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Proceedings from NJF-seminar No. 327
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DARCOF

Danish Research Centre for Organic Farming

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DARCOF Report no. 3
Printed from www.foejo.dk

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Danish Research Centre for Organic Farming 2002

DARCOF Report No. 3/2002

Urban Areas – Rural Areas and Recycling
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Proceedings from NJF-seminar No. 303
Copenhagen, Denmark, 20-21 August 2001

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Layout
Cover: Enggaardens Tegnestue
Content: Grethe Hansen, DARCOF

Photos at cover: Sine Claudell and Susanne W. Laursen

Print: DigiSource A/S, Viborg, Denmark

Paper: 90 g. Cyklus print

Paginated pages: 190

First published: September 2002

Publisher: Danish Research Centre for Organic Agriculture, DARCOF

ISSN: 1399-915X

Price: 100 DKK incl. consignment

To be bought at
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DK-8830 Tjele

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Impact of Production Method and Production Area on Energy Balance of Rye Consumed in Helsinki

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Abstract

The aim of the study was to find determine the impact of production method and production area when evaluating energy consumption in life-cycle analysis of rye. It is assumed that transportation and fertilizer production are the most important energy consumption factors in grain production. This study attempts to find out the importance of all the different factors which are involved in the energy consumption in rye production. The object of study is rye consumed in Helsinki.

The results of the study show that production of fertilizers is the biggest factor in the rye production chain. Therefore organic rye tillage is not as intensive in energy usage as conventional practices. The difference between these two alternatives is almost 50% when rye is cultivated in Finland. The third alternative in the study was rye produced in Germany, as part of the rye consumed in Finland is imported. The German rye was clearly better than the Finnish one when the criterion is energy consumption, but not as good as Finnish organic rye. The energy consumed for transportation does not play a big role in total energy consumption of rye consumed in Helsinki. For that reason and due to good cultivation conditions in Germany, the need of energy is higher per unit of rye produced in Finland than for imported rye.

We can see that in Finland the use of energy input in agriculture should be improved. The biggest opportunity for this is the movement for organic cultivation. On the other hand, the use of non-renewable energy sources should be replaced by the use of renewable energy production, for example in grain drying. Then the negative effects of energy use would be decreased and Finnish rye could be more competitive measured by energy accounting when compared to other production possibilities.

Index words
crop, ecological economics, energy balance, food system, rye

Introduction

Agriculture and food production industry have been very important factors in societies like Finland which have been concerned about for example the availability of food due to a crisis because of a political and geographical situation. For that reason the food sector has been largely regulated and domestic grain production has been a truism. Such a policy has been very expensive and caused overproduction problems (Spedding 1996, 17).

When Finland joined to the European Union also agriculture had to face the competition because it became possible to import grain. The globalisation of the food sector is a reality. Because of that the importance of price of grain production is usually very high. It is also quite easy to move food supplies from on country to another.

The global food system[1] tends to be very energy-intensive. One important energy user is transportation which uses mainly fossil fuels. There are many arguments for improving the food system to use less energy, but the main reason is to avoid negative environmental effects caused by fossil energy usage.

Because of decreasing food transportation a localised food system could be one chance to save energy. Another important possibility is organic farming. Conventional agriculture uses lots of nitrogen fertilizers whose production process requires lots of energy. In organic farming there is no need for fertilizers.

Today the energy efficiency of agriculture is not as good as before the modern technology. Although the total production per field unit has increased, farmers use more energy per unit of output than earlier (see Georgescu-Roegen 1972, Martinez-Alier 1990, Tiezzi et al. 1991). The aim of this paper is to determine the importance of the different factors when evaluating energy consumption of rye production chain and topoint out how these factors vary between different production possibilities of rye. The object of the study is rye consumed in Helsinki area.

[1] The concept of food system covers all activities linked to food production, processing and consumption. So it also has cultural, food safety and environmental dimensions.

Theoretical background

Ecological economics is a paradigm which concentrates on the relation of ecosystems and economic systems. It attempts to go beyond the limits of traditional sciences and with this synthesis to find some new insights to solve the problems. The main target is the problem, not the method. (Costanza et al. 1991, 3-6.) Ecological economics gives an opportunity to logical analysis on different interactions between societies and ecosystems (Faber et al. 1996, 12) and the main physical connections and dependence inside the economy (Christensen 1991, 80).

