

On-farm fossil energy use

Two comparisons between organic and conventional farming systems

Tommy Dalgaard examines energy use under two contrasting agricultural enterprises, arable and dairy, in Denmark

Agricultural energy use is defined by the United Nations Food and Agriculture (FAO) as the net fossil energy measured in joules used for production of agricultural products until they leave the farm.

Energy used on farms can be divided into two forms, direct and indirect. Direct energy is the energy used that can be described directly in energy units, thus diesel fuel, lubricants and electricity are in this category. Indirect energy is the energy used in the agricultural production system that cannot be described directly in energy units, such as fertilisers, pesticides and machinery, *i.e.* any item manufactured elsewhere but used on the farm.

This article examines two contrasting agricultural enterprises, arable and dairy, and compares the energy use under organic and conventional farming methodologies.

Dairy: milk production

This example considered the energy balances involved in milk production. The calculations were based on organic and conventional management over one year of a single Holstein Friesian milking cow. The organic ration included more roughage and grain than the conventional ration, and the energy used to produce these rations was assumed to be produced on-farm. However, the conventional diet did include more bought-in concentrates.

The resulting energy balance, which compares energy used per milk yield in organic and conventional dairy farming, is shown in Table 1. Due particularly to the low energy grassland grazing system and a lower import of energetically-expensive concentrates, the total energy used per kilogram of milk produced was lower in organic than in the conventional dairy farm.

Arable: barley grain production

In the second example, conventionally and organically grown spring barley was produced on an irrigated, sandy soil in Denmark. The type and number of field operations were similar between the two systems, except that the organic system, according to Danish regulations for organic farming, used mechanical weed control, and no pesticides, and spread slurry instead of the synthetic fertilisers

used in the conventional system.

The resulting energy balance showed that less energy was used to produce a kilogram of organic barley than a kilogram of conventional spring barley (Table 2). However, this was not the full picture. The organic system used 28% more direct energy than the conventional system. This was because mechanical weed control and spreading animal manures is heavy work and resulted in a higher fuel consumption than the lighter work of applying pesticides and synthetic fertilisers in the conventional example.

The indirect energy use, though, was substantially higher in the conventional than in the organic example. This is mainly because of the use of energy-expensive synthetic nitrogen fertilisers in the conventional example. In contrast, the use of pesticides involves the use of a comparatively small amount of energy (250 MJ/ha) and from an energy viewpoint is a good idea.

In conclusion, the total energy used to grow a hectare of organic spring barley was 35% lower than used to produce conventional spring barley on the same area. However, the organic yield was 28% lower, and therefore the energy used to produce a single kilogram of barley was only marginally lower for the organic than the conventional example. ■

Tommy Dalgaard
Senior Researcher
Danish Institute of Agricultural Sciences
email: tommy.dalgaard@agrsci.dk
website: www.agrsci.dk/jbs/tda/TDAhome
page2002/tommy.html

Table 1: Energy used (MJ) for milk production in Denmark for one milking cow in one year

| | Conventional | Organic |
|--------------------------|--------------|--------------|
| Feed ration: | | |
| Grazing | 3600 | 2300 |
| Grass silage | 2400 | 1500 |
| Whole crop silage | 1000 | 800 |
| Straw | 0 | 0 |
| Grain cereals | 2700 | 3300 |
| Imported concentrates | 7400 | 6700 |
| Straw bedding | 400 | 400 |
| Housing | 8000 | 8000 |
| Farm buildings | 2500 | 2500 |
| Total energy used | 28000 | 25600 |
| 1000 kg milk* | 9000 | 9000 |
| MJ/kg milk | 3.1 | 2.8 |

* Meat converted to milk on energy basis 1:10

Table 2: Energy accounts (MJ/ha) for spring barley grown on irrigated sandy soil in Denmark

| | Conventional | Organic |
|---------------------------|--------------|-------------|
| Direct energy | | |
| Fuel | 3400 | 5000 |
| Lubricants | 300 | 440 |
| Field irrigation | 1500 | 1500 |
| Drying | 500 | 360 |
| Subtotal | 5700 | 7300 |
| Indirect energy | | |
| Machinery | 1100 | 1600 |
| Fertilisers and lime | 6700 | 50 |
| Pesticides | 250 | 0 |
| Subtotal | 8050 | 1650 |
| Total energy use | 13750 | 8950 |
| Yield (kg/ha) | 5000 | 3600 |
| Energy efficiency (MJ/kg) | 2.8 | 2.5 |



PHOTO: KAREN SOEGGAARD

Left: Cattle and other ruminant animals are a major source of methane emissions, which along with carbon dioxide, is an important greenhouse gas.

