Chapter 9

Energy Analysis of Organic and Conventional Agricultural Systems

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Abstract   Energy parameters of a Swedish long-term field experiment comparing organic and conventional agricultural systems were evaluated. There is great potential for misinterpretation of system comparisons as a result of choice of data and how energy data are expressed. For example, reported yields based on single crops and not the whole rotation can result in significantly different interpretations. Energy use per unit yield was lower in organic crop and animal production than in the corresponding conventional system, as previously found in other studies. This is due to the exclusion of N fertiliser, the largest energy input in conventional cropping systems. Energy use per unit yield expresses system efficiency, but the term is insufficient to evaluate the energy characteristics of agricultural systems. Calculation of the most important energy component, net energy production per unit area, showed that conventional systems produced far more energy per hectare than organic systems. The energy productivity (output/input ratio), i.e. the energy return on inputs, was at least six in both types of agriculture, revealing the highly positive energy balance of crop production in general. Lower yields in the organic systems, and consequently lower energy production per unit area, mean that more land is required to produce the same amount of energy. This greater land requirement in organic production must be considered in energy balances. When the same area of land is available for organic and conventional crop production, the latter allows for complementary bio-energy production and can produce all the energy required for farming, such as fuels, N fertilisers, etc., in the form of ethanol. In a complete energy balance, options such as combustion, gasification or use as fodder of protein residues from ethanol production must also be taken into account. There is a common belief that the high fossil fuel requirement in N fertiliser production is non-sustainable. This is a misconception, since the use of N fertilisers provides a net energy gain. If N fertilisers were to be completely replaced by biological N_2 fixation, net energy production would be significantly lower. In addition, N fertiliser production can be based on renewable energy sources such as bio-fuels produced by gasification. Conventional crop production is thus energetically fully sustainable. Energy analyses of agricultural systems presented in this chapter illustrate that published data may require recalculation in relation to the background, prevailing trends and boundary conditions, and subsequent re-interpretation. New perspectives on energy use must also be considered.

Keywords Bio-fuel production · Cropping systems · Energy budgets · Energy parameters · Energy use

1. INTRODUCTION

Rising prices for fossil energy and the need to reduce carbon dioxide emissions are creating a demand for improved energy use in general and certainly also within the agricultural sector. A recurring opinion is that agriculture should become organic and thereby not rely so heavily on fossil fuels (e.g. Jørgensen et al., 2005). Organic agriculture is described as being more sustainable due to the exclusion of N fertilisers, the production of which requires large amounts of fossil fuels (Pimentel, 2006). Energy consumption by different types of agriculture is one parameter used to rate the sustainability of agricultural systems (Eckert et al., 1999).

A common way to express energy use in agriculture is to calculate the energy requirement per unit yield. According to this definition, organic production is more efficient than conventional and thus preferable (e.g. Refsgaard et al., 1998; Dalgaard et al., 2001; Mäder et al., 2002). The exclusion of N fertilisers and the associated energy saving in organic agriculture results in a lower energy use per unit yield. In fact, conventional agriculture has been criticised for its lower energy efficiency and thus lower sustainability than organic agriculture. This criticism deserves attention and evaluation.

A further possibility to characterise the energy use in agriculture is to calculate energy productivity – a ratio describing energy output over input. Calculations of this ratio show a decreasing trend in the energy productivity of conventional agriculture during the 1970s (e.g. Pimentel et al., 1973; Hirst, 1974), but more recent studies indicate a shift during the 1980s from decreasing to increasing energy productivity in agriculture as a whole (Balwinder and Fluck, 1993; Bonny, 1993; Cleveland, 1995; Uhlin, 1998; 1999). However, the calculation of output/input ratio is a poor measure for system comparisons as it only expresses the efficiency and not the total or net energy production. As all common calculations such as balances, flows, prices, etc. are based on amounts, total and net energy production needs to be a central measure. It is therefore astonishing that the most central calculations are disregarded when organic systems are evaluated with regard to energy (Refsgaard et al., 1998; Dalgaard et al., 2001; Mäder et al., 2002; Jørgensen et al., 2005).

A tool preferred by some to evaluate energy use in organic agriculture is 'emergy' calculations. Emergy is defined as the solar energy required for production or services transforming all forms of available energy into a common basis, solar emjoules (Odum, 1996). Emergy calculations have for example been applied to compare the energy efficiency of different ecosystems (Lefroy and Rydberg, 2003; Martin et al., 2006) and to quantify renewable and non-renewable energy use when using a horse or tractor (Rydberg and Jansén, 2002). Although the calculations allow integration of different kinds of energy and facilitate the definition of boundary conditions of a system, the evaluation of data remains critical. Land use requirement, production per unit land and efficiency ratios etc. must be evaluated in a stringent way in order to draw meaningful conclusions, but are unfortunately often disregarded in emergy calculations.