The main aim of an economic-ecological analysis is to develop the tools and institutions of environmental management and policy to meet the goals like economic efficiency, environmental quality, wealth of ecosystems and sustainability (Bergh 1996, 84).

A common way to approach a problem in ecological economy is **entropy.** Entropy is an index for non-useful energy in a thermodynamic system in a given moment (Georgescu-Roegen 1972, 4.) The demand of energy is always more than supply in every biological or economical process. That means that the entropy, the stock of non-useful energy has to increase (Georgescu-Roegen 1970, 54-55).

All changes in the nature or the economy require energy. Entropy is a very useful variable to describe all kinds of processes but especially the functions of economy. It is an important tool when one studies resource use and flows in an economy and their impacts on environment. The variable can be used when we describe the world, specify the problems, or try to find a common answer for problems which are linked with interactions between a economy and the nature. (Faber et al. 1996, 95-96.)

The qualitative change of energy is substantial when we study the energy use of economy. This variable can be observed by **thermodynamics**. According to the first law of thermodynamics, energy never disappears, it only changes its form (Phillipson 1970, 3). The second law, the law of entropy means that in a closed system entropy increases all the time (Georgescu-Roegen 1972, 7-8). In the economy, this shows as useful energy or raw materials turned into a non-useful form which decreases the stock of natural resources and the stability of systems (Ayres 1978, 271).

With the use of energy it is possible to recycle materials. There is also a flow of energy from the sun to the earth so, in principle, the material entropy would have not to increase. But our technology is heavily dependent on non-renewable energy sources which are decreasing according to the entropy law. So, in practice, both material and energy entropy are strongly increasing all the time.

All production systems work by the entropy law (Georgescu-Roegen 1971, 191-194). When one takes a look at materials and energy in the process the economy can be seen as a system which modifies natural resources to products and services. By physical meaning resources do not disappear. They only satisfy some human needs before altering to waste. (Ayres 1978, 289.) For example, the food system is an open system. Energy and materials flow through it. Thus, the main thing is how much and what kind of energy we need to use to get one unit of food for consumption.

Eco-efficiency is an action strategy based on quantitative input-output ratios. The aim is to maximize the efficiency of material and energy use by minimizing emissions and the use of raw materials per output unit. However, eco-efficiency alone does not give any definitions for sustainable consumption. There is still a possibility for absolute growth of production. (OECD 1997, 23-24.) One problem is also on the aggregation of different inputs and outputs together (Reijenders 1998, 16, Cleveland and Ruth 1999, 35 and 42-43). Only a material balance or energy consumption of a certain product gives no information from its total impact to environment or economic sustainability.

In this paper, the point is energy consumption of a product during its life-cycle. The solar energy utilized in photosynthesis is marked off. It is assumed that all other energy has been produced by non-renewable energy sources because that is practically true in Finnish agriculture at the moment. Therefore, we can aggregate all energy inputs used in the definite part of the food system and calculate the total energy consumption for one unit of output.

With a viewpoint of thermodynamics and biology we can see that we could minimize the growth of entropy by saving resources. For that, according to Tiezzi et al. (1991, 459), the food supply sector has to move towards decentraliz small-scale organisations which use renewable resources instead of non-renewable more than now. This is based on the thought that modern food industry is unable to use low intensity energy sources. Another reason is short transportation distances in a local food system.

The use of non-renewable natural resources is also dependent on other services of nature like the ecosystem's ability to manage emissions (Daly 1990, 4). At the moment, for example, the use of oil causes serious environmental problems like global warming, acidification, and particle emissions. Ecosystems probably cannot compensate for these emissions because of the large-scale oil use on the globe.

For sustainable development we should develop technologies which increase productivity of resources but do not increase the total use of resources (Daly 1990, 5). In agriculture this means that a grain unit should be produced by as few resources as possible. The good energy efficiency of production is very important because with modern technology almost all energy used is produced by non-renewable natural resources.

Energy consumption of rye production and transportation

In this study, there are three different possibilities for producing the rye consumed in Helsinki. The consumption place was chosen because a large part of Finnish people live on the southern coast and in the future still more people will probably live within urban food systems far away from food production areas. This underlines the importance of taking into consideration the urban areas when calculating the total energy consumption of food sector.

In this study, possible rye production scenarios are:

1. Organic farming in Finland
2. Conventional farming in Finland
3. Conventional farming in Germany

By studying these possibilities we can find the differences in energy consumption which are dependent on a production method and a geographical site of production. The study focuses on production of direct inputs, cultivation work, and transportation. The energy consumption of energy has not been observed here. The food chain ends when rye has been delivered to a mill near Helsinki. Bread processing is not included in this study.

