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ESTONIAN UNIVERSITY OF LIFE SCIENCES



**COMPUTER-AIDED OPTIMIZATION
OF PIG FARMING TECHNOLOGIES AND
MACHINERY USE**

SEAKASVATUSTEHNOLOOGIATE JA TEHNIKAKASUTUSE
ARVUTIPÕHINE OPTIMEERIMINE

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DENOTATIONS

a, b, c, f, g, g_s	– regression coefficients
a_s	– manure norm per one pig during the fattening period, ton
a_{ss}	– amount of manure produced by one breeding pig per year, ton
d	– theoretical average distance of transportation, km
e	– feed consumption of a one pig per year from the feeds produced on the company, kg
e_1	– yearly fodder need per one fatted pig place, kg
E_e	– excess or deficiency of feed, kg
e_{ss}	– feed consumption of a breeding pig per year from the feeds produced on the company, kg
h	– average yield of crops, kg per hectare
H_{ss}	– direct support per one breeding pig, in EEK
i	– interest rate on capital, %
$k_{1, ss, p}$	– keeping costs of breeding pigs per year, in EEK
$k_{1, ss, s}$	– costs of manure transportation, in EEK
$k_{2, ss}$	– depreciation for growing breeding pigs, in EEK
$k_{3, ss}$	– interest on capital for growing breeding pigs, in EEK
$k_{4, s}$	– salary of paid employees in pig farming, in EEK
$k_{4, y}$	– salary of paid employees in crop growing, in EEK
$k_{5, s, m}$	– miscellaneous costs (taxes, insurance, tenure etc), in EEK
$k_{5, ss, r}$	– repair and maintenance costs for growing breeding pigs, in EEK
l	– number of fields in rotation
l_a	– numbers of the animals in one animal unit
$l_{s, j}$	– material or service costs per one fatted pig (purchase piglets, feed additives, heating, electricity, veterinary services, veterinary drugs etc) in j -th of lot
l_{ss}	– material or service costs per one breeding pig (feed additives, heating, electricity, veterinary services, veterinary drugs etc)
l_u	– number of the animal units allowed to breed per one hectare
M_s	– cost of buildings, shed equipment etc per one fatted pig place, in EEK
M_{ss}	– cost of buildings, shed equipment etc per one breeding pig place, in EEK
n	– number of pig places
n_p	– production of piglets per year
n_{pn}	– number of working days per week
n_{pr}	– number of cull pigs
n_s	– number purchase lots of piglets

$n_{s,p}$ – number of working months of paid employees in pig farming per year
 $n_{s,j}$ – number of pigs in j -th of lot
 n_{sl} – number of pigs allowed to keep by manure utilization regulations per one hectare
 N_{so} – maximum limit of manure utilization, ton per (hectare·year)
 n_{ss} – number of breeding pigs
 $n_{y,p}$ – number of working months of paid workers in crop growing per year
 P_s – monthly salary of a paid employee, in EEK
 $p_{s,j}$ – cost of a unit of material or service in j -th of lot
 p_{ss} – cost of a unit of material or service
 $q_{s,j}$ – average pig realization live weight in j -th of lot, kg
 r_{ky} – complex fuel price (includes both fuel price and greasing agents), in EEK per litre
 r_p – average selling price of a piglet, in EEK
 r_{pr} – average selling price of a cull pig, in EEK
 $r_{s,j}$ – selling price per weight unit of pigs in j -th of lot, in EEK per kg
 r_{so} – selling price of manure, in EEK per ton
 r_t – price of feed grain, in EEK per kg
 S_e – excessive amount of the manure, ton
 t_a – working hours during the peak seasons per rotation's elementary unit, hours per (hectare·day)
 t_l – total consumption of working time, hours per day
 t_{lt} – length of working day during the high season of works, hours per day
 t_n – work load of one employee per week, hours
 t_s – working time in pig farming works, hours per day
 $t_{s,t}$ – working time in pig farming works of main employee, hours per day
 T_{ss} – income from growing breeding pigs, in EEK
 \bar{T}_{vs} – decrease of income from the sale of grain, in EEK
 t_y – working time in crop growing, hours per day
 U – arable land acreage, hectare
 U_s – fodder crops acreage, hectare
 $u_{s,a}$ – factor of depreciation assignments, %
 $u_{s,r}$ – factor of repair assignments, %
 γ – factor of increase in transportation distance
 δ – factor that shows the share of the fodder crops acreage in the total acreage of the arable land of company

φ – factor characterising the culling of pigs
 ω – relation of repair and maintenance costs to fuel costs
 η – factor of performance of pig places
 η_t – ratio of real number of the pigs in company and the allowed number n_{sl}
 ζ – factor providing of social security payments

INTRODUCTION

Pork production in Estonia has had its highs and lows. In the years 1990...1999 the production of pork mostly decreased (Lember *et al.*, 1999). In 2000...2001 pork production increased to some degree and in the years 2001...2006 there were no substantial changes (Põllumehe..., 2004; 14. maarahva..., 2006, Põllumajandussektori..., 2007). For a better overview a graph describing the changes in the number of pigs is presented.

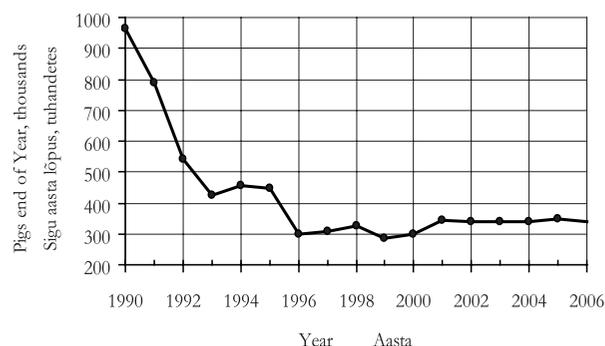


Figure 1. Number of Pigs in Estonia years 1990...2006

Joonis 1. Sigade arv Eestis aastatel 1990...2006

Recently new pig farms have been built in Estonia and the existing ones have been reconstructed, with support from different aid programmes (Meede 3.1..., 2005), also modern production technology solutions have been built (AS Ekseko and OÜ SF Pandivere slurry storage areas etc) (Meede 3.1..., 2004). This allows drawing the conclusion that in Estonia people wish to deal with pig farming and pork production should not decrease in the near future.

Pig farming technology comprises both the technology of feeding and keeping the pigs, as well as other activities related with pig farming (Farmide mehhaniseerimine, 1987). People use different machines and equipment for agricultural works. In order to ensure that the expenses on the unit of work made by the procured machines and equipment were as low as possible, the machines and equipment should be loaded with work as much as possible. The work load for people and machines is provided by the arable land, the animals etc, which is why it is necessary that the volume of work required for production in the company and the

potential volume of work made by machines in suitable agro-technical time periods were equal.

This doctoral thesis deals with the methods of planning in a pig farming and crop growing company with regard to four considerations.

Firstly. Pig farming involves the need to dispose the produced manure. The main possibilities are the following:

- as slurry to fertilise fields (Põllumehe..., 2004);
- mixed with different materials to make compost (Fleming and MacAlpine, 1999; Wanga *et al.*, 2003)
- for producing biogas (Nielsen, 2002; Tänavsuu, 2007).

This thesis handles the use of manure for fertilising fields and that is why arable land (either owned or rented) is needed (Sõnniku..., 2004). If the existence of arable land is necessary, also crop growing should be done.

Secondly. On a crop growing company the workload of machines and employees is seasonal. In pig farming, however, the workload is mostly constant throughout the year. This is why it is reasonable to join these two production areas to even out production in these two areas. In a pig farming and crop growing company the working time is divided between those two production areas, securing year-round work for the employees and presumably also higher income.

Thirdly. A pig farming and crop growing company can reduce the expenses on made on purchased feed on account of grain produced in its crop growing line. As a confirmation of this fact, AS Ekseko, the large pig farming company, also grows crops (13. maarahva..., 2005).

Fourthly. By evaluation of the sustainable pig production is reasonable to concern both branches together pig farming and crop growing as it possible (Stern *et al.*, 2005).

If the company has both the pig farming and crop growing line, it is natural to determine the crop rotation so that it would satisfy as well as possible the needs of pig farming and that amount of feed components, which is too low or non-existent in the feed produced on the company and which need to be purchased, would be the lowest possible. For instance, if pork is produced, it would be sufficient if the crop rotation consisted

of grain cultures. If other cultures are grown, it may be necessary to procure more and expensive machines. This is why the size of the arable area and the growing areas of the corresponding cultures and the applied production technologies should ensure full workload for the machinery procured for crop growing works. Also the number of pigs and the chosen pig farming technology should load the pig farming machines and equipment. Both production areas together should guarantee the load of the employees on the company.

1. REVIEW OF THE LITERATURE

1.1. Pig farming technology and environmental impacts

1.1.1. Pig farming technology

In pig farming two types of operation are differentiated – **fatted pig farming** and **breeding pig farming**, therefore production may be operated in three ways:

- 1) piglets are purchased, i.e. partial production cycle;
- 2) piglets are kept in the same company, i.e. full production cycle;
- 3) company that kept only sows and produces piglets.

In case of full production cycle free and gestation sows are kept together with boars in the same pigsty and at least a week before planned farrow sows are taken to farrow pigsty where they farrow and stay until weaning of piglets. Weaned piglets are taken to weaning house where they weigh about 30 kg. Further on the young pigs are placed to fattening pigsty where they stay until marketing. They are kept in the fattening pigsty about as long as they stay in farrow pigsty and weaning house altogether. Therefore, to accommodate the next phase there must be another fattening pigsty (Lember *et al.*, 1999).

In fatted pig farming the fattening period can be divided differently (Lember *et al.*, 1999):

- 1) division into three periods (3-phase pig farming), i.e. weanlings (10...20 kg), young pigs (20...60 kg) and fatted pigs (over 60 kg);
- 2) division into two periods (2-phase pig farming), i.e. weanlings (10...30 kg) and fatted pigs (over 30 kg).

In case of 2-phase pig farming the piglets are taken from farrow pigsty to fattening pigsty when they are 90 days old, there is no weaning house for weanlings.

The farming types (Lember *et al.*, 1999) for different pig groups are the following:

- 1) weanlings are kept in a group pen, an average number of fatted pigs may reach until 20;
- 2) weanlings are also kept in a group pen, 10 fatted pigs on average in a pen;

- 3) free and gestation sows are kept mainly in group pens, 4...10 sows in a pen. Free and gestation sows are also kept in individual pens;
- 4) lactating sows are kept in individual pens of farrow pigsty both in a box and free. In order to avoid piglets to get crushed by sows barriers are used in free pens;
- 5) breeding boars are commonly kept in individual pens, young boars may be kept in group pens (2...4 boars in a pen).

From the feeding point of view pigs are divided into different groups according to feeding schemes. For example, according to Vitamex feeding scheme fatted pigs are divided as follows, whereby every period has different feed additives:

- 1) suckling pigs (from birth until weaning);
- 2) weanlings (10...20 kg);
- 3) young pigs (20...40 kg);
- 4) young pigs (40...60 kg);
- 5) fatted pigs (over 60 kg).

Companies Anu Ait and Feedline feeding schemes use the same additive for young pigs and fatted pigs, but its content in feed mixture varies. There are special feed additives for gestation and lactating sows.

Pig farming technologies differentiate the following bedding types:

- 1) keeping without bedding;
- 2) keeping with bedding;
- 3) keeping on deep litter.

With respect to this, pig pens can be classified according to bedding and litter location as follows (Farmide mehhaniseerimine, 1987; Brent, G., 1991):

- 1) simple pen;
- 2) pen with litter area;
- 3) pen with partial slotted floor;
- 4) slotted floor;
- 5) pen with litter alley, or Danish pen;
- 6) one litter alley for two pens, or Swedish pen;
- 7) individual keeping pens with cages or stalls.

Technological solutions vary in the construction of pen floor (pens with slotted floor, partially slotted floor and solid floors), as well as in bedding

types. Slotted floor material can be concrete, steel or plastic. The cross section of the slot may be of different shape (triangular, trapeze etc). The construction of manure removal system depends on the construction of the floor. Pig farms may have manure cellars, different channel systems as well as scraper devices.

In EU countries pigs are kept mainly on partial slotted floors or slotted floors and slurry systems are used. Due to environmental requirements the usage of slotted floor is decreasing while partial slotted floor is increasing in Holland, Denmark and Switzerland. In Great Britain, Norway and several Eastern European countries a remarkable part is made up of solid manure (Manure Management, 2003).

1.1.2. Environmental restrictions on pig farming and slurry application

On the bases of environmental impacts in agricultural production the following pollution subdivisions can be distinguished (Lember *et al.*, 1999):

- a) point pollutants (animal farming, manure storages etc);
- b) diffuse pollution (e.g. pollution from manure distribution in the fields).

Point pollution of agricultural production is determined mainly by production technology, whereas diffuse pollution is determined by concentration of animals. In the foundation of a new pig farm building it is essential to consider thoroughly the planning, land usage, sewage and waste water treatment. Production buildings are not allowed to be constructed straight on the shore of a water body. The allowed distances are stipulated in the relevant laws.

Emissions into soil and ground water due to manure application can be avoided by balancing it with soil requirements. Application rate is a ratio of nutrients in the manure and the amount of manure concentration, to the manure distribution area. Nutrient absorption by soil and plants is a complex of factors including soil, climate conditions, season and plant species. In order to decrease excessive application of nutrients it is not advisable to use more manure than the soil and harvest circumstances allow. The balance of nutrients equals to the difference between the input and output of all nutrients directed into soil. For this calculation a universal model has been worked out which shows applied nutrients

(N and P) and gives an overview about the efficiency of nutrients applied in agriculture. The calculation covers input of mineral fertilizer, manure and other organic waste, nitrogen precipitation from atmosphere, biological determination of nitrogen and crops application.

In accordance with “Water Act” (Veeseadus, 1994) it is allowed to give with manure up to 170 kg nitrogen on average per 1 hectare cultivated land a year. The amounts of mineral nitrogen exceeding 100 kg per hectare must be given in portions. It is allowed to keep on average as many animals per ha as equals to 2 animal units. One animal unit equals to an agricultural animal excreting 70 kg general nitrogen in the form of manure and liquid manure. Organic and mineral fertilizers are not allowed to be distributed during the period from December 1 until March 31 and other time when ground is covered with snow, frozen or periodically flooded or waterlogged soil. In nitrate sensitive and unprotected groundwater areas with glaze up to 2 metres and karst areas additional restrictions could be established. In accordance with “Protection Regulation for Pandivere and Adavere-Põltsamaa Nitrate Sensitive Area” (Pandivere..., 2003) it is not allowed:

- 1) to give more than 120 kg nitrogen with mineral fertilizers per hectare, and as an one-time amount of nitrogen not over 80 kg per hectare a year for winter grains and pastures with multiple cutting;
- 2) to keep animals exceeding the number of 1 animal unit per hectare of cultivated land ;
- 3) to use waste water sediment.

In addition to that several regulations and acts have to be followed related to production capacity of an company. A review of relevant legislation is given in table 1 (Sõnniku..., 2004).

Table 1. Environmental permits and other requirements depending on the production capacity of a company

Tabel 1. Seakasvatuse keskkonnaloalad ja muud nõuded sõltuvalt ettevõtte tootmis-mahust

Requirement Nõue	Number of fatted pigs (with body weight over 30 kg) Nuumsigade arv (arvest. kaaluga üle 30 kg)	Number of sows with piglets or boars Emiste arv koos põrsastega või kultide arv
Manure storage is obligatory Sõnnikuhoidla on kohustuslik	101	31
Distribution plan of liquid manure Vedelsõnniku laotamisplaan	3 001	910
Waste permit for waste production Jäätmeluba jäätmete tekitamiseks	1 000	300
Complex permit Kompleksluba	2 000	750
High-risk environmental activities, environmental auditing necessary Kõrgendatud keskkonnariskiga tegevus, vajalik keskkonnauditeerimine	3 000	900
Activities of remarkable environmental impact, environmental impact assessment necessary Olulise keskkonnamõjuga tegevus, vajalik keskkonnamõju hindamine	3 000	900
Water special use permit Vee erikasutusluba	Water is obtained from surface water body over 30 m ³ per 24 hours or ground water over 5 m ³ per 24 hours. Waste water or other pollutants are directed into debouchment of the river / Võetakse vett pinnaveekogust enam kui 30 m ³ /ööpäevas või põhjavett enam kui 5 m ³ /ööpäevas. Juhitakse heitvett ja teisi saastavaid aineid suublasse.	

Slurry should be distributed in spring before spring ploughing or on already sprouted grain and growing graminaceous plants. In autumn manure should be spread late towards winter, but still before the ground is frozen, otherwise nutrients will move straight into surface or ground water after snow melts or weather gets warmer. Ammonia loss can be diminished by distribution of slurry as fertilizer on growing plants. Slurry may be spread on vegetation with height up to 20 cm. For distribution of slurry it is recommended to operate with devices that perform surface-banding techniques and this way decrease the evaporation of gases and spreading the unpleasant odour (Sõnniku..., 2004).

Application of liquid manure during vegetation has been researched by ERIA (Estonian Research Institute of Agriculture) scientists Gennadi Bogun and Peeter Viil. The initiative to carry out the experiments was taken by the company OÜ Linnamäe Peekon. Fertilizers should be placed directly on the soil surface in a form of concentrated bands or shallow ridges between the crop rows. In this case a trailing hose system or injection system should be used. The results showed that little damage and smear was done to plants. The amount of extra crop depended on soils and certain plant remaining between 16...47 per cent (Põllumehe..., 2004; Bogun, G., Viil, P., 2005).

1.1.3. Modern technology in pig farming

Technological operations in pig farming are constantly improving and therefore up-to-date technology is changing in time. According to “IPPC Directive 96/61/EÜ (Nõukogu..., 1998) and relevant Estonian law “Integrated Pollution Prevention and Control Act” (Saastuse..., 2001) all companies trading with intensive pig farming (if there are over 2 000 pigs with body weight over 30 kg or over 750 sows) will have to start full operation of best available techniques on 31 October 2007. Best available techniques shall comply with the most effective and advanced stage in the development of activities and their methods of operation. Best available techniques shall provide in principle the basis for emission limit values designed to prevent and, where that is not possible, to reduce emissions and the impact on the environment as a whole.

Within the meaning of “best available techniques” (Saastuse..., 2004): *techniques* – includes both the technology used and the way in which the installation is designed, built, maintained, operated, terminated and closed;

available techniques – means up-to-date techniques (whether or not used or produced in Estonia) reasonably accessible to the operator and the implementation of which is economically and technically viable, taking into consideration the costs and advantages, and which ensures the best compliance with the environmental requirements;

best – means most effective in achieving a high general level of protection of the environment as a whole.

