

Energy Management of Future Farms

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Abstract. Energy management in agriculture will be of current interest in the near future. Modern agriculture is run by fossil energy and it is unclear how this energy input will be replaced with renewable energy. The year 2008 gave some foretaste how rapidly and how much energy price can rise. Energy saving and exploiting farm's own energy resources are ways to reduce dependency on oil. Nitrogen fertilizer is the most significant energy input in plant production because ammonia manufacturing is very energy intensive. Crop rotations including legumes, green fertilization, and better manure management are measures to replace synthetic nitrogen. Traditional work chains can be replaced with more energy efficient operations. Direct drilling and grain preservation methods other than drying are good examples. Animal housing requirements for inside temperature and air quality define the demand for heating and ventilation. Along with milking and milk cooling, they are the most significant energy inputs in animal production. Animal welfare has to be respected always; however, by means of heat recovery and biogas production it is possible to save energy and exploit energy from manure. Energy should not be considered as a separate question; on the contrary, a farm has to be considered as a whole and as a part of the rest of the society. Better energy management and plant nutrient recycling are combined issues and require more comprehensive approach than it has been the case.

Key words: Energy, management, bio energy, agriculture

INTRODUCTION

World energy consumption is increasing and the increase is based on fossil energy availability. At the same time fossil energy resources are diminishing and the wide use of fossil energy has already caused global warming. This has led to discussions and usage of bio energy and renewable energy. At the moment the share of renewable energy is about 13% of the whole energy supply (IEAE Key world energy statistics, 2008). Renewable and bio energy usage and research has been favoured in many countries, for instance the EU has decided to stop global warming to two degrees and the share of renewable energy in 2020 should be 20%.

Fossil energy resources are decreasing, which means that their prices will be increasing and in the future there will be shortage of fossil energy. This means changes also in agricultural production. Although agriculture uses a lot of fossil energy, it is at the moment in plant production energy positive, we get more energy out of production in the form of food and feed than we use in the production. In the future the farms must be more and more self-sufficient in energy usage. This means energy savings, better nutrient recycling and at the end the farm could be energy positive in the sense that besides food, feed and non-food it would also produce

energy. In energy savings new methods which consume less energy than old methods must be introduced. For instance direct drilling consumes less energy than conventional drilling and unheated cattle houses consume less energy than the heated houses.

Fig. 1 presents the usage of fields, crop yield and the usage of fertilizers during the years 1961–2008 (Faostat, 2010). During this period the world population has more than doubled, crop field area has remained almost the same, fertilizer use has become six-fold, and crop yield has doubled. From the picture the conclusion can be drawn, that world population has been nourished with an increasing usage of fertilizers. Some 94% of the energy consumed by the fertilizer industry is used for ammonia synthesis and fertilizer production consumes 1.2% of the world's total energy on an annual basis. Natural gas is the primary hydrocarbon feedstock used in ammonia synthesis from which almost all nitrogen fertilizers are derived. (Energy efficiency and CO₂ emissions in ammonia production.)