Bottom right: Soil tillage affects soil microbial activity, which has consequences for emissions of carbon dioxide and nitrous oxide. However, these effects are currently not considered in national emission inventories.

Greenhouse gas emissions

... and

contributions from organic farming

Using fossil fuels in any form releases carbon dioxide that has been tied up in the fossilized plant matter for millions of years. This means that any human activity, including agriculture, that uses non-renewable energy contributes to greenhouse gas emissions. However, agriculture is responsible for emissions of other greenhouse gases.

Jørgen E. Olesen explains.

The global average surface temperature has increased over the 20th century by 0.6°C, and there is an increasing body of evidence to suggest that most of the warming over the last fifty years is due to human activities, particularly emissions of greenhouse gases. The global emissions of greenhouse gases are still increasing, and it is projected that this will cause an increase in the global mean temperature and a rise in sea level during the 21st century.

Data on greenhouse gas emissions are compiled by individual nations under the United Nations Framework Convention for Climate Change (UNFCCC). The continued negotiations under the UNFCCC have led to the Kyoto agreement, which commits industrialised signature countries to specified emissions reductions. In Denmark this has led the government to publish a strategy for reducing greenhouse gas emissions. The focus is mainly on CO₂ emissions from the energy sector, but at-

tention has also been put on methane and nitrous oxide emissions from agriculture.

In Denmark, agriculture contributes to 26% of the total greenhouse gas emissions. Of this 10% comes from direct fuel use, 17% from electricity and indirect energy use, 21% from methane emissions and 51% from nitrous oxide emissions. These estimates do not include changes in soil carbon.

Methane

Methane is formed by fermentation under anaerobic conditions, *i.e.* in situations without oxygen. Such conditions occur in the rumen of animals like cattle and sheep. The feeding practice employed on a farm has considerable influence on the amount of methane produced. In general, more concentrated feeds and a more intensive feeding system will give less methane per kilogram of product (milk or beef). The methane emissions from ruminant animals provide the largest contribution of methane from agriculture.

Methane is also emitted during storage of both liquid and solid manures, and results from anaerobic fermentation processes in stored manures. Anaerobic conditions are found in deep litter mats, and give rise to significant emissions of methane. During outdoor storage of solid manure, methane can be produced at high rates in the central parts of the heap. This methane can be partly oxidized to CO₂ during transport to the surface. The emissions of methane from anaerobically

stored slurry greatly increases with temperature. A porous surface cover on the stored slurry may reduce methane emissions by up to 40%, probably due to methane oxidation in the cover.

Nitrous oxide

Nitrous oxide is formed by the nitrification and denitrification processes, which convert ammonium to nitrate and nitrate to nitrogen gas (N₂), respectively. These processes occur in suitable environments with both aerobic and anaerobic phases. Nitrous oxide may escape to the atmosphere before being reduced to nitrogen. Formation of nitrous oxide occurs during microbial processes in manures, in the soil and in aquatic environments. The nitrous oxide emissions therefore depend on the amount of nitrogen being applied and recycled in the agroecosystem.

Very high nitrous oxide emission rates have been found for pig deep litter. Slurry stores are anaerobic, but nitrous oxide can be produced in porous surface covers such as natural surface crusts, straw or leca pebbles, while no nitrous oxide is emitted from uncovered slurry. Less than 1% of the total nitrogen is emitted as nitrous oxide from solid manure stores. Analyses of large datasets of nitrous oxide emissions from field applied manure and nitrogen fertilisers suggest that the emission from applied manure is relatively higher than from mineral fertilisers. However, the largest but also the least known quantity of emissions occur from nitrogen in crop residues and nitrogen lost by nitrate leaching.