BAT techniques application in pig farming requires the implementation of the following activities (Sissejuhatus..., 2004; Parim..., 2004):

- 1) use low protein pig feed which reduces the emission of ammonia and other compounds with unpleasant smell. It is recommended to use liquid or granulated food if possible as this is remarkably diminishing the emission of dust;
- 2) use full solid floors with curved or inclined surface, or gutters with slanting side walls, and slurry tanks in the front part of pens;
- 3) not to use full slotted floors and reduce the surface area of slotted floors;
- 4) construct automatic drinking water systems which exclude the formation of bad drinking water;
- 5) slurry shall be removed from slurry channels depending on techniques as often as possible which rules out anaerobic processes in standing slurry in the slurry channels;
- 6) when keeping animals the capacity of slurry storage tanks shall accommodate minimum 10 months' slurry;
- 7) in order to reduce bad odour natural barriers like hedges, trees or combination of high and low vegetation shall be used. Wooden, brick and concrete walls are constructed on the premises of slurry storage tanks. These walls are to block the wind and the opening of tank shall be downwind of common wind direction of the area;
- 8) aeration due to slurry storage in the tanks can be reduced by using tanks and ponds with smaller diameter or surface;
- 9) emission from slurry storage tanks can be reduced by lowering the filling level which lessens the surface exposed to winds;
- 10) it is essential to lower the evaporation from the surface of slurry in the tanks. Minimal evaporation can be achieved by mixing slurry as little as possible and only to get a homogeneous mass just before opening the storage tank for emptying;
- 11) agitating the slurry and directing it through circulation pump

should be preferably carried out as close to the base of tanks as possible;

- 12) covers should be used in order to reduce the emissions of ammonia and odour compounds from slurry storage tanks. It must be observed that the temperature of slurry will not raise to the level of starting the biochemical reactions that bring along unpleasant odour and lower the quality of slurry;
- 13) in the distribution of slurry to use subsurface deposition applicators or surface-banding techniques;
- 14) if possible, to perform harrowing or in-ploughing after distribution of slurry;
- 15) select carefully the suitable area, technology and time for distribution of slurry. New technological solutions should be introduced first in these fields that are located in the close vicinity of densely populated areas;
- 16) not to perform slurry distribution near densely populated areas during longer hot periods in summer. As in hot weather the slurry spread on the ground will evaporate fast it may cause high concentration of pollutants and exceeding the maximum limits of pollution level in the region.

1.2. Pig farming and crop growing company

It is quite complicated to identify the exact number of pig farming companies which also trade in crop growing. The problem is that the links between pig farming and crop growing can be very diverse.

Pig farming company grows crops and uses its grain in making pig feed mixtures. In most cases there is less grain than needed and some more is purchased to cover the needs. For example, in the company OÜ Linnamäe Peekon 23% is self-grown grain and 77% more is purchased, in AS Ekseko 37% concentrated feed is produced in the company and 63% is bought from concentrated feed factory (13. maarahva..., 2005), in Veskimetsa farm 40% is self-grown grain and 60% is purchased grain (Veskimetsa...).

Pig farming company grows crops but does not use its grain in pig feeding. Agricultural products are sold to concentrated feed factories and concentrated feed is bought for pigs.

On the bases of one-time large soviet companies several private limited companies or public limited companies have been founded, one company trades with pig farming and another with agriculture. Pig farming company purchases grain for pig feed from agricultural company and spreads its manure in the fields of agricultural company.

Estonian Chamber of Agriculture and Commerce members included 22 companies which have recorded their trade field as pig farming. Out of these 22 companies 15 have also recorded crop growing as their field of trading (Eesti...).

In Farm Accountancy Data Network (FADN) pig farming is represented in two production lines. In Estonia the corresponding production results in 2005 were the following (Põllumajandustootjate..., 2006):

- 1) granivores (type G) – the population of agricultural holdings included 71 holdings of granivores type of farming (1.0% of the population of agricultural holdings) and 11 sample agricultural holdings. Holdings of granivores type of farming had 37.4 ha of utilized agricultural area of which 14.3% was rented utilized agricultural area. Over half (64.1%) of the utilized agricultural area was under forage crops, 14.2% was under cereals. Crop production accounted for 0.4%, grazing livestock for 77.0%, other production for 21.1% and subsidies for 1.5% of total output;
- 2) mixed (type H) – agricultural holdings of mixed type of farming include holdings specialized both in field crops production and grazing livestock production, therefore, it is difficult to define which type prevails. The population of agricultural holdings included 1,791 holdings of mixed type of farming (26.3% of the population of agricultural holdings) and 80 sample agricultural holdings. In 2005 holdings of mixed type of farming had 102.7 ha of utilized agricultural area of which 65.5% was rented utilized agricultural area. Approximately half (52.2%) of the utilized agricultural area was under forage crops, 38.9% was under cereals. Agricultural holdings of mixed type of farming had 38.3 animal units on average. Breakdown of animal units by type of livestock was as follows: dairy cows 11.0, other cattle 12.6, pigs 12.8 and other livestock 2.0 animal units.

1.3. Computer software used in pig farming

Quite a number of descriptions of pig farming-related computer software can be found on the Internet. Generally, on the basis of the 45 program descriptions collected from the Internet (Agricultural..., 1998), the computer software can be divided into 4 groups:

- 1) computer software for collecting and preserving various pig farming-related data in a pig farming company and for comparing the production data of different years (PORKPLANNER, SWINESOFT, SWINE HERD MANAGEMENT, etc);
- 2) computer software for calculations of feed rations APOLLO, WINPAS, NEWSWINE, etc);
- 3) computer software related with pig breeding (SIGAPIG, AGRIS-SCHWEINEZUCHT, etc);
- 4) computer software for collecting the pig farming data in the company, forwarding the data to the control institution, forecasting events on the basis of data and compiling work schedules (AGRIS-SAUENPLANER, DB-PLANER, etc).

Some of the computer programs are of the kind that enable several of the above-mentioned activities (SWINE BREEDING AND FARROWING SCHEDULE – program is meant for planning both the breeding of sows and farrowing in stages). Some of the programs determining the contents of feed rations enable the immediate realisation of the prepared ration in feeding machines.

Many computer programs work in packages. For example, the software package KW-Computer (KW-Agrarcomputer) of Klöpffer & Wiege GmbH includes many different modules. The modules KW-Ackerdat, KW-Bodenbuch and KW-Fruchtdat deal with crop growing. In cattle farming KW-Superkuh and KW-Bullenmast are used. For pig farming companies there are KW-Supersau and KW-Multimast. With the help of KW-QUISS the quality of pork is tested. For poultry farming there are the modules KW-Geflügelmast and KW-Ei & Huhn. The modules are interlinked by KW-VARIO. KW-Rational and KW-Optimahl enable to reduce the expenses by means of optimisation of feed rations. KW-Finanz Plus and KW-ABS are accounting programs. For salary accounting there is KW-Agrarlohn and for receiving meteorological information, KW-Meteodat.

1.4. Computer software in Estonian pig farming companies

In Estonia the personal computer program db-Planer (db-Planer, 2000) is used for collecting basic performance monitoring data of pigs and there are about 50 users of this program. This program was bought within the PHARE project „Improvement of pig production in Estonia” and was also translated into Estonian. Working with the program makes it possible to gain extensive information about the economic results of the company at any given moment. If db-Planer is used within the company only and the collected data is not forwarded to the Performance Monitoring Centre, the evaluation of pigs takes place within the cattle. In such case the genetic evaluation of pigs does not take place and the production results of the cattle cannot be compared to the averages of other company's. The given program is outdated, however, and there are failures in its operation in Windows-based computers. This is why the Performance Monitoring Centre started working out a new program for collecting performance control data in 2002. The program is called „Possu” and in 2005 this program should replace db-Planer (Possu vahetab välja db-Planeri, 2005). There are also other sow herd management programs in use, for instance PigChamp and WinPig.

Feeding is generally done on the basis of the feeding schemes provided by companies who supply feed additives (Vitamex, FeedLine, Anu Ait etc). These companies also have the computer software for calculating the composition of the feed ration. Some pig farming companies use their own computer software for determining the composition of feed ration. For example, the feed ration program working in MS Excel developed by Andres Hellenurme and the WinOpti program by the Danish firm Agrosoft are used.

Some pig farming companies are also using the complex pig farming software of the consultation and information system „TALUTARK” (FARMWISE), created in Estonian Farmers' Federation by the author of this thesis. General scheme of the pig farming planning is presented in appendix A. Block diagram of the complex pig farming planning program is presented in appendix B and example program code is presented in appendix D. Some program windows is presented in appendix C.

1.5. Possibility for modelling in agriculture

1.5.1. Modelling of crop growing

The simulation model for field machinery operations is developed by deToro (deToro, 2004). A discrete event simulation technique enabling timeliness costs and their annual variability to be estimated in a long-term assessment are used. High daily effective field capacity machinery sets not only showed lower timeliness costs but also lower annual variation. In daily effective field capacity timeliness costs were more affected by a stepwise reduction than a stepwise increase of the same magnitude. The insufficiency of this model is lacking a methodology to determine available field works.

Farm planning models are often based on linear programming. Due to uncertainties related weather, the constraints for this type of model may involve random variables, either as coefficients or as right-hand sides. Usually, these constraints are replaced by deterministic constraints that are meant to approximate the constraints involving the random variables. The formulation of these deterministic constraints is often based on rules of thumb that are left fixed even when technology changes. Discrete stochastic programming and dynamic programming are the two most common rigorous solution techniques for this purpose (Etyang *et al.*, 1998).

Farm planning models has been dealt with in the article (Gunnarsson and Hansson, 2005). Field machinery for organic crop production differs to some extent from the machinery used for conventional crop production. An optimal crop and machinery system is important for organic farming to be economically competitive. For optimisation of farm machinery systems, a method based on linear programming was used. The optimal size of the seed drill and combine harvester increased when the arable farm in this study converted to organic production. This model asserts the facts of the lower yields and the higher product prices in organic farming than conventional.

Modelling agricultural production systems using mathematical programming are described in the doctoral work (Ekman, 2002). Mathematical programming can be used to maximise profit given constraints on available capital and labour. Mathematical programming models developed by agricultural economists can be divided into two main categories: farm models and sector models. Farm models focus on the optimal organisa-

tion of farm production, given limited resources such as land and labour. Agricultural sector models are used to analyse producers' reactions to external changes, at the aggregate level.

The crop yields substantially depend upon the weather conditions during the vegetation period. The composed methods and computer software application (Asi *et al.*, 1999) of profit and production risk prognostication enable to decide whether the company's soil fertility is sufficient for profitable crop growing and what the arable land acreage has to be to guarantee the minimum machinery costs and maximum profitability.

These literary sources give an overview of modelling and used models of the crop growing company, but they do not concern pig farming. Therefore, they are not dealt with in detail.

1.5.2. Modelling of pig farming

The modelling of pig farming and the used models are thoroughly described in the collection of articles (Moughan *et al.*, 1995), which emphasises the importance of optimum feeding. Financial gross margins for various combinations of daily lysine and energy intakes, are generated using a simulation model and the economically optimal feeding regimen is identified. This models is associated with pig breeding and feeding, but not dealt with various technological solution. The impact of different feeding strategies on the increase of profit has been dealt with in the article (Alexander, 2000). In this article also the respective optimization algorithms are published. Linear programming to determine least cost diets is used as a component of a larger optimization routine, by which the challenge of diet formulation to maximize gross return per pig place per year can be answered. A pig growth model and a combination of optimisation techniques allow the composition and quantity of feed to be optimised so as to maximise the return to the farmer. This model optimizes only feed ratio. A nutritional model in the finishing pigs is handled in the article (Lizardo *et al.*, 2002). A dynamic model was developed to study the effects of diet composition on pig meat quality. The model is composed of two modules: a basic nutritional model describing growth in pigs and a specific model for lipid growth and fatty acid composition. Application area of this model is even more restricted than in case of the previous one – it describes only the influence of nutrient proportions on pigs' weight gain.

For modelling pig farming also an object-oriented simulation model has been developed, which is described in the article (Jørgensen and Kristensen, 1995). The simulation model is programmed in Borland Pascal. The herd is described consisting of the animal, and its biological states, as well as the housing system, the confinement. The system, a pig herd, is not stable, and rely on the managers continuous correction of the production flow. The objects in the model communicate by a message-passing scheme that also handles the dynamic updating of the model. The modelling of the physiological state of the animal relies, on detailed models and a number of parameters. The model is expected to be of great value in the development phase of new information systems to the pig producers, and will allow an assessment of the value of the systems before the development reaches the phase with development of user interface. Stochastic model described in the article explains the moving of production in the farm excluding technological factors.

Mathematical modelling of pig farming is also possible on the Internet (Thyssen *et al.* 2003). A dynamic simulation model of pig growth is developed at the Danish Institute of Agricultural Sciences. Based on the simulated rates of nutrient transactions in the pigs, the model is able to predict growth rate and the composition of growth from weaning to maturity. The input data for the model are the used feed components, the desired pig growth intensity, the age of pigs at the beginning of the model and the final weight of fattening. The output data of the model are the following:

- 1) production data (length of fattening period in days, daily weight growth, feed need during the period, average feed need per day etc);
- 2) economic and environmental indicators (dead weight, total release of nitrogen, percentage of lean meat, cost of feed, income from the sales of pigs etc).

The required inputs to the model are provided by the user and the results of multiple simulation runs can be viewed and compared in tables and graphs. However, the model is one-sided describing only what happens in the farm.

Investigating and developing methods for monitoring the production of weaner and finishers, based on time related observations are observed in the doctoral work (Madsen, 2001). There was used a dynamic linear model of the monitoring drinking behaviour of young pigs. The model

allows prognosticating the daily gain and inspecting the pig welfare. To avoid random errors in the model used Kalman filter. On the model based pig farming watching software "Farm Watch", that is in large usage of farmers.

The so-called SALSA models (Systems Analysis for Sustainable Agriculture) were developed in doctoral thesis (Elmqvist, 2005). It is a flexible tool for different kinds of studies with the focus on evaluation of alternative production scenarios. This model helps to investigate impact of crude protein ingredients in feed stuff to the environment and the energy demand to product unit, but still involves very narrow area. One interesting model focused on describing the balance of nitrogen has been given in the article (Yue Zeng *et al.*, 2006). This model observes a group of pig farms where a farm is like a black box and observation objects are: feed, animal, manure and soil. A determining parameter in this model is the number of animals and their density.

Often the modelling of pig farming takes into consideration the environmental impacts. The common aim of doctoral thesis (Campos Labbé, 2003) relates to farmers decisions on specific technologies in relation to animal welfare and environmental regulations. The aim of this thesis is analysed in four different articles, which can be divided in two parts. The first part concerning the assessment of economic values of technologies in production. Technologies include building design, feeding systems and managerial practices. The second part of this thesis concerning the economic implications of technology use in relation to production externalities. Models are based on microeconomic methodology concerning production, optimal control theory and the statement of maximisation problems and revealed preferences. The production is modelled as a simultaneous equation system estimated using the three-stage-least-squares method. Changes in profit are evaluated considering whether a specific technology is in use or not. The use of ventilation system, evacuation gas, gross-trough box and wet feed increase total weight and reduce feed consumption, having positive effect on profit. The research shows that the selection of an appropriate technology set tends to reduce externalities originating from manure production and in many cases improve animal welfare.

In the article (Lansink and Reinhard, 2004) are described Data Envelopment Analysis (DEA) to investigate the possibilities for improving the technical, economic and environmental performance of Dutch pig farms

relative to currently applied technologies and new technologies that are currently available but not yet applied. DEA is based on linear programming models. Data on specialised pig fattening farms are obtained from FADN (Farm Accountancy Data Network). The model is concentrated on the comparison of different technologies and the efficiency evaluation of new technologies before application.

1.5.3. Modelling a pig farming and crop growing company

In organic pig farming the two production lines – pig farming and crop growing are integral parts of production cycle in a company. Crop growing produces feed for pigs which pig farming turns into organic fertilizer for fields increasing soil fertility and improving soil structure (Mahepõlumajanduslik..., 2005). Main emphasis is laid on welfare of pigs, environment-friendly production and pig farming is closely connected with crop growing. This type of pig farming is scientifically researched in several places throughout Europe. In Estonia this type of company is represented by Jalukse Farmer OÜ, a daughter company of OÜ Linnamäe Peekon, with 40 fattening places. The building has 16 rooms with verandah, 25 fatlings in each room. There are partial slotted floors in pens, slurry is removed by vacuum system and emptied once a week. Feeding with automatic dry feeder, with 2 nipple drinkers and a straw manger.

The doctoral thesis (Strid Eriksson, 2004) deals with the model of environmentally friendly and sustainable pig farming. Swedish authors (Stern *et al.*, 2005) observed pig farming and crop growing together from the following three point of view: animal welfare and natural behaviour of animals, low impact on the environment and efficient use of natural resources including energy and product quality and safety. The environmental impact of the scenarios was analysed with Life Cycle Assessment, using the same data sheet as in the economic evaluation. The production cost per kg meat produced was highest for the animal welfare scenario, whereas there were similar costs for the environmental-friendly scenario and the product quality scenario. Similar research in Germany is described in the article (Jungbluth *et al.*, 2006). The following four pig farming technologies have been compared mutually:

- 1) conventional stable with slatted floor and slot reduced lying area;
- 2) sloped floor stable with minimum straw litter;
- 3) open front stable with sleeping boxes;
- 4) exercise stable with two area pen and straw litter.

The mean labor time input for the systems was well differentiated. The invest costs were the lowest with the system open front stable.

Modelling an organic company dealing with pig farming and crop growing in Austria is introduced in the article (Omelko und Schneeberger, 2005). This research investigates the profitability of organic pig farming using a linear planning model. The model results indicate that pig husbandry has a significant effect on cropping activities.

How to find the optimum size of a pig farming company in Germany is handled in the article (Kleversaat und Nellinger, 1997). The aim was to find the optimal size for pig fattening farms under consideration of environmental regulations, in conjunction with semi-liquid manure application consistent with the law. The article also presents the following options for determining the optimum size of the company:

- 1) traditional approach – the size of the company both as a single company and from the aspect of national economy is optimum if long-term average expenses for a unit of production are minimum;
- 2) based on agricultural household theory – the optimum size of agricultural household is achieved, when the contribution of the agricultural household for maximising the total income ensuring the agricultural profit, is optimum.