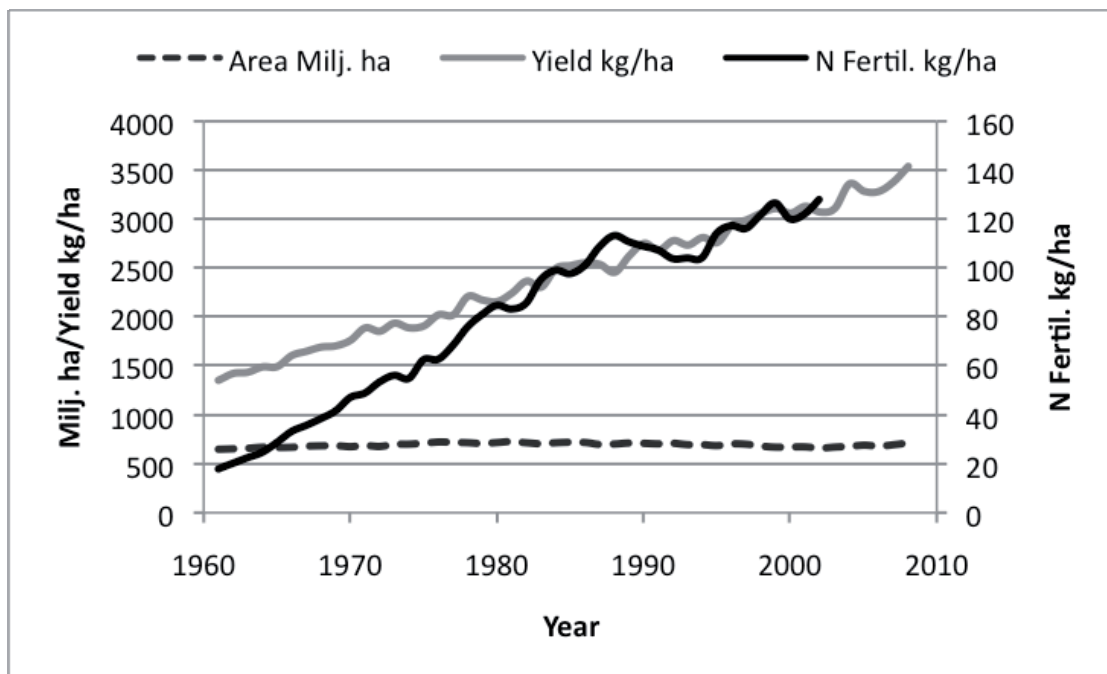


Fig. 1. World crop production and fertilizer use.

The increased food production hinges thus heavily on fossil fuels. World population is at the moment 6.8 billion and it is increasing so that in 2040 the estimation for world population is 9 billion (UN, 2004). This means that food production must increase in the future. This means increased crop field area and increased fertilizer production and possibilities for bio energy production decrease.

Bio energy has also negative environmental effects. During the bio fuel production fossil energy is used. For instance nitrogen fertilizer is mainly produced from fossil energy and its share in the inputs of field bio energy is in many cases dominating. Usage of fossil energy and fertilizers cause also emissions and when this is taken into account the effect of bio energy usage can be environmentally negative. Bio fuels are analyzed according to their energy efficiency, energy ratio and their GHG (Green House Gas) effect. GHG-analysis is normally calculated

using the IPCC methods (IPCC, 1996). When biomass is used for energy production, the energy used in the fuel production must be taken into account. This is often expressed as a net energy ratio (NER) (Farrel et al., 2006), which shows the ratio of output energy to input energy. A ratio of one means that the produced fuel includes as much energy as has been used in the production. The ratio should be over one in order to get some energy profit.

The energy used for bio fuel production can be divided into two parts, direct and indirect energy (Ortiz-Canavate & Hernanz, 1999). Direct energy includes the fuel and electricity used during the production. Indirect energy includes manufacturing energies, fertilizers, machines and buildings. For instance, in barley production in Finland the indirect energy forms the larger part of the energy consumption. One of the problems with indirect energy is that machine manufacturing energy figures are hard to get (Ahokas & Mikkola, 2007).

Fig. 2 shows an example of energy distribution between different categories. Fertilizer manufacturing (fertilizer + lime) consumes the most of the energy. In Finnish conditions the crop yield has to be dried to preserve the harvest and drying consumes large amount of energy. Because weather conditions, crop moisture content and soil conditions vary between years, the figures are not constant but change over years. The NER value is in Finland for rapeseed and barley production between 3 and 5 (Mikkola & Ahokas 2009). When emissions to atmosphere are considered N₂O emissions from the soil dominate. Nitrous oxide originates from nitrogen nutrients of soil and is rated to be 298 times more harmful than CO₂ (Forster et al., 2007). Emissions from fertilizer manufacturing take second place.

