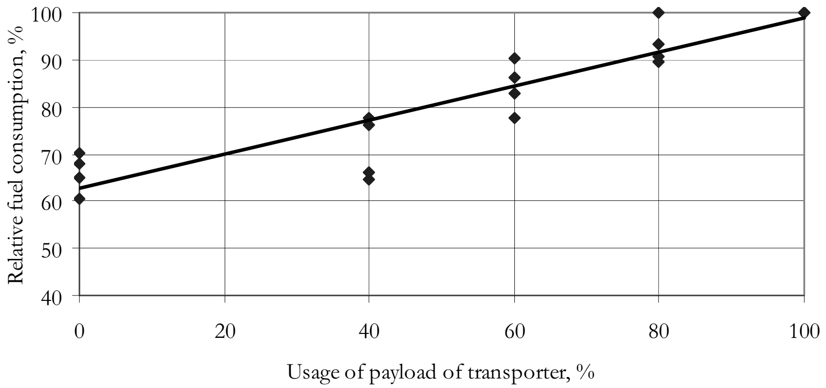


Figure 3.2. Data points of the relative fuel consumption to the fuel consumption of a transporter with totally used payload according to usage of the payload; and a regression line according to these

If we replace Γ and Φ in equation 3.57 with the formulae 3.58 and 3.59, and abandon the percentage, we could calculate the relative fuel consumption with the following formula:

$$\mu = \frac{(G_k - G_t)x + G_t}{G_k} . \tag{3.60}$$

Formula 3.60 will be needed if the payload is used partially. If the payload of a transporter is used totally, $\mu=1$; and if idle travel is made,

$$\mu_0 = \frac{G_t}{G_k} . \tag{3.61}$$

Fuel consumption units are different in different data sources. ATK (1984) gives fuel consumption in l/h. KTBL (Fröba and Funk 2005) gives fuel consumption in l/ha. Also given are the transportable amounts per hectare and distances. Thus, the fuel consumption can be recalculated to l/(t·km). If we know the average driving speed and the payload of the transport machine, then it is possible to recalculate the fuel consumption to l/h. Similarly if some data source gives fuel consumption in l/(t·km).

3.5.4 Number of transportation cycles

The amount of material related to the plot is often so large that several transportation cycles are needed. Thus, the transportation costs for one material depend on the number of travels to the plot. If the amount of material is smaller than the payload of a transporter, nevertheless travel will be needed unless there is another possibility for transport (e.g. transporting the seed in the box of driller). If one type of material is transported, the number of transportation cycles of a transporter will be calculated with the formula (**XIII**):

$$Y = \frac{100QF\lambda}{xg} \tag{3.62}$$

where g - payload of a transporter, kg;
Q - amount of material, kg/ha; and
λ - share factor of a transporter transporting one type of material, if the whole material is transported by one transporter, then $\lambda = 1$.

Often several transporters are used to transport large amounts of material. These transporters may have different payloads, travelling speeds and prices per work hour. So we have to calculate what is the proportion of material transported by a transporter to the total amount. While it is difficult to predict the performance of a transporter due to durations of load and unload, especially when several transporters and loaders are used, the weight factor as simplification is used to indicate the proportion of material transported by a specified transporter to the whole essential amount. The sum total of the weight factors for one material should be 1.

The weight factor for one transporter is calculated with the formula (**XIII**):

$$\lambda = \frac{w_v \tau_v}{\sum_{i=1}^{n} w_{v,i} \tau_{v,i}} \tag{3.63}$$

where w_v - performance of a transporter, t/h (section 3.5.5); and
τ_v - time loss factor of a transporter by transporting one type of material.

Calculating the number of transportation cycles we have to consider that the last cycle is probably partially loaded. The fractional portion of the number of cycles Y also indicates the load of the cycle. Thus, if the integer of the result of the equation 3.62 is lesser than Y *i.e.* $[Y] < Y$, then the last transportation cycle is partial, so the cost of this cycle should be calculated separately. If $[Y] = Y$, then the last cycle also has a full load and the cost of that should not be calculated separately.

In the case of a partial load we have to calculate the amount of material in the last load:

$$Y_j = Y - [Y] \tag{3.64}$$

where Y_j - relative rate of remaining load.

And usage of the payload of a transporter in that case is:

$$x_j = xY_j, \tag{3.65}$$

where x_j - usage of the payload of an FOU, transporting the remaining load. We have to use x_j instead of x in the formula 3.60.

Sometimes, when several transporters are transporting one type of material, the results of the calculation indicate that all these have the last load as the remaining load. However, this is actually not correct because usually only the last transporter has the remaining load. Therefore, we have to divide the remaining amounts so that only one transporter will have the remaining load.

Therefore we have to find the sum of the remaining loads of all transporters and from that the sum of the remaining amounts of material. We will find the remaining amount transported by one FOU first, subtracting the number of full loaded transport cycles from the number of transport cycles and multiplying the difference by the payload of a transporter and by the factor of usage of the payload characterizing the material:

$$J_{ag} = 10^{-2} gx(Y - [Y]). \tag{3.66}$$

If we sum the remaining amounts of all transporters we get:

$$J_s = 10^{-2} x \sum_{i=1}^{n} g_i (Y_i - [Y_i]). \tag{3.67}$$

It would presumably be most effective if the remaining amount is transported by a transporter whose payload is the least over the remaining amount. If the sum of the remaining amounts is greater than the greatest payload available, the remainder of that will be calculated in turn, and the most suitable transporter will be sought for the new remaining amount. The number of transportation cycles is recalculated for all FOUs:

$$Y_k = [Y] + 1\,. \tag{3.68}$$

The value of the remaining load is calculated again for the last transporter missed out on the full load from the remaining loads. For this purpose the weight of one load of all transporters, with corrected number of full loads, is subtracted from the remaining amount J_s and the converse operation of formula 3.66 is performed:

$$Y_{j,k} = \frac{J_s - 10^{-2} x \sum_{i=1}^{n} g_{k,i}}{10^{-2} gx}, \tag{3.69}$$

where g_k - payload of a transporter with corrected number of full loads, kg; and

$Y_{j,,k}$ - relative rate of the remaining load for a transporter that did not get the full load from the remaining amount of a material.

We have to use $Y_{j,k}$. instead of Y_j in formula 3.65.

If the remaining amount is very small it will not pay to travel to the plot for it. It would be more sensible to start the transport from such a remaining amount that the resulting income would be greater than the cost of the transportation cycle. These relationships will not be discussed here, but we call it a minimum value of remaining amount (J_{min}), that can be determined by the users of this method themselves according to their own experience. Thus, if $J > J_{\min}$, the remaining amount J will also be transported.

3.5.5 Calculating the performance of a transporter

To calculate the performance of a transporter we have to find out the duration of a transportation cycle i.e. the time needed to load the transporter, travel from point A to point B, unload it at point B and travel back to point A:

$$w_v = \frac{gx}{1000\left(t_{pl} + t_s + t_{ml}\right)} \tag{3.70}$$

where t_s - travelling duration of a transporter, h;

t_{pl} - loading time, h; and
t_{ml} - unloading time, h.

Travelling duration:

$$t_s = \frac{2d}{v} \tag{3.71}$$

Loading time:

$$t_{pl} = \frac{gx}{1000 w_{pl}} \tag{3.72}$$

where w_{pl} - loading performance, t/h.

Unloading time:

$$t_{ml} = \frac{gx}{1000 w_{ml}} \tag{3.73}$$

where w_{ml} - unloading performance, t/h.

After replacements the performance of a transporter is the following (**XIII**):

$$w_v = \frac{gx}{gx\left(\frac{1}{w_{pl}} + \frac{1}{w_{ml}}\right) + \frac{2000d}{v}}. \tag{3.74}$$

There is data about loading and unloading performances available in the literature (Kask 1977, ATK 1984).

3.5.6 Total cost of transporting the material

From formula 3.54, the travelling cost of a transporter transporting one material per unit of area is the following:

$$V_s = \frac{dY}{vF}\left[2P_m + P_f\left(\mu + \mu_0\right)\right]. \tag{3.75}$$

Let us mark factor μ, that takes fuel consumption into account, according to usage of the payload of a transporter as μ_t for full load and as μ_j for partial load, calculating which we should apply payload usage x with the corresponding index (Paragraph 3.5.3).

To calculate transportation costs we have to sum transportation costs of full and partial loads:

$$V_s = \frac{d}{vF}\left\{[Y]\left(2P_m + P_f\left(\mu_t + \mu_0\right)\right) + 2P_m + P_f\left(\mu_j + \mu_0\right)\right\}, \quad (3.76)$$

and transforming this, we get:

$$V_s = \frac{d}{vF}\left\{\left(2P_m + P_f\mu_0\right)\left([Y]+1\right) + P_f\left(\mu_t[Y]+\mu_j\right)\right\}. \quad (3.77)$$

If several transporters are used for one material (**XIII**):

$$V_s = \frac{d}{F}\sum_{i=1}^{n}\frac{\left(2P_{m,i} + P_{f,i}\mu_{0,i}\right)\left([Y_i]+1\right) + P_{f,i}\left(\mu_{t,i}[Y_i]+\mu_{j,i}\right)}{v_i}. \quad (3.78)$$

Thus the total transportation costs of all materials related to the plot within the determined production year is (**XVIII**):

$$V = \sum_{s=1}^{l} V_s \quad (3.79)$$

where l - number of materials related to the plot within the production year.

Considering transporters that have the corrected number of transportation cycles, $[Y_k]$ should be used instead of $[Y]$.

3.6. Dependence of income on travelling distance

3.6.1 Relationships between yield and calendar period of work

Nowadays costs of grain production depend largely on the machinery used on the farm (Figure 2). On the other hand, the income of production is also related to the structure and usage of the machinery. On the grounds of plot tests carried out over the years we know that the more the working time deviates from the optimal time point the less the yield processed on these areas at that time point is, compared to a plot processed at the optimal time point (Möller 1981, Möller 1985). This regularity, also called timeliness, is a basis for method used for estimation of the workload of cereal production farm machinery, and for calculation of the optimal value for the workload (**I, II, IV, VI, VII, VIII, IX, X**, Tamm 1999).

Yield of cereals depends on every kind of qualitative and quantitative parameter of the field work (Haller 1969, Heinsoo *et al.* 1986, Penu *et al.* 1995) such as tillage or seeding depth, overlaps and gaps between work passages, applied amounts etc. Among others it also depends on the working time. In the case of many work procedures we have a lack of timeliness data. Many studies have been carried out by researchers (Karmin 1975, Möller 1981, Möller 1985) about the more important works such as sowing, harvesting and autumn ploughing, and farmers have the possibility of using the corresponding data. These studies indicated that yield depends on the working time (day), there is the so called best time for every operation, and cereals can be sown before or after that.

The starting point of the present thesis is the effect of timeliness on sowing. There are the following two reasons.

1. There is a significantly greater (2...4 times) timeliness effect of sowing than of harvesting or autumn ploughing (Vipper 1989).
2. Different cereals have different ripening times. Well organized sowing work, and well chosen areas for crops (Мёллер *et al.* 1989), are the prerequisites for smooth harvesting , where harvesting ripeness of cereals arrives in a defined sequence so that harvesting machines can work without interruptions, and 6…8 days of harvesting time is available for every crop. Therefore this allows the cost of timeliness for harvesting to be minimised. However, concerning sowing, there are dissimilarities.

> In principle, all cereals are suitable for sowing if the soil is ripe for seeding. Starting with the sowing of one crop the others must wait, and this would give rise to a timeliness effect.

Currently the model takes only the timeliness costs of sowing into account (**XVIII**). In future, the model will be improved with the possibility to consider timeliness of other field operations, including harvesting.

In the discussed method the parabolic relationship has been used so far to express the timeliness effect of sowing (3.82). However, the question arises, is this the only possible function appropriate for the case, or would some other functions describe that relationship better? The suitability of different equations is subsequently analyzed to describe sowing timeliness.

3.6.2 Comparison of equations describing sowing timeliness

Many studies (Möller 1981, Möller 1985) of timeliness of sowing have been carried out in Estonia. The field tests have been performed for a long period during the year – with the start 10…20 days before, and the end 30…56 days after the best sowing day. We are interested in the time span from the best sowing time until 20 days after the best time, firstly because the calculations of optimal work load of machinery made to date (Tamm 1999) show that profitability of grain production is the highest when the area of grain production is large enough to perform spring sowing within 20 days after the best sowing time. Secondly, the data set from the tests received from the latest time after the best sowing day is probably insufficient, while presumably the yield from these test plots was not harvested, but this is not reflected in the set of raw data.

The reason for exploring only the period after the best sowing time is that most of the cereals are spring crops in Estonia, and the best time for spring sowing is usually a time when a wheeled tractor is first able to travel on the plot, thus the sowing starts at the agro-technically best time. But if there happens to be a possibility to start sowing before the best time, it will just be a time gain for a farmer, while yield loss before the best time is lower than that after , with the same time span (Figure 3.3) (Tamm 1999).

As a result of this the relationships for calculating the predictable income from grain selling are established depending on sowing duration, where the best sowing day as the starting day of the sowing period is taken.

Earlier a linear relationship 3.80 was used in Estonia to handle timeliness problems (Möller 1981, Möller 1985), because it was easily usable and enabled the deduction of a rule of thumb, showing the timeliness effect of one sowing day (e.g. barley has a yield loss of 1.4% per day). During the first years of the 1990s, when personal computers developed and spread rapidly, and it became easier to perform statistical analyse,s timeliness data were studied again, and regression coefficients for parabolic function were found (3.82) with the help of computers (Лобосок 1995). A parabolic equation was used (**I, II**, **XI**, Tamm 1999) because it describes the timeliness effect more naturally compared to a linear function, and it was also already in use elsewhere in the world (Witney 1988). There is drastic dramatic transition from prior to and after the best sowing time (Fig. 3.3) in the case of the linear function of timeliness, while the transition is actually smooth and may last for couple of days. Secondly, the yield does not fall after the best day at an even tempo, but relatively slowly at the beginning and then more and more rapidly, as the parabolic relationship describes (Fig. 3.4, Table 3.3).

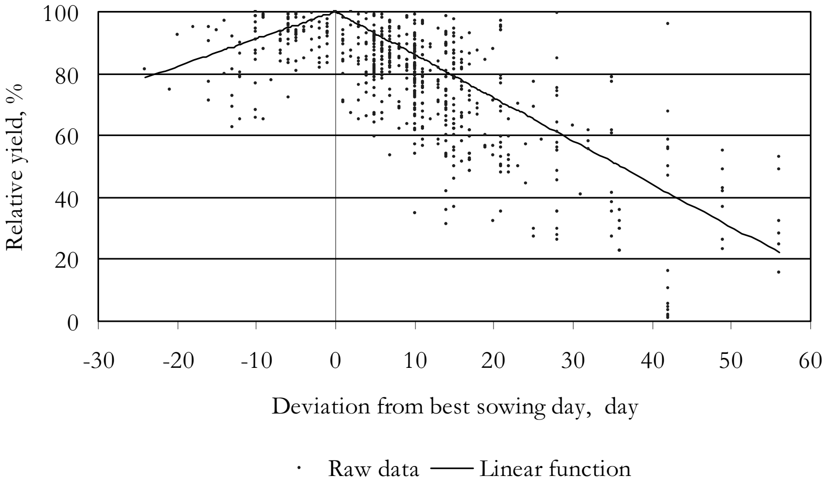


Figure 3.3. Linear function describing sowing timeliness

It has been proposed to use such a function (e.g. cubic polynomial) (tables 3.3 and 3.4 by some researchers to describe timeliness for which the fall of yield decelerates after a long period and remains at a minimum yield level. An equation with such a pattern is often used to describe some processes in nature, but it is inappropriate for timeliness of sowing, because if sowing is too late, the yield will not mature and even if it does, there will be no possibility to harvest it in Estonia. Secondly, if we compose a cubic polynomial based on the data collected during the time span of 20 days after the best sowing day, the function will describe timeliness of sowing quite similarly to the equation of a parabola 2 (3.82) (Fig. 3.3), but the latter is easier to use and therefore we have no reason to reject it.

Table 3.3. Different possible forms of sowing timeliness relationship

Name of function	Function for calculating yield from area, seeded *C* days after best sowing day (**V**)	
Linear function	$h_t = 10^{-2} h_{\max}(a + bC)$	(3.80)
Parabolic function 1	$h_t = 10^{-2} h_{\max}(a_1 + b_1 C + c_1 C^2)$	(3.81)
Parabolic function 2	$h_t = 10^{-2} h_{\max}(a_2 + b_2 C^2)$	(3.82)
Exponential function	$h_t = 10^{-2} h_{\max} a_3 e^{b_3 C}$	(3.83)
Cubic polynomial	$h_t = 10^{-2} h_{\max}(a_4 + b_4 C + c_4 C^2 + d_4 C^3)$	(3.84)

Symbols used in table 3.3:
h_t - yield from farm area, seeded in day C, kg/ha;
h_{max} - yield from farm area, seeded in the best day (highest yield), kg/ha;
a, a_1, a_2, a_3, a_4, b, b_1, b_2, b_3, b_4, c_1, c_4, d_4 - regression coefficients; and
C - number of days deviating from the best sowing day.

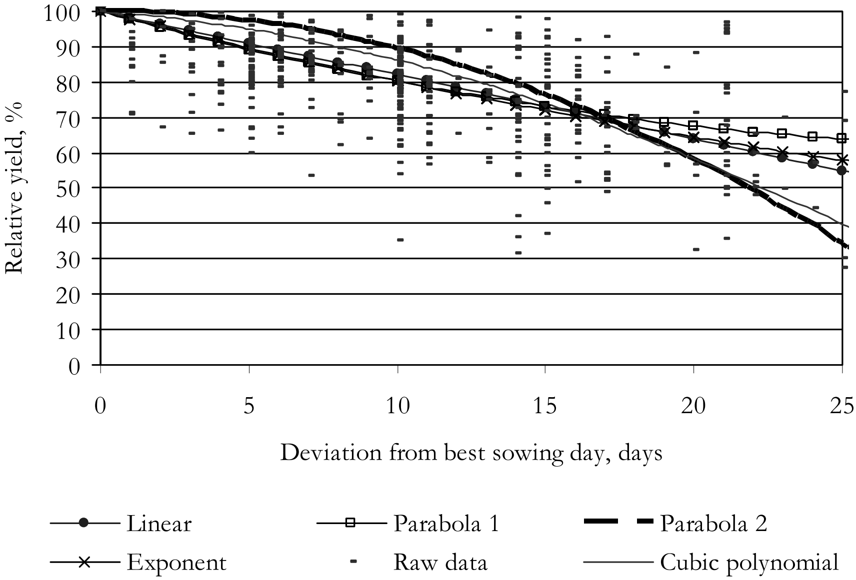


Figure 3.4. Graph of different functions it is possible to use to describe the relationship between yield and sowing time of cereals

The value of free member *a* in all of the regression equations is 100. Values of the regression coefficients for the other cereals for parabolic (3.82) function are given in table 3.6.