The same article also views the optimum size of an agricultural company and the environmental impact. For example, the slurry produced in pig farming should be incorporated into the soil, but a fixed amount of fertilisers is allowed for a unit of the field per year. This is why a certain area of field land is required as well as expenses on transportation. Various scenarios were created involving differences in the permitted amounts of nutrient introduced per hectare and the different feeding strategies employed to reduce nutrient excretion per pig. Optimal size was determined using linear optimization with a farm model which reflected livestock rearing and arable farming with equal differentiation. The measure of farm size was based on the number of feeding spaces available per farm. It is not possible to determine an exact optimal size of a company as it should be always considered that optimal means best, most suitable or beneficial solution from a certain viewpoint. It must be made clear what the optimizing criterion was and which restrictions were set in order to work out the optimal model.

2. AIM OF THE STUDY

The environmental regulations in Austria, Sweden and German are somewhat different from the ones valid in Estonia (Sõnniku..., 2004). That is why the modelling of a company dealing with both crop growing and pig farming (preparation, analysis and application of the model) is handled in this thesis on the basis of environmental requirements enforced in Estonia.

The original task was to plan the values of the main parameters of a pig farming and crop growing company under the balanced conditions, i.e.:

- the total time limit of the employees is fully used for production work;
- there is so much arable land that it is possible to produce the needed quantity of feed and to dispose of the produced manure;
- there are so many pigs that all the produced feed is fed to own pigs.

In reality the achievement of the balanced conditions is complicated due to several circumstances (crop yield is changeable depending on the weather etc). This is why also the following situations are under observation:

- use of partially or fully purchased feeds and disposal of the excess manure produced in the company outside the company, on the basis of contracts;
- use of extra labour force for crop growing and/or pig farming works.

The aim of the study was to develop methods for finding optimum values for parameters characterising different pig farming technologies (time consumption of human work, need for feed, necessary area of arable land etc) in a company involved in pig farming and crop growing.

Consequently, the tasks were:

- 1) to compile the methods and the respective computer software application for determining the working time consumption in the case of different pig farming technologies;
- 2) to compile the methods and the respective computer software application, which would enable to determine the necessary area of arable land both for growing feed cultures and disposal of the produced manure;
- 3) to compile the methods and the respective computer software application for finding the number of pig places depending on the duration of working day during the high season, considering the restriction on the use of manure.

The novelty of this research lies in the creation of the methods and the respective computer software application, by means of which it is possible

to find the optimum size of a pig farming and crop growing company in the case of different crop yield levels and pig farming technologies, depending on the length of working day during the high season of the works, and also considering the restriction established on the use of manure proceeding from the environmental requirements enforced in Estonia.

3. MATERIAL AND METHODS

3.1. Forecasting the working time consumption

Working time is divided between working on machinery used for crop growing works and pig farming machinery for pig farming. Total consumption of working time per day is expressed as a sum

$$t_l = t_y + t_s \quad , \quad (1)$$

where t_l – total consumption of working time, hours per day;
 t_y – working time in crop growing, hours per day;
 t_s – working time in pig farming works, hours per day.

Consumption of working time for keeping pigs (tending works) can be divided into two: daily works (feeding, removal of manure, etc) and special works that are done at certain times (placing pigs in pens, replacement if needed, disinfections of pens etc). The volume of daily works is largely dependent on the type and technology of pig farming and also on the type and technology of feeding. Working time spent on animal husbandry is determined usually by group of animals (e.g. in pig farming for ten pig places). In literary sources (KTBL, 1992; KTBL, 1996; KTBL, 2000; Maatalouden työnormit, 1988) the values of time consumption of pig tending works is shown in tables, according to the technology of works and the size of herd, by ten pigs. For forecasting the working time consumption in the case of intermediate numbers of pig places a regression equation is made, the values of coefficients for some pig tending works are presented as a table in the article (table 1; Möller *et al.*, 1997). In Estonia, too, working time consumption in pig farming works has been measured (Reppo and Sada, 2000; Sada, 2003; Sada and Reppo, 2006) and the received results can be used for forecasting the working time consumption. For forecasting the working time consumption for the whole pig herd (Vettik, 2000) for different pig farming technologies the regression equation is used in the form

$$t_s = an^2 + bn + c \quad , \quad (2)$$

where t_s – working time in pig farming works, hours per day;
 n – number of pig places;
 a, b, c – regression coefficients.

In the master's thesis of the author (Vettik, 2000) different forms of regression equations have been compared. It was found out that the parabolic regression equation gave better results for forecasting the working time consumption for the whole pig herd. The regression coefficients of the equation for determining working time consumption (formula 2), the standard errors of coefficients, correlation indices and determination factors were found with the help of a computer program. Coefficient values and statistic data in the case of five pig farming technologies of quite different labour intensity have been presented as a table 3.1.

Table 3.1. Coefficients and statistics for formula 2

Tabel 3.1. Valemi 2 regressioonikordajad ja statistikud

No. Nr.	Regression coefficients Regressioonikordajad			Standard error Kordaja standardviga			R^2
	a	b	c	m_a	m_b	m_c	
1.	$-44.82 \cdot 10^{-6}$	0.3256	17.03	$4.6 \cdot 10^{-6}$	0.00488	1.05386	0.99985
2.	$-47.82 \cdot 10^{-6}$	0.3723	24.50	$4.9 \cdot 10^{-6}$	0.00517	1.11682	0.99987
3.	$-11.09 \cdot 10^{-5}$	0.6447	21.38	$1.5 \cdot 10^{-5}$	0.00837	0.91996	0.99997
4.	$13.29 \cdot 10^{-5}$	0.3093	26.44	$1.6 \cdot 10^{-5}$	0.01021	1.32515	0.99996
5.	$63.69 \cdot 10^{-5}$	0.4645	44.77	$2.2 \cdot 10^{-4}$	0.06838	4.55925	0.99942

The following pig farming technologies have been compared mutually (the figures in brackets show the number of pigs in the pigsty, about which data were found in literary sources):

- 1) keeping without bedding on partial slotted floor, fodder is distributed by stationary cable-washer conveyor, (50...1000);
- 2) keeping with bedding, manure is removed by conveyor, fodder is distributed by stationary cable-washer conveyor, (50...1000);
- 3) keeping with bedding, manure is removed by conveyor, feeding with a bucket from a wheelbarrow, (50...500);
- 4) keeping without bedding on partial slotted floor, liquid feed is distributed by pipeline feeding system (120...500);
- 5) keeping with bedding, manure is removed by conveyor, liquid feed is distributed with a bucket from a wheelbarrow, (60...250).

For technologies 1 to 3 the self-feeding system is used (water is added to the troughs and then dry fodder is distributed) (Põllumajandusloomade söötmise ABC, 1984). For technologies 4 and 5 liquid feeding is used. The

figure 3.1 has been made on the basis of the table 3.1. The figure shows the time consumption of company with different pig farming technologies, for 10 porkers per day, in the case different number of pig places.

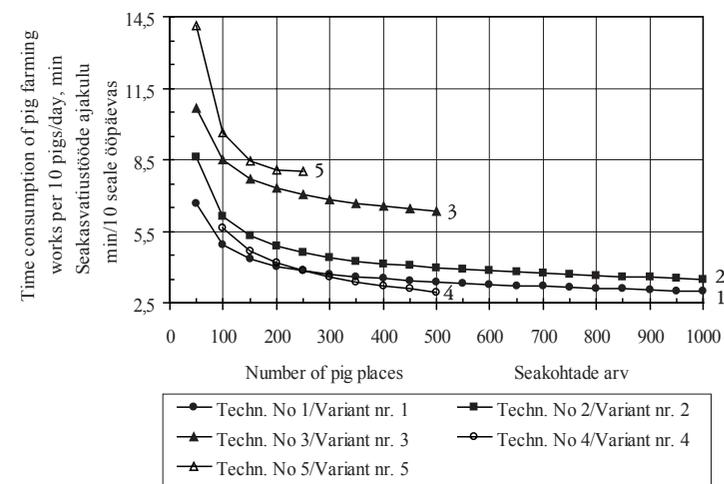


Figure 3.1. Time consumption of pig farming works per 10 pigs/day in dependence on number of pig places with different pig farming technologies

Joonis 3.1. Seakasvatustööde ajakulu 10 seale ööpäevas sigade erinevate pidamis- tehnoloogiate korral

The methods of forecasting the consumption of human labour in the case of different pig keeping and feeding technologies is applied in the complex pig farming program of the advisory and information system "TALUTARK" (FARMWISE) of Estonian Farmers' Federation. Program window with prognosticated consumption of human labour is presented in figure C1 [APPENDIX C].

For determining **working time consumption for crop growing works**, a method is used in which the working time consumption is determined for the primary unit of a crop rotation at the high period of the works (sowing or harvesting) in hours per day. The value of the base unit of rotation depends on the number of fields in rotation, i.e. for four-field rotation it is 4 hectares (4 fields /, the area of each is 1 hectare). Thereafter the load schedules for machines are made according to the technological cards of the cultures grown in different fields. After the load schedules are corrected, the consumption of human labour during the maximum load of works can be determined (Witney, 1998; deToro, 2004). For

forecasting the consumption of human working time per primary unit of crop rotation, depending on the yield of culture, the program for making machinery load schedules compiled by K. Tamm was used (Tamm, 1999). In case of four-field rotation the time consumption per base unit of rotation is 0.50...0.70 hours per day, depending on the crop yield. The relation t_a / l shows the consumption of human labour in hours per one hectare a day. The consumption of working time for the entire arable land can be found according to the following formula

$$t_y = U \frac{t_a}{l} , \quad (3)$$

where t_y – working time in crop growing, hours per day;
 U – arable land acreage, hectare;
 t_a – working hours during the peak seasons per rotation's elementary unit, hours per (hectare·day);
 l – number of fields in rotation.

Under the condition that the main pig feeds (grain) are produced on the company, the crop growing rotation is determined in the way that it would include as many as possible cultures suitable for pig feed. Because of that it is natural that the necessary area of arable land is determined proceeding from the feed need of the pigs (Stern *et al.*, 2005). In dependence on the chosen rotations, soil fertility and other production conditions, the fodder crops acreage are determined and, according the land cultivation technologies, labour costs for the feed production are calculated.

3.2. Forecasting the yearly feed need of pigs

Expenses on feeding take up to 70 per cent of production costs (Oll and Nigul, 1991). The economically optimal feeding and the impact of different feeding strategies on the increase of profit has been dealt with in the collection of articles (Moughan *et al.*, 1995) and in the article (Alexsander, 2000), which is why it is essential that feed rations were balanced and the cheapest possible. For that reason the methods of determining the composition of pig feed rations (Oll *et al.*, 1996) and the corresponding computer software application was developed. At first an application made in MS Excel environment was used (Asi *et al.*, 1998). Later a similar computer software application developed by the author was taken into use – this operates in the environment of Visual Fox Pro database program and forms a part of the complex pig farming program of the consultation

and information system „TALUTARK” (FARMWISE) of the Estonian Farmers' Federation (Vettik, 2000). Program window for composing feed rations is presented in figure C2 [APPENDIX C]. In the collection of articles (Moughan *et al.*, 1995) used simulation model enabled to find financial gross margins for various combinations of daily lysine and energy intakes. Developed computer software application for the complex pig farming program, tries to find such forage amounts that satisfy all the needs of the 20...30 feed factors while the price of ration remains at its minimum. This application helps to find the feed rations that satisfy the feed needs of the pigs and are the cheapest, as well as the feed need per day on different fattening weeks and per year. The yearly feed need of pigs in its turn determines the necessary volume of feed production (in the case where as many components of pig feed as possible are produced on the company) and consequently, also the workload of feed production machines. The described methods of forecasting feed need and the corresponding computer software application is more precisely described in article (Vettik *et al.*, 1999). Let be the consumption of fodder produced in company for fattening one pig e kg. The fattening period is less than one year and estimated by the use factor η of one pig place. Then the yearly fodder need e_1 , per one pig place equals

$$e_1 = e \eta . \quad (4)$$

The fodder crops acreage according to the feed need of pigs is expressed in

$$U_s = \frac{n e \eta}{h} , \quad (5)$$

where U_s – fodder crops acreage, hectare;
 n – number of pig places;
 e – feed consumption of a one pig per year from the feeds produced on the company, kg;
 η – factor of performance of pig places;
 h – average yield of crops, kg per hectare.

The actual sowing area (U) is larger, because due to cropping, cultures unsuitable for pig feed are grown on part of the area. How much the growing area of cultures suitable for feed need makes up of the total area

of arable land, is shown by factor ($\delta = U_s/U$). Making the necessary replacements in formula 3, the working time consumption for the total arable land can be found in

$$t_y = \frac{U_s t_a}{\delta l} = \frac{n e \eta t_a}{h \delta l} . \quad (6)$$

When finding the total working time consumption, it must be considered that the working time consumption of pig farming works, found by the regression equation (formula 2), is given in minutes. To find the working time consumption in hours, the division by 60 must be added. Consequently, the total working time consumption per day, with the necessary replacements made in formula 1, is expressed in

$$t_l = \frac{n e \eta t_a}{h \delta l} + \frac{a n^2 + b n + c}{60} . \quad (7)$$

Choosing the length of working day during the high season of works (t_l), the number of pig places can be found by solving the following square equation

$$\frac{a}{60} n^2 + \left(\frac{\eta e t_a}{h \delta l} + \frac{b}{60} \right) n + \frac{c}{60} - t_l = 0 . \quad (8)$$

The number of pigs is restricted by the allowed amount of produced manure per unit of arable land. In accordance with “Water Act” (Veeseadus, 1994) and “Protection Regulation for Pandivere and Adavere-Põltsamaa Nitrate Sensitive Area” (Pandivere..., 2003) it is permitted to keep 1...2 animal units per hectare of arable land, depending on the nature of soil, whereas each animal unit equals to three sows with piglets, three boars or ten at least two-month old fatteners. If the farmer has made contracts for marketing the manure to other consumers (farms not dealing with animal husbandry etc) and there are manure storage facilities of sufficient size, the number of animal units may be bigger per hectare of arable land, provided that only the allowed quantity of manure is laid on own land. The norms are in force for ten and more animal units.

Therefore, the allowable number of fattening pigs per one hectare of

arable land is expressed in

$$n_{sl} = l_u l_a \eta_t , \quad (9)$$

where n_{sl} – number of pigs allowed to keep by manure utilization regulations per one hectare;
 l_u – number of the animal units allowed to breed per one hectare;
 l_a – numbers of the animals in one animal unit;
 η_t – ratio of real number of the pigs in company and the allowed number n_{sp} ; if $n = n_{sp}$ $\eta_t = 1$, and if $\eta_t > 1$, excessive manure should be sold.

Due to the restriction established on the use of manure, the area of arable land on the company must be bigger than or equal to the necessary area for laying the manure

$$U \geq \frac{n}{l_u l_a \eta_t} . \quad (10)$$

In case the remaining manure could be disposed elsewhere, this condition does not have to be taken into account. The excess manure can be found according to the following relation

$$S_e = a_s \eta (n - n_{sl}) , \quad (11)$$

where S_e – excessive amount of the manure, ton;
 a_s – manure norm per one pig during the fattening period, ton;
 n – number of pig places;
 η – factor of performance of pig places;
 n_{sl} – number of pigs allowed to keep by manure utilization regulations per one hectare.

The possible area of arable land in the company can be found, considering the working time consumption on both pig farming and crop growing, according to

$$U = (t_u - t_s) \frac{l}{t_a} . \quad (12)$$

3.3. Forecasting the optimum size of pig farming and crop growing company

Consequently, to find the number of pig places depending on the length of the working day during the high season of works (t_H), taking into account the restriction of manure use, an optimization task shall be solved. The optimization criterion is the maximum number of pig places ($n \rightarrow \max$) and the restrictions (using the relations 8, 10 and 12) are expressed as follows:

$$\begin{cases} n > 0 \\ \frac{a}{60}n^2 + \left(\frac{\eta e t_a}{h \delta l} + \frac{b}{60}\right)n + \frac{c}{60} \leq t_H \quad (13, 14, 15) \\ (t_H - t_s) \frac{l}{t_a} \geq \frac{n}{l_u l_a \eta_t} \end{cases}$$

The first restriction determines that the number of pig places is positive. The second restriction determines that the total duration of human working time per day would be lower than or equal to the chosen length of working day during the high season of works. The third restriction is used to control that the company had as much or more arable land than needed for disposing the produced manure. To solve this optimization task, a program application was made, using the optimization module working in MS Excel „SOLVER” (figure 3.2).

With the help of this application the numbers of pig places are found in the case of pig farming technology no. 3 and the areas of arable land in the case of different crop yield levels, depending on the length of the working day during the high season of works, and these numbers is presented graphically figure 3.3.

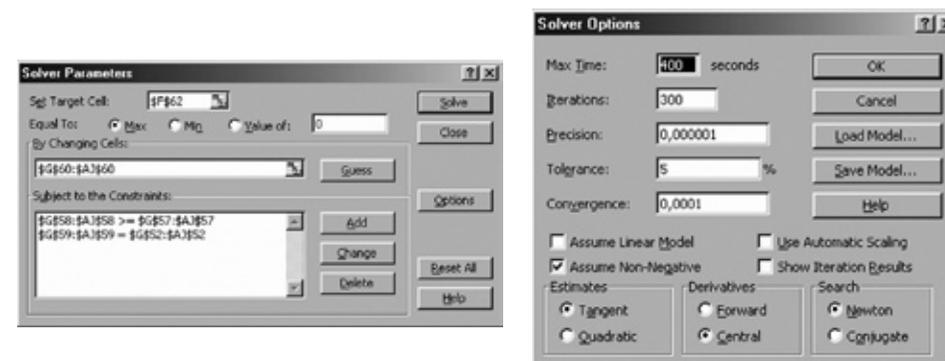


Figure 3.2. The optimization module in MS Excel „SOLVER”

Joonis 3.2. MS Exceli optimeerimismoodul „SOLVER”

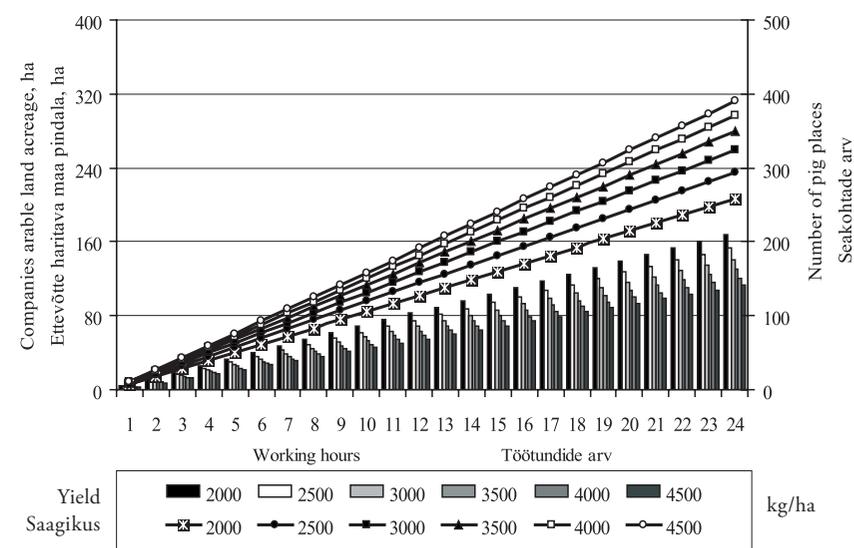


Figure 3.3. Numbers of pig places (lines) and companies arable land acreages (bar graphs) in dependence on daily working hours during the labour peak periods on different yield levels

Joonis 3.3. Seakohtade arv (jooned) ja ettevõtte haritava maa pindala (tulpdiaagramm) sõltuvalt päevasest tööajakestusest tööde tippkoormuse perioodil erinevate teravilja saagikustasemetete korral

Finding the working time consumption for crop growing works is more complicated due to the fact that the crop yield is a variable measure. Agricultural scientists have worked out connections which enable to find out the amount of plant nutrition elements covered with organic or mineral fertilizers and which are needed for certain soil productivity and achievement of crop level for a cultivated plant. In order to use manure most effectively as an organic fertilizer we must know how much nutrients it contains. As to find out the actual content of plant nutrients in manure at a given pig farming company we should analyze the manure. To calculate a figure of reasonable amount of manure application also the sequence of plants in sowing order, manure fertilizing after-effects on the following year and the time of manure distribution should be taken into account (Lember *et al.*, 1999). For example, in the fertilizer programme of the consultation and information system „TALUTARK” (FARMWISE), created in Estonian Farmers’ Federation (compiled by Kalvi Tamm) the needs of plant nutrition elements (N, P, K) are worked out according to the field’s soil analysis data, anticipated crop level of the cultivated plant and data connected with preceding crop by the general growth balance method. When the needs of plant nutrition elements are figured out it will be possible to cover these needs both with organic and mineral fertilizers. The programme is naturally in accordance with environmental requirements.