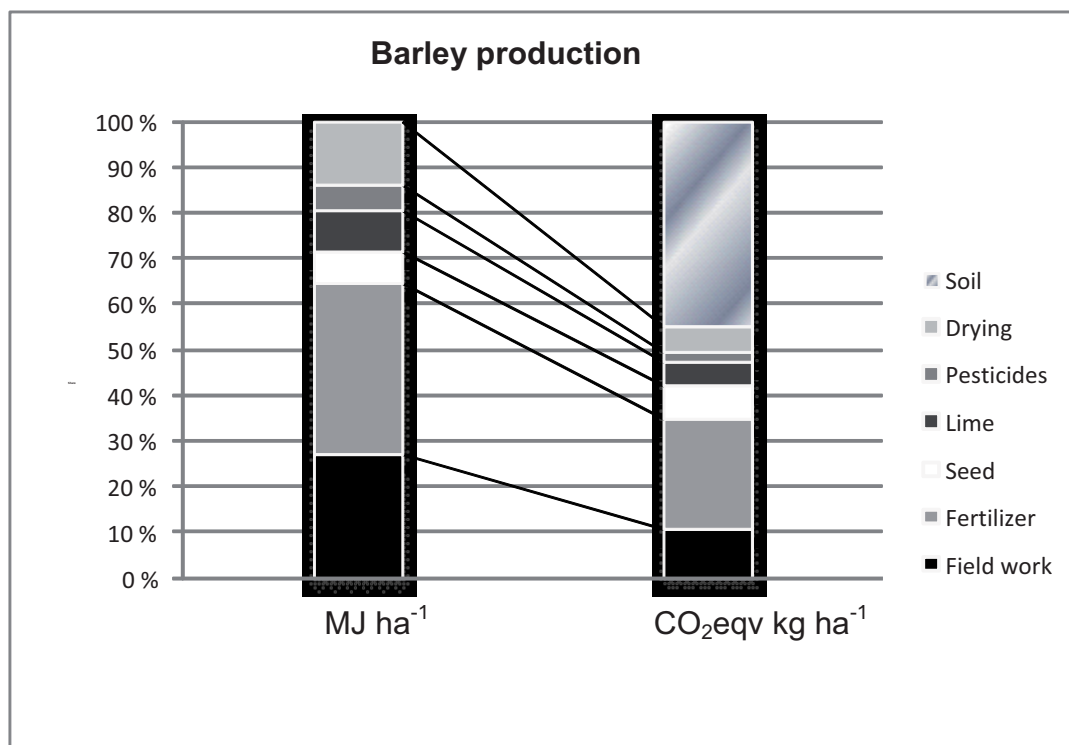


Fig. 2. Energy use in Barley production (11.8 MJ kg⁻¹) and CO₂ emissions (2,122 kg ha⁻¹).

So far energy has been a less important economic factor in agricultural production. Energy has been inexpensive and it has been well available. In the future energy questions will be more important and the farmers must first think about energy saving methods. Later on they could also produce energy for themselves and in the best case for the market.

POTENTIAL OF BIO ENERGY

Wolf et al. (2002) made a study of the potential land area for bio energy production. The study showed that 55% of the agricultural land area at the global level is needed for food production in the future (i.e. year 2050), if a high external input system of agriculture is applied and the remaining 45% can be used for biomass production. If a low external input system is used for food production, then no land area would be available for biomass production. Holm-Nielsen et al. (2006) concluded that by the year 2050 it will be possible to meet the world energy demand with 75-90 percent of all energy by renewable energy (bio energy, wind, hydro power, and solar energy) and bio energy alone can fulfil between 30-40 percent of the entire world energy need. Bio energy potential depends much on world population increase and fertilizer production. At the moment in many countries there is overproduction of agricultural products meaning that the possibilities for field bio energy production are good.