Contributions from organic farming

Intensive animal production systems are characterised by dramatically increased flows of energy and nutrients compared to natural systems. Losses to the environment surrounding the agroecosystem are inevitable. Nitrogen cycling in organic farming systems are expected to be less 'leaky' due to a reduced intensity of nitrogen flows and a tighter nitrogen cycle. This will tend to reduce the emissions of nitrous oxide. However, in reality not all nitrogen sources contribute equally to emissions, and recent research indicates that the nitrous oxide emissions may be relatively higher from nitrogen in organic form (manures and crop residues) than from mineral fertilisers.

For methane, a reduced feeding intensity will tend to increase the emission rate. This will be enhanced by the higher use

of roughages in the feed for ruminant animals in organic farming. Additionally, recent research indicates that the methane emissions may be higher from grazing compared with housed cattle.

There are thus large uncertainties associated with our current understanding of the greenhouse gas emissions from organic farming compared with conventional production. Ongoing European re-

search in national and joint European research programmes attempt to provide a better understanding. One such project is the EU-funded project Midair (www.energetik-leipzig.de/Midair/midair_index.htm).

Jørgen E. Olesen
Danish Institute of Agricultural Sciences
Research Centre Foulum, DK-8830 Tjele
email: JorgenE.Olesen@agrsci.dk
website: www.agrsci.dk/pvj/plant/jeo

Reduction of green house gases through organic agriculture?

Evidence linking greenhouse gas emissions, in particular carbon dioxide, and climate change is increasingly accepted. Organic agriculture has a large potential in sequestering carbon dioxide; soils under organic agriculture have higher humus content, farming and cropping systems have a higher biomass above the soil and, their use of fossil energy is much lower than in conventional agriculture. It is a promising win-win strategy to combine the two ideas: carbon dioxide sequestration and the extension of organic agriculture. Acknowledging that this subject is becoming increasingly important, IFOAM realised that a debate on the subject would:

- Bring more awareness in the organic community on the use of fossil fuel energy in farming, transport and processing.
- Give the relevance of organic agriculture from an environmental perspective another boost.

Clearly, the impact of organic agriculture can have on reducing carbon emissions and increased carbon sinks should be assessed scientifically. With this in mind, IFOAM has established a Green House Gas Task Force, which will advise the IFOAM board on the subject and be a platform for dialogue. It will also help to assess and compile information on the subject, provide guidance for relevant project activities and formulate background information about organic agriculture and climate change.

Two initiatives to reduce emissions that have been put in place are:

- The Clean Development Mechanism and respective funds that are becoming available to finance reduced carbon emission and increased carbon absorption. Such funds can assist farmers to convert to organic agriculture.
- A payment for carbon fixing helps organic farmers to focus more on organic matter management, improving the sustainability of the organic farming systems.

For further information contact Johannes Kotschi.
email: kotschi@agrecol.de



PHOTO: JULIE STEDING-JESSEN

Renewable energy from biomass in organic farming

A basic principle of organic farming, as specified in the IFOAM norms, is to use, as far as possible, renewable resources in production and processing systems and to avoid pollution and waste. So far, however, little progress has been made in introducing renewable energy into organic farming, and consequently, energy aspects are rarely included in the organic farming regulations. To redress this neglect a project is being conducted in Denmark to investigate the potential of woody nitrogen-fixing trees as a biomass crop. Uffe Jørgensen gives the details.

Several sources of renewable energy can be installed on-farm, e.g. windmills for power production and solar-cells to power vehicles for hand weeding and field transport in vegetable production. However, biomass is a key energy carrier with a good potential for on-farm development. In addition, woody, perennial crops grown for the production of biomass do not need to strain the organic farms' nutrient-balance. Such crops tend to have high nutri-

ent use efficiencies with low losses to the environment.

Some fertilisation would be advantageous to maintain a high yield level of short rotation coppice, but this could be achieved by intercropping with N-fixing legumes. Furthermore, the bulk of the crop's nutrients can be recycled with the ash from the combustion, the energy-producing process. Unfortunately, nitrogen, which is lost as gaseous compounds during combustion, cannot be reclaimed in

this way. To address this nitrogen loss an interesting approach is to utilise nitrogen-fixing woody crops for biomass production. Such a crop is alder (*Alnus* spp.), which has a symbiotic relationship with the micro-organism, *Frankia*, that is able to fix nitrogen from the air.