The crops of a given year are remarkably influenced by climatic conditions and therefore the actual crop level is different from the calculated one. The crop yield values 2000...4500 kg per hectare as used in the relations and programs (Asi *et al.*, 1999) are the average values gained over a long period, and according to crop farming researchers, can be forecast proceeding from the fertility of the field soil (Möller *et al.*, 1999; Möller *et al.*, 2000). The yield in different years, however, is dependent on the impact of weather conditions (deToro, 2004; Möller *et al.*, 1998). The lower the crop yield, the more sowing land is needed to produce feed for the pigs and the higher is the time consumption of crop growing works. Having found the total working time consumption in the case of different pig farming technologies and different yield levels, it was ascertained that the character of changes in total working time consumption in the case of different pig farming technologies is similar (Vettik *et al.*, 2005). This is why figure 3.4 presents the total working time consumption at different yield levels only for pig farming technology no. 1.

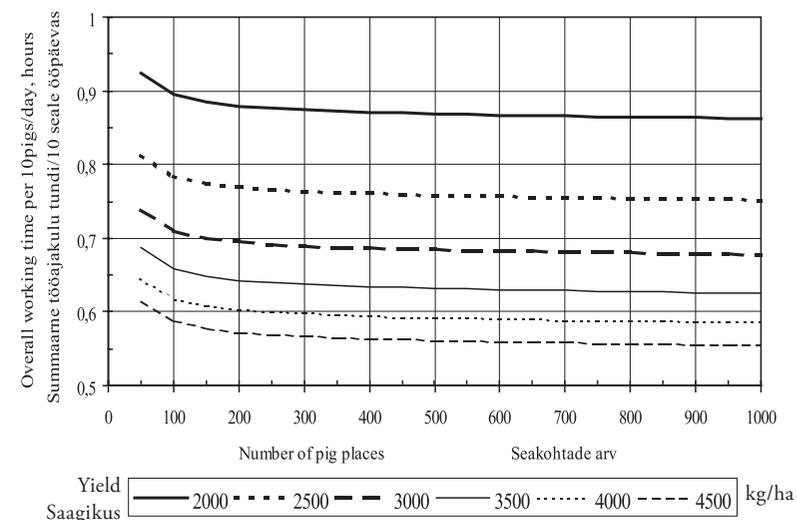


Figure 3.4. Overall working time per 10 pigs/day in dependence on number of pig places with different crop yield levels

Joonis 3.4. Summaarne tööajakulu 10 sea kohta ööpäevas teravilja erinevate saagikustasemetel korral

In the case of higher yield levels the amount of cultures suitable for pig feed produced in crop growing can be higher and in the case of lower yield it can be lower than the feed need of pigs per year. The excess or deficiency of feed can be found using the following relation

$$E_e = \frac{l\delta h(t_{lt} - t_s)}{t_a} - n\eta e, \quad (16)$$

- where E_e – excess or deficiency of feed, kg;
 l – number of fields in rotation;
 δ – factor that shows the share of the fodder crops acreage in the total acreage of the arable land of company;
 h – average yield of crops, kg per hectare;
 t_{lt} – length of working day during the high season of works, hours per day;
 t_s – working time in pig farming works, hours per day;
 t_a – working hours during the peak seasons per rotation’s elementary unit, hours per (hectare·day);
 n – number of pig places;
 η – factor of performance of pig places;
 e – feed consumption of a one pig per year from the feeds produced on the company, kg.

3.4. Forecast of economic indicators

For forecasting the economic indicators of a pig farming and crop growing company, the model of forecasting the parameters of crop growing company (Tamm, 1999) was used and on that basis the author developed a draft model for forecasting the values of the main parameters in a pig farming company, which is published in article (Möller *et al.*, 1999) and the master's thesis of the author (Vettik, 2000). If crop growing is supplemented by fattening of pigs, the main changes are the following:

- 1) part of the grain is used for feeding pigs, therefore the income from the sale of grain is decreased by that amount;
- 2) income from the sale of pigs is added;
- 3) variable costs related with pig farming are added;
- 4) fixed costs related with pig farming are added.

This methods did not enable to forecast the economic figures related with growing breeding pigs. To use the model in forecasting the economic indicators in a pig farming company of full production cycle, additions and improvements were made in the methods.

Improvements made in forecasting the income

Income from the sale of grain decreases by T_{vs} , because part of the grain is used as feed for breeding pigs. At the same time, the income from growing breeding pigs increases by T_{ss} .

The decrease of income from the sale of grain is expressed in

$$T_{vs} = n_{ss} e_{ss} r_t, \quad (17)$$

where T_{vs} – decrease of income from the sale of grain, in EEK;
 n_{ss} – number of breeding pigs;
 e_{ss} – feed consumption of a breeding pig per year from the feeds produced on the company, kg;
 r_t – price of feed grain, in EEK per kg.

Income from growing breeding pigs can be found by the following relation

$$T_{ss} = n_{pr} r_{pr} + \left[n_p - n \eta \left(1 - \frac{\varphi}{2} \right) \right] r_p + n_{ss} H_{ss}, \quad (18)$$

where T_{ss} – income from growing breeding pigs, in EEK;
 n_{pr} – number of cull pigs;
 r_{pr} – average sales price of a cull pig, in EEK;
 n_p – production of piglets per year;
 n – number of pig places;
 η – factor of performance of pig places;
 φ – factor characterising the culling of pigs;
 r_p – average sales price of a piglet, in EEK;
 n_{ss} – number of breeding pigs;
 H_{ss} – direct support per one breeding pig, in EEK.

Improvements made for forecasting variable costs

The keeping costs of breeding pigs can be found according to the following relation

$$k_{1,ss,p} = n_{ss} l_{ss} p_{ss}, \quad (19)$$

where $k_{1,ss,p}$ – keeping costs of breeding pigs per year, in EEK;
 n_{ss} – number of breeding pigs;
 l_{ss} – material or service costs per one breeding pig (feed additives, heating, electricity, veterinary services, veterinary drugs etc);
 p_{ss} – cost of a unit of material or service.

The transportation costs of manure to the fields, taking into account the area of the company, i.e. the average distance of transportation, can be found as follows

$$k_{1,ss,s} = n_{ss} a_{ss} (f_s d \gamma + g_s) (1 + \omega) r_{ky}, \quad (20)$$

where $k_{1,ss,s}$ – costs of manure transportation, in EEK;
 n_{ss} – number of breeding pigs;
 a_{ss} – amount of manure produced by one breeding pig per year, ton;
 f_s – regression coefficient;
 g_s – regression coefficient;
 d – theoretical average distance of transportation, km;
 γ – factor of increase in transportation distance;
 ω – relation of repair and maintenance costs to fuel costs;
 r_{ky} – complex fuel price (includes both fuel price and greasing agents), in EEK per litre.

Improvements made for forecasting fixed costs

If the cost of buildings, shed equipment etc per one pig place (M_{ss}) is known, the depreciation, interest on capital and repair and maintenance costs for growing breeding pigs are expressed in

$$k_{2,ss} = n_{ss} u_{s,a} M_{ss}, \quad (21)$$

where $u_{s,a}$ – factor of depreciation assignments (3...7%),

$$k_{3,ss} = n_{ss} i M_{ss}, \quad (22)$$

where i – interest rate on capital, %,

$$k_{5,ss,r} = n_{ss} u_{s,r} M_{ss}, \quad (23)$$

where $u_{s,r}$ – factor of repair assignments (14...25%).

Forecasting the salary costs

If there is one employee on the company, the sum of the necessary income (salary) for his/her family is taken into consideration with the crop growing costs. If paid labour force is used for crop growing works, the corresponding salary costs are expressed as follows

$$k_{4,y} = \frac{n_{pn} t_y}{t_n} n_{y,p} P_s (1 + \zeta), \quad (24)$$

where $k_{4,y}$ – salary of paid employees in crop growing, in EEK;
 n_{pn} – number of working days per week;
 t_n – work load of one employee per week, hours;
 t_y – working time in crop growing, hours per day;
 $n_{y,p}$ – number of working months of paid workers in crop growing per year;
 P_s – monthly salary of a paid employee, in EEK;
 ζ – factor providing of social security payments.

Also, it is possible to use paid labour for pig farming works, the respective salary costs can be found according to the following relation

$$k_{4,s} = \frac{n_{pn}}{t_n} n_{s,p} t_s P_s (1 + \zeta), \quad (25)$$

where $k_{4,s}$ – salary of paid employees in pig farming, in EEK;
 n_{pn} – number of working days per week;
 t_n – work load of one employee per week, hours;
 $n_{s,p}$ – number of working months of paid employees in pig farming per year;
 t_s – working time in pig farming works, hours per day;
 P_s – monthly salary of a paid employee, in EEK;
 ζ – factor providing of social security payments.

Forecasting the profit

Adding to the model of forecasting of the profit fatted pig breeding company complementary elements, published in the master's thesis (Vettik, 2000) (formulas 17...25), is possible to prognosticate profit by given model such pigsties for porkers or breeding pigs. Either is possible to calculate workers salary costs as in the pig farming and the crop growing. Potential annual profit Q_{sk} from pig farming is predictable by formula:

$$\begin{aligned} Q_{sk} = & \sum_{j=1}^{n_s} n_{s,j} q_{s,j} r_{s,j} \left(1 - \frac{\varphi}{2}\right) + n_{pr} r_{pr} + \left[n_p - n \eta \left(1 - \frac{\varphi}{2}\right) \right] r_p + \\ & + n_{ss} H_{ss} + \left[l_u \left(\frac{n_{ss}}{l_a} + \frac{n}{l_a} \right) - U \right] N_{so} r_{so} - (n \eta e + n_{ss} e_{ss}) r_t - \\ & - \sum_{j=1}^{n_s} n_{s,j} l_{s,j} p_{s,j} - n_{ss} l_{ss} p_{ss} - \left[\frac{l \delta h (t_l - t_s)}{t_a} - n \eta e - n_{ss} e_{ss} \right] r_t - \\ & - \left[(n \eta a_s + n_{ss} a_{ss}) (f_s d \gamma + g_s) (1 + \omega) r_{ky} \right] - n u_{s,a} M_s - \\ & - n_{ss} u_{s,a} M_{ss} - n i M_s - n_{ss} i M_{ss} - n u_{s,r} M_s - n_{ss} u_{s,r} M_{ss} - \\ & - \frac{n_{pn} t_y}{t_n} n_{y,p} P_s (1 + \zeta) - \frac{n_{pn}}{t_n} n_{s,p} (t_s - t_{s,t}) P_s (1 + \zeta) - k_{s,s,m}, \end{aligned} \quad (26)$$

where n_s – number purchase lots of piglets;
 $n_{s,j}$ – number of pigs in j -th of lot;
 $q_{s,j}$ – average pig realization live weight in j -th of lot, kg;
 $r_{s,j}$ – selling price per weight unit of pigs in j -th of lot, in EEK per kg;

φ – factor characterising the culling of pigs;
 n_{pr} – number of cull pigs;
 r_{pr} – average selling price of a cull pig, in EEK;
 n_p – production of piglets per year;
 n – number of pig places;
 η – factor of performance of pig places;
 r_p – average selling price of a piglet, in EEK;
 n_{ss} – number of breeding pigs;
 H_{ss} – direct support per one breeding pig, in EEK;
 l_u – amount of the animal units allowed to breed per one hectare;
 l_a – numbers of the animals in one animal unit;
 U – arable land acreage, hectare;
 N_{so} – maximum limit of manure utilization, ton per (hectare·year);
 r_{so} – selling price of manure, in EEK per ton;
 e – feed consumption of a one pig per year from the feeds produced in the company, kg;
 e_{ss} – feed consumption of a breeding pig per year from the feeds produced on the company, kg;
 r_t – price of feed grain, in EEK per kg;
 $l_{s,j}$ – material or service costs per one fattened pig (purchase piglets, feed additives, heating, electricity, veterinary services, veterinary drugs etc) in j -th of lot;
 $p_{s,j}$ – cost of a unit of material or service in j -th of lot;
 l_{ss} – material or service costs per one breeding pig (feed additives, heating, electricity, veterinary services, veterinary drugs etc);
 p_{ss} – cost of a unit of material or service;
 l – number of fields in rotation;
 δ – factor that shows the share of the fodder crops acreage in the total acreage of the arable land of company;
 h – average yield of crops, kg per hectare;
 t_{lt} – length of working day during the high season of works, hours per day;
 t_s – working time in pig farming works, hours per day;
 t_a – working hours during the peak seasons per rotation's elementary unit, hours per (hectare·day);
 a_s – manure outlet per one pig during the fattening period, ton;

a_{ss} – amount of manure produced by one breeding pig per year, ton;
 f_s – regression coefficient;
 g_s – regression coefficient;
 d – theoretical average distance of transportation, km;
 γ – factor of increase in transportation distance;
 ω – relation of repair and maintenance costs to fuel costs;
 r_{ky} – complex fuel price (includes both fuel price and greasing agents), in EEK per litre;
 M_s – cost of buildings, shed equipment etc per one fattened pig place, in EEK;
 M_{ss} – cost of buildings, shed equipment etc per one breeding pig place, in EEK;
 $u_{s,a}$ – factor of depreciation assignments;
 i – capital interest rate, %;
 $u_{s,r}$ – factor of repair assignments;
 n_{pn} – number of working days per week;
 t_n – work load of one employee per week, hours;
 t_y – working time in crop growing, hours per day;
 $n_{y,p}$ – number of working months of paid workers in crop growing per year;
 P_s – monthly salary of a paid employee, in EEK;
 ζ – factor providing of social security payments;
 $n_{s,p}$ – number of working months of paid employees in pig farming per year;
 $t_{s,t}$ – working time in pig farming works of main employee, hours per day;
 $k_{s,s,m}$ – miscellaneous costs (taxes, insurance, tenure etc), in EEK.

Example program code for forecasting of economic indicators is presented in appendix E.

4. RESULTS

4.1. Pig farming and crop growing company with one main employee

The division of the working time of an employee working in his/her own company between pig farming and crop growing works is generally studied between the two limit situations observed in the article (Asi *et al.*, 1997):

- 1) one employee deals with both the pig farming and crop growing works;
- 2) one employee works in pig farming all the year round and hires the necessary amount of labour force and uses rented machinery for crop growing.

Firstly. In a company with several production lines one employee deals with both the pig farming and crop growing works. The length of a working day during the high season of works is ten hours and the proportion of the growing area of pig feed cultures in the crop rotation was half of the total area of arable land. Main parameter values are presented in table 4.1.

Table 4.1. Main parameter values of a pork-producing company if one employee works alone doing pig farming and crop growing works $t_{it} = 10$ h

Tabel 4.1. Seakasvatuseettevõtte põhiparameetrite väärtused juhul, kui töötaja töötab üksi nii seakasvatus- kui ka taimikasvatustöödel $t_{it} = 10$ h

	Possible number of pig places (upper numbers) and the area of arable land (bottom numbers) depending on the yield of cereals Võimalik seakohtade arv (ülemised arvud) ja haritava maa pindala ha (alumised arvud) sõltuvalt teravilja saagikusest					
Yield ton per hectare Saagikus t/ha	2.0	2.5	3.0	3.5	4.0	4.5
Techn. No 1	119	137	153	166	176	184
Variant 1	73	68	63	59	54	50
Techn. No 2	116	134	149	162	172	179
Variant 2	72	66	61	57	53	49
Techn. No 3	111	127	140	151	160	166
Variant 3	68	63	58	53	49	46

In the observed situation the number of pig places was limited by the insufficiency of feed produced on the company, because the working time left for crop growing was not sufficient for growing feed cultures to the required extent. Therefore the article (Asi *et al.*, 2000) studies a situation where the proportion of the growing area of pig feed cultures in the crop rotation was increased to three fourths of the area of arable land. In this case, with crop yield of 2000...2500 kg per hectare, the number of pig places was also limited by the insufficiency of feed produced on the company, but if the yield was 3500...4500 kg per hectare, the restrictive factor for the number of pig places became the quantity of manure produced in pig farming. In the case of the crop yield of 3000 kg per hectare, the amount of manure produced in pig farming was exactly equal to the allowed amount and the amount of grain suitable for pig feed produced in crop growing equalled precisely to the yearly feed consumption of pigs. To increase the amount of feed grain produced in crop growing, also the length of the working day in the high season of works could be increased. In the table 4.2 and figure 4.1 are presented a situation, where the working day was lengthened to 11.8 hours during the high season of works.