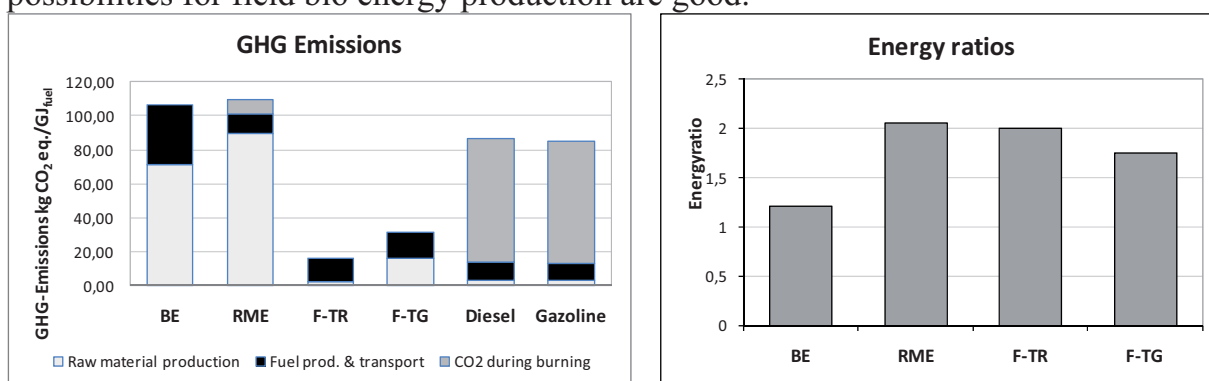


Fig. 3. Green House Gas emissions of fuels (BE = bioethanol, RME = rape methyl ester, F-TR = Fischer-Tropsch fuel made from wood residues, F-TG =Fischer-Tropsch fuel made from green canary grass, Diesel = fossil diesel fuel, Gazoline = fossil gazoline).

Liquid bio fuels

Bio fuels can be divided into two categories, the 1st generation and the 2nd generation bio fuels (BIOFRAC report). The 1st generation bio fuels are mainly conventional bio fuels produced in the traditional way and the 2nd generation fuels can better utilize the lignin and cellulose of biomaterials thus improving the bio fuel yield from the raw material. Fig. 3 shows that the 1st generation bio fuels have significantly higher emissions than the 2nd generation fuels in Finnish conditions (Mäkinen et al., 2006).

Ethanol production has the lowest energy ratio, near one, meaning that in ethanol production almost as much energy is used for production as the product has energy. Biodiesel (RME) and Fischer-Tropsch diesel have better energy ratios, the

ratio is near two. The energy ratio depends on the raw material, on the manufacturing system and also on how the residues from the production are utilized. For instance in ethanol production distiller's dried grain with soluble (DDGS) is produced and this can be utilized as feed for pigs.

Fig. 3 shows also GHG emissions for the same fuels and for two reference fuels, fossil diesel and gasoline (Mäkinen et al., 2006). Ethanol and biodiesel (RME) have higher GHG emissions than direct use of diesel or gasoline and in this sense the usage of these fuels is not so friendly from the environmental point of view. The usages of fossil fuels have lower GHG emissions than ethanol and RME. Fischer-Tropsch diesel, using forest residues or reed canary grass as raw material, has much lower GHG effect than ethanol or RME. The field bio energy has a problem with fertilizers. Because of fertilizing nitrogen oxide (N_2O) is generated in the soil and this has a global warming coefficient of 298 resulting in large emissions expressed in CO_2 equivalents. The analyses are in many cases done by allocating all the soil emissions to the produced plant. The soil causes emissions also without any agricultural production. When this so-called natural emission is subtracted from the total N_2O emissions, the situation of biofuels is much more favourable.

The USA and Brazil are dominating in fuel ethanol production. In 2007 their combined share of world production (50,000 mill. litres) was 88%. The USA was producing 50% and Brazil 38% (Annual World Ethanol Production, year 2007). The energy ratios vary from under 1 to about 8 (Macedo et al., 2008, Pimentel & Patzek, 2008) depending on raw material, production efficiency, and analysis boundaries. Macedo et al. (2008) report an energy ratio of 8.3–9.3 for ethanol production from sugar cane in Brazil and in 2020 they expect it to be 11.6 when surpluses are better utilized. Also the GHG effect of sugarcane ethanol was positive.

The EU sets for biofuels and bioliquids 35% GHG saving criteria and starting in 2017 the saving must be 50%. The directive gives detailed instructions for the GHG saving calculations. (EU Directive, 2009/28/EC)

Solid bio fuels

Solid bio fuels such as wood and straw are mainly used for direct burning but they also form the raw material basis for the 2nd generation fuels, when their lignin and cellulose can be dispersed and the hydrocarbon chains are broken and fermented. Efficiency in direct burning is good. Efficiency demands for heating boilers less than 300 kW are given in EN 303-5 standard (EN 303-5) and the classification starts from about 50% efficiency in the lowest class and boilers with the lowest power and ends at 82% efficiency in the highest class for 300 kW boilers. In district heating systems with large boilers the efficiency of energy production is high, but if only electric power is produced in power plants, the efficiency is poor due to the process. In combined heat and power production (CHP) the efficiency can be increased considerably and these types are favoured nowadays.