The yield in different scenarios is the average rye yield per hectare in the years 1997-1999 (FAO 1999, 28). In Germany yields are about twice as high as in Finland and the possibility of crop failure is much smaller. In organic farming rye yields are about 30% smaller than in conventional farming (Maaseutukeskusten liitto 2000, 7). The yields used here are 1548 kg/ha for organic farming and 2211 kg/ha for conventional farming in Finland. In Germany the mean yield is 5259 kg/ha.

The cultivation practices are mainly same in every scenario. There is some variation which can be seen in table 1. Only the fuel consumption has been observed, other factors like use of lubricants are the same and quite trivial in every scenario.

In organic farming the preceding plant collects nitrogen from atmosphere and that can be used as fertilization for rye. Therefore, we have to take a part of the energy consumption of the tillage and add it to the rye calculations. This means that we add half the energy consumption of the preceding plant seeding and a consumption of hay cutting to the energy need of rye tillage. The difference between organic and conventional rye cultivation practice is 7,3 l/ha meaning that organic farming uses more energy. The energy demand of plant protection is the same for both alternatives. The total energy consumption in cultivation practices of organic rye tillage in Finland was calculated to be **77,9 l/ha.**

Table 1 The fuel use in conventional cultivation practices in Finland and in Germany

Finland	l/ha	**Germany**	l/ha
Ploughing	25,1	Ploughing	25,5
Cultivation*2	12,2	Cultivation 1	5,9
		Cultivation 2	7,8
Seeding + fertilizing	3,6	Seeding	3,3
Fertilizing	1,6	Fertilizing*2	6,9
Pesticide spraying*2	3,6	Pesticide spraying	10,9
Harvesting	13,1	Harvesting	16,0
Straw boling	2,9	Straw boling	9,1
Straw transportation	7,0	Straw transportation	8,6
Grain transportation (1 km)	1,5	Grain transportation (4 km)	5,6
		Ploughing *2	24,7
Total	**70,6**	Total	**124,3**

Source: Palonen & Oksanen, 1993

Table 2 The fertilizer usage and the sum of nutrients per hectare in conventional rye tillage

	Pellon Y7 (kg)	Suomensalpietari (kg)	**Nutrients (kg)/hectare**
Finland	214	162	70 N, 15 P, 28 K
Germany	343	204	98 N, 24 P, 44 K

Fertilizer manufacturing uses energy 15200 MJ/t (Pellon Y7) and 19200 MJ/t (Suomensalpietari)[2]. These two fertilizers are typically used in rye tillage in Finland and it is assumed that the same kind of fertilitzers are used in Germany. The total energy consumption includes fertilizers' life-cycle energy demand when the product is packed in a factory.

Nutrient use numbers in table 2 are from international statistics of fertilizer use (IFA et al. 1999) with some corrections resulting from the actual support system in Finland. Based on the calculated fertilizer usage numbers we get the energy demand per hectare **6400 MJ** in Finland and **9000 MJ** in Germany.

[2] Notification 14.6.2000. Anna Ilomäki, Kemira Engineering Ltd.

In Finland, there is no energy usage information available from **pesticide manufacturing.** Producers do not report any exact numbers to importers. In this study, the estimate is 360 MJ per kg effective material based on calculations of the Finnish Environmental Institute.[3] The use of pesticides per hectare in conventional grain tillage is 2.6 kg in Germany (Hoevenagel et al. 1999 ref. Oskam et al. 1997, 13) and 1.1 kg in Finland (based on total sale numbers). So, the energy demand per conventional cultivated rye hectare is **396 MJ** in Finland and **936 MJ** in Germany.

Grain has to be dried to acceptable moisture (15%). In Germany there is no need for that (Palonen and Oksanen 1993, 40) but because of the weather conditions in Finland we usu-

[3] Notification 6.6 2000. Juha Grönroos, Finnish Environmental Institute.

ally have to use energy for drying. In an average year, the energy demand of **grain drying** is about **1 MJ** per kg when the drier is oil heated like most dryers in Finland.