The value 11.8 hours was chosen due to the following considerations. The yearly workload of one employee is ~1880 hours. In the calculations, the yearly workload of an employee working in both pig farming and crop growing was ~1540 hours (in case the length of the working day during the high season was ten hours). This is about 82 per cent of the desirable work load. The main crop growing works are done during six months, whereas during the whole period the work load is not even. Top loads fall to the sowing period in spring and the grain harvesting period in autumn. Therefore, to increase the yearly workload in a pig farming and crop growing company, the length of the working day during the high season of works was prolonged by 18 per cent. The calculation results revealed that in none of the cases of division of working time between the pig farming and crop growing works in a company with one worker, the machinery that is based on a 60-kW tractor can be sufficiently loaded (Vettik, 2000). To guarantee an optimum load for the machinery, the area of arable land should be larger (depending on the yield of grain, ~75...90 hectare) (Tamm, 1999). The total working time of one employee, however, does not enable that.

Table 4.2. Daily working hours in pig farming and crop growing during the high season of the works; arable land acreage in dependence on crop yield level

Tabel 4.2. Ajakulu seakasvatustöödele, tööaeg taimekasvatuses tööde tipp-koormuse perioodil ja talu haritava maa pindala erinevate saagikustasemetel korral

	Number of pig places / Seakohtade arv								
	100	110	120	130	140	150	160	170	180
Daily working hours in pig farming Ajakulu seakasvatustöödele, tundi päevas	1.41	1.52	1.62	1.72	1.82	1.93	2.03	2.13	2.23
Daily working hours in crop growing during the high season of the works Tööaeg taimekasvatuses tööde tippkoormuse perioodil, tundi päevas	10.39	10.28	10.18	10.08	9.98	9.87	9.77	9.67	9.57
Yield, kg per hectare Saagikus, kg/ha	Arable land acreage, hectare Haritava maa pindala taimekasvatuses, ha								
2000	83.1	82.3	81.4						
2500	76.9	76.2	75.4	74.7	73.9				
3000	71.6	70.9	70.2	69.5	68.8	68.1			
3500	67.0	66.3	65.7	65.0	64.4	63.7	63.0		
4000	63.0	62.3	61.7	61.1	60.5	59.8	59.2	58.6	
4500	59.4	58.8	58.2	57.6	57.0	56.4	55.8	55.3	54.7

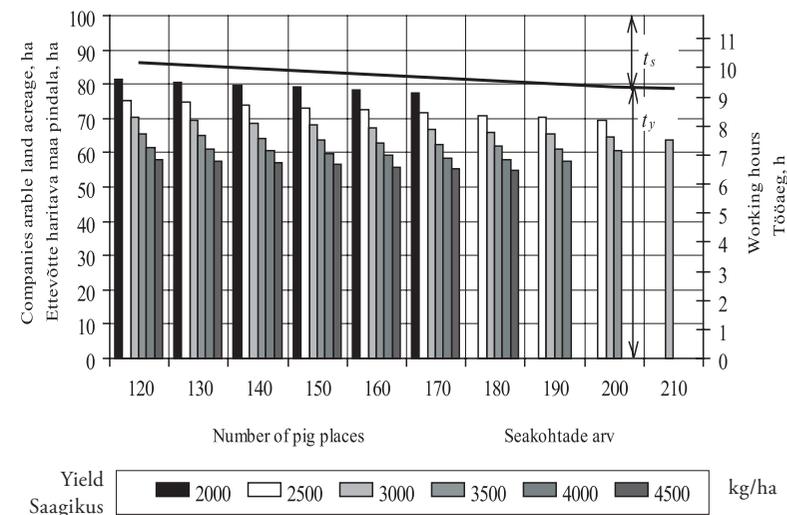


Figure 4.1. Main parameters of pig farming and crop growing company in dependence on number of the pig places; 75% of the arable land acreage is under the fodder grain crops; daily working hours number in crop growing during the high season of the works is 11.8

Joonis 4.1. Sea- ja teravilja kasvatusega tegeleva ettevõtte põhinäitajad sõltuvalt seakohtade arvust ettevõttes, tingimusel et söödateravilja kasvatatakse 75% külvipinnast ja tippkoormuse ajal on tööpäeva kogukestus 11.8 tundi päevas

Secondly. One employee works in pig farming approximately for 5 hours a day all the year round and hires the necessary amount of labour force and uses rented machinery for crop growing. The shorter working day was chosen in pig farming, because in addition to the crop growing works the employee must also deal with hiring the proper amount of paid workers for the right time for crop growing works and check the quality of their work. According to the growing area of feed cultures necessary for satisfying the feed need of pigs, the area of arable land of the company is found. In the sample calculation there was the four-field crop rotation and the proportion of the growing area of feed cultures in the rotation made up a half of the total area of arable land. Main parameter values are presented in table 4.3.

Table 4.3. Main parameter values of a pig farming company if main employee himself works on pig farming $t_s = 5$ h and hired labour is used on crop growing

Tabel 4.3. Seakasvatuseettevõtte põhiparameetrite väärtused juhul, kui põhitöötaja töötab ise seakasvatustöödel $t_s = 5$ h ja taimekasvatuses kasutatakse palgatöölisi

Yield ton per hectare Saagikus t/ha	Seakohtade arv Number of pig places	Necessary area of arable land hectare (upper numbers) and necessity of overall working time during the high season of the works hours (bottom numbers) depending on the yield of crops Vajalik haritava maa pindala ha (ülemised arvud) ja summaarne töötaja vajadus tööde tippkoormuse perioodil päevas h (alumised arvud) sõltuvalt teravilja saagikusest					
		2.0	2.5	3.0	3.5	4.0	4.5
Techn. No 1 Variant 1	1000	613 76.6	490 65.5	409 58.3	350 53.4	307 49.9	273 47.8
Techn. No 2 Variant 2	800	490 61.3	392 52.4	327 46.6	280 42.7	245 39.8	218 38.2
Techn. No 3 Variant 3	470	288 36.0	231 30.9	192 27.4	165 25.2	144 23.4	128 22.4

The amount of manure produced a year per one hectare equalled in the sample exactly to the allowed amount. In the necessary working hours per day, in the case of different crop yield levels and pig farming technologies no. 1 and no. 3 are presented in graphs (figure 4.2).

In figure 4.2 it is revealed that in the case of the average estimated crop yield of 3000...3500 kg per hectare and the most labour-consuming pig farming technology (no. 3), the area of the arable land on the company should be ~200 hectare and the required paid work ~40 hours a day. In the figure we can see that the higher the yield, the lower is the need of the company for arable land and also the number of paid working hours per day.

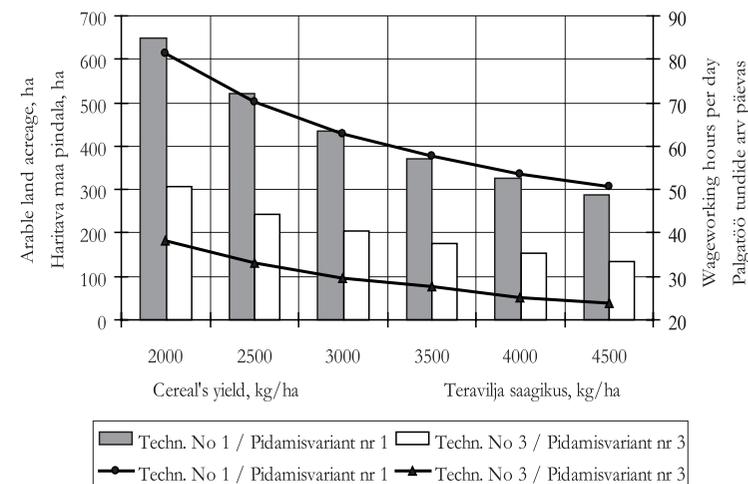


Figure 4.2. Arable land acreages (bar graphs) and necessary wageworking hours per day in crop growing (lines). Fodder crops cover 50% of the arable land acreage

Joonis 4.2. Haritava maa pindala (tulbad) ja vajalik taimekasvatuse palgatööliste töötundide arv päevas (jooned). Söödakultuurid moodustavad 50% haritava maa pindalast

The situation changes if the proportion of the growing area of feed cultures was three fourths of the total arable land (figure 4.3). The numbers of pig places were the same as in the previous example. In the case the average yield is 2000...3000 kg per hectare, the amount of manure produced in a year per one hectare is exactly equal to the allowed amount. However, if the yield is 3500...4500 kg per hectare, the arable land of the company should be expanded, because otherwise the amount of manure produced in pig farming per one hectare would exceed the allowed amount (Vetik *et al.*, 2003). Therefore also the need for paid working time per day increases, respectively.

If the restriction on manure was not taken into account (the excess amount of manure would be disposed outside the company) and the needed area of arable land is found according to the feed need, the area of arable land and also the need for paid working time would be lower. The corresponding figures are presented in figure 4.4.

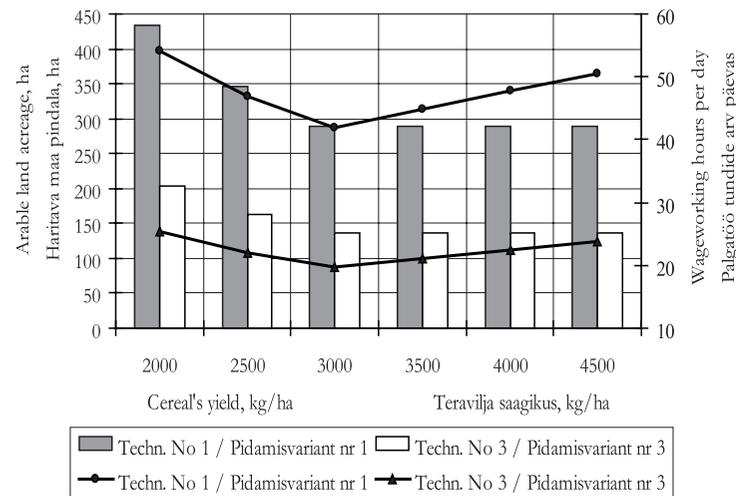


Figure 4.3. Arable land acreages (bar graphs) and necessary wogworking hours per day in crop growing (lines). Fodder crops cover 75% of the arable land acreage

Joonis 4.3. Haritava maa pindala (tulbad) ja vajalik taimekasvatuse palgatöölise töötundide arv päevas (jooned). Söodakultuurid moodustavad 75% haritava maa pindalast

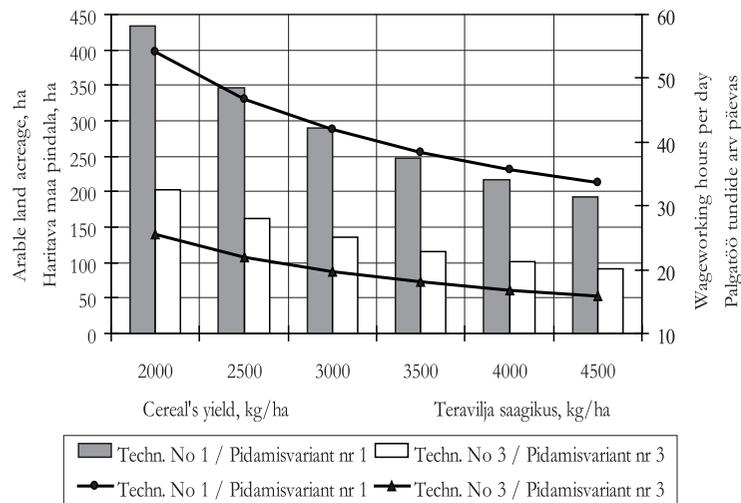


Figure 4.4. Arable land acreages (bar graphs) and necessary wogworking hours per day in crop growing (lines). Fodder crops cover 75% of the arable land acreage and manure utilization restrictions is neglect

Joonis 4.4. Haritava maa pindala (tulbad) ja vajalik taimekasvatuse palgatöölise töötundide arv päevas (jooned), söodakultuurid moodustavad 75% haritava maa pindalast, sõnnikupiirangut ei arvestata

To forecast the working time consumption in the case of these two limit situations and also in the case of intermediate possibilities, the author has developed a computer software application working in the environment of MS Excel. The article (Vettik *et al.*, 2003) presents the numbers of pig places in the case of one possible farming technology (no. 3) and the areas of arable land in the case of different yield levels, depending on the length of working day during the high season of works, as found by means of the computer software application.

4.2. Pig farming and crop growing company with several main employees

In the following calculation samples some possibilities of dividing the working time of two employees between the pig farming and crop growing works are shown.

Example 1. In order to guarantee sufficient workload for the machinery of the company, for instance, another worker can be hired to help with crop growing works, to work 10 hours a day during the high season of plant growing works. All the works are done with the machinery based on one tractor. In the given case the length of the working time a day was 15 hours during the high season. The main worker works in pig farming and crop growing ~5 hours a day in total during the high season, and ~2.5 hours during other periods.

In the article (Vettik *et al.*, 2003) it was revealed that if the proportion of the growing area of pig feed cultures were 75 per cent, and the yield was over 3000 kg per hectare, the number of pig places was restricted by the need of the arable land area for disposing the manure. This is why in this calculation example the proportion of the growing area of pig feed cultures makes up half of the total arable land and the four-field rotation system is used. Two pig farming technologies, quite different in terms of labour-intensity, are compared:

- 1) keeping without bedding on partial slotted floor, fodder is distributed by stationary cable-washer conveyor (techn. no. 1);
- 2) keeping with bedding, manure is removed by conveyor, feeding with a bucket from a wheelbarrow (techn. no. 3).

The compiled methods and the results found with the help of the respective computer software application are presented in graphs (figures 4.5 and 4.6).

In these figures the bar showing the area of arable land corresponding to some of the pig places is missing. This is justified by the fact that in the case of the respective yield levels the area of arable land does not guarantee sufficient feed amounts for the pigs. Therefore, the figures read that in the case of the crop yield 2000 kg per hectare and using pig farming technology no. 1, the largest possible number of pig places is 170, and in the case of technology no. 3, 150. However, if the crop yield is 4500 kg per hectare, the corresponding numbers of pig places are 260 and 240.

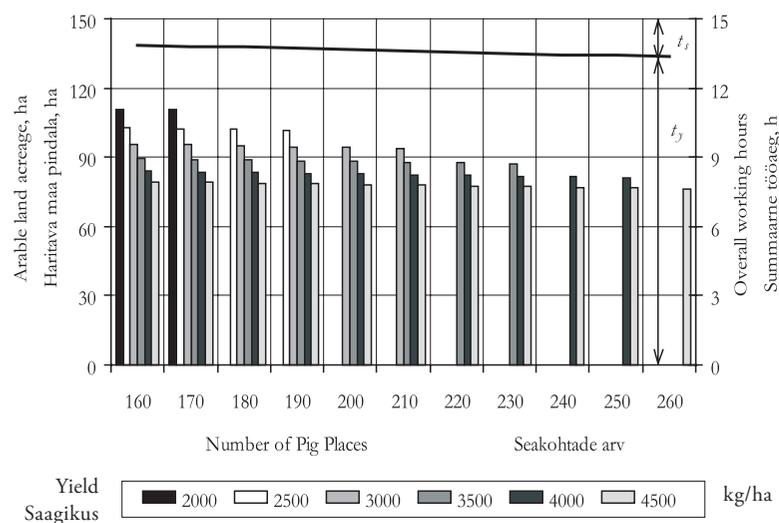


Figure 4.5. Distribution of 15-hour overall working time between pig farming works (t_s) and crop growing (t_y) with pig farming technology no 1 (lines) and arable land acreage (bar graphs) with different crop yield levels

Joonis 4.5. 15-tunnise summaarse tööaja jagunemine pidamisvariandi 1 puhul seakasvatusele (t_s) ja taimekasvatusele (t_y) (jooned) ning haritava maa pindala (tulbad) eri-nevate saagikustasemetete korral

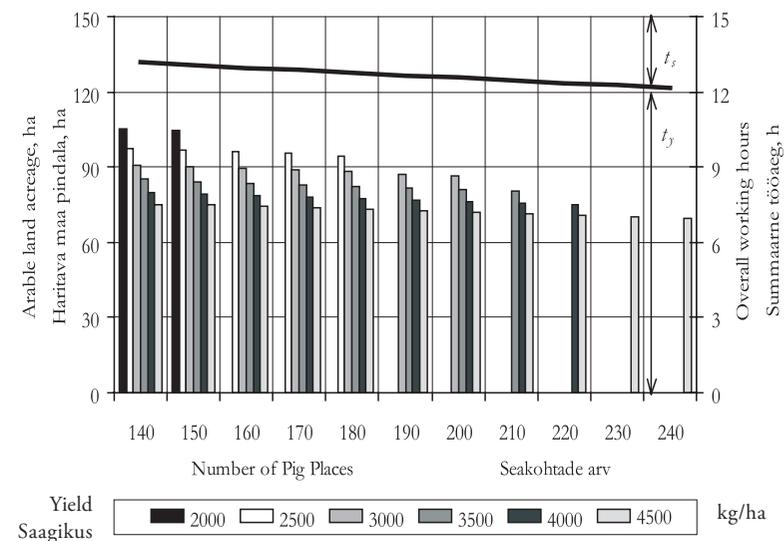


Figure 4.6. Distribution of 15-hour overall working time between pig farming works (t_s) and crop growing (t_y) with pig farming technology no 3 (lines) and arable land acreage (bar graphs) with different crop yield levels

Joonis 4.6. 15-tunnise summaarse tööaja jagunemine pidamisvariandi 3 puhul seakasvatusele (t_s) ja taimekasvatusele (t_y) ning haritava maa pindala (tulbad) eri-nevate saagikustasemetete korral

Example 2. If we depart from the yearly working time limit of one employee of ~1880 hours (Asi *et al.*, 2000), the pig farming worker should work ~5 hours a day all the year round. In this case his workload in the case of technology no. 1 would be ~9 hours a day during the most intensive period (total number of working hours of two employees is 19, figure 4.7) and in the case of technology no. 3, about 7 hours a day (total number of working hours of two workers 17, figure 4.8).