Good efficiencies with solid bio fuels can also be seen in their energy ratios. For solid biofuels the ratio is normally 14-30 and it is much higher than for liquid bio fuels, which have energy ratios of 1-6 (Venendaal et al., 1997).

In direct burning of biomass bio fuel characteristics vary considerably. Wood material is easy to use because of high density and low ash content. Straw materials are often hard to burn because their density is low and ash content is high. The straw ash has also corrosive substances and ash smelts easily in the furnace complicating burning. The furnaces have to be designed according to the fuel demands and it is hard to use several types of bio fuel in the same furnace.

Biogas

Waste biomaterial and biomass can be utilized for biogas production. When biogas is produced, the energy ratio, when calculated from the energy in the gas, is 2.5-5.0 (Tuomisto, 2006; Berglund & Börjesson, 2006). The energy ratio is high if the biogas can be used directly for heating. If electricity is produced with combustion engines and generators, energy ratio decreases considerably, because the efficiency of the electricity production is low. About 70% of the biogas energy is wasted if engine heat is not utilized. This means that in electricity production without heat utilization the energy ratio of biogas system is about one.

When green biomass is used for biogas production, the mass must be conserved after harvest for later use during winter, when energy demand is high. Besides this proper building, a reactor and gas storage must be built as well as investment in engine and generator is required in electricity production. This is a big investment and if not subsidized, the economy of biogas production will be poor.

Problems with bio fuels

Bio fuel usage is not as easy and trouble free as fossil fuel usage. Biogas plants as well as bio fuel furnaces need service. In electricity production from biogas with combustion engines, regular oil change, filter replacement and other necessary maintenance means must be used. In heat production with direct burning fuel acquisition, fuel charging and ash removal must be done. Compared to fossil fuels this means more maintenance work and also higher costs.

Modern combustion engines are made for sophisticated and homogenous fuels. Also emission values are measured with these fuels. Biofuels have often poorer quality and they are heterogeneous. This can introduce damages to the fuel system or to the engine and it can also increase emissions. The ability to use biofuels varies between engines and before usage the allowed biofuel concentration should be checked. Biofuels have special problems in cold climate. Biodiesel pouring point must be low enough in order to be able to use it. Ethanol has problems with cold starting and also with water in the fuel.

Nowadays fields are mostly used for food or feed production. Energy production differs from these requirements and for fuel production different types of plants should be used, so that the goal would be good energy productivity. Also the collection of biomass may differ from the normal agricultural production needing new harvesting technologies.

ENERGY SAVING IN AGRICULTURAL PRODUCTION

Energy saving is understood in most cases as a measure to save money and to improve economy. People have a low motivation to save energy if it does not improve their possibilities to consume money for other purposes in a relatively short period. Energy has been cheap and only peak oil prices in the 1970s and 2000s have really shaken people to save energy and to look for alternative energy sources.

Energy has a much wider role as a production factor in agriculture than pure energy costs show. Crude oil price reflects immediately to diesel and gasoline prices but also with a short delay to prices of coal, natural gas, nuclear power, and also the price of bio energy. This, for one, reflects the prices of fertilizers, fodder, transport, machines, etc. Modern agriculture is strongly dependent on the fossil energy input. Productivity in agriculture has been increased by replacing human and animal power with machines and technology powered with fossil fuels and electricity.

Energy saving measures usually focus on processes, actions or materials which require a major energy input to the system. This is understandable because significant savings can be gained only from targets which cover the main part of the total energy input. Energy analysis is a measure to identify major energy consumers. Energy use in plant and animal production and possibilities to save energy is considered in the following chapters.

CONCLUSIONS

In plant production, agrochemicals are responsible for half or three quarters of the total energy consumption. Agrochemicals mean in this case fertilizers, lime and pesticides. When the agrochemical group is split further into smaller parts, nitrogen manufacturing is the biggest energy consumer followed by lime and pesticides. Fig. 2 shows how agrochemicals dominate the energy input in plant production. In the case of Fig. 2, application rates for N, P and K were 80, 12 and 36 kg ha⁻¹.