Table 3.4. Values of regression coefficients, used to construct the figure 3.4

Function	*b*	*c*	*d*
Linear function	-1.8	-	-
Parabolic function 1	-2.34	0.036	-
Parabolic function 2	-0.105	-	-
Exponential function	-0.022	-	-
Cubic polynomial	-0.6128	-0.0794	0.0003

With the help of average yield equations presented in the table 3.5 incomes from area seeded during *C* sowing days (Fig. 3.5) are calculated The equations in table 3.5 are created by integrating the equations in table 3.3 in the interval *C* and dividing by the number of sowing days *C*. We can see in the figure that there is no significant difference in predicted income for the short sowing period and the usage of different regression equations. With longer sowing periods we can see that income calculated using an exponential relationship is noticeably lower in comparison with the income found with the other equations, and is therefore unsuitable to use for income prediction. This phenomenon is caused by the different behaviour of the exponential function of integration compared to other functions (Tables 3.3 and 3.5).

Table 3.5. Different possible forms of average yield calculation formulas based on sowing timeliness relationships, given in table 3.3.

Name of function	Function for calculating average yield from area, seeded during *C* days	
Linear function	$h = 10^{-2} h_{\max}\left(1 + \frac{bC}{2}\right)$	(3.85)
Parabolic function 1	$h = 10^{-2} h_{\max}\left(1 + \frac{b_1 C}{2} + \frac{c_1 C^2}{3}\right)$	(3.86)
Parabolic function 2	$h = 10^{-2} h_{\max}\left(1 + \frac{b_2 C^2}{3}\right)$	(3.87)
Exponential function	$h = 10^{-2} h_{\max} a_3 e^{b_3 C}$	(3.88)
Cubic polynomial	$h = 10^{-2} h_{\max}\left(1 + \frac{b_4 C}{2} + \frac{c_4 C^2}{3} + \frac{d_4 C^3}{4}\right)$	(3.89)

This author has used function 3.82 in the method of optimizing the work load of farm machinery (**VI, VII, VIII, IX, XI, XIII,** Tamm 1999) and has found that there is no need to use any other function because they do not give more exact results within the observed time span (20 days after the best sowing day).

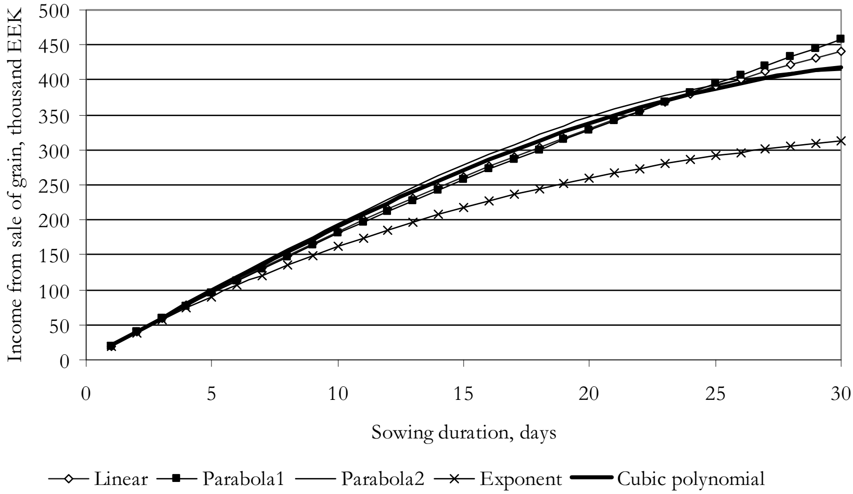


Figure 3.5. Income from grain depending on sowing duration, calculated using different functions

Table 3.6. Value of regression coefficients (a, b) and correlation coefficient (r) if results from experiments made before (b.), after (a.) or before and after (b.& a.) best sowing day are taken into account (Tamm 1999)

Crop	Before (b), after (a) or before and after (b. & a.)	Considered are results from all experiments.			Considered are results from experiments made 15 days before or after best sowing day			Considered are results from experiments made 10 days before or after best sowing day		
		a	*b*	*r*	*a*	*b*	*r*	*a*	*b*	*r*
Spring barley	b.	0.9564	0.000509	0.499	0.9702	0.000972	0.587	0.9709	0.001010	0.456
	a.	0.8622	0.000275	0.672	0.9390	0.001173	0.622	0.9528	0.001756	0.583
	b. & a.	0.8824	0.000289	0.676	0.9493	0.001188	0.632	0.9591	0.001635	0.564
Oat	b.	0.9578	0.000892	0.603	0.9738	0.001316	0.697	0.9741	0.001578	0.575
	a.	0.8995	0.000403	0.768	0.9491	0.001072	0.532	0.9745	0.002302	0.675
	b. & a.	0.9110	0.000417	0.756	0.9574	0.001146	0.578	0.9756	0.002115	0.649
Spring wheat	b.	0.9710	0.000631	0.288	0.9710	0.000631	0.288	0.9744	0.000830	0.344
	a.	0.9130	0.000745	0.760	0.9488	0.001200	0.675	0.9712	0.002160	0.733
	b. & a.	0.9259	0.000768	0.756	0.9570	0.001201	0.654	0.9722	0.001846	0.642
Rye	b.	0.9605	0.001390	0.569	1.0027	0.002467	0.758	0.9898	0.001957	0.585
	a.	0.8399	0.000229	0.807	1.0070	0.002027	0.873	0.9981	0.001831	0.906
	b. & a.	0.8561	0.000239	0.773	1.0039	0.002416	0.778	0.9936	0.001899	0.674
Winter wheat	b.	0.9154	0.000460	0.402	0.9819	0.001847	0.745	0.9761	0.001574	0.556
	a.	0.9191	0.000349	0.472	0.9767	0.001705	0.712	0.9765	0.002148	0.685
	b. & a.	0.9154	0.000379	0.432	0.9793	0.001780	0.730	0.9763	0.001795	0.607

3.6.3 Model for considering the travelling distance

As discussed previously, the yield depends on the duration of work, and the quicker the work is performed the minor the yield loss is in comparison with the day the most suitable for that work. Work pace means here that a specified area is processed within one time unit i.e. hectares per hour (ha/h). Every FOU has its own performance it is able to achieve on average, if the work is to be done without any time losses. Nevertheless, besides other time losses (due to whether, technical reasons and operator personal needs) the time travelling to the plot and back, and thus the area processed in a work day, is generally less than the daily performance of the FOU.

The longer the travelling distance is, the greater part of the workday is wasted travelling to the plot and back. But at the same time the time available for work on the plot decreases, and thus the number of workdays (formulas 3.21 and 3.26) necessary to perform the work on the plot increases. With the greater number of workdays an increase in the deviation from the best working time is accompanied by a decrease in average yield (**XVIII**).

Thus, we have to find out how the average yield depends on the travelling distance. As we have most knowledge about the relationships of timeliness of sowing we will clarify here how timeliness is affected by the travelling duration of seedbed preparation units and sowing units.

First we need to know how the work is organized on the plot. If there is only one tractor all operations will be done on the plot sequentially. Thus, we have to consider the travelling time of every FOU affecting sowing time, and the formula for calculating the sum of travelling time is the following (**XIII**):

$$C_{d,r} = \frac{dn_t}{D_t} \sum_{i=1}^{n} \frac{\sum_{j=1}^{o} Z_{i,j}}{v_i}, \tag{3.90}$$

where $C_{d,r}$ - sum of travelling durations affecting sowing time, if all works are done sequentially, days.

Only spring works are considered here. The time for transporting the materials to the plot should additionally be taken into account while there is no additional labour performing these operations alongside the main operations.

But if there is more than one tractor and one worker on the farm, the work will probably be organized in such a way that the sowing unit should wait only on the first day of sowing season and after that the work will be performed alongside in the different plots, and sowing duration will mostly be affected by travelling duration of the sowing unit(s).

Travelling duration of the sowing unit to the specified plot is calculated with the following formula (**XIII**):

$$C_{d,k} = dn_t \frac{Z_k}{v_k D_{t,k}} \tag{3.91}$$

where Z_k - the number of days a sowing unit should visit the plot to seed it (calculated with the formula 3.22);
v_k - travelling speed of the sowing unit, km/h; and
$D_{t,k}$ - length of a workday of the sowing unit, h.

We should subtract from this the duration of the last journey back to the farm centre in some cases, because it does not affect sowing time. That would be the case, when the plot is seeded last, but if this is not the case, the return travel duration will affect the sowing time on the next plots. While we do not know which of the plots is in the sequence, but we are aware that only one of the plots can be the last and the t of them are not, we should consider that the time travelling back will affect the average yield.

Now we know the travelling time prolonging the sowing period. Next we have to answer the question: how to calculate the fall of the average yield due to prolonging of the sowing period? If the sowing period for the whole sowing area on the farm is C_k days (including the area of the observed plot), together with the travelling time C_d related to the plot it will be as follows:

$$C = C_d + C_k . \tag{3.92}$$

Starting from formula 3.87 the average yield on the farm, not considering the travelling time, is (**I**, **II**; **XI**):

$$h_1 = h_{\max}\left(1 - \frac{bC_k^2}{3}\right) \tag{3.93}$$

and the average yield considering the working time together with the travelling time is:

$$h_2 = h_{\max}\left(1 - \frac{bC^2}{3}\right). \tag{3.94}$$

Yield loss per hectare because of travelling time is $\Delta h = h_1 - h_2$ or

$$\Delta h = \frac{bh_{\max}}{3}\left(C^2 - C_k^2\right) \tag{3.95}$$

While $C^2 = \left(C_d + C_k\right)^2 = C_d^2 + 2C_dC_k + C_k^2$, then

$$\Delta h = \frac{bh_{\max}C_d}{3}\left(C_d + 2C_k\right) \tag{3.96}$$

where C_d - sum of the travelling durations affecting the sowing period calculated according to the way the work is organized with the formula 3.90 or 3.91, days; and

C_k - sowing period, not considering the travelling times, days. The period is determined as an expert evaluation by experience or using a method of calculating the optimal duration of the sowing period (Tamm 1999).

While the average yield loss is calculated according to the period of spring sowing needed for seeding the whole spring sowing area, then to calculate the total yield loss we have to multiply the average yield loss by the value of the area, and by the factor defining the proportion of the area that was not seeded before starting with the observed plot:

$$\Delta S_e = \frac{\Delta h F_e \theta}{10^5} \tag{3.97}$$

where F_e - area of arable land in the farm, ha;

ΔS_e - total yield loss in the farm caused by travelling to the plot, t (Fig. 3.6); and

θ - factor showing the proportion of the tillage area of spring cereals that is not seeded before seeding the observed plot, %.

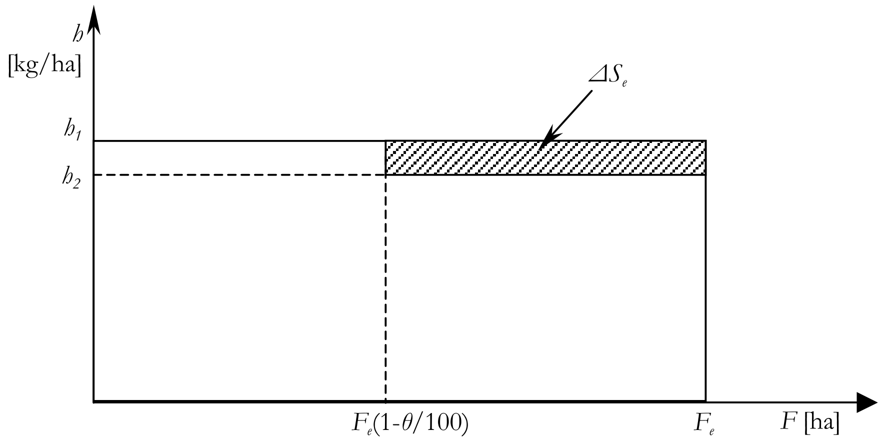


Figure. 3.6. Calculation of total yield loss according to decrease of average yield and unseeded area of spring sowing

Loss of income is calculated with the following formula:

$$\Delta B = r\Delta S_e \tag{3.98}$$

where r - sale price of cereal, EEK/t.

If ΔS_e and Δh are replaced, then:

$$\Delta B = \frac{bhrC_d F_e \theta}{3 \cdot 10^5}\left(C_d + 2C_k\right). \tag{3.99}$$

Income loss caused by the travelling distance per unit of the plot area is:

$$\Delta B = \frac{bhrC_d F_e \theta}{3 \cdot 10^5 F}\left(C_d + 2C_k\right). \tag{3.100}$$

3.7. Costs for management travel

If the plots are large and located far away from the farm centre it will be rational to organize transport of fuel, lubricants, parts for FOUs and food for operators besides the technological materials related to the plot (Fortuna 1985). Sometimes transport of operators can also be necessary. The production manager should also visit the plots often to clarify the condition of these, and both the performance and work quality of the FOUs.

The definition of the number of management travels is based on the need to evaluate the status of the plot and quality of operations (**XVIII**). Cost of a plot visit is as follows (**XIII**):

$$M_1 = \frac{2dP_t}{v_t}. \tag{3.101}$$

And total cost of all management travels to the plot during the whole production year is (**XIII**):

$$M = \frac{2d}{F} \sum_{i=1}^{\omega} \frac{P_{te,i}}{v_{te,i}}, \tag{3.102}$$

where P_{te} - hourly cost of travelling of the service vehicle, EEK/h;
v_{te} - travelling speed of the service vehicle, km/h; and
ω - the number of service travels to the certain plot within the production year.

3.8. Calculating the maximum travelling distance

Previously the methods described were produced to calculate the travelling costs of a specified production technology, plot area and travelling distance. The producer is often interested in what can be the maximum travelling distance to plot by defined area of the plot and technology; or what is the minimum area of the plot to achieve profitable production at a specified travelling distance. So the following calculation method was composed to answer these questions.

In order to determine the economically feasible maximum distance between the farm centre and the plot, considering its area and technology, the distance in the case of $K_{h,max}$ must be found ($K_{h,max}$ is calculated with formula 3.4) (**XVIII**). While the distance cannot be analytically found by the system of formulae composed for calculating K_h, then the iterative method is used. This method enables the distance to be found in which the sum of the costs is the nearest to the limit value. i.e., $K_h \rightarrow K_{h,max}$. The plot area and the technology are fixed while seeking distance *d*. In the case of the iterative method, it is necessary to define the tolerance δ; when this has been achieved, the calculation procedure will be completed. In other words, the following condition should be fulfilled (**XVIII**):

$$\left|K_h - K_{h,\max}\right| \leq \delta , \qquad (3.103)$$

where δ - tolerance of solution, EEK/ha.

If condition (3.103) is met, then the distance used for finding parameter K_h is the economically feasible maximum distance between the farm centre and the plot, considering its area and technology (**XVIII**).

There are three phases of the iterative method: we used the determination of the initial solution, the secant method (Weisstein 2006a) and bisectioning (Weisstein 2006b). The calculations thus far show that 50 cycles are enough to reach a satisfying solution. After having tested the model, the following schema is proposed for the solution: 1) 1st Cycle – calculating the initial solution, 2) 2nd-5th Cycle – secant method, and 3) 6th – 50th Cycle – method of bisecting the interval (**XVIII**).

<u>Calculating the initial solution</u>

While it is attempted to find a more and more exact solution in every calculation cycle for iterative solving of a calculation model, there will be a need for the initial solution in respect of what to compare the solutions of the next calculation cycles with and to start correcting the initial conditions. Therefore, we have to give some realistic arbitrary value. In software the present value is d_1=10 km. Afterwards the sum of costs $K_{b,1}$ is found.

<u>The secant method is</u> an algorithm which assumes a function to be approximately linear in the region of interest. In the case of the first cycle of the secant method, the linear equation, intersecting zero and the initial value ($K_{b,1}$, d_1) is used to calculate the distance for the next calculation cycle:

$$d_2 = d_1 \frac{K_{b,\max}}{K_1}. \tag{3.104}$$

The geometrical explanation is given in figure 3.7. The line **s** can be fit on the points ($K_{b,1}$, d_1) and (0, 0). Intersection of the point of $K_{b,max}$ and line **s** gives the new travelling distance d_2; and the sum of costs $K_{b,2}$ is calculated for that distance. Then the line **u** can be fit on the points ($K_{b,1}$, d_1) and ($K_{b,2}$, d_2).

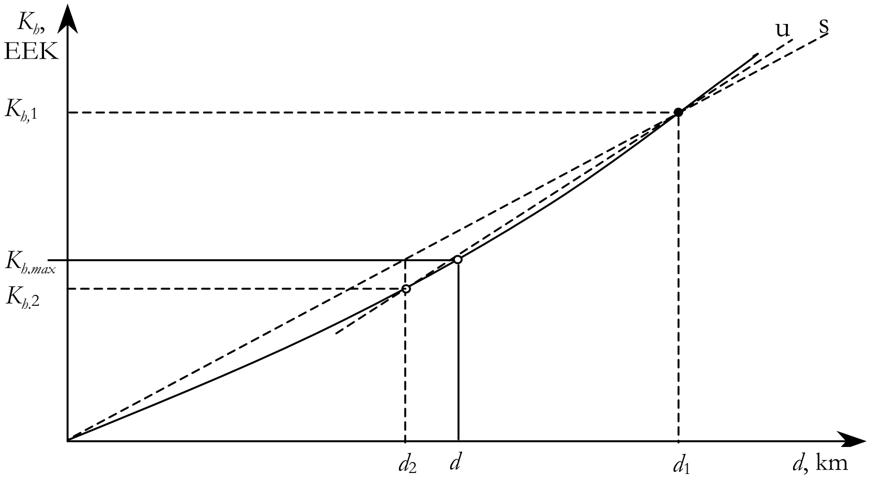


Figure 3.7. Approximation, using linear interpolation. The black dot on the curve is the initial solution

All the following distances are calculated via the linear interpolation formula:

$$d_{i+1} = d_{i-1} + \left(d_i - d_{i-1}\right)\frac{K_{h,\max} - K_{h,i-1}}{K_{h,i} - K_{h,i-1}}, \qquad (3.105)$$

where i is the number of the computation cycle.

Computing is continued until condition (3.103) is satisfied, or the defined number of cycles (presently 5 cycles in software) has been exceeded.

By testing and adjusting the algorithm, it became clear that in most cases it will be sufficient to use only the linear interpolation to find the exact solution, and the convergence of solution will take place within a couple of calculation cycles. Calculations show that up to the field distance of 40 km, the relationship between distance and costs is nearly linear. With longer distances, the growth of costs accelerates and then the secant method fails to give satisfying convergence. Hence, this method will help us to find solutions on both sides of the searched point that are needed in stage 3.

Bisecting of the interval. If the convergence of solution has been insufficient during the process of the secant method, another method will be used for further approximation – bisecting the interval between the two nearest points on both sides of the searched point. The two nearest cost sums, one larger and one smaller than the cost limit $K_{h,max}$, are determined, and thus the interval where the searched solution is located is defined:

$$\begin{aligned} d_s &= d_i \text{ if } K_{h,i} > K_{h,\max} \text{ and} \qquad (3.106)\\ d_v &= d_i \text{ if } K_{h,i} < K_{h,\max}, \end{aligned}$$

where d_s - travelling distance if the travelling costs are greater than the limit value, km;

d_v - travelling distance if the travelling costs are smaller than the limit value, km;

d_i - travelling distance used in the calculation cycle i, km; and

$K_{h,i}$ - sum of the travelling costs, calculated in the cycle i, EEK/ha.