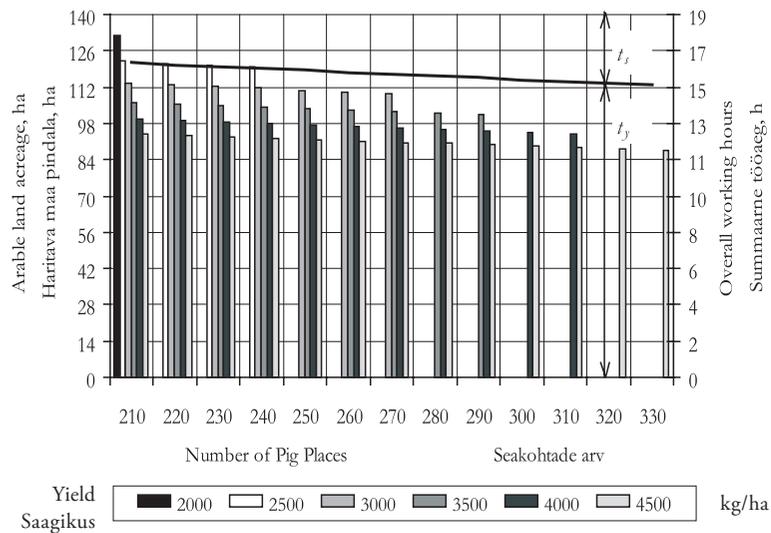


Figure 4.7. Distribution of 19-hours overall working time between pig farming works (t_x) and crop growing (t_y) with pig farming technology no 1 (lines) and arable land acreage (bar graphs) with different crop yield levels

Joonis 4.7. 19-tunnise summaarse tööaja jagunemine pidamisvariandi 1 puhul seakasvatusele (t_x) ja taimekasvatusele (t_y) ning haritava maa pindala (tulpdiaagramm) eri-nevate saagikustasemetel korral

The calculation sample observed two different possibilities of dividing the working hours of two workers. Actually there are much more possibilities. Also, there might be more than two workers. Choosing the number of employees and determining the division of their working time between pig farming and crop growing, the respective calculations can be made with the help of the methods and the computer software application developed by the author.

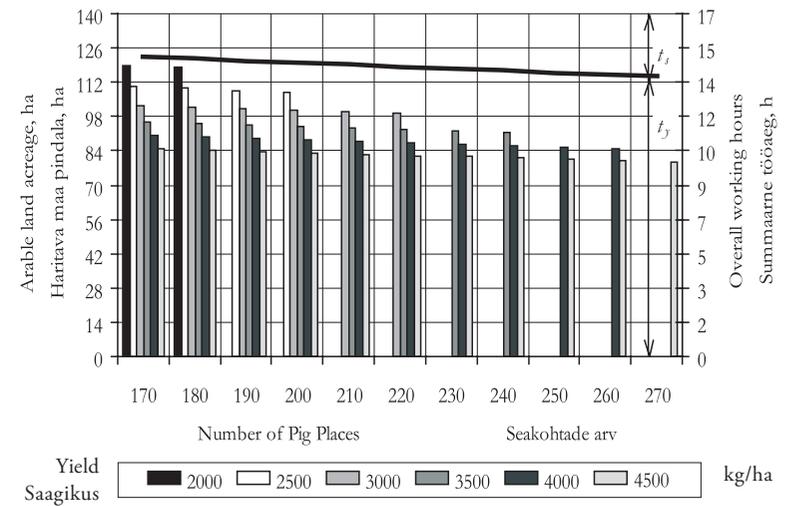


Figure 4.8. Distribution of 17-hours overall working time between pig farming works (t_x) and crop growing (t_y) with pig farming technology no 3 (lines) and arable land acreage (bar graphs) with different crop yield levels

Joonis 4.8. 17-tunnise summaarse tööaja jagunemine pidamisvariandi 3 puhul seakasvatusele (t_x) ja taimekasvatusele (t_y) ning haritava maa pindala (tulpdiaagramm) erinevate saagikustasemetel korral

4.3. Pig farming company be founded on feed of purchase

Composed methods and computer software application enable prognosticate also production results of pork production company using only feed of purchase. For example need for feed in pig production company with 300 places is by calculations done with computer software application following:

- 17.8 ton feed for weanlings;
- 84.1 ton feed for young pigs and
- 117.2 ton finishing feed.

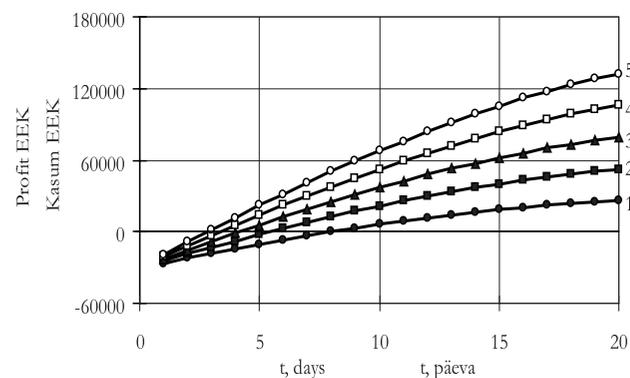
There are fattened 750 pigs and produced 531 ton of slurry per year. Initial data used in calculations are:

- weanling with 10 kg is fattened until fattening with 100 kg;
- length of fattening period is 147 days and
- average increase of weight is 615.7 g per day.

4.4. The workload of the machinery and the profit of pig farming and crop growing company

The methods developed for forecasting the economic figures enables to forecast the impact of the duration of the grain sowing period on the profit of the pig farming and crop growing company. In such a case all the working time that remains after pig farming works is spent on sowing grain in the sowing period. The impact of the workload of the machinery on the results of a pig farming and crop growing company in the case of one pig farming technology has been dealt with in articles (Möller *et al.*, 2001, Vettik *et al.*, 2001).

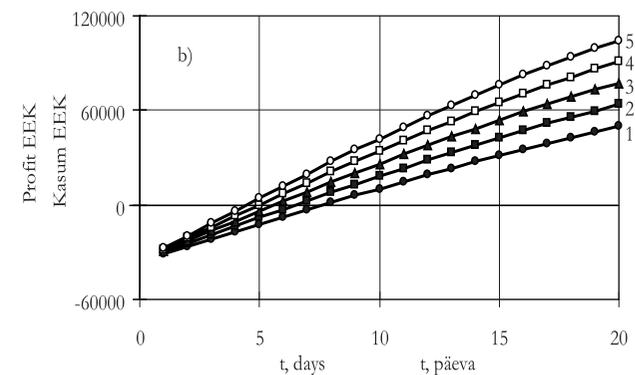
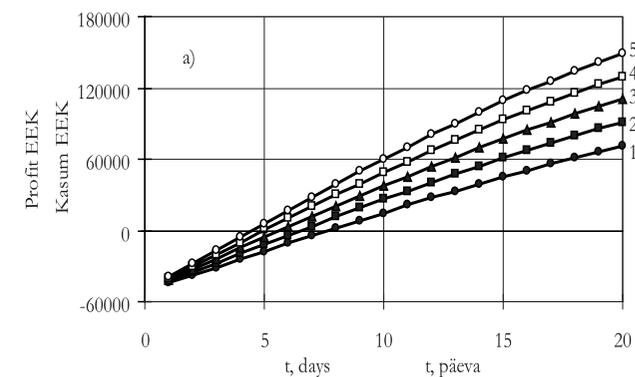
The given examples are estimated for machinery based on a 60-kW tractor. Pigs are fattened up to 100 kg of weight, the deadweight makes up ca 75% of live weight, the length of fattening period is 140 days and average weight gain per 24 hours is 622 g. One pig needs 290 kg feed during the fattening period, 40 kg feed additives and 250 kg grain. Feed additive costs 8.5 EEK per kg and grain 1.7 EEK per kg. Keeping costs amount to about 100 EEK per pig. Purchasing price of pork is 26 EEK per kg and 21 EEK per kg comparatively and the price of purchased piglet 600 EEK per kg and 400 EEK per kg respectively. The calculated results are shown in figures 4.9 and 4.10.



1 - 2500 kg/ha, 2 - 3000 kg/ha, 3 - 3500 kg/ha, 4 - 4000 kg/ha, 5 - 4500 kg/ha

Figure 4.9. Crop growing company profit prognoses on the different crop yield levels in dependence on sowing time

Joonis 4.9. Tulemused teravilja tootmisettevõtte kasumi prognoosimisel teravilja erinevatel saagikustasemetel sõltuvalt külvitööde kestusest



1 - 2500 kg/ha, 2 - 3000 kg/ha, 3 - 3500 kg/ha, 4 - 4000 kg/ha, 5 - 4500 kg/ha

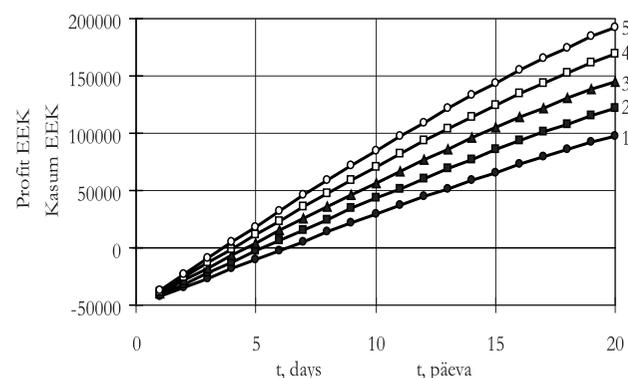
Figure 4.10. Pig farming and crop growing company (a – purchasing price of pork 26 EEK per kg and price of purchased piglet 600 EEK, b – purchasing price of pork 21 EEK per kg and price of purchased piglet 400 EEK) profit prognoses on the different crop yield levels in dependence on sowing time

Joonis 4.10. Tulemused sealihateravilja tootmisettevõtte (a – sealiharealiseerimishind 26 kr/kg ja ostupõrsa hind 600 kr, b – sealiharealiseerimishind 21 kr/kg ja ostupõrsa hind 400 kr) kasumi prognoosimisel teravilja erinevatel saagikustasemetel sõltuvalt külvitööde kestusest

Using the methods created for forecasting the economic figures, it appeared that depending on the grain and pork realisation price levels, the profit of a grain producing and pig farming company (figure 4.10) could be higher (a) or lower (b) than the profit of a company producing only grain (figure 4.9). For example, in case of 15 sowing days the profit of pig farming and crop growing company was on average 15 000 EEK higher (at 2 500 kg per hectare crop level 26 000 EEK and at 4 500 kg per hectare crop level 4 000 EEK) at the pork purchase price of 26 EEK per kg. In case of lower

pork price (21 EEK per kg) the profit of the company was still higher at the crop levels of 2 500 kg per hectare and 3 000 kg per hectare (13 000 EEK and 2 400 EEK respectively), but at higher crop levels pig farming reduced the company's profit (at crop level 3 500 kg per hectare by 8 000 EEK and at crop level 4 500 kg per hectare by 29 000 EEK).

In order to get better workloads of machinery and higher profits it must be considered to have longer workdays during the spring sowing time. The following calculation is drawn for workdays of 11.5 hours and the results are given in figure 4.11.



1 - 2500 kg/ha, 2 - 3000 kg/ha, 3 - 3500 kg/ha, 4 - 4000 kg/ha, 5 - 4500 kg/ha

Figure 4.11. Pig farming and crop growing company profit prognoses on the different crop yield levels in dependence on sowing time. Daily working hours peak 11.8 hours

Joonis 4.11. Tulemused sealihha-teravilja tootmisettevõtte kasumi prognoosimisel teravilja erinevatel saagikustasemetel sõltuvalt külvitööde kestusest. Tööpäeva pikkus tippkoormuse perioodil on 11.8 tundi

Extending the length of workdays during spring sowing season increased remarkably the company's profit. For example, comparing drawings 4.10 and 4.11 in case of 15 sowing days the growth in profit on average was 28 000 EEK (at crop level 2 500 kg per hectare 21 000 EEK and at crop level 4 500 kg per hectare 35 000 EEK).

The method worked out and computer programme applications enable to estimate the amount of profits in pig farming and crop growing company according to input parameter values in relevant equations and estimate the efficiency of selected production scheme.

5. TESTING MODEL AND DISCUSSION

5.1. General description of test company

A pig farming company with full production cycle OÜ Linnamäe Peekon was the basis of testing model. There were 3 520 places in the fatteners pigsty, 1 920 places in the weaners pigsty and 530 basic sows, 120 young sows, 13 basic boars in the pig breeding farm.

In the weaning house there are mainly slotted floors, slurry is removed daily with scrapers located in the channels, manual feeding is performed. Fatted pigs are kept without bedding on partial slotted floor. Removal of slurry is performed with an aid of vacuum system once a week. Feeding is performed with multiphase sensor feed system with liquid feeding. Farrow pigsty has metal slotted floor, slurry is removed daily with scrapers. Floor heating is installed for piglets. Automatic dry feeding. In sows and boars pigsty the scrapers are under the floor and slurry is removed daily. Gestation sows are kept in pens with boxes. Automatic dry feeding.

For slurry storage there are two tanks with capacity of 2 000 m³ and one with capacity of 4 524 m³. The capacity of slurry storage tanks of the company per year is 9 000 m³ - this is the amount that is produced during at least 8 months. In the distribution of slurry trailing hose system is used and transport is performed with 2 tank trunks equipped with agitators.

5.2. Testing model

The data of a smart farm planning programme have been inserted and presented in figure 5.1. The mean weight gain of fattening pigs during different fattening periods and the mean prognosticated weight gain during whole fattening period are seen in figure. The mean prognosticated number of piglets per sow a year is given there.

SEAKASVATUS 2006. aastal. Testettevõtte Nr: 2

Lähteandmed Prognosid

Algus

Lihatootmistalu Kasvatatakse lihasigu Keskiiperiood 20.60 kg

Nuumakohade arv 3520 Nuuma lõppkaal 95 Põrsed kasvatatakse talus

Tootvate emiste arv 530 Asendusemiste arv 133 Keskmine põrsaste arv emiselt aastal 20,700

Ni kuldid kui ka kunstlik seemendus Tootvate kuldide arv 13 Asenduskuldide arv 3

Söötis- ja pidamistehnoloogia veski veski

Vedelsöötmine sööda valmistus Söödvalm

Sõnnikueemaldusseade Sõnniku ee

Söödaraatsioonid Nuumaperioodi pikkus päevades 112 Keskmine nuumatsükli arv aastas 3,3

Massi-übed g. võõrpõrsastel 0 kesikul 610 nuumikul 750 keskmine 671,3

Faktiline tootmine Tootmise planeerimine Taluplaneeri salvestamine

Figure 5.1. Program window for the data of the pig farming company
 Joonis 5.1. Programmiaken seakasvatustettevõtte andmetega

Prognosticated production indicators based on the testing model are presented in figure 5.2. Figure 5.3 gives a prognosis of feed components need per year.

Seakasvatustalu üldnäitajad 21.06.2006 10:07:47

Ettevõtte nimi: Toomatalu

Omaniku nimi: Jaan Jalakas

Plaanivariant: Testettevõtte

TaluTark 110032

Raivo Veltik

KESKINE TÖÖAJAKULU

Tööajakulu öö-päevas:	2133,4min
Tööajakulu nuumaperioodil:	3982,3h
Tööajakulu aastas:	13141,6h

TOODANG AASTAS

Sead eluskaalus:	1086,96tonni	Prakeeremiste arv:	106
Liha tapakaalus:	760,87tonni	Prakeerkuldide arv:	1
Sõnnik:	9017,03tonni		

Figure 5.2. Prognosticated production indicators by pig farming program
 Joonis 5.2. Seakasvatustaluga seotud prognoositud tootmisnäitajad

Söödakomponentide vajaduse prognoos aastal 21.06.2006 10:15:12

Ettevõtte nimi: Toomatalu

Omaniku nimi: Jaan Jalakas

Plaanivariant: Testettevõtte

TaluTark 110032

Raivo Veltik

Söödakomponent	Kogus kilogrammides
Kaerajahu	109578
Odrajahu	1491937
Nisusöödajahu	1226181
Sojasrott	230083
Rapsikook	251773
Põrsaste prestartersööt	55271
Söödakriit	25459
Tünni emis 15%	9905
Kesku/nuumiku konts. 6%/4%	79422
Imetava emise kontsent. 15%	10524

Figure 5.3. Feed component need per year prognosticated by pig farming program
 Joonis 5.3. Seakasvatustaluga seotud prognoositud söödakomponentide tarve aastal

Testing model is rather time-consuming and labour-intensive. Therefore only by some production indicators (feed consumption, consumption of working time, fattening pigs' production in live weight, pigs' slurry per year, etc) model prognostication and the real values of the corresponding indicators of the pig farming company during 2 years (Year 1, Year 2) have been studied.

Table 5.1. Comparison of model prognosticated and actual production indicators of the pig farming company

Tabel 5.1. Mudeliga prognoositud ja seakasvatuseettevõtte tegelike tootmisnäitajate võrdlus

Production indicator Tootmisnäitaja	Model Mudel	Year 1 Aasta 1	Year 2 Aasta 2	Mean Keskmine	Model– mean Mudel– keskmine	Difference Erinevus
Feed consumption in fattening period, kg Söödakulu nuuma- perioodil, kg	231	207	224	215.5	15.5	7.19%
Feed consumption per year, ton Söödakulu aastas, t	3491	3933	3721	3827	-336	-8.78%
Weight gain of fattening pigs, g per 24 hours Nuumsigade kaaluive, g/ööpäevas	671.3	707	693	700	-28.7	-4.10%
Mean consumption of working time, min per day Keskmine tööajakulu ööpäevas, min	2130	2310	2340	2325	-195	-9.01%
Slurry per year, ton Sealäga aastas, t	9017	8500	9000	8750	267	3.05%
Pig live weight per year, ton Sead eluskaalus aastas, t	1087	1205	1119	1162	-75	-6.45%
Piglets per sow, pcs Põrsaid emiselt aastas, tk	20.7	21.9	20.7	21.3	-0.6	-2.82%
Needed area for crop growing, hectare Teravilja kasvatamiseks vajalik pindala, ha	797	412	412	412	385	93.45%
Needed area for manure spreading, hectare Sõnniku paigutamiseks vajalik pindala, ha	372	412	412	412	-40	-9.71%

5.3. Discussion

The difference is about 10% in most observed indicators (8 indicators out of 9). The difference between model prognostication and the actual indicators for needed arable land area of crop growing was rather high (93%).

By the model the needed cultivated land area of the cereals (barley, wheat, oats) would be by

$$U_s = \frac{n \eta e}{h} + \frac{n_{ss} e_{ss}}{h} = \frac{3520 \cdot 3,3 \cdot 187,9}{3500} + \frac{663 \cdot 913}{3500} \approx 797 \text{ hectare.}$$

The amount of cereals needed for forage can be increased with buying it. That is why the needed area for crop growing by model prognostication can be higher than the area cultivated by the company.

The arable land area of the company was 412 hectare (table 5.1). It is allowed to keep 20 fattening pigs, 6 sows with piglets or 6 boars per 1 hectare arable land (Veeseadus, 1994). In that case the needed area for manure spreading in the given company would be by

$$U = \frac{n}{l_a} + \frac{n_{ss}}{l_a} = \frac{1980 + 3520 + 120}{20} + \frac{530 + 13}{6} \approx 372 \text{ hectare.}$$

It is not allowed to spread manure over 170 kg nitrogen per hectare of arable land a year (Veeseadus, 1994). Consequently, in case of 9 017 ton of slurry containing 3.6 kg per ton general nitrogen (Sõnniku..., 2004) the minimal area of arable land of the company of the model testing would be the following $\frac{9017 \cdot 3,6}{170} \approx 191$ hectare of arable land needed.