Organic farming is a cultivation system which has to be managed without synthetic nitrogen and there are many measures which could also be utilized in traditional farming. Crop rotations including nitrogen fixing plants, green fertilization, catch crops and under sown crops, good manure management are examples which could be implemented in a wide scale to replace synthetic nitrogen. Känkänen (2001) has discussed versatile issues about these questions and concludes that there are many possible ways to apply biological nitrogen fixing in cereal production. However, it is difficult to express in figures how much these measures, alone or jointly, could cut the energy use.

In grassland cultivation, nitrogen is even more in focus than in cereal production because the share of nitrogen varies between 55-60% from the total energy input. Possibilities to save energy in milk and beef production are excellent, however, because traditional grassland species timothy, meadow fescue and tall fescue produce good yields in terms of mass and quality as mixtures with legumes (Nykänen et al., 2010; Kurki & Sormunen-Christian, 2010). Growing these mixtures requires sometimes more liming and contouring field surface because

plants do not stand low pH and standing water, but otherwise there should not be any special obstacle to use the mixtures.

Varied crop rotations and increased cultivation of legumes have also other advantages than energy saving. Perennial plants have a strong root system which increases porosity and humus content in soil. Soil structure improves. Plant diseases and insects are easier to control. Ecological diversity increases when monocultures are interrupted with varied crop rotations.

Agricultural machines also consume a lot of energy (Fig. 2). Direct drilling is a good example about how the traditional cultivation method with heavy primary and secondary tillage operations can be successfully replaced with one less energy consuming operation. Fuel requirement of the traditional work chain from ploughing to drilling is some 35 litres diesel per hectare while only seven litres is needed for direct drilling (Danfors, 1988). Energy demand for field operations is cut to 1-5 of the original energy demand. Besides energy saving, direct drilling reduces labour demand, decreases erosion problems and helps to control nutrient leaching. A similar new thinking is needed in other farm operations, too.

Energy consumption for grain drying is also high, depending on the harvest crop moisture content. Energy use could be decreased with other preservation methods and with improved grain dryer technology.

Animal production

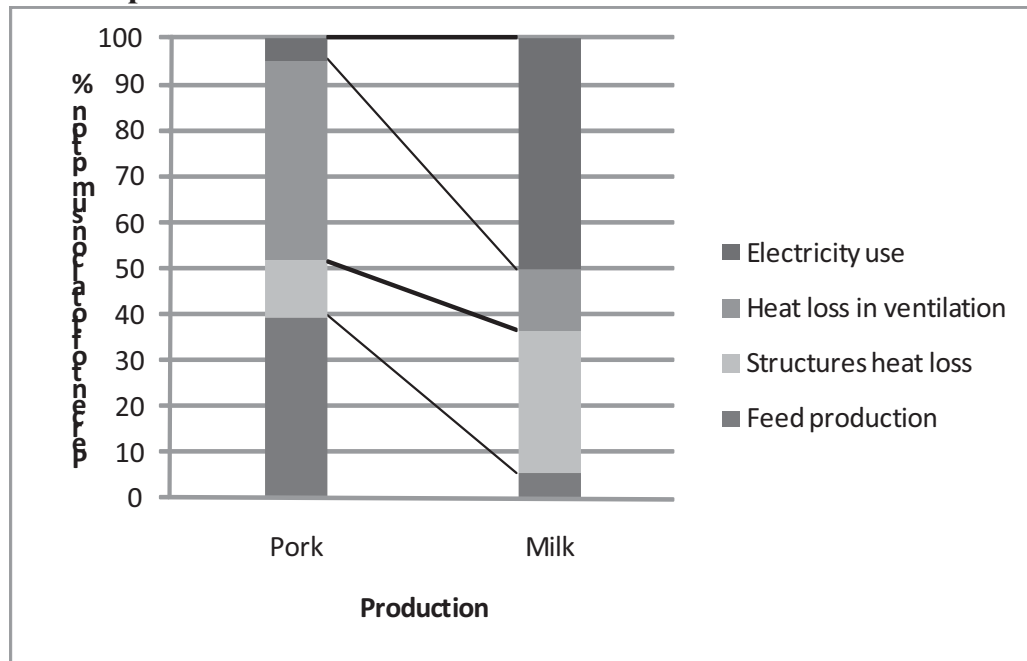


Fig. 4. Share of energy use in pork and milk production.