If the nearest cost sum, larger or smaller than the cost limit, was not determined during the previous calculation cycles, zero should be used for the driving distance d_v and the value of d_s should be an integer that is greater than the probable driving distance for limit cost $K_{h,max}$, (e.g. 1000 km) accordingly.

A new driving distance used in the next calculation cycle is calculated with the formula:

$$d_{i+1} = \frac{d_s + d_v}{2}. \tag{3.107}$$

If the bisection point does not match the condition (3.103), studied which of the half-sections contains the searched value $K_{h,max}$ it will estimated and this half-section will be bisected again, and so on. The iterations are continued until the moment when the condition (3.103) is satisfied or the value of solution starts to repeat itself due to rounding, so the search for a more exact solution is complete.

This mathematical construction also enables us to search for the minimum area of plot at a known distance (**XVIII**). The machines would still travel back and forth at least once even for a tiny plot. Thus the farmer has transportation costs independent of plot size. However, the plot can be so small that the income does not cover the transportation costs, especially when the distance is long. This means that where $K_h > K_{h,max}$ - the transportation costs are larger than the amount of money available for transportation expenses. The larger the plot, the smaller the transportation costs per ha (costs are divided by the area) (Table 4.19) unless two trips are made - then the sum of transportation costs per ha increase sharply and then start to decrease again (Figure 4.4.). If the market conditions are favourable for the farmer, then by increasing the plot size the income for the whole plot grows faster than the costs; at some point, the value of the area is $K_h < K_{h,max}$. The condition $K_h = K_{h,max}$ is the indicator that shows the minimum value of a plot area.

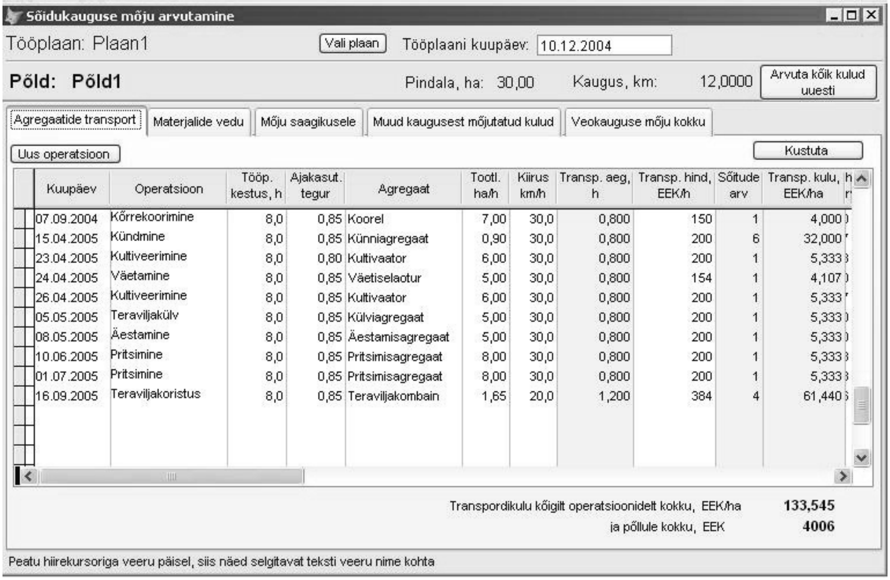
The minimum area of the plot is calculated with the same algorithm as for the maximum distance (**XVIII**). The difference is that initially a value for distance d is fixed, and thereafter the minimum plot area is searched by the specific value of the limit cost $K_{h,max}$. If the distance is relatively long, and the value of limit cost is relatively small, it is possible that the minimum area of the plot cannot to be determined. Thus, the value of limit cost should be increased and it should be recalculated.

4. SIMULATIONS

4.1. Software, “Field distance”

The amount of initial data and the scope of calculations that apply to the estimation of the rationality of plot usage concerning travelling distance between the plot and the farm centre are large (Figure 3.1.). This author has projected and programmed a DSS (Decision Support System) software “Field distance” to manage all the data and to perform the necessary calculations. The software was programmed by developer software Microsoft Visual FoxPro 8.0.

The program “Field distance” includes calculation models needed to calculate the costs related to the travelling distance (Figure 4.1). There is a possibility to draw up different plans, to manipulate them and to compare the results. The user can enter all the work performed on the plot within the production year, all the technological materials and management travels related to the plot. An income loss is also computed. The total costs are given as a result, related to the travelling distance to the plot. The maximum travelling distance, or the minimal area of the plot, can also be calculated if the maximum value of total costs and the plot area, or the travelling distance, according to these are predefined.



Tööplaan: Plaan1

Tööplaani kuupäev: 10.12.2004

Põld: Põld1

Pindala, ha: 30,00

Kaugus, km: 12,0000

Kuupäev	Operatsioon	Tööp. kestus, h	Ajakasut. tegur	Agregaat	Tootl. ha/h	Kiirus km/h	Transp. aeg, h	Transp. hind, EEK/h	Sõitude arv	Transp. kulu, EEK/ha
07.09.2004	Kõrrekoorimine	8,0	0,85	Koorel	7,00	30,0	0,800	150	1	4,000
15.04.2005	Kündmine	8,0	0,85	Künniagregaat	0,90	30,0	0,800	200	6	32,000
23.04.2005	Kultiveerimine	8,0	0,80	Kultivaator	6,00	30,0	0,800	200	1	5,333
24.04.2005	Väetamine	8,0	0,85	Väetiselaotur	5,00	30,0	0,800	154	1	4,107
26.04.2005	Kultiveerimine	8,0	0,85	Kultivaator	6,00	30,0	0,800	200	1	5,333
05.05.2005	Teraviljakülv	8,0	0,85	Külviagregaat	5,00	30,0	0,800	200	1	5,333
08.05.2005	Äestamine	8,0	0,85	Äestamisagregaat	5,00	30,0	0,800	200	1	5,333
10.06.2005	Pritsimine	8,0	0,85	Pritsimisagregaat	8,00	30,0	0,800	200	1	5,333
01.07.2005	Pritsimine	8,0	0,85	Pritsimisagregaat	8,00	30,0	0,800	200	1	5,333
16.09.2005	Teraviljakoristus	8,0	0,85	Teraviljakombain	1,65	20,0	1,200	384	4	61,440

Transpordikulu kõigilt operatsioonidelt kokku, EEK/ha **133,545**

ja põllule kokku, EEK **4006**

Peatu hiirekursoriga veeru päisel, siis näed selgitavat teksti veeru nime kohta

Figure 4.1. A window, related to travelling costs of FOUs, in the DSS program “Field distance”

4.2. Data for sample calculations

The data chosen for the simulations were previously used in the calculations for economic comparison of different pre-sowing tillage and sowing technologies (direct drilling, conventional and minimum tillage) (**X, XI**). The machinery was chosen considering an average Estonian cereal production family-farm where most machines are farm owned machines. It cannot be said that this is the best or optimum machinery, but here is considered the opinions of experts at the Estonian Research Institute of Agriculture.

In the calculations, for the purpose of simplification, it is assumed that all travels related to the plot start from the farm centre (**XVIII**). To determine the number of working hours of the farm machines, it is presumed that the farm has 450 ha of arable land with 75% under spring cereals and 25% under winter cereals. The operational performances and hourly work costs of the FOUs depend on tractors (Tables 4.1, 4.2 and 4.3). There are two tractors among the machinery, with engine powers of 100 kW and 75 kW (T1 and T2 in tables). The fuel price of 10.8 EEK/l serves as the basis for calculating the hourly costs.

Table 4.1. Work and capacities as well as annual time consumption of those on the farm for conventional tillage technology

	T1 (100kW)			T2 (75kW)		
	Performance ha/h	Area ha	Working time, h	Performance ha/h	Area ha	Working time, h
Stubble ploughing	7	450	64			
Ploughing	1.1	247	225	0.9	203	225
Cultivating				5	450	90
Transporting water					1.350	17
Spraying	7	1.350	193			
Loading fert. and seed				10	450	45
Transporting fert. and seed					450	13
Loading N- fert.				10	112	11
Transporting N- fert.					112	1
Distributing N- fert	5	112	22			
Sowing	3	450	150			
Harrowing shoots	10	450	45			
Transporting grain		225	54		225	54
Total, h/year			754			456

In all variations, the average length of the working day is at value D_t=8 h and daily time loss factor τ=0.85 are considered. The average length of the work day takes into account that all workdays cannot be used because of unsuitable weather conditions. These factors influence the number of workdays and trips to the plot. Area *F* of the observed plot is 16 ha and the travelling distance from the farm centre is *d*=20 km.

Table 4.2. Work and capacities as well as annual time consumption of those on the farm for minimum tillage technology

	T1 (100kW)			T2 (75kW)		
	Perform-ance ha/h	Area ha	Working time, h	Perform-ance ha/h	Area ha	Working time, h
Stubble ploughing	7	450	64			
Cultivating				4	450	113
Transporting water					1.35	17
Spraying	7	1.350	193			
Loading fert. and seed				10	450	45
Transporting fert. and seed					450	13
Loading N- fert.				10	112	11
Transporting N- fert.					112	1
Distributing N- fert	5	112	22			
Sowing	3	450	150			
Harrowing shoots	10	450	45			
Transporting grain		225	54		225	54
Total, h/year			529			254

Table 4.3. Work and capacities as well as annual time consumption of those on the farm for direct drilling technology

	T1 (100kW)			T2 (75kW)		
	Perform-ance ha/h	Area ha	Working time, h	Perform-ance ha/h	Area ha	Working time, h
Spreading straw				7	450	64
Transporting water				10	1.46	22
Spraying	7	1.462	209			
Loading fert. and seed				10	450	45
Transporting fert. and seed					450	13
Loading N- fert.				10	112	11
Transporting N- fert.					112	1
Distributing N- fert	5	112	22			
Sowing	3	450	150			
Transporting grain		225	54		225	54
Total, h/year			435			210

In conventional technology, two FOUs plough simultaneously, and therefore the work capacity is divided according to their performances (Table 4.1). It is presumed for all three technologies that there are three spraying operations at different points in time covering the whole plot (Tables 4.1, 4.2 and 4.3).

A loader is usually mounted to the tractor FOU transporting the material to the plot and therefore transportation expenses of the loader are compensated for by the transportation cost of material.

4.3. Calculating the travelling costs of FOUs

Next the prices of working hours of the tractors (Table 4.4.) and combine (Table 4.5.) are calculated considering the different work capacities for different technologies.

Table 4.4. Calculation of price *P* of travelling hour of tractor, with unlike technologies

	Conventional		Minimum		Direct drilling	
Tractor	T1	T2	T1	T2	T1	T2
Engine power, kW	100	75	100	75	100	75
Daily fuel consumption depending on work type	0.5	0.5	0.5	0.5	0.5	0.5
Purchase price, thousand EEK	750	550	750	550	750	550
Annual work capacity, h	754	456	529	254	435	210
Fuel consumption, l/h	13.4	10.0	13.4	10.0	13.4	10.0
Fuel price, EEK/l	6.00	6.00	6.00	6.00	6.00	6.00
Lubricant consumption, kg/h	0.27	0.20	0.27	0.20	0.27	0.20
Lubricant price, EEK/kg	20	20	20	20	20	20
Maintenance, % of price	2	2	2	2	2	2
Operator salary, EEK/h	50	50	50	50	50	50
Extra fee for maint., rate, %	10	10	10	10	10	10
Social +unempl. tax rate, %	20.5	20.5	20.5	20.5	20.5	20.5
Health insurance rate, %	13	13	13	13	13	13
Fuel cost, EEK/h	80.2	60.2	80.2	60.2	80.2	60.2
Lubricant cost, EEK/h	5.3	4.0	5.3	4.0	5.3	4.0
Maintenance cost, EEK/h	20.1	24.4	28.7	44.4	35.0	53.9
Operator salary, EEK/h	55.0	55.0	55.0	55.0	55.0	55.0
Social tax +heal. ins. EEK/h	18.4	18.4	18.4	18.4	18.4	18.4
Total costs, EEK/h	179	162	188	181	194	190

The components of the fixed costs of field machines are not considered by calculating the hourly cost of idle travel. The components of the fixed costs of machines - depreciation, interest, housing costs and insurance - are presumably already reflected in the hourly costs of the field operation and thus in the prime price of the product (paragraph 3.4.3)

The transportation velocities of machines used in the calculations are given in table 4.6. The speed chosen for the calculations is the average travelling speed considering the roads between the farm centre and the plot - in Estonia they can sometimes be in a bad condition. Also taken into account was the fact that large field machines should travel carefully on narrow roads. And with water tanks drivers must be particularly carefully on bends - at high speeds they can fall over onto their sides.

Table 4.5. Calculation of price *P* of travelling hour of combine

Parameter	Value
Purchase price, thou. EEK	1 800
Annual work capacity, h	450
Fuel consumption, l/h	35
Fuel price, EEK/l	6.00
Lubricant consumption, kg/h	0.7
Lubricant price, EEK/kg	20
Maintenance, % of price	2
Operator salary, EEK/h	50
Extra fee for maintenance, % of salary	2
Social +unemployment insurance tax rate, %	20.3
Health insurance rate, %	13
Fuel cost, EEK/h	210
Lubricant cost, EEK/h	14
Maintenance cost, EEK/h	80
Operator salary, EEK/h	51
Social taxes +health insurance EEK/h	17.0
Total costs, EEK/h	372

If traffic conditions are better than presumed in the present calculations then higher average travelling velocities can be used and costs depending on travelling distances then decrease.

Table 4.6. Average travelling velocities *v* (in the case of transporting the materials, it is the average of transportation and idle travel)

FOU	Velocity *v*, km/h
Tedding FOU	30
Water transporter	25
Spraying FOU	30
Transporting FOU (Tractor +trailer)	30
Fertilizer distributor	30
Drill	30
Harrowing FOU	30
Grain harvesting combine	20

The data given in tables 4.4, 4.5 and 4.6 were used to estimate the influence of tillage technology on the costs, depending on travelling distance and plot area (Tables 4.7, 4.8 and 4.9). Discussion of the calculation results is given in paragraph 4.8 and in chapter 5.

Table 4.7. Travelling costs of FOUs (a.) for conventional tillage technology

FOU	Velocity v, km/h	Performance w, ha/h	Price of travelling hour P, EEK/h	Daily travelling time t_{mp}, h	Work days z_m	No. of visits Z	Duration of rem. day D_j, h	Travelling cost U, EEK/ha
Stubble ploughing	30	7	179	1.3	0.40	1	2.7	14.9
Ploughing (T1)	30	1.1	179	1.3	1.41	2	2.7	29.8
Ploughing (T2)	30	0.9	162	1.3	1.41	2	2.7	27.0
Cultivating	30	6	162	1.3	0.47	1	3.1	13.5
Drilling	30	5	179	1.3	0.57	1	3.8	14.9
Harrowing	30	5	179	1.3	0.57	1	3.8	14.9
Spraying	30	8	179	1.3	0.35	1	2.4	14.9
Spraying	30	8	179	1.3	0.35	1	2.4	14.9
Spraying	30	8	179	1.3	0.35	1	2.4	14.9
Combine	20	1.5	372	2.0	2.09	3	0.6	139.5
TOTAL								300

Two FOUs plough simultaneously in the case of conventional technology and therefore the work capacity is divided according to the performance. Three plant protection treatments for the whole plot are anticipated by this technology (Table 4.7).

Expressing the duration of the remaining day (D_j) it will be possible to decide whether there is any sense in carrying out the work during the last working day or if it is more rational to lengthen the duration of the working day a little bit and to divide thus the remaining day between the previous working days. Following the example (table 4.7) we can see that the length of the remaining, or the third working day of 0.6 h considering the combine, is obviously too short a period to keep it for the last working day. It would be sufficient to prolong the length of the working day (D_t) by 0.3 h in this case. The number of plot visits would decrease from three to two and the travelling cost of the combine would be 93 EEK/ha.

Table 4.8. Travelling costs of FOUs (a.) for minimum tillage technology

FOU	Velocity v, km/h	Performance w, ha/h	Price of travelling hour P, EEK/h	Daily travelling time t_{mp}, h	Work days z_m	No. of visits Z	Duration of rem. day D_j, h	Travelling cost U, EEK/ha
Stubble ploughing	30	7	188	1.3	0.40	1	2.7	15.7
Cultivating	30	6	181	1.3	0.47	1	3.1	15.2
Drilling	30	5	188	1.3	0.57	1	3.8	15.7
Harrowing	30	5	188	1.3	0.57	1	3.8	15.7
Spraying	30	8	188	1.3	0.35	1	2.4	15.7
Spraying	30	8	188	1.3	0.35	1	2.4	15.7
Spraying	30	8	188	1.3	0.35	1	2.4	15.7
Combine	20	1.5	372	2.0	2.09	3	0.6	139.5
TOTAL								248.7

Table 4.9. Travelling costs of FOUs (a.) for direct drilling technology

FOU	Velocity v, km/h	Performance w, ha/h	Price of travelling hour P, EEK/h	Daily travelling time t_{mp}, h	Work days z_m	No. of visits Z	Duration of rem. day D_j, h	Travelling cost U, EEK/ha
Tedding	30	7	194	1.3	0.40	1	2.7	16.2
Drilling	30	5	194	1.3	0.57	1	3.8	16.2
Spraying	30	8	194	1.3	0.35	1	2.4	16.2
Spraying	30	8	194	1.3	0.35	1	2.4	16.2
Spraying	30	8	194	1.3	0.35	1	2.4	16.2
Combine	20	1.5	372	2.0	2.09	3	0.6	139.5
TOTAL								220.3

4.4. Calculating the transportation costs

Calculating the price of the working hour of a transporter, the annual work capacity of transporters (Table 4.10) price of working hour of tractor and trailer (Table 4.11 and 4.12) and material properties (Table 4.14) are considered. However, for a tractor the fuel and lubricant costs are not considered, while these are calculated separately. The farm has two trailers labelled H1 and H2 and the water tank (VT).

Table 4.10. Calculation of annual work capacity of transporters

Trailer	H 1	H1	H1	H2	VT
Material	Seed + fertilizer	Grain yield	N-fertil.	Grain yield	Water
Area, ha	450	225	112	225	450
Amount t/ha	0.53	4.5	0.1	4.5	0.3
Total amount, t	238.5	1013	11.2	1013	135
Payload, t	10	10	10	10	5
Number of loads	23.85	101.3	1.12	101.3	27
Number of transportation cycles	24	102	2	102	27
Avg. travelling distance on farm, km	8	8	8	8	8
Avg. travelling speed, km/h	30	30	30	30	25
Avg. travelling time of one cycle, h	0.53	0.53	0.53	0.53	0.64
Total travelling time, h/year	12.8	54	1.07	54	17.3

Although the fixed costs of the machines were not considered when calculating the travelling costs of FOUs, the fixed costs of transporting the materials should still be considered. The reasons are explained in paragraphs 3.4.3 and 3.5.2.