The areas calculated by the amount of slurry and number of animals different, because the number of fattening places is not constant. After shifting a new fattening group pens will be cleaned and disinfected. In conformance with Environmental Service slurry spreading plan in 2006 8400 m³ (8652 ton) of slurry will be spread on 262 hectare, in 2007 8806 m³ (9070 ton) on 252 hectare and in 2008 9804 m³ (10098 ton) on 280 hectare.

CONCLUSIONS

1. It is composed methods and the respective computer software application for finding optimum values for parameters characterising different pig farming technologies in a company involved in pig farming and crop growing.
2. The developed methods of determining the composition of feed rations enables to find as satisfying and at the same time as sheap as possible feed rations, the feed need per day, in different fattening weeks, per year and the deficiency of food in the case of lower yield and the excess amount of feed in the case of higher yields. The developed methods have been applied in the complex pig farming program of the consultation and information system "TALUTARK" (FARMWISE) of the Estonian Farmers' Federation.
3. Tests done with computer software application used for composing of feed ration cleared that composition of feed ration is similar to composition given in feeding recommendations of firms (Anu Ait, Feedline, Vitamex, etc.) selling feed additives. That is in case if feed additives are used produced by corresponding firms.
4. The working time consumption found with the help of the regression equation in the course of forecasting the time consumption of pig keeping works is comparable in the case of similar technology technologies with the respective data collected in Estonia. The developed methods of forecasting the need for human labour have been applied in the complex pig farming program of the consultation and information system "TALUTARK" (FARMWISE) of the Estonian Farmers' Federation.
5. The methods developed by the author and the respective computer software application working in MS Excel environment, by means of which the optimum size of a pig farming and crop growing company can be found depending on the length of the working day during the high season of works, and also taking into consideration the restriction on manure use. The calculations can be made for different pig farming technologies and in the case of different crop yield levels.
6. The calculation results revealed that a pig farming and crop growing company with one employee, in which also the main feed for pigs is produced, cannot provide sufficient workload for the machinery based on a 60-kW tractor. For the better loading of the machinery the area of arable land should be larger. But the working time left for crop growing works does not enable it. Therefore extra labour force should be used in the high season of crop farming works (sowing and harvesting). Another possibility would be to increase the proportion of purchased feeds.
7. The calculation results revealed that if the proportion of the growing area of pig feed cultures were 50 per cent, the number of pig places on the company was restricted by scanty feed in the case of every production technology). If the proportion of the growing area of feed cultures was increased to 75 per cent of the total arable land, the number of pig places was also restricted by scanty feed in the case of crop yields of 2000...3000 kg per hectare. If the yield was 3500...4500 kg per hectare, the number of pig places was restricted by the amount of manure produced in the company.
8. There are many options of distribution of the working time between the pig farming and crop growing works in a company with more than one employees. If there are many workers, the machinery of the company can be sufficiently loaded with work, e.g. by using the shift system etc.
9. The methods of forecasting the production figures of a pig farming and crop growing company enable to calculate the impact of the duration of grain sowing period on the production figures.
10. Composed methods and computer software application enable prognosticate also production results of pork production company using only feed of purchase.
11. The improved methods of forecasting the economic results of a pig farming company enable to make calculations also for a pig farming company of full production cycle.
12. The method of prognostication the pig farming and crop growing company profit was developed and adequate computer program application composed.
13. Using the methods created for forecasting the economic figures, it appeared that depending on the grain (grain price 1.7 EEK per kg) and pork realisation price levels, the profit of a grain producing and pig farming company could be higher (purchasing price of pork 26 EEK per kg, **price of purchased piglet 600 EEK**) or lower (purchasing price of pork 21 EEK per kg, **price of purchased piglet 400 EEK**) than the profit of a company producing only grain.
14. The difference between model prognosticated and the actual production indicators (basis of pig farming company OÜ Linnamäe Peekon) is about 10 per cent in most observed indicators.

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KOKKUVÕTE

Raivo Vettik. *Seakasvatustehnoloogiate ja tehnikakasutuse arvutipõhine optimeerimine.* Väitekiri filosoofiadoktori kraadi taotlemiseks põllumajandustehnika erialal. Eesti Maaülikool, Tartu, 2007. Väitekiri koosneb sissejuhatastest ja viiest peatükist, milles on 6 tabelit, 15 graafikut, 4 joonist. Kasutatud kirjanduse loetelus on 78 nimetust. Tööga seotud lisad on koondatud viie nimetuse alla.

Märksõnad: SIGADE PIDAMISTEHNOLOOGIA, SIGADE SÖÖT-
MISTEHNOLOOGIA, INIMTÖÖ AJAKULU, TÖÖAJAKULUDE
PROGNOOSIMINE REGRESSIOONIVÕRRANDITEGA, SÖÖDAR-
ATSIION, SÖÖDAKULU, TERAVILJA SAAGIKUS, MASINAPARGI
TÖÖKOORMUS, SÕNNIKU REALISEERIMINE, OPTIMEERI-
MINE.

Väitekirja kirjanduse analüüsi osas on kirjeldatud seakasvatustehnoloogiaid, seakasvatusega kaasnevaid keskkonnakaitse nõudeid, "parimat võimalikku tehnikat" (PVT) seakasvatuses ning on esitatud ülevaade seakasvatuse kasutatavatest arvutiprogrammidest maailmas ja Eestis. Samuti on kirjeldatud sea- ja teraviljakasvatuse modelleerimise võimalusi. Töö eesmärgiks oli välja töötada meetodid erinevaid seakasvatustehnoloogiaid iseloomustavatele parameetritele optimaalsete väärtuste leidmiseks sea- ja teraviljakasvatusega tegelevas ettevõttes.

Eesmärgist lähtuvalt koostati meetodikad ja vastavad arvutiprogrammi rakendused:

- 1) tööajakulude määramiseks erinevate seakasvatustehnoloogiate korral;
- 2) nii söödakultuuride kasvatamiseks kui ka toodetava sõnniku realiseerimiseks vajaliku haritava maa pindala määramiseks;
- 3) seakohtade arvu leidmiseks sõltuvalt tööpäeva kestusest tööde kõrgeperioodil, arvestades sõnniku kasutamise piirangut.

Uurimistöö uudsus seisnes meetodika ja vastava arvutiprogrammi rakenduse loomises, mille abil on võimalik leida ja sea- ja teraviljakasvatusega tegeleva ettevõtte optimaalne suurus teravilja erinevate saagikustasemetega ja sigade pidamistehnoloogiate korral, sõltuvalt tööpäeva kestusest tööde tippkoormuse perioodil, arvestades ühtlasi sõnniku kasutamise piirangut Eestis kehtivatest keskkonnakaitse nõuetest lähtudes.

Koostatud söödaratsioonide koostise ja söödavajaduse määramise metoodi-

ka on kasutusel Eestimaa Talupidajate Keskliidu nõuande- ja infosüsteemi "TALUTARK" komplekses seakasvatuseprogrammis. See võimaldab leida sigade söödavajadusi võimalikult täpselt rahuldavad ja samas odavaimad söödaratsioonid, samuti söödavajaduse päevas, erinevatel nuumanädalatel ja aastast. Söödavajaduse prognoosimise meetodika võimaldab leida madalamate saagikuste korral seakasvatuse puudujääva ja kõrgemate saagikuste korral seakasvatusest ülejääva söödakoguse.

Söödaratsioonide koostise määramise arvutiprogrammi rakenduse testimisel selgus, et söödaratsioonide koostis oli sarnane söödaliseid pakkuvate firmade (Anu Ait, Feedline, Vitamex jne) söötmissoovitustes esitatud koostisele. Seda muidugi juhul kui söödaratsioonides kasutatakse vastavate firmade söödaliseid.

Sigade talitustööde ajakulu prognoosimisel regressioonivõrrandiga leitud tööajakulud on sarnaste tehnoloogiavariantide korral võrreldavad Eestis kogutud talitustööde ajakulu andmetega (Reppo ja Sada, 2000; Sada, 2003). Koostatud inimtöö vajaduse prognoosimismetoodika on rakendatud Eestimaa Talupidajate Keskliidu nõuande- ja infosüsteemi "TALUTARK" komplekses seakasvatuseprogrammis.

Autori poolt on koostatud meetodika ja vastav arvutiprogrammi rakendus MS Exceli keskkonnas, mille abil on võimalik leida teravilja- ja seakasvatusega tegeleva ettevõtte optimaalne suurus sõltuvalt tööpäeva kestusest tööde kõrgeperioodil, arvestades ühtlasi sõnniku kasutamise piirangut. Arvutusi on võimalik teostada sigade erinevate pidamistehnoloogiate ja teravilja erinevate saagikustasemetega korral.

Arvutustulemustest selgus, et ühe töötajaga sea- ja teraviljakasvatusega tegelev ettevõtte, kus toodetakse ka sigade põhisisõdad, ei suuda masinaparki, mis baseerub 60 kW-sele traktorile, piisavalt koormata. Masinaparki paremaks koormamiseks peaks olema mitu töötajat. Mitme töötajaga ettevõtte töötajate tööaja taime- ja seakasvatuse vahel jaotumise võimalusi on palju. Mitme töötaja korral on võimalik ettevõtte masinapark piisavalt koormata, nt vahetustega töö kasutamiseks jms.

Arvutustulemustest selgus, et sigade söödakultuuride kasvupinna 50%-lise osakaalu korral külvikorras, piiras seakohtade arvu ettevõttes iga vaadeldud tootmisvariandi korral söödanappus. Suurendades söödakultuuride kasvupinna osakaalu kolmveerandini haritava maa pindalast, piiras saagi-

kuste 2000...3000 kg/ha korral seakohtade arvu samuti söödanappus. Saagikuse 3500...4500 kg/ha korral muutus seakohtade arvu piiravaks teguriks ettevõttes toodetav sõnniku kogus.

Sea- ja teraviljakasvatusega tegeleva ettevõtte tootmisnäitajate prognoosimise meetodika võimaldab arvestada teraviljade külviperioodi kestuse, st ka masinapargi töökoormuse, mõju tootmistulemustele.

Kasutades majandusnäitajate prognoosimiseks loodud meetodikat selgus, et sõltuvalt teravilja (teravilja hind 1,7 kr/kg) ja sealiha realiseerimishinna vahekorrad võib teravilja- ja seakasvatusega tegeleva ettevõtte kasum olla suurem (sealiha realiseerimishind 26 kr/kg, ostupõrsa hind 600 kr) või ka väiksem (sealiha realiseerimishind 21 kr/kg, ostupõrsa hind 400 kr) ainult teravilja kasvatamisega tegeleva ettevõtte kasumist.

Mudeli testimisel OÜ Linnamäe Peekon tootmisandmetega selgus, et enamike vaadeldud tootmisnäitajate korral jäi erinevus mudeliga prognoositud ja tegelike tootmisnäitajate vahel 10% piiresse. Suur erinevus (94%) oli mudeliga prognoositud vajaliku teravilja kasvupinna ja ettevõtte tegeliku haritava maa pindala vahel. See on seletatav sellega, et oma põldudel kasvatatav teravili moodustab ainult 23% sigadele söödaks vajalikust teraviljast ja ülejäänud 77% ostetakse juurde.

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vene (lugemine 3, kõnelemine 1, kirjutamine 1).
8. **Teenistuskäik:**
2003...k.a Eesti Maaviljeluse Instituut, teadur;
1997...2002 Eestima Talupidajate Keskliit, informaatika konsulent.
9. **Teadus- või akadeemiline kraad:**
Tehnikateaduse magister põllumajandustehnika erialal.
10. **Kraadi välja andnud asutus:**
Eesti Põllumajandusülikool, 2000.
11. **Tunnustused:**
II preemia Eesti üliõpilaste teadustööde 2001. a riiklikul konkursil teadustöö „Sealihatootmistalu põhiparameetrite prognoosimine masinapargi töökoormuse järgi“ eest.
14. **Teadustöö põhisuunad:**
Põllumajandustehnika valiku ja kasutamise modelleerimine ning optimeerimine
15. **Osalemine uurimisprojektides:**
15.1. ETF Grant nr 4103 „Põllu- ja farmitehnika kasutamise ja töökeskkonna uurimine ning modelleerimine ergonoomiliselt ja ökoloogiliselt kahjutu ning tehnoloogiliselt sobivate masinasüsteemide kujundamiseks talus või ühistus“, täitja aastatel 2000...2002;

15.2. ETF Grant nr 2612 „Optimeerimisprogrammide ja andmebaaside loomine põllumajandustehnika valiku põhjendamiseks, kasutusviiside ja tootmistehnoloogiate kujundamiseks talus või põllumajandusühistus“, abijõud aastatel 1997...1999.

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- 2) **Vettik R.**, Möller H., Asi M. Planning Of Human Labour And Machinery Use In Farm With Several Production Lines. Proceedings 31. International Symposium on Agricultural Engineering. - Actual tasks on agricultural engineering - Croatia, Opatija, 2003, pp. 125...132. (Current Contents Proceedings, ISI – Index to Scientific & Technical Proceedings, CAB International – Agricultural Engineering Abstracts, Cambridge Scientific Abstracts – Conference Papers Index, InterDok)
- 3) Möller H., Asi M., Soonets K., **Vettik R.** Masinapargi töökoormuse mõjust sealihatootmistalu töötulemustele. – Akadeemilise Põllumajanduse Seltsi Toimetised, 15. – Tartu, 2001, lk 51...54. (AGRIS, CAB International – Agricultural Engineering Abstracts)
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- 3) Möller H., Asi M., Soonets K., **Vettik R.** Masinapargi töökoormuse mõjust sealihatootmistalu töötulemustele. APS VI aastakonverents. 5...6. aprill 2001 Tartu.
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APPENDIXES

APPENDIX A

General scheme of the pig farming planning Seakasvatuse planeerimise üldine skeem

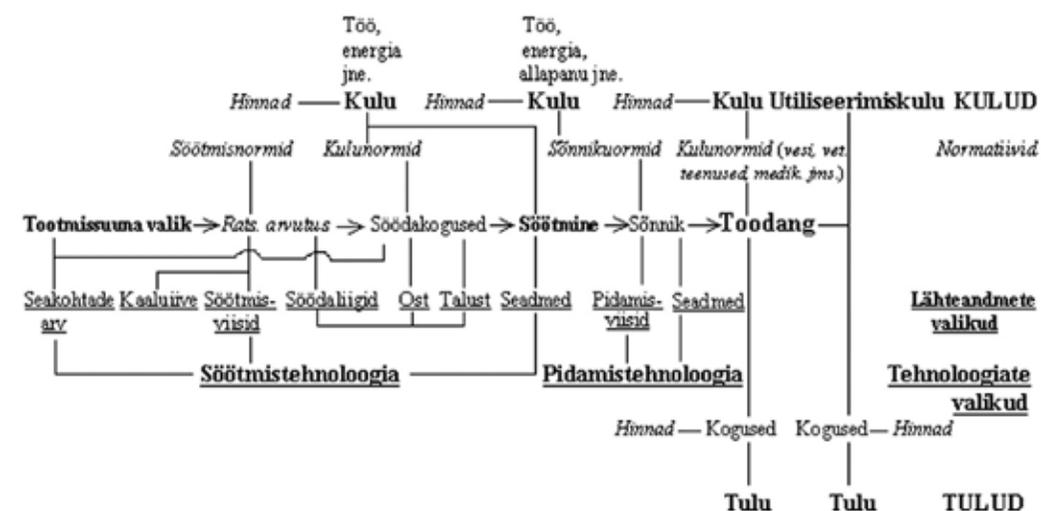


Figure A1. General scheme of the pig farming planning
Joonis A1. Seakasvatuse planeerimise üldine skeem

APPENDIX B

Block diagram of the pig farming planning program

Seakasvatuse planeerimise programmi plokk skeem

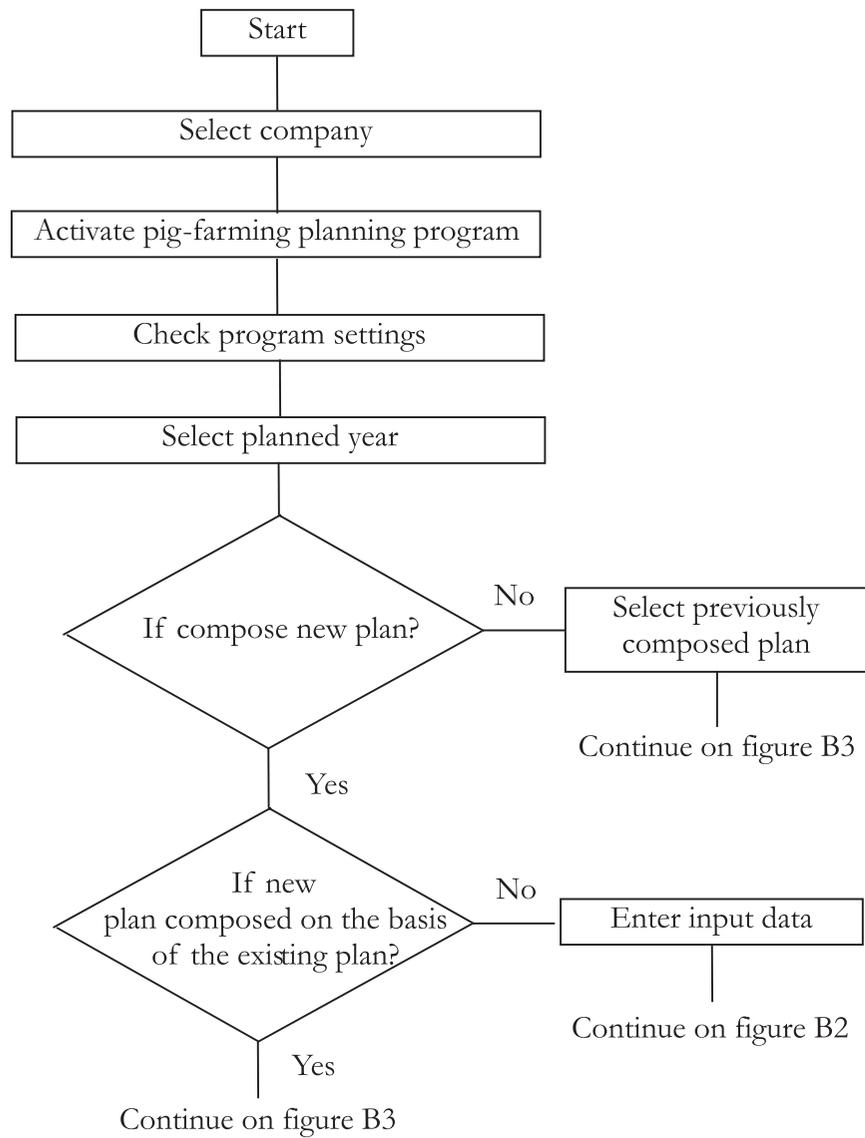


Figure B1. Block diagram of the pig farming planning program
 Joonis B1. Seakasvatuse planeerimise programmi plokk skeem