In this study, **transportation** covers all grain and fertilizer transportation outside the farm. **Loading and unloading** covers only the work done in harbours because it is the only loading variable differing between the scenarios. The transportation chains have been randomly chosen so that the distances and routes are typical for every scenario. The mill has been located at Hyvinkää, which is one of the largest mills near Helsinki. For simplicity all transportation variables which are the same in each scenario have been left out. The total road transportation distance for Finnish rye calculated in this study is 120 km. German rye travels 320 km on road and 1060 km on sea. The total energy consumption is then **0.07 MJ** per kg for a Finnish rye and **0.44 MJ** per kg for the German alternative. Loading and unloading at a harbour uses further **0.02 MJ** energy per kg when importing foreign grain. A fertilizer transportation consumes 0.09 MJ per kg in both countries which means **0.02 MJ** in Finland and **0.01 MJ** in Germany per one kg of rye product.

Results and conclusions

The summary of energy consumption per one kg of rye product in each scenario is presented in table 3.

Table 3 Energy consumption (MJ) per one kg rye product of different alternatives

	Organic (FIN)	Convent. (FIN)	Convent. (GER)
Tractor fuels	1.4	0.9	0.7
Harvesting	0.4	0.2	0.2
Fertilizers	0	2.9	1.7
Pesticides	0	0.2	0.2
Grain drying	1	1	0
Transportation	0.07	0.09	0.45
Loading & unload.[a]	0	0	0.02
Total	**2.87**	**5.29**	**3.27**

[a] Only in harbours

Based on the results of this study, we find that the Finnish organic rye consumes less energy per one kg of rye produced. The German rye consumes about 14% more and the Finnish conventional rye wholly 84% more energy than the best alternative. The organic rye tillage demands more tractor fuel than the conventional one but manufacturing of fertilizers and pesticides is so energy-intensive that organic tillage uses less energy in total. The need of grain drying weighs a lot in Finnish alternatives. The energy need of grain transportation is quite small.

For the reliability of the results we can change some of the presumptions. According to calculations these results are not sensitive to changes of variables. In a good year, Finnish rye is more competitive with German rye than the results show, but because of variability of climate conditions the long-time average yield is quite low in Finland. In Germany yield is quite steady year after year. The fertilization rate could change yields in Finland but it also depends on weather conditions. In a suitable year there is no or little need for grain drying, but this is quite unusual. Changes of transportation distances within production country affect energy consumption by only a few per cent in each scenario.

In all, these changes may reduce differences of energy consumption between alternatives, but in the long run the sequence of compared scenarios does not change with technology and cultivation methods of rye today.

The results show that organic farming uses less energy than conventional tillage on rye production. Another important and surprisingly clear point is that transportation of grain uses quite little energy compared to, for example, grain drying. That is the reason why Finnish rye production cannot compete with the Central-European rye production in energy efficiency, assuming that they have the same production method.

Most of the energy in conventional rye tillage is used for fertilizer manufacturing. This is caused by a high-energy demand of nitrogen production. Therefore, also the production methods of conventional farming could be improved for example by using different natural nitrogen fertilization methods.

Because of its geography, Finnish agriculture has an unfavourable situation when compared with more southern areas. The energy needs of grain drying are high and it cannot be compensated in any way given the production method is same as in Germany. If energy for grain dryers could be produced by renewable energy sources, its weight on energy consumption calculations could be smaller because of decreasing environmental effects. This is a great challenge for organic and conventional farming in Finland in the future.

For the Finnish agriculture, the results of the study give support to change a large part of the rye production to an organic tillage system. Probably there is no possibility of effectively decreasing energy consumption of conventional rye tillage the actual technology and cultivation methods. The main problem is a low yield per hectare which causes energy consumption per one kg produced rye relatively high. The cultivation methods themselves are already at least as energy efficient per cultivated hectare as in Germany.

From the point of view of energy consumption it would be reasonable to produce only organic rye in Finland. Because of lower yields the need of rye import would then be higher than now. Economically, however, it is impossible because of the structure of the actual support system, and also the quality of rye could be a problem at time. But in the future negative effects of energy use will be more actual while on the other hand, the price of will probably energy be higher than now. Then there can be some difficulties to finding reasons for rye tillage in Finland with high need of expensive and imported energy inputs. Now it would be very important to give some attention to energy use of agriculture and get a leading position for energy efficient methods and technology. That would be one reason to keep the agriculture alive in the north because it has also many positive effects to landscape, regional economies, ecosystems and peoples of rural areas. Money may not be the only argument when we decide what is the future of agriculture in Finland.

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