Table 4.11. Calculation of the hourly cost of a tractor ($P_{m,t}$) belonging to transportation unit (excl. fuel and lubricant cost), for different engine power and technologies

	Conventional		Minimum		Direct drilling	
Tractor	T1	T2	T1	T2	T1	T2
Engine power, kW	100	75	100	75	100	75
Term of loan, years	5	5	5	5	5	5
Rate of self-financing, %	25	25	25	25	25	25
Purchase price, th., EEK	750	550	750	550	750	550
Lifetime, year	12	12	16	16	18	18
Annual work capacity, h	754	456	529	254	435	210
Interest rate, %	10	10	10	10	10	10
Price of housing, EEK/m^2	1000	1000	1000	1000	1000	1000
Need for housing, m^2	24	24	24	24	24	24
Lifetime of garage, years	25	25	25	25	25	25
Insurance of garage, %	0.3	0.3	0.3	0.3	0.3	0.3

	Conventional		Minimum		Direct drilling	
Tractor	T1	T2	T1	T2	T1	T2
Insurance of tractor, %	1.5	1.5	1.5	1.5	1.5	1.5
Maintenance cost rate, %	2	2	2	2	2	2
Operator's salary, EEK/h	50	50	50	50	50	50
Extra fee for maintenance, %	10	10	10	10	10	10
Social +unemployment tax, %	20.5	20.5	20.5	20.5	20.5	20.5
Health insurance, %	13	13	13	13	13	13
Depreciation, EEK/h	82.9	100.5	88.6	135.3	95.8	145.5
Interest, EEK/h	15.5	18.8	16.6	25.4	18.0	27.3
Housing, EEK/h	2.9	4.8	4.2	8.6	5.0	10.5
Tractor insurance, EEK/h	7.5	9.0	10.6	16.2	12.9	19.6
Total of fixed costs, EEK/h	108.8	133.2	120.0	185.6	131.7	202.9
Maintenance costs, EEK/h	19.9	24.1	28.4	43.3	34.5	52.4
Operator's salary, EEK/h	55.0	55.0	55.0	55.0	55.0	55.0
Social +unempl. tax., EEK/h	18.4	18.4	18.4	18.4	18.4	18.4
Total of var. costs, EEK/h	93.3	97.5	101.8	116.7	107.9	125.8
Total hourly cost, EEK/h	202	231	222	302	240	329

The increased cost of travelling hours in the case of minimum tillage and direct drilling is related to the increase of the proportion of fixed costs in the hourly cost (Table 4.11). This is a result of the decrease in the number of operations and, thus, in the annual load of the tractor.

Table 4.12. Calculation of hourly cost of a trailer (P_h)

Trailer	Trailer H1	Trailer H2	Water tank VT
Payload, t	10	10	5
Term of loan, years	5	5	5
Rate of self-financing, %	25	25	25
Purchase price, th., EEK	50	50	40
Life-time, year	15	15	20
Annual work capacity, h	68	54	17
Interest rate, %	10	10	10
Maintenance cost rate, %	5	5	5
Price of housing, EEK/m^2	1000	1000	1000
housing needed, m^2	20	20	12
Lifetime of garage, years	25	25	25
Insurance of garage, %	0.3	0.3	0.3
Insurance of machine, %	1.5	1.5	1.5
Depreciation, EEK/h	49	62	118
Interest, EEK/h	9	12	22
Housing, EEK/h	27.4	34.4	65.6
Machine insurance, EEK/h	5.5	6.9	17.6
Maintenance costs, EEK/h	37	46	118
Total hourly cost, EEK/h	128	161	341

While winter cereals have an additional chemical treatment in the case of direct drilling, the water tank has 22 working hours and the price of the working hour is 263 EEK/h. This is the only difference between the technologies.

The price of working hours of a transporter (Table 4.13) is the result of summing the working hours of the tractor and the trailer (Tables 4.11 and 4.12).

Table 4.13. Data for calculation of transportation costs of materials

Transporter	Hourly cost without fuel cost $P_{m,t}$, EEK/h			Fuel use by full load G_k, l/h	Fuel use by idle load G_t, l/h
	Conventional	Minimum	Direct drilling		
T2+H2	392	463	490	16.5	11.6
T1+H1	330	350	368	17.5	11.9
T2+VT	572	643	592	15.1	9.8

It is presumed that lubricant consumption is 2 % of fuel consumption and the price of the lubricant is 20 EEK/l.

Table 4.14. Technological materials necessary to transport, and amount for different tillage technologies of spring cereals

Material	Amount Q, kg/ha	Usage rate of payload x	Loading performance, w_{pl}, t/h	Unloading performance, w_{ml}, t/h
Barley seed	230	1	28	20
NPK-fertilizer	300	1	28	15
Water for spraying	300	1	40	20
Yield of barley	4 500	1	40	1 800

Loading performances derived from the literature (ATK 1984, KTBL 2002/2003, Maatalouden työnormit 1988).

A compact overview of material transportation costs depending on the tillage technology is given in table 4.15.

Table 4.15. Transportation costs of materials for different technologies

Material	Transporter	Velocity v km/h	Hourly cost of transporter P_m EEK/h	Fuel and lubricant cost P_f, EEK/h	Proportional rate of transporter λ	Number of loads Y	Travelling time of transporter t_s, h	Transportation capacity w_v, t/h	Transportation cost V, EEK/ha
CONVENTIONAL TILLAGE									
Barley seed	T1+H1	30	330	112	1	0.37	1.33	4.6	34.4
Water	T2+VT	30	572	96	1	0.96	1.33	2.9	54.3
Mineral fertil.	T1+H1	30	330	112	1	0.48	1.33	4.2	34.6
Barley yield	T1+H1	30	330	112	0.5	3	4	6.3	136.7
Barley yield	T2+H2	30	392	105	0.5	3	4	6.3	156.2
TOTAL									**416**
MINIMUM TILLAGE									
Barley seed	T1+H1	30	350	112	1	0.37	1.33	4.6	36.1
Water	T2+VT	30	643	96	1	0.96	1.33	2.9	60.2
Mineral fertil.	T1+H1	30	350	112	1	0.48	1.33	4.2	36.2
Barley yield	T1+H1	30	350	112	0.5	3.00	4	6.3	143.4
Barley yield	T2+H2	30	463	105	0.5	3.00	4	6.3	179.9
TOTAL									**456**
DIRECT DRILLING									
Barley seed	T1+H1	30	368	112	1	0.37	1.33	4.6	37.6
Water	T2+VT	30	592	96	1	0.96	1.33	2.9	55.9
Mineral. fertil.	T1+H1	30	368	112	1	0.48	1.33	4.2	37.7
Barley yield	T1+H1	30	368	112	0.5	3.00	4	6.3	149.4
Barley yield	T2+H2	30	490	105	0.5	3.00	4	6.3	188.9
TOTAL									**469**

4.5. Calculating income loss

As discussed with previous calculations, the length of the sowing period for all tillage technologies is 150 h. While the average length of the working day is 8 h, and the time usage coefficient is 0.85 (paragraph 4.2.), the number of sowing days is 150:8:0.85=22.1. While under if 75% of the arable land is under spring cereals , the duration of spring sowing is 22.1:75:100=16.6 days.

While the factors affecting the loss of yield are the same for all the mentioned technologies, the values presented in the table 4.16 are valid for all three technologies.

Table 4.16. Initial data and results of the calculations of income loss as the result of travelling distance

Parameter	Value
Farm's spring sowing area (F_e), ha	337.5
Portion of spring sowing area (included observed plot), remaining to seed (θ), %	50
Average sale price of spring cereal (r), EEK/t	1450
Average yield of spring cereal from best sowing day (h_{max}), t/ha	4,5
Average regression coefficient for spring cereals (b)	0.00115
Length of sowing period (C_k) days	16,6
Travelling time, affecting the sowing period (C_d), days	0.167
Income loss ΔB, EEK/ha	**147**

4.6. Costs for management travel

It is presumed in the sample calculations that a plant production manager visits the plot as many times and as often as work is performed there. An additional journey is taken to observe the plot and, for example, to determine the need for plant protection treatment. The fuel for a combine is transported to the plot once during every working day. In the case of conventional technology, the fuel for ploughing FOU is also transported to the plot once during every working day. The calculation results of the management travels are presented in table 4.17.

Table 4.17. Results of a calculation of the costs of management travel.

Reason for plot visit	Name of vehicle	Hourly cost P_{te}, EEK/h	Velocity v_{te} km/h	Number of visits c	Travelling cost M, EEK/ha
CONVENTIONAL TILLAGE					
Plot observ.	Car	300	60	1	12.5
Fuel transport	Fuel tank	400	50	3	60
Supervising work	Car	300	60	9	112.5
TOTAL					**185**
MINIMUM TILLAGE					
Plot observ.	Car	300	60	1	12.5
Fuel transport	Fuel tank	400	50	2	40
Supervising work	Car	300	60	8	100
TOTAL					**152.5**
DIRECT DRILLING					
Plot observ.	Car	300	60	1	12.5
Fuel transport	Fuel tank	400	50	2	40
Supervising work	Car	300	60	6	75
TOTAL					**127.5**

4.7. Sum of travelling costs

To sum up the results of the four types of costs, the total of costs will be calculated depending on the travelling distance (table 4.18 and 4.19).

Table 4.18. Costs (EEK/ha) depending on distance if the plot distance is 20 km and the area is 16 ha

Type of cost	Conventional	Minimum	Direct drilling
Travelling cost of FOUs U	300	248	220.3
Cost of transporting materials V	416	456	469
Income loss, ΔB	147	147	147
Cost of management travel, M	185	152.5	127.5
Total K_b	**1 047**	**1 004**	**964**

Table 4.19. Cost depending on plot distance and area in the case of conventional technology

Distance	Transportation cost K_b, EEK/ha		
	10 ha	15 ha	20 ha
10 km	921	695	607
20 km	1 846	1 393	1 ,217
30 km	2 768	2 173	1 839

4.8. Maximum travelling distance

In the calculations, made for similar production conditions to represent simulation, is a cereal production profit of 890 EEK/ha and machinery costs were 3000 EEK/ha (Older 1999). It was Presumed that 110 EEK/ha of these costs are already accounted to costs depending on travel distance. Thus the amount of money available for costs ($K_{b,max}$), depending on the travelling distance, should not exceed 1000 EEK. Under these conditions the maximum value of the travelling distance for the defined plot area was calculated.

With minimum tillage the number of operations, and thus travel, is smaller compared to conventional technology; these figures are smallest with direct drilling. However, after calculation, it became clear that differences in maximum distances to the plot are small across the different technologies (Figure 4.2). In the case of direct drilling, the cost of transportation of machines and management travels is less than when other technologies are used, but the cost of transporting materials is higher (Table 4.18). This is because of the larger proportion of fixed costs in the hourly cost of the tractor, caused by the smaller number of operations performed and, consequently, less annual work time of the tractor compared to other technologies. Many operations with low hourly costs were compared, with few operations with high hourly costs.

Depreciation is a cost resulting from wear, obsolescence, and age of a machine. The degree of mechanical wear may cause the value of a particular machine to be somewhat above or below the average value for similar machines when they are traded or sold. The introduction of new technology, or a major design change, may result in an older machine suddenly becoming obsolete, causing a sharp decline in its remaining value. But age and accumulated hours of use are usually the most important factors in determining the remaining value of a machine (Edwards 2005).

Previous results were more suitable for the situation when depreciation is calculated for a known number of years. This can be the case if a bank loan is used for purchasing the machinery, and the fixed costs are mainly used to serve the loan for fixed number of years. Or if it is planned to sell the machine after a specified number of years and depreciation is calculated according to the predicted selling price. However, if depreciation should cover the decline in the machine's value over its service life, then fixed costs do not depend on the technology used. For example, the average service life of tractors is 10,000 hours (Gazzarin and Gregor 2009) for all three cultivation technologies.

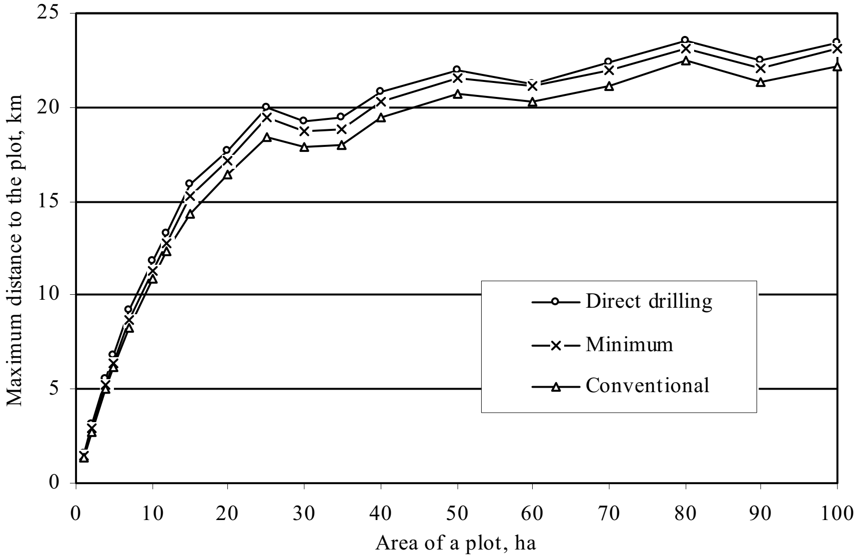


Figure 4.2. The maximum plot distance depending on plot area for different tillage technologies, if costs depending on the distance do not exceed 1000 EEK/ha. The annual workload of machines depends on the technology

In comparison, to the previous calculation, in all technologies, the machines had the same annual work load. as well as hourly cost. as conventional tillage. In these circumstances all costs, except income loss, decrease along with a reduced number of operations, and the differences of maximum distances of the plot are of greater importance (Figure 4.3) than in the case of different annual workloads. For example, for conventional tillage, minimum tillage and direct drilling on a 30 ha plot in with different workloads, the maximum distances are, respectively, 17.9, 18.7, and 19.2 km. With similar workloads, these distances are 17.9, 19.4 and 20.4 km.

Depending on the plot area, the maximum distance increases by determined $K_{h,max}$ at the beginning almost proportionally until the approximate plot area of 15 ha. From then on, growth slows down slightly, but continues intensively until a plot area of 20 ha is reached; after this, the distance value will approximate asymptotically to a limit value. In the economic conditions used in this simulation, the economically maximum distance for larger plots falls within the interval of 18 – 25 km (**XVIII**).

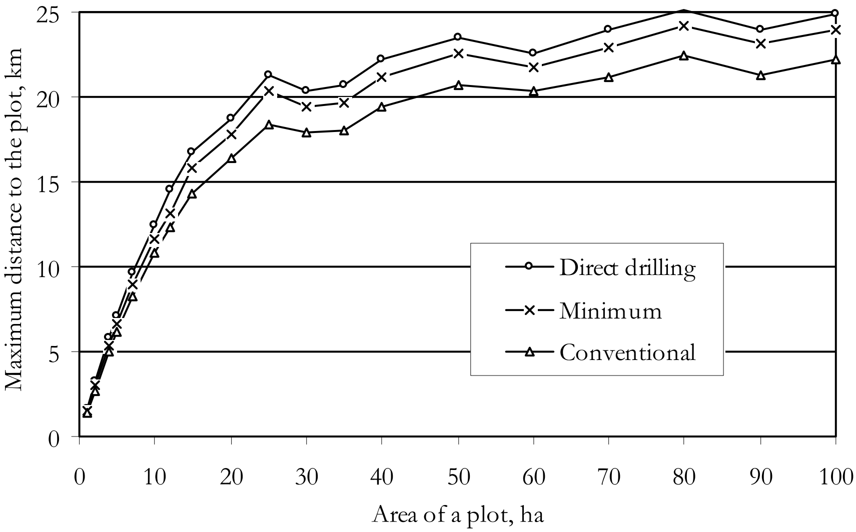


Figure 4.3. The maximum plot distance depending on plot area for different tillage technologies, if costs depending on the distance do not exceed 1000 EEK/ha. The annual workload of machines are, for all technologies, the same as for conventional tillage

However, these calculations are valid only for the example farm chosen for this present thesis. There could be alternative choices – using trailers to transport the field machines to distant plots or using trucks to transport materials between plot the and storage area.

If the plot distance is estimated to be too long, then the farmer has to search for other possibilities; to use satellite farm centres or other places for the intermediate storage of machines and materials.

The anomalies in the smooth curves on the graphs (Figure 4.2 and 4.3) are caused by changes in the number of the travelling times related to the specific work or material transported. For example, in the case of the 28 ha plot area, the sowing unit would be transported to the plot on two workdays, doubling the travelling time, resulting in a sharp growth in income loss per hectare. However, while the total value of costs is limited, the other costs should decrease accordingly and it will result in the need for a shorter distance (Figure 4.4.). Although the cost related to the transport of the sowing unit increases, then a decrease in the transportation costs of other FOUs, due to a shortened distance, is sufficient to slightly decrease the total transportation cost of FOUs (**XVIII**).

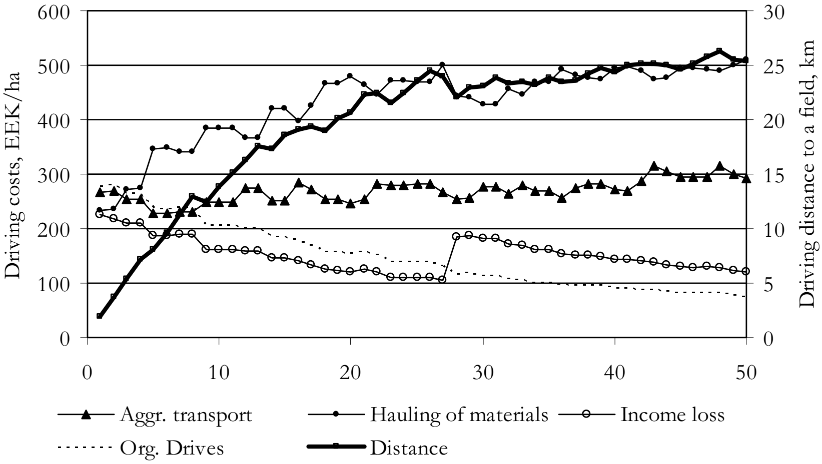


Figure 4.4. The maximum plot distance and costs depending on plot area for conventional technology. The costs depending on the distance should not exceed 1000 EEK/ha

4.9. Minimum area of the plot

In figure 4.2 we can determine the minimum plot area in the case where the total travelling costs of a predefined distance will be kept in the certain limits. Additionally it is seen in the figure that, if the plot distance exceeds a certain value, approximately 28 km in the given case, the value of the limit area could not be determined. In that case the initial data used in calculations should be changed, or the limit value of the total costs depending on the travelling distance should be increased.

4.10. The influence of fuel price

In order to examine the influence of the fuel price, conventional tillage technology was simulated, and hourly prices of machines were computed for three fuel price levels (Figure 4.5).