In animal production, plants produced in the fields are fed to animals. Main part of the products come from own farm, but, in addition, concentrates are bought to give the animals all the necessary nutrients. In animal production, the efficiency is lowered and the energy ratio is in most cases less than one, which means that production consumes more energy than what is used in the production (Mikkola & Ahokas, 2009). In borealis conditions, good shelters are needed for the animals,

which means extra energy needed for construction and running of the buildings. Fig. 4 shows the portions of energy consumption in pork and milk production (Mikkola & Ahokas, 2009). In pork production, the indoor temperature of the building must be rather high due to high heat losses. With heat recovery systems this could be decreased. In milk production the cows can be kept in cold cow houses without difficulties and this would remove the energy needed for heating the houses. Milk production consumes much electricity by milking and milk cooling. The efficiency can be improved for instance with milk cooling energy utilization.

DISCUSSION

Energy price and energy availability will probably have a fundamental impact on agriculture during the next decades. If there is not any good substitute for diesel oil having nearly the same properties and a reasonable price, agriculture will face big changes along with other production sectors. Increasing energy costs inflate also prices of other productive goods and especially the price of fertilizers. Year 2008 was a good lesson. Table 1 presents what happened to costs in Finnish agriculture from year 2006 to 2008. During that period fuel prices approximately doubled (Oil Prices, Statistical Review, BP).

Table 1. Costs of Finnish agriculture in 2006 and 2008 and the change of costs (Niemi & Ahlstedt, 2007; Niemi & Ahlstedt, 2009)

Cost	2006, mill. €	2008, mill. €	Change, %
Fertilizers and lime	212	333	+57
Animal fodder	340	437	+29
Energy	353	442	+25
Salaries and employer's obligations	245	468	+91
Machinery and equipment	661	728	+10
Buildings	335	378	+13
Intrest and rents	268	336	+25
Other costs	707	607	-14

Year 2008 showed that the market can be volatile and unpredictable. Together with rising input prices, prices of agricultural products rose fast as well. No economist had predicted such a rapid change. On the other hand, after that peak prices have recovered approximately to the same level where they were before.

Due to depleting oil resources it is high time to start adapting scanting of fuel supply. Farms which succeeded in cutting their dependence on external energy supply and have energy efficient processes are in a better position facing the increasing energy prices than farms which continue as if nothing has happened. Finnish farms consume a lot of energy but they have also such resources as wood, straw, and manure which can be used to generate energy. There is technology available to exploit these resources but the energy price has been so low up to now that it has not motivated the use of these resources. There is a strong possibility that

energy efficient cultivation methods and development of energy production systems on farm level will be in focus in agricultural engineering research.

Energy question should be assessed together with plant nutrient supply, crop rotations, and animal production because good energy efficiency can be achieved only by fitting these sectors optimally together. The idea is not to return to self-sufficiency and the agrarian society, but there are certainly lessons to be learned from the past centuries and also from the practice of organic agriculture.

CONCLUSIONS

At the moment part of the field area can be used for bio energy production and part of fossil energy usage can be substituted with bio fuels. In the future the fields are needed more and more for food and feed production because world population is increasing and the availability of fertilizers can be reduced. Both in animal and plant production by-products (manure, straw, waste) are produced, which could be better utilized in the future for energy and nutrient production.

More effort would be needed to demonstrate energy efficient crop rotations, nutrient recycling, technologies for the use of renewable energy, as well as energy saving technologies in plant and animal production. Tests should be made more in farm conditions because promising tests in laboratories do not always work in practical conditions. Farm-scale tests would also give information about the economy of the new technology.

Energy and emission analyses can be conducted in different ways and the basic data for the calculations vary. This is especially so with indirect energy calculations. For these analyses it is necessary to have a standardized method and common source data.

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