Production studies on alder indicate that it has a biomass production potential similar to the better known biomass crops such as poplar (*Populus* sp.) and willow (*Salix* sp.). In the cool temperate climate of north-western Europe, alder is one of the only woody crops with the ability to fix nitrogen. There are many species of alder and they all seem to have the necessary symbiotic relationship.

In Sweden, grey alder has been tested in the Energy Forestry Programme since the late 1970s, but de-

spite fast juvenile growth and low susceptibility to frost of alder, willow was chosen as the main energy crop. This was mainly due to willow's easy establishment from cuttings, and even faster juvenile growth. Yields, however, were good in grey alder, and a number of studies have been made to determine the level of N-fixation in grey alder. In summary, fixation levels of 30 to 185 kgN/ha/yr may be reached in unfertilised stands. Although *Frankia*, the symbiotic, nitrogen-fixing organism, is present in most soils, it is recommended that seedlings should be inoculated with a suspension of crushed nodules before planting to ensure optimal nodulation.

Red alder (*A. rubra*) is slightly more frost sensitive than grey alder. It was tested in Scotland in a comparison with poplar (*Populus balsamifera* x *P. trichocarpa*) and willow (*Salix viminalis*) at different spacings and cutting regimes. At 1 m² spacing, yields of alder and poplar were virtually equal. Coppicing red alder before the second growing season caused 50% mortality, but after six years, there was little difference between yields of alder, poplar and willow. The level of N-fixation in red alder usually exceeds 70 kg N/ha.

Alders prefer moist and nutrient-rich sites with access to lime. However, they are less sensitive to low pH than *Salix viminalis* and *Populus trichocarpa*. No serious diseases have so far been observed on grey alder and in the Scottish trial the red alder was not attacked by the Phratora beetles that damaged both poplar and willow.

Compared with leaves of other deciduous trees, alder leaves have high N-concentrations even at defoliation in au-

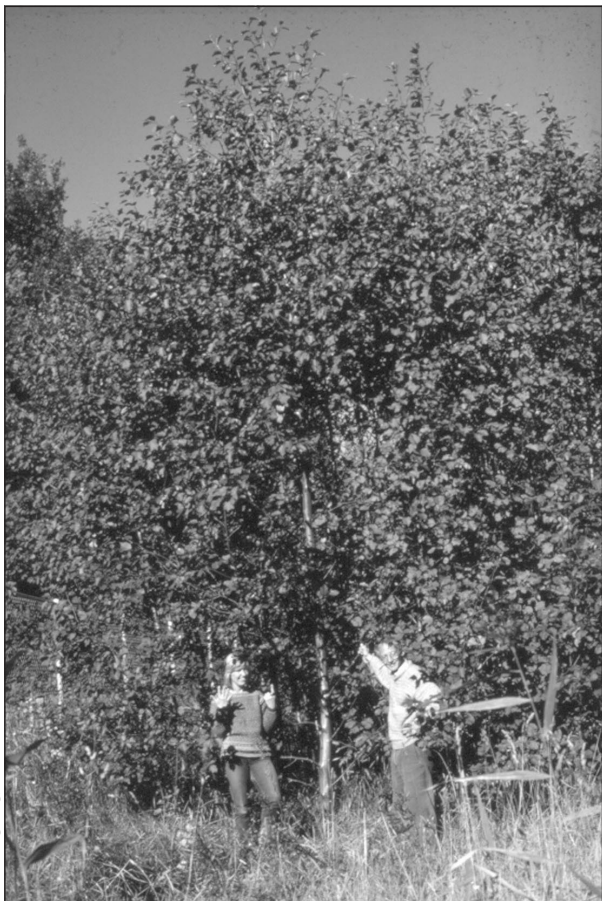


PHOTO: ULF GRANHALL

Stand of six-year old alder trees.

tumn and thus contribute to improving soil quality. In addition, there are several studies that show that alder increases phosphorus availability in soil, which may be caused by increased mycorrhiza activity or through the discharge of phosphatase enzymes in root exudates. These improvements in soil nutrient content or availability are important for organic farming, and may be exploited through a long-term crop rotation. Tree crops in the farm rotation will furthermore be an effective suppressor of grain crop diseases and of certain problematic annual weeds that may be difficult to suppress in organic farming. On the other hand, long-term production of short rotation crop (SRC) may result in the development of certain perennial weed infestations.