In Estonia, special-purpose diesel fuel can be used in agricultural production. This diesel fuel has less excise tax than that paid by ordinary consumers. The excise tax on special-purpose diesel fuel began to rise early in 2008, increasing the fuel price from about 8.9 to 10.8 EEK/l. The third price level is included on the basis that the farmer might use the fuel priced for the ordinary consumer, at 15 EEK/l.

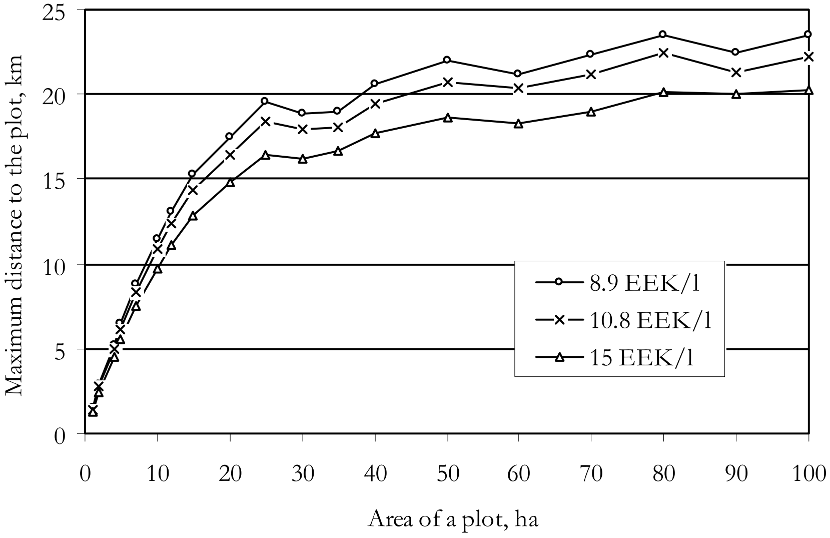


Figure 4.5. The maximum plot distance depending on plot area, at different fuel prices. The costs depending on the distance should not exceed 1,000 EEK/ha

If the plot area increases, then the fuel price affects the maximum distance of the plot until a certain value is reached– in the present case approximately at 25 km. After this distance the differences of distances for unlike price levels remain roughly the same. For example, for a plot area of 30 ha, the maximum distances are 18.7, 17.9 and 16.2 km from the lowest to the highest price level. Therefore, the higher the fuel price, the more the farmer must think about the rationality of exploiting distant plots (**XVIII**).

Consequently, there exists the possibility that a plot located at a distance, that has provided profitable production in the past, becomes unprofitable due to rising fuel prices. In Estonia, this has already occurred in 2008, because of the increase in fuel prices.

A high fuel price can also hinder farm size. The greater the fuel price the higher are field operation and transportation costs, and increased operation costs reduce the available of funding for transportation. Therefore the fuel price has a doubly damaging effect on the economically feasible transport distances. Thus at a certain point, the fuel cost can limit the maximum distance to the plot, regardless of plot size, cultivation technology or choice of crop.

4.11. The influence of the grain price and yield

The grain price and yield influence the income obtained from a plot, and thus the limit value reached by its costs $K_{h,max}$, depending on the distance. The limit value of the costs affects the maximum distance of the plot significantly (Figure 4.6). In the current simulation, with a 30 ha plot, using limit values of 1,565, 1,000 and 782 EEK/ha, the maximum distances are, respectively, 27.3, 17.9 and 14.1 km. Raising the limit value by 782 EEK/ha allows the use of a 30 ha plot located within the next 13 km range (**XVIII**).

On the other hand, due to increasing selling price and yield, the income loss increases with every delayed sowing day (**XIII**) (Figure 4.7 and 4.8). Thus, the optimum performance of sowing operations and minimising travelling time is more important for plots with a high yield potential than for those with poorer soil properties; the drill must be transported to the high yield plot as fast as possible, and the plot seeded, without intermediate travels to the farm centre.

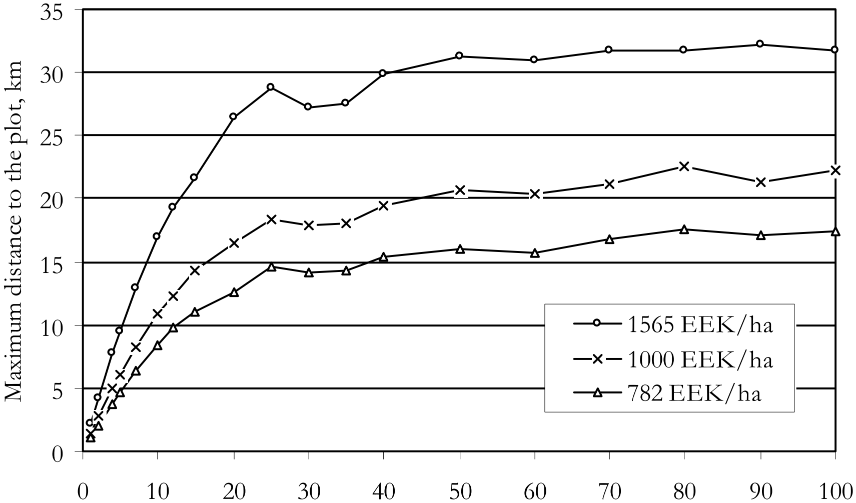


Figure 4.6. The maximum plot distance depending on plot area in the case of conventional technology, if the costs depending on the distance do not exceed 1565, 1000 and 782 EEK/ha

One of the future tasks would be to clarify which conditions would be most rational: to return with the application FOU to the farm centre after the work day, leave the FOU near the plot, or perform the operation with a number of consecutive shifts. We plan to supplement the model with algorithms to calculate the income loss due to transportation time for machines other than the sowing unit (**XVIII**).

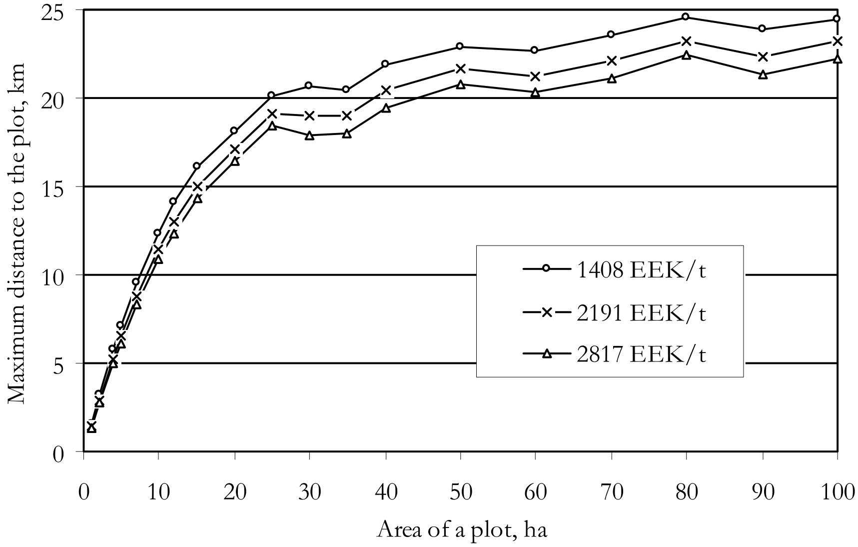


Figure 4.7. The maximum plot distance depending on plot area, in the case of different grain prices. The costs depending on the distance should not exceed 1,000 EEK/ha and grain yield is 4500 kg/ha

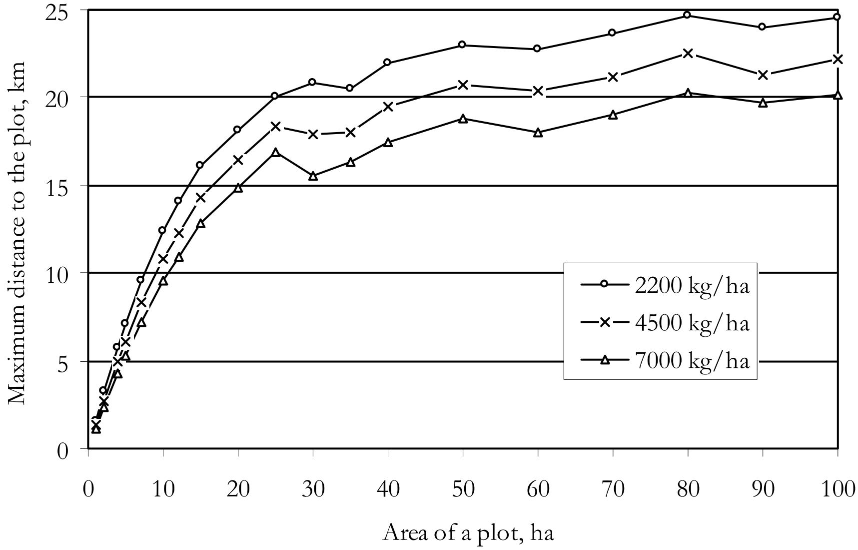


Figure 4.8. The maximum plot distance depending on plot area for different grain yields. The costs depending on the distance should not exceed 1 000 EEK/ha and grain price is 2 817 EEK/t

The current model does not consider the soil type. The soil type influences the germinating environment of seed (Haller 1969). The optimal sowing time for spring cereals on heavier soils is shorter than average (EVP 1992), meaning that yield loss for every delayed day is greater for a heavy soil than for a light soil. In this case, for the regression coefficient *b,* a value higher than in table 3.4 should be selected. However, the model can be supplemented by considering the type of soil as soon as the values for a correction factor depending on soil type are available.

4.12. Sensitivity analysis

An example farm was used for simulations, and different scenarios were calculated. The maximum driving distances, depending on plot area, were calculated for different values of several parameters: fuel price, money available for costs depending on travelling distance, cereal price and cereal yield (paragraphs 4.10 and 4.11). The influences of each unit on the change of the maximum distance by different plot sizes were calculated (Figure 4.9).

These parameters have different influences on the costs depending on distance. The fuel price affects all costs, except the timeliness cost (Chapter 3) – the higher the fuel price the higher are the travelling costs (formula 3.14). Yield and its price influence proportionally the timeliness cost (formula 3.100); in combination with plot area these parameters have a major influence on differences in the maximum distance, where the number of travels-to-plot of drilling machine changes (see paragraph 4.8; Figure 4.4 and 4.9). A higher yield also causes an increase in yield transportation costs and a decrease in the combine's hourly hectare-productivity. Falling combine performance can result in more harvesting days and an increase in the number of travels to the plot (formula 3.21) and thus, rising combine travel costs. Yield and its price also influence, the income proportionally, through the amount of money available for costs depending on distance ($K_{h,max}$ in formula 3.4). Maximum distances depending on different values of $K_{h,max}$ were described in paragraph 4.11. The greater is limit value $K_{h,max}$ which may be all four types of costs, depending on distance and the further is the maximum distance is to the plot.

The differences of maximum distance show stable growth until a plot area of about 12 ha for all parameters and until about 25 ha for fuel price. As is shown in figures 4.2-4.8, the change of a plot area larger than 25 ha has less of an influence on the maximum distance than a change of smaller plot areas. After stable growth, the difference of maximum distance starts to oscillate at a defined interval, for all parameters. Thus consolidating plots with an area below 25 ha has a greater effect on transportation costs than consolidating plots with an area above 25 ha.

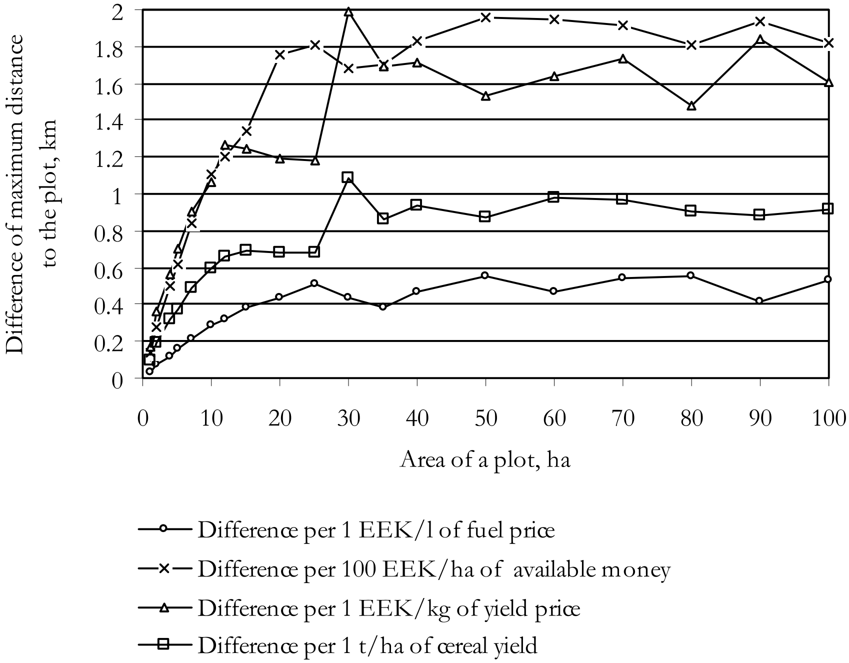


Figure 4.9. Difference of maximum distance to the plot depending on parameter

On average the difference of the maximum distance on studied parameters is::

1) 1.38 km per 100 EEK/ha of available money for costs depending on distance;
2) 1.26 km per 1 EEK/kg of yield price;
3) 0.7 km per 1 t/ha of cereal yield and
4) 0.36 km per 1 EEK/l of fuel price.

4.13. Influence of auto-steering on travelling costs

The timeliness relations of sowing works are established to estimate the effect of the decline in the sowing duration on the yield caused by the use of auto-steering. The calculations made so far present an economical effect caused by a significant reduction of turning times (EMVI 2005).

Another positive effect related to precise steering lies in the possibility to perform the work with a reduced number of plot visits. While auto-steering enables the performance of FOUs to be increased, and sometimes prolongs the duration of theworking day (enabling the tractor to be steered in conditions of poor visibility), plot processing during the shortened working days is possible. Thus the number of plot visits and the travelling costs will decrease.

With the help of the previously described software, the effect of auto-steering on the travelling costs was studied. The earlier calculations show that, if the FOU is equipped with an auto-steering device enabling decrease reduction in the passes and the turning times on the plot, this will help to improve the work performance. Let us presume that a grain harvesting combine has performance growth from 1.5 ha/h to 1.65 ha/h and it works on a 30 ha plot situated 8 km away from the farm centre. Then, as a result of this increase in performance, it will be possible to decrease the number of working days and thus the number of plot visits from four to three. The travelling costs of the combine will accordingly be 41 EEK/ha and 31 EEK/ha, thus the decline in the costs will be 10 EEK/ha (**XII**). Other similar calculations in the literature were not found with which to compare these results.

4.14. Influence of travelling distance on the fertilising options

4.14.1 Introduction

Changes in world energy prices influence the price of mineral fertilisers. A globally growing need for food encourages farmers to increase the production of milk and meat, thereby resulting in an increase in the production of manure. The plot distance from the farm centre, and fertiliser prices, influence the farmer’s choices regarding the use and logistics of fertiliser (**XIV**).

If a farm has its own slurry, it should be clarified under what conditions it is rational to use the slurry instead of mineral fertiliser. At the farm, 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 mixing, loading, transportation, and land application 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 and 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,, Osei *et al.* 2003b, Ribaudo and Agapoff 2004).

According to the "Integrated pollution prevention and control act", farms with intensive animal production should establish the best available technique for handling manure (RT I 2001). In suggestions of spring feeding of winter cereals, the slurry should be distributed either: before springtime ploughing, onto cereals already emerged or onto grasses that have begun to grow. With regard to these requirements, in spring the slurry can be distributed onto the grassland with a distributor fitted with a trailing hose or an injection system. The initial capital investment for these methods is greater than for conventional broadcast spreading with a splash plate (Rodhe and Rammer 2002). Therefore farmers should calculate the possibility of using customised operators for these works.

The technologies and economics of spring feeding of cereals have been studied in several locations in the world (Mattila 2006, Hiltbrunner *et al.* 2005, Huijsmans *et al.* 2004, Leick 2003). Animal slurry is transported in tankers, which is both laborious and technically demanding. For all the countries within the European Union, manure transport incurs considerable operating costs (Sørensen *et al.* 2003). Despite a higher price when compared to manure, it is more beneficial to use mineral fertilisers because of lower transportation costs in the case of long travelling distances.

In the present chapter, the costs of using mineral fertiliser versus slurry are compared, depending on the travelling distance to the plot. The distance is important because various types of fertilisers have very different application rates per hectare and this has a dramatic effect on the transportation costs. The outcome of this calculation should assist farmers in their decision making regarding transport distances and fertilising options. Regarding the distance between plot and farm centre, the costs for different application techniques are computed with the help of the model.

In this study, the following five technologies have been compared:
1) spreading mineral fertiliser with a disc distributor, using a vehicle to transport fertiliser to the plot;
2) slurry is transported and distributed with a trailing hose system;
3) slurry is transported and distributed with a disc injection system;
4) slurry is transported to the plot with a customised tank truck and distributed with a trailing hose system
5) slurry is transported to the plot with a customised tank truck and distributed with a disc injection system.

4.14.2 Data used in simulation

It is presumed in these calculations that the farm has 400 ha of arable land. Spring feeding on this land is done to cover the need for nitrogen. In simulation the calculations are made for fertilisation rates of 40 kg total ammoniacal nitrogen (TAN) per ha. The slurry includes nitrogen both inorganic (mineral) as well as organic sources. The mineral nitrogen, mainly as ammonium ions (NH_4^+), is easily obtainable by plants, but is also volatile and vulnerable to losses into the atmosphere (Leick 2003). The content of TAN is estimated to be 50% of total nitrogen of ammonium nitrate (34% N). The fertilisation rate is therefore calculated considering these factors (Table 4.20). The hectare rate of slurry is determined taking into account the average (TAN) content in cattle slurry (2 kg/t) (Rodhe & Rammer, 2002). Presuming that the average ammonia volatilisation after disc injection is estimated to be 5%, and with a trailing hose 20 % of TAN applied by the manure (Rodhe & Rammer, 2002), then the average nitrogen amount in soil available for plants is respectively 1.9 kg/t and 1.6 kg/t, and thus the rate of slurry distributed to the plot is calculated (Table 4.20). The price of ammonium nitrate (34% N) is 6,100 EEK/t. Slurry is produced on the farm itself and is therefore without cost.

Table 4.20. Fertiliser distribution rates corresponding to the need of nitrogen

Fertilizer and technology	Fertiliser rate, t/ha
Mineral fertilizer and disc distributor	0.235
Slurry and trailing hose	25
Slurry and disc injector	21

Technologies and machines

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

- Technology No. 1: the loading, transportation and spreading costs of the mineral fertiliser as well transportation cost of distributor;
- Technology No. 2: the mixing, spreading and transportation cost of the slurry in the case of a trailing hose system. Added to this are also the costs for transportation of the disc harrow and for soil tillage needed after slurry distribution with the trailing hose system;
- Technology No. 3: the mixing, spreading and transportation costs of the slurry in the case of a disc injection system;
- Technology No. 4: the mixing, spreading (farm machines) and transportation costs of the slurry (customised vehicle) in the case of a trailing hose system. Added to this are also the costs for transportation of the disc harrow and the slurry distributor and for soil tillage;
- Technology No. 5: the mixing, spreading (farm machines) and transportation (customised vehicle) costs of the slurry in the case of a disc injection system. Added to this are also the costs for transportation of the slurry distributor.