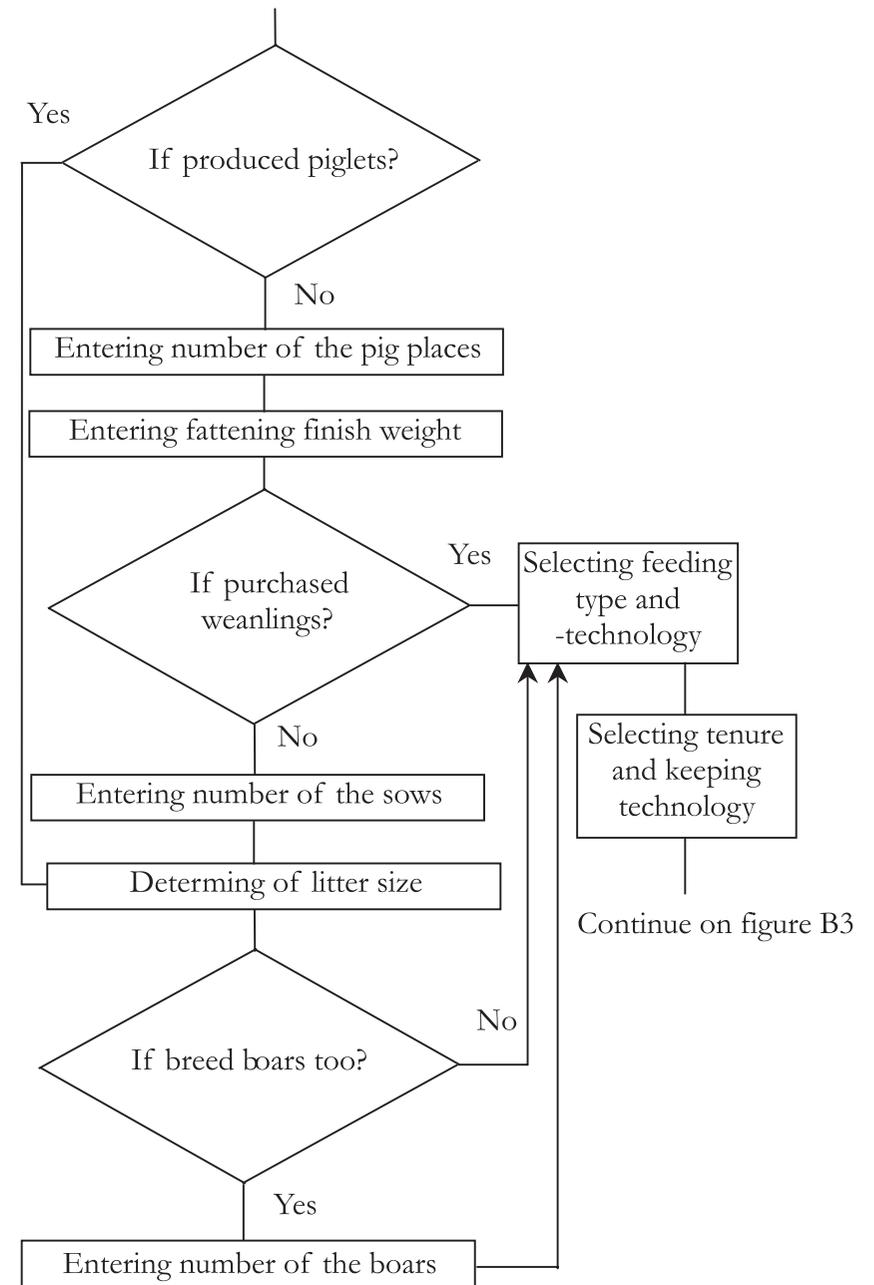


Figure B2. Follow-up of the figure B1
 Joonis B2. Joonise B1 järg

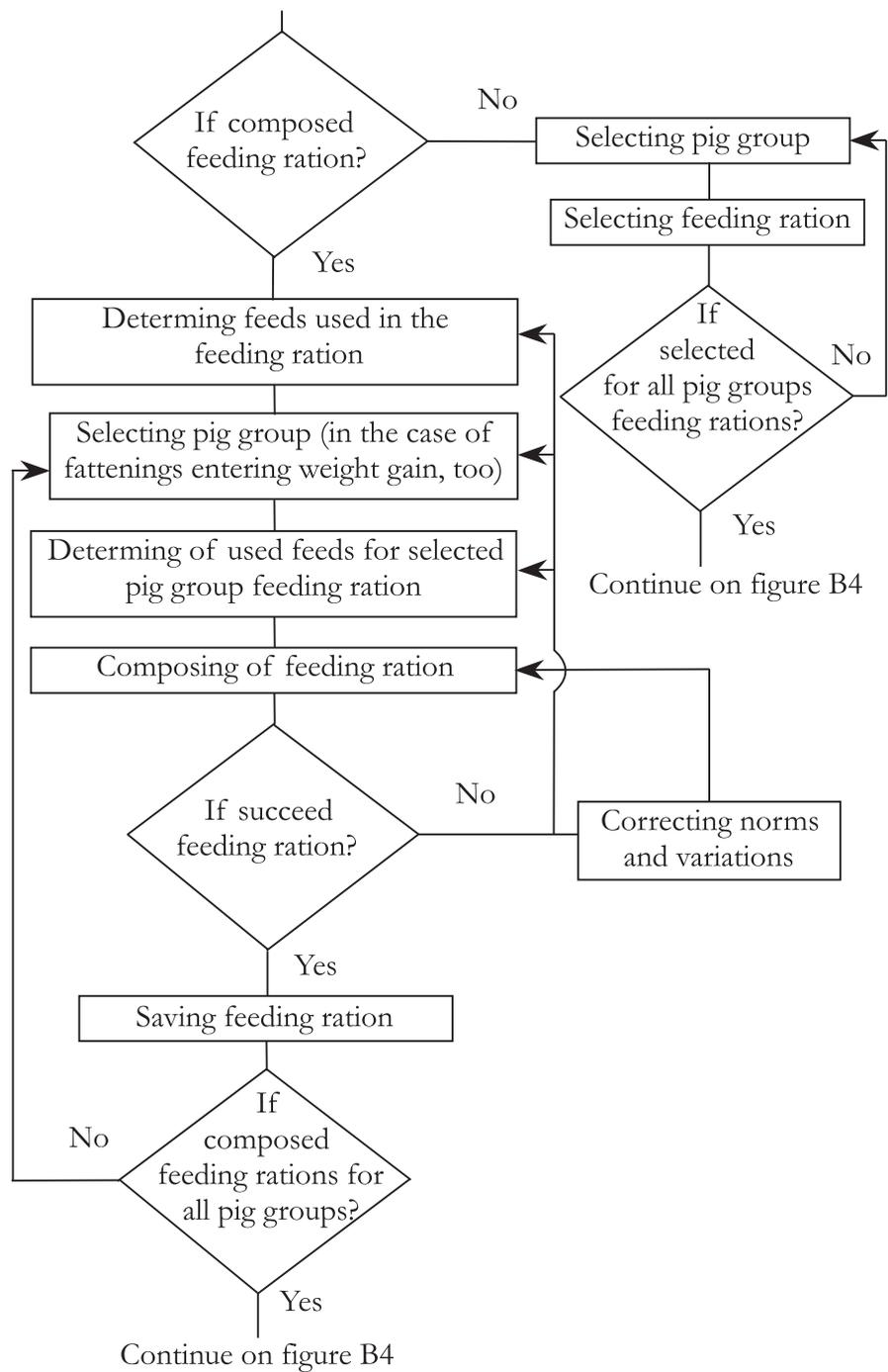


Figure B3. Follow-up of the figure B1
Joonis B3. Joonise B1 järg

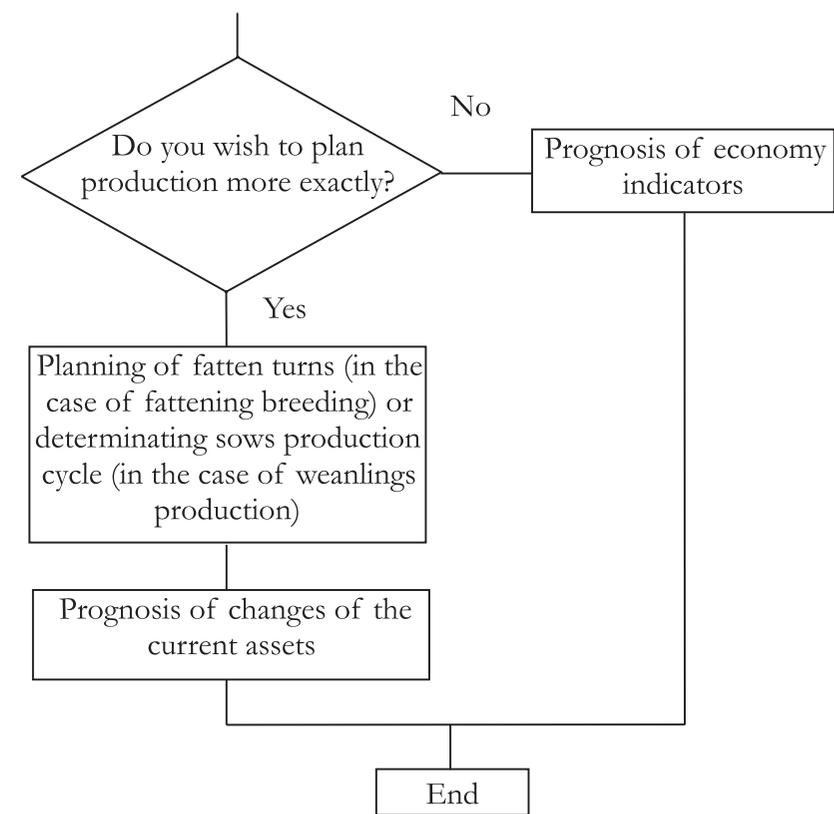


Figure B4. Follow-up of the figure B1
Joonis B4. Joonise B1 järg

APPENDIX C

Examples program windows from complex pig farming program Komplekse seakasvatuse programmi tööakende näited

Söödakoostis	Kogus päevas g	3000
Corajahu	2628	100
Kesk-nuunik 12-20%	267	100
	0	100
	0	100
	0	100
	0	100
	0	100
	0	100
	0	100
	0	100
	0	100

	Ratsiooni on	Norm	Erinevus
Külvainet max g	2493	2552	-58.9
Metabol. en. MJ	36.9	36.2	0.2
Proteiin g	401.2	401.2	0.0
Lüsiin g	26.3	17.3	3.9
S-aminohap. g	13.1	10.1	3.0
Kaltsium g	13.8	14.4	-0.6
Fosfor g	14.8	11.5	3.2
Kaalium g	13.4	5.7	7.6
Naatrium g	2.7	2.8	-0.1
Raud mg	206.8	115.8	91.0
Karotiin mg	25.8	11.5	14.8
E-vitamiin mg	124.0	43.4	80.6
B4-vitamiin g	2.9	1.7	1.1
B12-vitamiin µg	37.3	14.4	22.9
Päevase ratsiooni maksumus EEK			6.8

Figure C1. Program window for composing feed rations
Joonis C1. Söödaratsiooni koostamisaken

Mõneregularid arvutused	Majandusnäitajate prognoos	Aruanded ja võrdlusnäitajad
KULUTUSTE PROGNOOS AASTAS		
Ostupõraste arv	751	
Veevajadus	1207.50 m ³	
Alloppainvajadus	0.00 tonni	
Elektrenergia tarbimine	0.0 kWh	
Kütuste tarbimine	0.00 m ³	
Lauda ventilatsioon, kütte	8.25 tuh. EEK	
Praktise seeneridus	0.00 tuh. EEK	
Veterinaarsed teenused, medikamentid ja lauda hügieen	16.50 tuh. EEK	
Lisakuludused	12.75 tuh. EEK	
Söödakogused kogu karja kohta	Söödakogused päevas	
Söödakulu ruumaperioodil	301.8 kilogrammi sea kohta	
TOODANGI PROGNOOS AASTAS		
Sead eluskaalus	73.87 tonni	
Liha tootmisel	51.71 tonni	
Sõnnikukogus	492.45 tonni	
Müügilõpõraste arv	0	
Prakteerimiste arv	0	
Prakteeritute arv	0	
HEKSMISE TÖÖAJAKULU PROGNOOS		
Tööajakulu päevas	110.9 minutit	
Tööajakulu ruumaperioodil	271.7 tundi	
Tööajakulu seasta	679.3 tundi	

Figure C2. Program window for prognosticated production indicators
Joonis C2. Programmiaken prognoositud tootmisnäitajatega

APPENDIX D

Example code from complex pig farming program Komplekse seakasvatuse programmi koodi näide

```

*****
PROCEDURE rahkontr
*****
IF !_stop#2
IF !USED("lkvara")
USE alltrim(ketas)+"\taltark1\loomkasv\seakasv"+"baas"+"lkvara" in 0
ENDIF
SELECT lkvara
SET ORDER TO TAG nad
SET RELATION TO nad INTO tabel
LOCATE for abs(lkvara.Traha)#lkvara.Traha
IF found()
GO top
CALCULATE min(lkvara.Traha) to jm
GO top
LOCATE for lkvara.Traha=jm
IF found()
jum=lkvara.nad
jrm=lkvara.Traha
ENDIF
GO top
LOCATE for abs(lkvara.Traha)#lkvara.Traha
IF found()
ju=lkvara.nad
jr=lkvara.Traha
WAIT window alltrim(str(ju))+" nädalal tekib raha puudujääk "+alltr
im(str(abs(jr),5,1))+" tuh. EEK!";
+chr(13)+alltrim(str(jum))+" nädalal tekib suurim raha puudujääk
"+"alltrim(str(abs(jrm),5,1))+" tuh. EEK!" timeout kest
cMessageTitle ='Tootmise planeerimine'
cMessageText = 'Kas suurendada seakasvatuse alustamiseks';
+chr(13)+'eraldatud rahasummat?'
nDialogType = 4 + 32 + 0
nAnswer = MESSAGEBOX(cMessageText, nDialogType, cMessag-
eTitle)

```

```

        IF nAnswer = 6 && Yes
            _stop=1
        ELSE
            _stop=2
        ENDIF
    ENDIF
ENDIF
RETURN
*****
PROCEDURE tabelid
*****
ON key label 'rightmouse' do naitabel
IF !USED('sigafail')
    USE (alltrim(ketas)+'\taltark1\ndata\sigadata\sigafail.dbf') in 0
ENDIF
DEFINE window brtab from 0,0 to 30,130;
    font 'arial' 8;
    close;
    float;
    color scheme 10
SELECT sigafail
BROWSE window brtab font 'arial', 8;
    title 'Seakasvatusprogrammi tabelite nimekiri';
    nodelete nomenu rest
Release window brtab
ON key label 'rightmouse'
sul_t('sigafail')
RETURN
*****
FUNC uu_a
*****
PARA kuhu,kust
SELECT(kuhu)
Dele all
PACK
APPEND from(kust)
GO top
ENDFUNC
*****

```

```

FUNC sul_t
*****
    PARA tanm
    SET safety off
    IF USED(tanm)
        SELECT (tanm)
        set filter to
        Delete tag all
        USE
    ENDIF
    SET safety on
ENDFUNC
*****
PROCEDURE soot_aru
*****
SELECT nouid
INDEX on nouid tag nouid additive
set order to nouid
select sootvali
SET RELATION TO nouid INTO nouid
CREATE CURSOR st_aru (soot C(30),kogus n(10,1),prn I;
nouid I,ssegu c(20),skogus n(10),etv_kok N(10,1),etv_mn c(20))
select st_aru
scan
    select sootvali
    locate for alltrim(sootvali.soot)=alltrim(st_aru.soot)
    if found()
        if sootvali.nkok#0
            funn=round((st_aru.kogus*1000)/sootvali.nkok,1)
        endif
        replace st_aru.nouid with sootvali.nouid,st_aru.etv_kok;
        with funn,st_aru.etv_mn with nouid.nou_nimios
    endif
select st_aru
endscan
RETURN
*****

```

APPENDIX E

Example program code for forecasting of economic indicators

Majandusnäitajate prognoosimise programmi koodi näide

```
Maple V Release 4 - [variant1_tran_sea.mws - Student Edition]
File Edit View Insert Format Options Window Help
STUDENT > # Seakasvatusega seotud kordajad
STUDENT > # Sigade arvu tegur
STUDENT > a1:=koht*etal:
STUDENT > # Seakohtade arvu tegur
STUDENT > a2:=a1/etal:
STUDENT > # Sigade muugitulu tegur
STUDENT > a3:=a1*qs1*hsi*(1-F1/2):
STUDENT > # Pörsaste ostukulude tegur
STUDENT > a4:=a1*hp*(1+F1/2):
STUDENT > # Ostusootade tegur
STUDENT > a5:=a1*qo*ho:
STUDENT > # Pidauskulude tegur
STUDENT > a6:=a1*psi:
STUDENT > # Sigade arv
STUDENT > ns:=a1:
STUDENT > # Omasoot sigadele
STUDENT > TSS:=qv*rk*ns:
STUDENT > # Sissetulek sigade muugist
STUDENT > TSI1:=a3:
STUDENT > # Tulu sigade muugist
STUDENT > TSI:=-TSI1-TSS:
STUDENT > # Kogutulu viljast ja sigadest
STUDENT > T:=-T+TSI:
STUDENT > # Seakasvatuse kulude komponendid
STUDENT > KS1:=(a4+a5+a6)*tt:
STUDENT > KS1:=KS1+a1*sit*rk*(gsit+0.05642*sqrt(tt*wk/beta)*fsit*qa*ka)*
tt*(1+omega):
STUDENT > KS2:=-a2*tt*(c1*ue+c4*ut+a2*tt*(c2*ue+c5*ut)+(c3*ue+c6*ut)*(a2*
tt)^2):
STUDENT > KS34:=-i*a2*tt*(c1+c4+(c2+c5)*a2*tt+(c3+c6)*(a2*tt)^2)+0.1482*P
S*(1+d)*d1*(c7+(c8+c9*a2*tt)*a2*tt):
STUDENT > # Seakasvatuse kulud
STUDENT > KSI:=KS1+KS2+KS34:
```