One drawback with alder is that it is very difficult to propagate vegetatively, causing establishment costs to be higher than those of willow. Root cuttings may, however, be used for propagation and this needs further investigation. Despite a few breeding programmes in alder 40-50 years

ago in Sweden, the potential for genetic improvements in grey alder is largely untapped. Breeding of hitherto unexploited species may give positive results over the short term; the Swedish breeding programme on willow initiated 1987, has so far resulted in yield increases of up to 63%.

The harvesting cycle and harvesting equipment for alder need to be investigated in more detail before its commercial introduction as an energy crop. Alder has slower juvenile growth than willow and will accordingly require slightly longer harvesting intervals. Early cutback should be avoided, at least red alder. Root suckers may form dense mats disturbing the original planting pattern and interfering with harvesting equipment. However, in grey alder the root suckers exert little competition to shoots from stumps, which will form the main shoots at harvest time



Cutting weeds between poplar trees a few times a year until the canopy covers the ground is a possible weed control strategy.

so the original planting pattern is not seriously disturbed.

Win-win solutions with Short Rotation Coppice

The production of energy from biomass implies that a substantial part of a holding's land is utilised for the biomass crop. This may conflict with the need for land for other purposes. In order to make bioenergy a viable option there is, therefore, a need for multi-purpose biomass production systems with additional products or benefits other than just biomass for energy. Such win-win solutions may also help improve the economics of biomass production for energy, which are still often doubtful. By introducing SRC in the rotation on organic farms, some general positive effects on soil organic matter and on soil borne diseases of the agricultural crops can be expected. ■

Uffe Jørgensen

Fax: +45-8999-1619

email: uffe.jorgensen@agrsci.dk

Danish Institute of Agricultural Sciences (DIAS), Dept. of Crop Physiology and Soil Science, Research Centre Foulum, P.O.Box 50, DK-8830 Tjele, Denmark.
website: www.darcof.dk

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Please contact the author for the references used to research this paper.

The Danish Research Centre for Organic Farming (DARCOF) was established in 1995 as a so-called 'centre without walls' where the actual research is performed in interdisciplinary collaboration between the participating research groups. The Centre's leader is Erik Steen Kristensen.

Work on the possibilities of reducing energy consumption in organic farming and on the production of energy on individual farms is being carried out by a group of 26 experts with different fields of expertise. This will be finalised during 2003.

Two specific advantages of SRC on organic farms

Protection of water quality

Organic farming is often promoted as a good tool for the protection of drinking-water quality. This is perfectly true with respect to the risk of contamination from pesticides, but with respect to nitrate leaching organic farming often differs only marginally from conventional farming systems. Several studies have shown that, apart from the establishment phase, the production of SRC crops reduces nitrate leaching to a very low level.

Animal keeping in SRC

High animal welfare standards is a key issue in organic farming, and this includes access to outdoors area for pigs and poultry. Both pigs and poultry could be allowed to range in SRC fields, finding food and satisfying their natural foraging behaviour such as rooting and ground pecking. Additionally they will find shade and shelter, which is important for these animals as well.

Pigs and geese were kept in willow at the Danish farmer Aage Bach. Geese continuously thrived in the willows. The combination of pigs and willow initially worked very well: the pigs kept weeds down without damaging the willows and apparently enjoyed life in the 'woods'.

However, after some time the pigs discovered the taste of the willow roots, and started turning over the willow crop, which effectively put an end to the practice.

However, this may not be the final story, as it is likely that it will be possible to find some clones that the pigs will not disturb. At the willow-breeding site, Svalöf Weibull in Sweden, it was observed that wild animals did not browse some of the willow clones, while others were severely affected. Also, alders are very resistant to browsing from wild animals. Furthermore, trials to establish which seasons SRC is affected by pigs and whether certain feeding strategies may be effective in reducing damage need to be performed.



Pigs in willow at Aage Bach.