For spreading mineral fertiliser, a 75 kW tractor and rotating disc distributor are used. The field work cost for a particular machine is estimated with algorithms of machinery hourly cost. The mineral fertiliser is transported to the plot by a 150 kW tractor and a 10 t wagon. For slurry distribution a 150 kW tractor and liquid manure distributor with a shallow injection system is used (tanker size 15 m^3 and work width 6 m). For the 12m trailing hose system (tanker size 15 m^3) a tractor with 100 kW is used. The slurry is transported to the plot by a customised truck with a 29 m^3 - sized tank.

Since the present study is focussed on the influence of plot distance on the choice of fertilising technology, it also includes calculations of the transportation cost of distributing machines as well the tillage machine. The model works both in the case of mineral and organic fertiliser spreaders provided that the fertiliser is transported to the plot by a separate vehicle. The transportation costs are calculated by means of the model presented previously to estimate the rationality of exploitation (paragraph 3.4.) of a plot, whereas the decisive criterion is the distance from the farm centre.

If customised work for the transportation of slurry to the plot is used, then a tanker lorry with an initial cost of 20 EEK/m^3 is rented. If the distance is greater than 7 km, then 1 EEK/m^3 for every additional km must be added to the initial cost.

4.14.3 Results and discussion

The costs of fertiliser application were calculated for the selected range of plot distances and slurry application techniques (Figure 4.10). If customised work was used for slurry (technologies No. 4 and 5) then the fertilisation cost per hectare was constant up to 7 km when the additional transportation cost triggered increased costs with distance to the grassland. Compared to slurry, the mineral fertiliser the fertilising costs (technology No. 1) were less influenced by plot distance, because the amount, and thus transportation cost, of slurry was much higher.

The lowest costs until a plot distance of 6 km were found for technology no. 3, where the disc injector system was used (Figure 4.10) After 6 km is the most economical solution is the use of mineral fertiliser, where the high cost of ammonium nitrate is compensated for by the low cost of distribution.

Comparing slurry distribution technologies it was observed that that, up to a plot distance 8 km, technology no. 3 (disc injector also transports the slurry) had the least costs and for more distant plots, technology no. 5 (customised tank truck) proved most economical (Figure 4.10). The cost of technology No. 3 is less at short distances compared to technology No. 5, because there is no expense for the tank truck. If the distance to the slurry store is short, then transporting with the distributor costs less compared to a customised lorry. If the plot is situated close to the manure store, the cost of slurry transport is near to zero. But the slurry distributor and a powerful tractor are expensive, so the cost of one work hour of this application FOU was higher than the tank truck. The more distant the plots, the more time the distributors must spend on the road, and transportation costs per hectare increase more rapidly than in technologies where a tank truck is used.

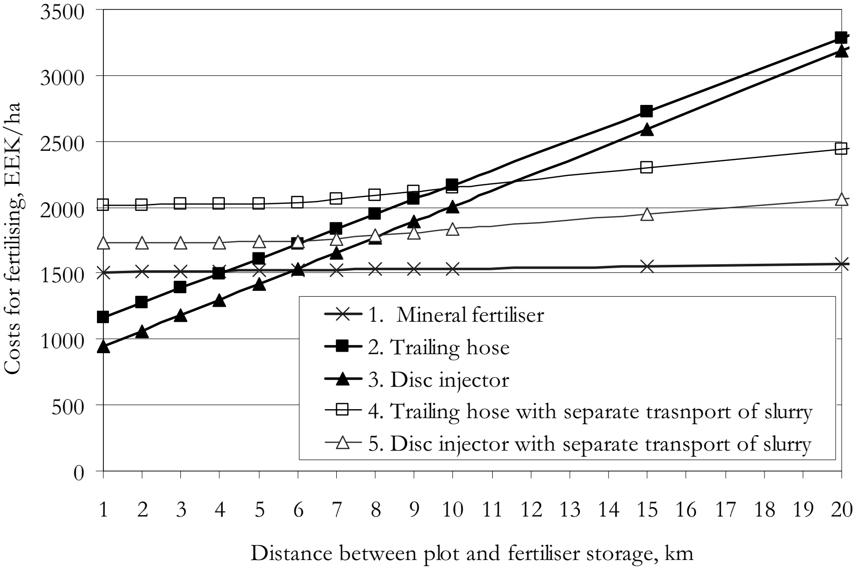


Figure 4.10. The fertilisation cost depending on plot distance, in the case of the five technology variants, when 40 kg/ha TAN with fertiliser was applied

Similar calculations for Estonian conditions are unknown. Paudel *et al.* (2009) carried out a survey to develop a minimum cost spatial dairy manure transportation model, where environmental quality and crop nutrient requirements were treated as constraints. The survey was carried out in the state of Louisiana in the USA,. They found that, because of the high cost of commercial nitrogen (US$1,000), farmers should only use dairy manure up to a cut-off distance of 30 km and a combination of both dairy manure and commercial nitrogen thereafter to compensate for the high cost of transportation and application. The optimal cut-off distance for dairy manure application is 15 km each for P2O5 and K2O consistency.

Wiens *et al.* (2008) carried out a study to conduct a thorough accounting of energy used to transport liquid pig manure from farm storage to the field and to surface-apply the manure. The manure transport distance could be increased up to 8.4 km before the energy cost per kg of available N from pig manure was equivalent to anhydrous ammonia, and up to 12.3 km before the energy cost of manure N was equivalent to urea N.

However the conditions and criteria used in these two models differ from previously presented data (4.13.2), thus the results are not directly comparable.

5. DISCUSSION

5.1. Discussion about options of using plots depending on distance

There are several studies (De Garis de Lisle 1982; Myyrä and Pietola 2002) researching choices of crop mix affected by plot structure. Cereal crops are less expensive to transport than intensive crops such as potato, therefore it is more economic to include more cereals in arable land that is farther from the centre.

A similar pattern appeared in paragraph 4.11 where cereal price and yield were analysed. Due to increasing selling price and yield, the income loss increases with every delayed sowing day; it causes also an increase in transportation costs. Also, the transportation costs per hectare are higher for higher yields. An analogous phenomenon has already been mentioned by von Thünen (Crosier, 2009): "The land within the closest ring around the market produces products that are profitable in the market, yet are perishable or difficult to transport. As the distance from the central market increases, the land use shifts to producing products that are less profitable in the market, yet are much easier to transport". Thus, crops with a high yield and price should be produced on plots near to the farm centre.

In economic conditions discussed in the present thesis, the economically maximum distance for larger plots falls within an interval of between 18 – 25 km. Lötjönen *et al.* (2003) analysed the production costs of grain harvesting, considering among other factors the influence of plot size and distance. They found that if the farmer works alone, the maximum economic distance is less than 10 km. If there are two workers at harvesting time, the economic distance may even be 20 – 30 km.

In the present model the loss of yield and income depend upon the crop. There are different timeliness factors (regression coefficient *b* in table 2) for spring and winter cereals. Winter cereals are more sensitive to a delay of sowing time than spring cereals. Distant cereal plots increase transportation time; this, in turn, lengthens the sowing period. A prolonged sowing period decreases average crop yield, therefore, winter cereals should be cultivated closer to the farm centre than spring cereals (**XVIII**).

Secondly manure is often used for fertilising winter cereals. When distance is a factor, this can be significant in the choice of plots for cereal. Paudel *et al.* (2009) also state that breakeven distances for nutrients vary by crop requirements for the nutrients Transportation of manure is expensive compared to mineral fertilisers (**XIV**) and plots near the manure pile should be chosen for winter cereals. This approach – using mineral fertilisers instead of manure on distant plots - can be an economical solution for other crops as well (**XV, XVI, XVII**). Wiens *et al.* (2008) reported that, despite the high energy cost of delivering liquid pig manure from storage to field, the much lower cost per kg of available N compared to inorganic fertilizer N highlights the opportunities that exist for improving the energy efficiency of industrial agriculture by replacing inorganic fertilizers with manure.

In the calculations the plot structure was fixed at 75 % for spring cereals and 25% for winter cereals. If the proportion of winter cereals is larger it is likely that more distant plots will be chosen because of lack of suitable plots near the farm centre. However, this can lead to a decrease in average yield per hectare of winter cereals. On the other hand, the average yield of winter cereals is generally higher than spring cereals (Older 1999): the total yield of cereals can be increased by increasing the area of winter cereals.

As presented in the results the economically maximum distance to the plot is comparative to the size of that plot. Therefore it is rational to consolidate distant smaller plots, or to use the same cultivation technology on neighbouring plots to consolidate work and minimise trips to the farm centre. The model can evaluate this approach by using the sum of adjoining plot areas. The sensitivity analysis showed that consolidation of plots smaller than 25 ha has a greater effect on transportation costs than consolidation of plots larger than 25 ha. Kapfer and Kantelhardt (2008) calculated key economic figures with regard to plot structure improvements and stated that, from an economic point of view, an optimal plot has a minimum size of about 20 ha. This number is approximately in the same size class as found by the current author.

Lötjönen *et al.* (2003) stated that networking of farms reduced the costs of all participating farms. Networking meant, in this case, that the farms used machines in common. Thus neighbouring plots using the same cultivation technology but belonging to different farms can be processed with one machine in common. Alternatively the farmer could cultivate plots located far away from their network companion but near to the farmer's machinery centre.

There are other possibilities for maximizing the use of small, distant plots: some farmers rent them out to other land users, or arrange to exchange plots with an adjacent farmer. Vidicin (2009) reported that Romanian farmers join farming associations to improve the exploitation of their plots fragmented due to land restitution to former owners after post-socialist land reform. A completely different land use is a possibility, e.g. creating a feeding area for wild animals to develop hunting tourism. However, if fuel costs are high, and the potential income from yield is low; it may be economically sensible to let small distant plots lie fallow. The greater the input (fuel, fertilizer, labour, etc) costs, and the smaller the yield, the more likely it is that the fallow area will be increased in size. Without alternative options, however, and if the land tax is economically onerous, selling the plot may be the best solution.

At the same time, it is rational to increase production of plots near the farm centre: either rent or buy them, or turn non-agricultural land use to agricultural use if conditions are suitable for crop production. The general implication of a liberalised land market is that it could enable landowners to consolidate their plots by selling land further away from the farm centre and purchasing land closer to the farm centre and/or existing plots (Rahman and Rahman 2009). In this way, the farmer could mitigate the constraints imposed by a wide scatter of plots to some extent. Lötjönen *et al.* (2003) stated that the larger the plots are, the more economical they are to hire or to buy. Concerning the average size of plots, they should not become smaller when a farm enlarges its acreage. Myyrä (2002) has detected that the average size of plots should be 3.3 ha for a farm which has a total arable area of 40 ha and the average size should grow by 0.1 ha when the farm enlarges the acreage by 20 %.

Given the many factors to be considered to make farming economically sustainable, decision support systems are necessary. The present model has been developed to support the farmer in her/his decisions regarding choice of plot for cereal cultivation considering distance, plot area and technology used on that plot. Various scenarios, market and production conditions can be substituted into the calculations.

5.2. Discussion about reliability of calculation models

Using mathematical models, the question always arises of how reliable the results that are calculated with the model are.

Many initial data of parameters used in the mathematical models described in the present doctoral work are estimates. If the model is used on a specific farm, these estimates will be based on the experience of that farm. Prices of materials (e.g. fuel price) depend mostly on the stock price. The question is how much the value of any initial data affect the results of the calculations?

The average values are used for some initial data such as travelling speed, performance, coefficient of the usage of engine power etc. It is presumed that if the factual value varies from the average, there will be deviations in the different directions considering much of the initial data and these deviations will balance each other out.

While there is a computer program created on the basis of the model, we can quickly clarify, with the help of this, how the difference in some of the initial values affect the result of the calculations. This is presented also in paragraphs 4.10 -4.12

6. CONCLUSIONS

1. Studying the literature it became clear that there are several methods used to calculate the average travelling distance of a farm, and to find out the optimal travelling distance in the farm. Several researchers have studied ways to reform the logistics of transporting materials on-farm. The influence of the plot distance from the farmstead on the cropping patterns internal to the farm has also been studied. The methods have been created to help a farmer to decide about using his plots concerning the plot properties.

2. However, from the practical point of view it is also essential to find out about every distinct plot, what the effect of the distance from the farm centre is on the profitability of production of the plot. Therefore the goal was set in the present thesis to create an universal method and computer software based on this, which would help the farmer to decide about the rationality of the usage of a plot considering the travelling distance between the farm centre and the plot. The method should incorporate every kind of cost affected by the plot distance.

3. According to the tasks described at the beginning of this thesis, the models were composed to calculate the following: 1) travelling costs of FOUs; 2) costs related to transporting the technological materials between the plot and the farm centre; 3) income loss caused by the distance between the plot and the farm centre; 4) costs related to management travels between the plot and the farm centre; and 5) maximum travelling distance according to the plot area and production technology applied on the plot (**XIII, XVIII**)

4. The different functions were compared to describe the timeliness of sowing works and the following was concluded, that a simplified quadratic polynomial function is the most appropriate (**V**).

5. A software “Field distance” was proposed and programmed on the basis of the discussed calculation methods, and sample calculations were composed with the help of the software. The set of initial data is different for every distinct plot and production technology and it should be recalculated for all cases. This is not very time-consuming thanks to the software.

6. On the basis of the calculations performed by means of the model, it can be concluded that the economically profitable distance increases proportionally with plot size. In the economic conditions used in the current thesis, the economically maximum distance for larger plots falls within the interval of 18 – 25 km (**XVIII**). It also became clear that, considering very large plot areas, the income loss is so great, that the other costs should be decreased and thus the maximum travelling distance should be minor.

7. In economic conditions used in the current thesis, a change of plot area greater than 25 ha has less of an influence on the maximum distance than a change of the smaller plot areas. Thus consolidation of plots smaller than 25 ha have a greater effect on transportation costs than consolidation of plots larger than 25 ha.

8. These calculation methods enable estimate of the effect of a certain technological solution, such as the use of auto-steering for example, on the travelling costs. Manipulating the calculations, it emerged that using an auto-pilot improves the performance of an FOU and the working time will shorten, resulting sometimes in a lower number of plot visits and therefore a decline in the travelling costs.

9. Comparing the tillage technologies it appeared that there were no major differences in the costs related to the travelling distance. This is because the hourly cost of tractors is related to the number of works used in the technology. The greater the number of the works is, the greater the annual work load of a tractor is and the smaller proportion of the fixed costs is in the hourly cost of a tractor. The results of the simulations showed that tillage technology has more of an influence on the maximum distance when annual workloads of machines are equal in all technologies, compared to the case when the workload depends on technology (**XVIII**).

10. The calculation outcomes also show that the prognosticated price of fuel must be taken into account when making plot-related decisions. Using distant plots that have been cost-effective until now may become unprofitable due to higher fuel costs(**XVIII**).

11. Larger yield or a higher selling price of production increase the limit value of costs and, thus, increase the profitable distance of the

plot. On the other hand, income losses are increase due to the timeliness of operations, reducing the tendency to increase distance(**XVIII**).

12. With the help of the calculation model related to the travelling costs of FOUs it is possible to divide the short remaining days between the previous working days, and thus avoid redundant travelling costs already at the planning stage.

13. On average the difference of the maximum distance on dependent on studied parameters is:

    1) 1.38 km per 100 EEK/ha of available money for costs depending on distance;
    2) 1.26 km per 1 EEK/kg of yield price;
    3) 0.7 km per 1 t/ha of cereal yield;
    4) 0.36 km per 1 EEK/l of fuel price.

14. It was discovered, in the sample calculations, that considering cereal production, the travelling cost of combine contributes a significant proportion of the travelling costs of all FOUs.

15. In calculations it was presumed that manure comes from a farm's own production, and the only costs arise from mixing, transporting and distribution. When compared to mineral fertiliser these costs grow more rapidly with the increase of the travelling distance, and therefore it is more economical to use manure only near to the farm centre. In economical conditions used in the current thesis, up to 6 km plot distance from fertiliser pin cattle slurry distribution with a shallow injection system is more economical compared to mineral fertiliser (**XVI, XVII**).

16. It can also be concluded that, compared to a distributor using tank truck for transporting slurry is beneficial on the plots that are further away(under the conditions used in the simulation the limit of distance was 8 km), especially then the hourly operation cost of the slurry distributor is very high (**XVI, XVII)**.

In the process of creating methods to evaluate the travelling distance of a plot from the economic point of view, presented in the thesis, it was clear that when establishing the methodology we should consider certain restrictions:

1) machines travel between the farm centre and the plot within a working day; and

2) the FOU travels back to the farm centre at the end of every working day.

The proposed model needs further elaboration. Currently, the model considers only the sowing work's influence on income losses related to travelling distance, but in the future the model needs to be complemented with other operations. Lötjönen *et al* (2003) reported that for farmers who cultivate small fields far away from the farm centre, the timeliness cost is still a significant cost factor in bad harvesting conditions. It would also be beneficial to create the possibility to evaluate which conditions would be most rational: to return to the farm centre with the FOU after the work day, leave it close to the plot, or perform the operation in several consecutive shifts.

In spite of these questions and limitations, the calculation methods presented in the thesis and software created by these methods are essential tools to plant production managers, advisors and researchers studying the possibilities of using farm plots considering different production technologies.

REFERENCES

Aaltonen, J., Järvenpää, M., Klemola, E. and Laurila, I. 1999. Viljan korjuu-, kuivaus- ja logistiikkakustannukset Suomessa . Maatalouden taloudellinen tutkimuslaitos. *Selvityksiä 2*/1999, 22 p.

Adhikari, M., Paudel, K.P., Martin Jr, N.R. and Gauthier, W.M. 2005. Economics of dairy waste use as fertilizer in central Texas. *Waste Management* 25, 1067–1074.

Agrar-Office. 2009. Das integrierte System für die Agrarwirtschaft. Internetilehekülg. http://www.agrar-office.de/

Astover, A., Roostalu, H., Mõtte, M., Tamm, I., Vasiliev, N. and Lemetti, I. 2006. Decision support system for agricultural land use and fertilisation optimisation: a case study on barley production in Estonia. *Agricultural and Food Science* 15 (2), p. 77-88.

ATK .1984. *Põllumajandustööde normid*. Mehhaniseeritud tööd. Eesti NSV Agrotööstuskoondise Info- ja Juurutusvalitsus. -Tln. 383 lk.

Bernhardt, F., (1996) Überlegungen zur optimalen Größe von Productionseinheiten in der Milchviehhaltung.- *Berichte über Landwirtschaft* / Zeitschrift für Agrarpolitik und Landwirtschaft vom Bundesministerium für Ernährung, Landwirtschaft und Forsten. Band 74(3). Münster-Hiltrup, S 481-493.

Berruto, R., Ess, D., Maier, D. E. and Dooley, F. 2003. Network simulation of crop harvesting and delivery from farm field to commercial elevator. *Proceedings of the International Conference on Crop Harvesting and Processing*, 9-11 February 2003., Louisville, Kentucky, USA.

Bogun, G. 2005. Väetiste hoidmine ja laotamine. http://www.eria.ee/public/files/Vaetiselaoturite_valik.pdf

Bosch, D.J. and Napit, K.B., 1992. The economics of transporting broiler litter to achieve more effective use as a fertilizer. *Journal of Soil and Water Conservation* 47, 342–346.

Bouma, J., Varallyay, G. & Batjes, N. H. 1998. Principal land use changes anticipated in Europe. *Agriculture Ecosystems & Environment* 67: 103-119.

Buckmaster, D. R. and Hilton, J. W. 2003. Computerized cycle analysis of harvest, transport, and unload systems. *Proceedings of the International Conference on Crop Harvesting and Processing*, 9-11 February 2003.

Burger, A. 2001. Agricultural development and land concentration in a central European country: a case study of Hungary. *Land Use Policy* 18: 259-268.

Burton, R. J. F. & Walford, N. 2005. Multiple succession and land division on family farms in the South East of England: A counterbalance to agricultural concentration? *Journal Of Rural Studies* 21: 335-347.

Collentine, D., Larsson, M. and Hannerz, N. 2002. Ask LENNART: Integrating heuristics and the Internet in a decision support system (DSS) for field management. *NJF-seminar 345 Farm Management Proceedings*, Gran, Hadeland, Norway, 2-5 October 2002. http://composit.dimea.se/filebank/files/20050807$213641$fil$QY0JG9Difj19s100wTcw.pdf

Crosier, S. 2009. Johann-Heinrich von Thünen: Balancing Land-Use Allocation with Transport Cost By Scott Crosier. Cited 26 January 2009. Updated 1 January 2009. Available on the Internet: http://www.csiss.org/classics/content/9.

De Garis De Lisle, D. 1978. Effects of distance internal to the farm: a challenging subject for North American geographers. *The Professional Geographer* 30 (3), p. 278-288.

De Garis De Lisle, D. 1982. Effects of Distance on Cropping Patterns Internal to the Farm. *Annals of the Association of American Geographers* 72 (1), p. 88-98.

De Toro, A. and Hansson, P. -A. 2004. Analysis of field machinery performance based on daily soil workability status using discrete event simulation or on average workday probability. *Agricultural Systems* 79 (1), p. 109-129.

Delchev, N. and Trendafilov, K. 2002. Justification of a method for selection of transportation vehicles for gathering grain crops depending on grain hopper capacity of the harvester and haulage distance. *Selskostopanska Tekhnika* (Bulgaria)v. 39 (3), p. 15-18.

Edwards, W. 2005. *Estimating Farm Machinery Costs.* Available on the Internet: http://www.extension.iastate.edu/Publications/PM710.pdf. Iowa State University, University Extension. Cited 29.02.2008. Updated August 2005.

EKI. 2009. Market prices of cereals in Estonia. Estonian Institute of Economic Research. http://www.ki.ee/.

Ekman, S. 2000. Tillage system selection: a mathematical programming model incorporating weather variability. *Journal Of Agricultural Engineering Research* 77 (3), p 267-276.

EMVI. 2005. Tera- ja kaunviljade ning õlikultuuride satelliitnavigatsioonipõhise täppisviljelustehnoloogia kasutusvõimaluste uuring Eesti oludes. Eesti Maaviljeluse Instituudi 2005. a lõpparuanne. Internetiväljaanne. http:// www.eria.ee / public/files/Lopparuanne_1.15.pdf.

EVP 1992. Suviteraviljad. Eesti Vabariigi Põllumajandusministeerium. Õppe-Metoodikakabinet.Tallinn, 64 p.

Farmconsult. 1996. *Uurimus põllumajanduse mehhaniseerimisest.* AS Rebellis. Saku. 1996. -119 lk.

Fechner, W., Pickel, P. and Fröba, N. 2002. Simulation landwirtschaftlichen Transportprozesse am Beispiel der Kornernte. *Tagung Landtechnik 2002.*

Fortuna, V. 1985. *Masinapargi ekspluatatsioon.* -Tln.: Valgus, 376 lk.

Fröba, N. und Funk, M. 2005. *Dieselkraftstoffbedarf bei Landwirtschaftlichen Arbeiten.* KTBL-Heft 58. Vertrieb KTBL Darmstadt. 32 s.

Fröba, N., Herrmann, A. and Weise, G. 2001. "Lastesel" meist besser als "Rennpferde" - Transportleistung bei verschiedenen Höchstgeschwindigkeiten.-*Neue Landwirtschaft*, Berlin (2001) H. 1, S. 36-38

Gazzarin, C.and Gregor, A. 2009. *Viel Neues bei der Maschinenkosten-berechnung.* Eidgenössisches Volkswirtschaftsdepartement EVD. Forschungsanstalt Agroscope Reckenholz-Tänikon ART. Available on the Internet: www.art.admin.ch/dienstleistungen/00882/00976/01187/index.html?lang=de. Cited 23.04.2009. Updated 25.02.2009.

Grisso, R. D., Vaughan, D. H. and Roberson, G. T. 2006. Method for Fuel Prediction for Specific Tractor Models. *2006 ASAE Annual Meeting.* Published by the American Society of Agricultural and Biological Engineers. Paper No. 061089.

Gunnarsson, C. and Hansson, P.A. 2004. Optimisation of field machinery for an arable farm converting to organic farming. *Agricultural Systems* 80 (1), p. 85-103.

Gwyer, B., King, T., McKenzie, B. & Stothers, S. 2005. Land Expansion: Establishing Values and Options. Manitoba Agriculture, Food and Rural Initiatives. Cited 30 August 2007. Updated May 2005. Available on the Internet: http://www.gov.mb.ca/agriculture/financial/farm/cap07s01.html

Hahn, J. 2006. Logistik. *Jahrbuch Agrartechnik/Yearbook Agricultural Engineering.* Band 18. VDMA Landtechnik/ VDI-MEG/ KTBL. Landwirtschaftsverlag. S 52-58.

Haller, E. 1969. *Idanemiskeskkonna mõju põllukultuuride saagile.* -Tln. 275 lk.

Harasimowicz S. 1997. Influence of plot and farm characteristics on the value of land. Zeszyty Naukowe Akademii Rolniczej im. H. Kollataja w Krakowie. *Geodezja* (Poland), no.16, p. 77-85.

Harasimowicz S. and Ostrągowska B. 2001. Influence of field extent on cultivation costs. Electronic Journal Of Polish Agricultural Universities, *Environmental Development* 4 (2).

Harrigan, T. 2003. M. Time-motion analysis of corn silage harvest systems. *Applied Engineering In Agriculture* 19 (4), p. 389-395.

Heikkilä, K. and Salo, R. 2002. Suurnevien tilojen haasteet. *Maa- ja elintarviketalous* 7. Maa- ja elintarviketalous tukimuskeskus, 103 s

Heinloo, M. 1998. Talu transpordikeskuse optimaalne asend. *APS Toimetised* 7. Tartu. lk 13-16

Heinsoo, J., Jaama, E., Jõudu, J.,Reimets, E. ja Viileberg, K. 1986 *Taimekasvatus*. -Tln. 319 lk.

Herrmann, A. 2000. Durchschnittliche Transportgeschwindigkeiten beim Einsatz von Traktoren mit unterschiedlichen bauartbedingten Höchstgeschwindigkeiten.- Halle, Martin-Luther- Universität Halle-Wittenberg, Institut für Agrartechnik und Landeskultur, *Forschungsbericht 2000*

Hiltbrunner, J., Liedgensa, M., Stamp, P. and Streit, B. 2005. Effects of row spacing and liquid manure on directly drilled winter wheat in organic farming. *European Journal of Agronomy* **22**. 441–447.

Huijsmans, J., Verwijs, B., Rodhe, L. and Smith, K. 2004. Costs of emission-reducing manure application. *Bioresource Technology* 93. 11–19.

Hunt, D. 2001. *Farm power and machinery management*. -10th ed. Iowa. 368 p.

Iannoni, A. P. and Morabito, R. 2006. A discrete simulation analysis of a logistics supply system. Transportation Research Part E: *Logistics and Transportation Review* 42 (3), p. 191-210.

Jabarin, A.S. and Epplin, F.M. 1994. Impacts of land fragmentation on the cost of producing wheat in the rain-fed region of northern Jordan. *Agricultural Economics* 11 (2-3), p. 191-196.

Jannot, Ph. and Cairol, D. 1994. Linear Programming as an Aid to Decision-making for Investments in Farm Equipment for Arable Farms. *Journal of Agricultural Engineering Research* 59 (3), p. 173-179.

Jürimäe, E. ja Velsker, K. 1984. *Matemaatika käsiraamat IX-XI klassile*. Tallinn: Valgus. 384 lk.

Kapfer, M. and Kantelhardt, J. 2008. A method to calculate economic key figures with regard to plot structure improvements. The 82nd Annual Conference of the Agricultural Economics Society Royal Agricultural College. 31st March to 2nd April 2008. Cirencester, UK. Cited 29.04.2009. Updated 02.04.2008. Available on the Internet: http://ageconsearch.umn.edu/bitstream/36858/2/Kapfer_kantelhardt.pdf.

Kapuinen, P. 2001. Logistic optimization of slurry transports between six farms and a common biogas plant - a case study. *Teadustööde kogumik. Eesti Põllumajandusülikool* Nr. 214, p. 87-92.

Kapuinen, P. 2003. Techniques, logistics and economy in manure application. Proceedings of Nordic Association of Agricultural Scientists 22nd Congress, July 1-4 2003, Turku, Finland.

Karmin, M. 1975. *Mullaharimise ja külvi kvaliteet*. -Tln: Valgus. -118 lk

Kask, H. 1977. *Transpordi- ja laadimistööd põllumajanduses.* -Tln.: Valgus. -278 lk.

Kilima, F. and Kenkel, P. 2004. Optimal Fertilizer Warehousing and Distribution for Farm Supply Cooperatives Department of Agricultural EconomicsOklahoma State Univesity. http://www.agecon.ksu.edu/accc/ncr194/Events/2004meeting/Kenkelwarehousepres.pdf

Koik, E., Tamm, K. ja Loko, V. 2003. Üldine masinakasutuse ökonoomika. Internetiväljaanne. Eesti Maaviljeluse Instituut. http://www.eria.ee/public/files/yldine__masinkasutus.pdf

Kryachkov, I. and Sharova, N. 2005. Justification of optimal sizes of agricultural enterprises. *Mezhdunarodnyi Sel'skokhozyaistvennyi Zhurnal*, 4, p. 30-33.

KTBL. 2002/2003. *KTBL-Taschenbuch. Landwirtschaft.* KTBL-Schriften-Vertrieb im Landwirtschaftsverlag GmbH, Münster-Hiltrup. 290 s.

KTBL. 2004/2005. *KTBL-Datensammlung-Betriebsplanung 2004/2005.* KTBL-Schriften-Vertrieb im Landwirtschaftsverlag GmbH, Münster. 573 s.

Kübler, S., Fechner, W., Wendt, K. and Pickel, P. 2004. Development of modular softare to simulate farming processes. *VDI Berichte. Conference: Agricultural Engineering 2004*, p. 293-299.

Käerdi, H. 2003. *Arvutusmeetodid.* Sisekaitseakadeemia, 44 lk.

Kärblane, H. 1996. *Taimede toitumise ja väetamise käsiraamat.* Eesti Vabariigi Põllumajandusministeerium. Tallinn. 285 lk.

Leick, B. C. E. 2003. Emission von Ammoniak (NH3) und Lachgas (N2O) von landwirtschaftlich genutzten Böden in Abhängigkeit von produktionstechnischen Maßnahmen. Doctoral Thesis. Fakultät Agrarwissenschaften der Universität Hohenheim. 157 pp.

Lötjönen, T., Suomi, P. and Mikkola, H. J. 2003. Modelling of grain harvesting from field to storage. Management and technology applications to empower agriculture and agro-food systems *XXX CIOSTA-CIGR V Congress Proceedings* Turin, Italy September 22-24, 2003 : volume 1. 395-399 pp.

Maatalouden työnormit. 1988. Työtehoseuran maatalous- ja rakennusosaston monisteita 2. 157s.

Mattila, P.K. 2006. Ammonia emissions from pig and cattle slurry in the field and utilization of slurry nitrogen in crop production. MTT Agrifood Research Finland, Plant Production Research, Soil and Plant Nutrition, 63 pp.

Morlon, P. and Trouche, G. 2005. New stakes of field work logistics for annual crops in French conditions. II. The spatial organization of crops: Examples and questions.*Cahiers d'études et de recherches francophones / Agricultures.* 14 (3), p. 305-11.

Myyrä, S. 2002. Tilusrakenteen vaikutus tuotannon järjestämiseen ja kannattavuuteen. Summary: The effects of the structure of arable land on the organization and profitability of production. Agrifood Research Finland, Economic Research (MTTL). *Research reports* 253. 35 pp.

Myyrä, S. 2004. Pellon kasvukunnon taloudellinen arvo. *MTT:n selvityksiä 66*. MTT Taloustutkimus. Helsinki. 45 s.

Myyrä, S. and Pietola, K. 2002. Economic importance of parcel structure on Finnish farms. *Agricultural and Food Science in Finland* 11 (3), p. 163-173.

Möller, H. 1981. *Traktoragregaatide efektiivsus põllutöödel*/ Mehhanisaatori raamatukogu -Tln.: Valgus. -96 lk. ill.

Möller, H. 1985. *Põllutööde kvaliteet ja põllukultuuride saagikus*. -Tln.: Valgus. -80 lk.

Möller, H., Reintam, A., Asi, M. ja Tallo, A. 1994. Taluüldpindala mõju kasumile põllundusest. *EPMÜ Teadustööde kogumik*. Põllumajandustehnika ja energeetika. Nr 177. Tartu. Lk 34-39

Möller, H., Soonets, K. ja Eerits, A. 1997a. Talu pindala suuruse mõju masinapargi töötulemustele. *APS Toimetised* 3, Tartu, lk 114-117.

Möller, H., Soonets, K., Asi, M. ja Eerits, A. 1997b. Keskmisest veokaugusest põllutöödel. *EPMÜ Teadustööde kogumik* 93, Tartu, lk 93-100.

Möller, H., Soonets, K., Asi, M. ja Vettik, R. 1998. Keskmisest veokaugusest põllutöödel vedude ellipsikujulise piirkonna korral. *APS Toimetised* 7, Tartu, lk 69-72

Naef, E. 1983. Working time requirement for field soil cultivation. Influence of the size, pattern as well as the distance of the field. *FAT Blaetter fuer Landtechnik* (Switzerland) 234, p. 1-6.

Nix, J. 1988. The economics of tillage. *Soil & Water* (Banbury) 15 (3-4), p. 15-18.

Older H. 1999. *Teraviljakasvatuse käsiraamat*. EV Põllumaj. Min., EMVI, Saku. 342 lk.

Osei, E., Gassman, P.W., Hauck, L.M, Neitsch, S., Jones, R.D., McNitt, J. and Jones, H. 2003a. Economic and environmental impacts of pasture nutrient management. *Journal of Range Management* 56, 218–226.

Osei, E., Gassman, P.W., Hauck, L.M., Jones, R., Beran, L., Dyke, P.T., Goss, D.W., Flowers, J.D., McFarland, A.M.S., Saleh, A.. 2003b. Environmental benefits and economic costs of manure incorporation on dairy waste application fields. *Journal of Environmental Management* 68, 1–11.

Paudel, K.P., Bhattarai, K., Gauthier, W. M., and Hall, L.M. 2009. Geographic information systems (GIS) based model of dairy manure transportation and application with environmental quality consideration. *Waste Management* 29(5) .1634-1643 pp.

Peart, R. M. and Shoup, W. D. 2002. Computer Tools for Agricultural Systems Management. *2002 ASAE Annual Meeting*. American Society of Agricultural and Biological Engineers. Paper No. 028029

Peltotuki Pro. 2009. Helppokäyttöinen peltoviljelyn suunnittelu- ja seurantaohjelma. Internetilehekülg. http://www.softsalo.fi/ohjelmaesittelyt/peltotuki-pro

Penu, P., Lemetti, I. ja Kõlli, R. 1995. Muldkatte otstarbekas kasutamine teraviljade tootmisel// Eesti Agraarökonomistide assotsiatsiooni väljaanne. Nr. 9. *Suviviljade tootmine ja töötlemine Eesti Vabariigis*. -AS "Infotrükk". Tln.: 1995. Lk. 40-44.

Pfister, F., Bader, H.-P., Scheidegger, R. P. and Baccini, P. 2005. Dynamic modelling of resource management for farming systems. *Agricultural Systems* 86 (1), p. 1-28.

PIKK. 2003. Internetiportaal. Eesti Põllumajandus - Kaubanduskoda. 2003. http://www.pikk.ee/169/z0zARTICLEy300.html.

Rahman, S. and Rahman, M. 2009. Impact of land fragmentation and resource ownership on productivity and efficiency: The case of rice producers in Bangladesh. *Land Use Policy* 26(1). 95-103 pp.

Recio, B. and Rubio, F. 2004. Decision Support System for Farms Mechanization. *2004 ASAE Annual Meeting*. American Society of Agricultural and Biological Engineers. Paper No. 043040.

Recio, B., Rubio, F. and Criado, J. 2003.. A decision support system for farm planning using AgriSupport II. *Decision Support Systems* 36 (2), 2003, p. 189-203.

Ribaudo, M. and Agapoff, J. 2004. Importance of cost offsets for dairy farms meeting a nutrient application standard. Selected Paper to be Presented at the American Agricultural Economics Association Annual Meeting, Denver, CO.

Rodhe, L.K.K. and Rammer, C., 2002. Application of slurry to ley by band spreading and injection methods. *Biosyst. Eng.* 83, 107–118.

Rotz, C. A. and Harrigan, T. M. 2004. Predicting Suitable Days for Field Operations in a Whole Farm Simulation. *2004 ASAE Annual Meeting*. American Society of Agricultural and Biological Engineers, Michigan, USA.

RT I. 2001. Saastuse kompleksse vältimise ja kontrollimise seadus. 2001. -Riigi Teataja I osa. [WWW] https://www.riigiteataja.ee/ert/act.jsp?Id=12773314 (01.02.2007).

Schnitkey, G and Lattz, D. 2008. Machinery cost estimates: Tractors. *Farm Business Management*. Department of Agricultural and Consumer Economics, University of Illinois. Cited 15.04.2009. Updated May.2008.

Available on the Internet: http://www.farmdoc.uiuc.edu/manage/machinery/machinery_tractors.html

Schnitkey, G. 2005. Growth in farm size. Farm business management. *Farm Economics Facts and Opinions*. University of Illinois Extension. Cited 28 August 2007. Updated 25 Juny 2005. Available on the Internet: http://www.farmdoc.uiuc.edu/manage/newsletters/fefo05_12/fefo05_12.html .

Singh, G. and Abeygoonawardana, K. A. R. 1982. Computer simulation of mechanical harvesting and transporting of sugarcane in Thailand. *Agricultural Systems* 8 (2), p. 105-114.

Somda, Z.C., Allison, J.R., Ely, L.O., Newton, G.L. and Wetzstein, M.E. 2003. Economic and environmental evaluation of dairy manure utilization for year round crop production. Selected Paper Presented at the Southern Agricultural Economics Association, Mobile, AL.

Statistics Estonia. 2009a. *Growing of cereals by county and kind of cereal.* Cited 25 January 2009. Updated 17 April 2008. Available on the Internet: http://www.stat.ee/agriculture.

Statistics Estonia. 2009b. *Agricultural land by size class and legal form of holder.* Cited 25 January 2009. Updated 17 April 2008. Available on the Internet: http://www.stat.ee/agriculture.

Steinsholt, H. 1997. Calculation system for working time need at changes in field size, field shape and distance within the farm area. *Informasjonsmoete i Landbruksoekonomi 1997*, Oslo (Norway), 4-5 Nov 1997.

Suomi, P., Lötjönen, T. and Mikkola, H. 2003. Modelling of grain harvesting and storing. Nordic Association of Agricultural Scientists 22nd Congress, July 1-4 2003, Turku, Finland.

Søgaard, H. T. and Sørensen, C. G. 2004. A Model for Optimal Selection of Machinery Sizes within the Farm Machinery System. *Biosystems Engineering* 89 (1), p. 13-28.

Sørensen, C.G., Jacobsen, B.H. and Sommer, S.G. 2003. An Assessment Tool applied to Manure Management Systems using Innovative Technologies. *Biosystems Engineering* 86 (3), 315–325.

Tamm, K. 1999. *Teraviljandustalu põhiparameetrite optimeerimine masinapargi töökoormuse järgi.* Väitekiri tehnikamagistri teadusliku kraadi taotlemiseks. / Juh. H. Möller, M. Asi; Eesti Põllumajandusülikool. Põllumajandustehnika instituut. - Tartu. 76 lk.

Tiigimäe A. 1980. *Põllunduse mehhaniseerimine.* Tln.: Valgus. 564 lk.

TTS. 2001. Urakointihinnat ja konetyö kustannukset. *Työtehoseuran maataloustiedote 6* . 2001(535) 12 s

Weisstein, E. W. 2006a. "Secant Method." From MathWorld--A Wolfram Web Resource. Cited 18 December 2007. Updated 24 March 2006.

Available on the Internet: http://mathworld.wolfram.com/SecantMethod.html.

Weisstein, E. W. 2006b. "Bisection." From MathWorld--A Wolfram Web Resource. Cited 18 December 2007. Updated 1 March 2004. Available on the Internet: http://mathworld.wolfram.com/Bisection.html .

Vidican, G. 2009. Assessing land reallocation decisions during transition in Romania. *Land Use Policy* 26(4).1080-1089 pp.

Wiens, M.J., Entz, M.H., Wilson, C. and Ominski, K.H. 2008. Energy requirements for transport and surface application of liquid pig manure in Manitoba, Canada. *Agricultural Systems* 98(2), 74-81 pp.

Vipper, H. 1989. *Maaviljeluse praktikum*. -Tln: Valgus. -372 lk.

Witney, B. 1988. *Choosing and Using Farm Machines*. New York, 412 p.

Бадевиц, З. 1982. *Математическаяа оптимизация в социалистическом сельском хозяйстве*. Москва. Колос. 549 с.

Линнас, Л. В. 1981. Об оптимальном составе машино-тракторного парка хозяйств. *Сб. научн. трудов Эстонской сельскохозяйственной академии* 138. Тарту. Ротапринт ЭСХА. С. 29...36.

Линнас, Л. В. 1989. Об определении оптимальной потребности в зерноуборочных комбаинах. *Сб. научн. трудов Эстонской сельскохозяйственной академии* 165. Тарту. Ротапринт ЭСХА. С. 12...18.

Лобосок, Г. 1995. *Оптимальная продалжительность полеводческих работ на фермском хозяйстве*. Дипломный проект. ЭСХУ, Тарту.

Мёллер, Х.Р., Луттер, Р.С., Вийдалепп, Р.Я. и Мёллер, М.Х. 1989. О планировании работы зерноуборочные агрегатов. –Проблемы повышения еффективности изпользования машин полеводстве. *Сб. научн. трудов Эстонской сельскохозяйственной академии* 165. Тарту. Ротапринт ЭСХА, 3- 12

Семенов, М. И., Яловнаров, В. И, Карибжанов, Ж. С. и Даниелян, А. А. 1982. *Оптимальное планирование средств механизации сельского хозяйства*. Москва. Россельхозиздат. 119 с

KOKKUVÕTE

Teraviljakasvatusettevõtte töötulemuste sõltuvus masinapargi koosseisust ja põldude asukohast

Põllumees teab, et mida suurem on tootmismaht ehk haritava maa pindala või loomade arv, seda paremini on võimalik oma tootmisvahendeid koormata ja seega vähendada püsikulude osakaalu toodangu omahinnas. Lisaks annab piisavalt koormatud masinpark võimaluse masinaid ettevõttes vahetada normaalse tööea järel ja seega kasutada moodsat tehnikat, mis omakorda on abiks tööviljakuse ja -kvaliteedi tõstmisel.

Suurem tootmismaht on aga ka eelduseks, et saada tootmisest enam kasumit. Piimatootjad üritavad tootmist laiendada ja Eestis kerkib üha uusi lautu, mis varasematega võrreldes on suuremad. Suuremad laudad mahutavad küll rohkem loomi aga see tähendab ka suuremaid sõnnikukogused, mis on vaja põldudele vedada. Keskkonnakaitsenõuetest lähtuvalt on ühele haritava maa pinnaühikule antava orgaanilise väetise kogus külvikorras piiratud ja seetõttu vajatakse suuremate sõnnikukoguste paigutamiseks ka suuremaid haritava maa pindalasid.

Ettevõtte haritava maa pindala suurendamisel tuleb kasutusele võtta aina kaugemaid põldusid, mis omakorda tingib sõidukauguse ja ka sellest sõltuvate kulude kasvu. Põllul kasutamise otstarbekuse määrab sellega saadav kasum. Kulud ja tulud sõltuvad nii põllu pindalast, sellel kasutatavast tehnoloogiast kui ka sõidukaugusest ettevõtte keskuseni. Kui põllu kaugus on nii suur, et selle kulud ületavad tulusid, ei tasu põllu kasutamine ära. Seega on oluline teada, milline peaks antud tehnoloogia juures olema põllu pindala ja sõidukauguse piirväärtused, mille korral tasuks veel põldu kasutada.

Kirjanduse ülevaatest ilmneb, et ükski teadaolev uurimus ei sisalda arvutusmudeleid kõigi põllu kaugusest sõltuvatest kulude, nagu agregaatide ja materjalide transpordikulu, tulukadu ning kulu organisatsioonilistele sõitudele, arvutamiseks. Sellest tulenevalt püstitati käesoleva töö eesmärk.

Doktoritöö eesmärk oli

1) uurida kulude sõltuvust põllu kaugusest teraviljakasvatuse ettevõttes,
2) koostada arvutusmudelid ja tarkvara, mille abil oleks võimalik arvutada põllu kaugusest sõltuvaid kulusid,
3) koostada meetod, mille abil otsustada põllu kasutamise otstarbekuse üle lähtudes nende kulude summast ning
4) uurida erinevate parameetrite mõju põllu majandustulemustele lähtuvalt selle kaugusest.

Metoodika põhjal loodav tarkvara on praktiliseks abivahendiks põllumehele, teadurile või nõustajale, võimaldades võrrelda erinevate tehnoloogiliste võtete mõju sõidukaugusega seotud kuludele.

Püstitatud eesmärgi täitmiseks:

1) tehakse ülevaade teraviljakasvatuse ettevõtte sisestel sõitudel kasutatavatest masinatest;
2) tehakse ülevaade kululiikidest, mis sõltuvad põllu ja masinakeskuse vahelisest sõidukaugusest;
3) koostatakse arvutusmetoodika põllutöömasinate põllu ja masinakeskuse vaheliste sõitudega seotud kulude leidmiseks;
4) koostatakse arvutusmetoodika tehnoloogiliste materjalide põllu ja masinakeskuse vahelise veoga seotud kulude leidmiseks;
5) koostatakse metoodika põllu ja masinakeskuse vahelise kaugusest tingitud tulukao leidmiseks;
6) koostatakse arvutusmetoodika põllu ja masinakeskuse vaheliste organisatsiooniliste sõitudega seotud kulude leidmiseks;
7) koostatakse metoodika, et leida suurim sõidukaugus vastavalt põllu pindalale ja seal kasutatavale tehnoloogiale;
8) koostatakse metoodika põhjal projekteeriti ja programmeeriti tarkvara „Põllu kaugus“ ja
9) programmi „Põllu kaugus“ abil testitakse ja redigeeritakse arvutusmetoodikat ning koostatakse arvutusnäited.

Tulemused ja järeldused

1.Kirjanduse läbitöötamisel selgus, et on loodud mitmeid meetodeid ettevõtte keskmise sõidukauguse leidmiseks, mille põhjal omakorda oleks võimalik leida ettevõtte optimaalne sõidukaugus. Uuritud on võimalusi põllumajandusettevõtte materjalideveo logistika parandamiseks. Samuti on uuritud põllu kauguse mõju kultuuride jaotusele ettevõtte põldude vahel. Loodud on metoodikaid põldude kasutamisega seotud otsuste tegemiseks lähtuvalt agronoomilistest parameetritest ja põllu töödeldavusest.

2. Vastavalt käeoleva töö eesmärgile koostati metoodika, mille abil oleks võimalik hinnata põllu kasutamise otstarbekust lähtuvalt selle põllu ja ettevõtte masinakeskuse vahelise kaugusest.

3. Eesmärgi saavutamiseks koostati arvutusmudelid, et arvutada: 1) agregaatide sõidukulu; 2) tehnoloogiliste materjalide põlluleveo kulu; 3) põllu kaugusest tingitud tulukadu; 4) põllu ja masinakeskuse vaheliste organisatsiooniliste sõitudega seotud kulud ning 5) suurim põllule sõidu kaugus vastavalt selle pindalale ja seal kasutatavale tehnoloogiale.

4. Võrreldi erinevaid matemaatilisi funktsioone saagikuse ja tööde tegemise aja vahelise sõltuvuse kirjeldamiseks ja leiti, et otstarbekaim on kasutada lihtsustatud ruutparabooli.

5. Põllu kasutamise otstarbekuse hindamise metoodika põhjal projekteeriti ja programmeeriti tarkvara „Põllu kaugus“, mille abil koostati arvutusnäited. Igal põllu ja tootmistehnoloogia korral on algandmestik erinev ja arvutused tuleb iga juhtumi korral uuesti teha. Tänu nimetatud tarkvarale saab arvutusi teha kiiresti.

6. Arvutused näitavad, et kui võtta aluseks mingi piirväärtus, mida sõidukaugusest sõltuvate kulude summa ei tohiks ületada, siis põllu pindala kasvades kasvab ka maksimaalne majanduslikult lubatav sõidukaugus kuni teatud piirini. Käesolevas väitekirjas kasutatud tootmistingimuste korral on üle 25 ha põldude majanduslik suurim kaugus vahemikus 18-25 km. Selgus ka, et ülisuurte pindalade korral muutub saagilangusest tulenev tulukadu nii suureks, et teisi kulukomponente tuleb vähendada ja seega väheneb ka maksimaalne sõidukaugus.

7. Arvutusnäidetes kasutatud lähtetingimuste korral ilmnes, et enam kui 25 ha põldude pindala muutus omab maksimaalsele sõidukaugusele väiksemat mõju kui sellest väiksemat põldude pindala muutus. Seega annab väiksemate kui 25 ha põldude liitmine suurema efekti maksimaalsele sõidukaugusele kui neist suuremate põldude liitmine.

8. Nimetatud metoodika võimaldab hinnata ka mingi tehnoloogilise võtte, nagu näiteks automaatroolimisseadme kasutamine, sõidukaugusega seotud kuludele. Automaatroolimisseadme kasutamisel agregaadi

tootlus kasvab ja seega tööaeg lüheneb, mis mõnel juhul tingib väiksema põllul-käikude arvu ja seega agregaatide sõidukulude vähenemise.

9. Mullaharimistehnoloogiate võrdlusest ilmnes, et sõidukaugusega seotud kulude osas märkimisväärseid erinevusi ei ole, kuna traktori tunnihind on seotud tehnoloogias kasutatavate tööde arvuga. Mida suurem on tööde arv, seda suurem on traktori aastakoormus ja seda väiksem on püsikulude osa traktori tunnihinnas. Võrdluseks tehtud arvutusnäitest ilmnes, et harimistehnoloogia omab maksimaalsele põllukaugusele suuremat mõju juhul kui kõigi tehnoloogiate korral masinate aastakoormused on võrdsed.

10. Arvutustulemused näitavad, et kütuse hinda tuleb arvestada , kui tehakse põlluga seotud otsuseid. Põlde, mida senise kütuse hinna juures oli tasuv kasutada, ei pruugi tulevikus kõrgema hinna juures olla otstarbekas ekspluateerida.

11. Mida suurem on saagikus ja saagi hind, seda suurem on raha kogus, mida on võimalik kasutada põllu kaugusest sõltuvate kulude katmiseks. Teisalt kasvab nende parameetrite väärtuste suurenedes ka tulukadu seoses parimast tööpäevast hälbimisega.

12. Keskmiselt sõltub maksimaalse kauguse muutus näitearvutustes uuritud parameetritest järgnevalt:

1) 1,38 km kuludepiiri 100 EEK/ha kohta (kuludepiir on summa, mida on võimalik kasutada kaugusest sõltuvate kulude katmiseks);
2) 1,26 km saagi hinna 1 EEK/kg kohta;
3) 0,7 km teraviljasaagi 1 t/ha kohta ja
4) 0,36 km kütuse hinna 1 EEK/l kohta.

13. Agregaatide sõidukuludega seotud arvutusmudeli abil on võimalik jaotada lühikesed jääkpäevad eelnevatele tööpäevadele ja seega juba planeerimise etapis vältida üleliigseid sõidukulusid.

14. Näitearvutustest ilmnes, et teraviljakasvatuse korral märkimisväärse osa agregaatide sõidukuludest moodustab kombaini sõidukulu.

15. Võrreldi väetamiskulusid lähtuvalt väetise liigist, väetamise tehnoloogiast ja põllu kaugusest. Arvutustes eeldati, et vedelsõnnik tuleb talu enda tootmisest ja sellega seotud kulud tulenevad segamisest, veost ja laotamisest. Võrreldes mineraalväetise kasutamisega veokauguse suure-

nedes kasvavad need kulud kiiremini ja seega on majanduslikult põhjendatud kasutada vedelsõnnikut põldudel, mis asuvad ettevõtte keskuse läheduses. Käesolevas väitekirjas kasutatud tootmistingimuste korral on kuni 6 km põllu kauguse korral kasutada vedelsõnniku muldapihustuslaoturit majanduslikult otstarbekam kui mineraalväetise laotamist.

16. Arvutustest kinnitasid ka, et vedelsõnniku veol tasub kaugematel põldudel kasutada laoturi asemel paakautot (arvutustes kasutatud tingimustes korral alates põllu kaugusest 8 km), eriti juhul kui vedelsõnniku laoturi töötunni hind on väga kõrge.

Käesolevas töös esitatud põllu sõidukauguse majandusliku hindamise metoodika koostamisel ilmnes, et selle metoodika rakendamisel tuleb arvestada teatud piirangutega:

1) masinad sõidavad põllu ja masinakeskuse vahet tööpäeva sees ja
2) põllutööagregaat sõidab tööpäeva lõpus alati masinakeskusesse tagasi.

Koostatud mudel vajab edasist arendamist. Praegu arvestab mudel seoses põllu kaugusega ainult külvitööde mõju tulukaole, kuid tulevikus vajab mudel täiendamist ka teiste tööde osas. Lötjönen *et al.* (2003) märgivad oma uurimuses, et põllumeestele, kes kasutavad ettevõtte keskusest kaugel asuvaid põldusid, on halbades koristustingimustes töö ajastamatusest tingitud kulud oluliseks teguriks. Lisaks tuleks luua algoritm, mille abil oleks võimalik otsustada kui põld on suurem kui vahetuse tootlus: kas oleks otstarbekaim põllult naasta, jääda põllu lähistele ööbima või sooritada töö mitme järjestikulise vahetuse vältel.

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Education:

1979-1990	Secondary school of Rakke
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2000-2004	Estonian Agricultural University, Faculty of Technology, Chair of Field Machinery, Ph.D. student in using of field machinery.

Professional employment

1997…2001	Estonian Farmers Federation, Informatics department, software developer. Projecting and programming computer programs for agricultural software package "Talutark", in area of plant production (Farm management,

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2001…2002	Leader of the informatics department in the Estonian Farmers Federation. Leading production of the agricultural software package “Talutark”.
2003…	Estonian Research Institute of Agriculture, researcher in Mechanization department. Developing computer software, studying economics of usage of field machines and precision farming, administrating of database of web-based plant protection DSS „I-Taimekaitse“ .

Academic degrees

1999	MSc degree in Engineering (Estonian Agricultural University), MSc thesis “Optimization of main parameters of a cereal growing farm by work load of machinery”

Research projects

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Dissertations supervised

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Täiendharidus:

2002	Kursus edasijõudnutele andmebaasi kujundamisest ja kasutamisest ning selle andmebaasi komponentide arendamisest SQL Server 2000 põhjal.
2001	Kursus dünaamiliste veebilehtede valmistamisest ja komponentide kasutamisest. JavaScript, CSS, ASP.
2000	Kursus Lätis Ozolnieki Nõustamiskeskuses "Internetitehnoloogia põhialuste kasutamine". Teemadeks olid: internetilehekülgede projekteerimine; HTML dokumentide struktuur ja objektid, JavaScript ja selle istutamine HTML dokumenti ning ASP kasutamine

	internetilehekülgede programmeerimiseks
2000	Kursus Taani Põllumajandusteaduste Instituudis kursusel “Andmebaaside disainimine ja programmi SQL Server installeerimine ning kasutamine”. Teemadeks olid SQL Server 7.0, selle konfigureerimine ja installeerimine, Taani taimekaitseprogrammi PC-Plant Protection internetiversiooni andmebaaside struktuurid.

Teenistuskäik

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2001…2002	Eestimaa Talupidajate Keskliidu informaatikaosakonna juhataja. Põllumajandusliku tarkvarapaketi "Talutark" tehnilise arenduse ja hoolduse ning turustamise juhtimine. Taimekasvatusprogrammide arendus ja hooldus.
2003…	Eesti Maaviljeluse Instituudi mehhaniseerimise osakonna teadur. Arvutiprogrammide koostamine, Masinakasutuse ökonoomika, täppisviljelus, veebipõhise taimekaitsenõustamise süsteemi „I-Taimekaitse“ andmebaasi administraator

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2003 Eesti Maaviljeluse Instituut. Uurimisprojekt 1.13. „Põllukultuuride tootmise tasuvuse selgitamine sõltuvalt sisendite hindadest, tootmistehnoloogiatest, tootmisüksuse suurusest ja kokkuostu hindadest“, teadur.

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