We are accustomed to think that minimising inputs of non-renewable energy is beneficial for saving natural resources. However, reducing the energy input to crop production through exclusion of N fertilisers is not automatically beneficial because cropping systems have a positive energy balance. The potential to bind more solar energy through higher energy input results in a large positive energy balance (Uhlin, 1999). In other words, more energy is produced than is consumed. In practice, the higher energy yield can be used to substitute for energy sources in other processes and thereby save energy in total. Therefore, evaluation of the sustainability of cropping systems cannot be based on characterising efficiency calculations only, but must be based on balancing of total energy amounts.

The overall objective of this chapter is to discuss and critically review the issues outlined above, based on energy calculations using data from a Swedish long-term field study in which organic and conventional forms of production were compared. Specific objectives were to: (i) compare energy parameters of organic and conventional crop and animal production systems; (ii) address pitfalls associated with energy analysis of agricultural systems and the link to land requirement; and (iii) correct misconceptions about energy use for N fertiliser production.

2. FRAMEWORK FOR ENERGY CALCULATIONS

Energy issues are concrete and easy to understand (Baumann and Tillman, 2004; Brentrup et al., 2004a) but no standard methods for energy calculations are currently available. The steps involved in life-cycle assessment (LCA) can be a useful basis for the discussion of energy use (ISO, 1997). In particular, agricultural systems need special attention with regard to boundary conditions affecting the land area requirement, which is incorporated in the latest revision of the LCA standard (Finkbeiner et al., 2006). Furthermore, energy analysis of cropping systems requires consideration of other aspects that are not commonly recognised, such as status of the applied technology and new ways of using energy (Uhlin, 1999; Hülsbergen and Kalk, 2001; Corré et al., 2003).

Production systems have different characteristics, which have to be considered in energy interpretations. Therefore, there should be a clear description of how and to what extent the following issues have been addressed.

● Organic systems often have lower nutrient inputs and rely on nutrients previously added to soils before conversion to organic agriculture. It may take decades until yields decline to levels reflecting true organic practices. Thus, there is a risk of energy outputs from organic systems being overestimated.

● Valid comparisons of systems must consider the total production of the systems. However, only crop-wise yields are usually reported, disregarding the area used to grow non-harvested green manure crops in organic agriculture. Therefore, total production over a whole crop rotation period and not crop-wise yields needs to be used to estimate the energy production of agricultural systems.

● Energy required by machinery used for cultivation of non-harvested crops or fallow must be included in a correct energy analysis of agricultural systems.

● It is important to use the most recent data in energy calculations. For example, in nitrogen fertiliser production, the best available technology often requires less energy (Ramirez, 2006) and emits less nitrous oxide than older technologies (Jenssen, 2004).

● Other aspects that need to be considered are whether the systems were run according to short-term profit maximisation with no or few restrictions from society or with a long-term view and environmental restrictions (Bergström et al., 2005). It must be established whether good agricultural practice such as rotations, maintenance of soil organic matter and structure, etc. were part of both systems or whether these aspects were considered for only one system?

A more detailed description of these production issues is given in Chapter 3 of this book (Kirchmann et al., 2008).

3. INTERPRETATION OF ENERGY DATA IN CROP PRODUCTION

Table 1. Yield and energy use in the Swedish long-term trials. Average data from three sites according to Törner (1999) and Ivarson and Gunnarsson (2001)

System and variable	Mean per crop						Mean per rotation
Conventional crop production (A)	W-wheat	Barley	Rape	W-wheat	Sugar-beet[a]	Peas	
Yield (Mg dry matter ha^{-1})	5.3	4.8	2.7	5.3	8.2	3.1	4.9
Energy for tractor (MJ ha^{-1})	2891	2848	3812	2891	3647	2765	3142
Energy for machinery (MJ ha^{-1})	792	842	1109	792	1303	814	942
Other energy need (MJ ha^{-1})	2113	2092	1588	2113	216	1703	1637
Energy for N fertiliser (MJ ha^{-1})[b]							4536
Total energy use (MJ ha^{-1})							10258
Organic crop production (D)	W-wheat	Beans	Barley	Green manure	Sugar-beet	Peas	
Yield (Mg dry matter ha^{-1})	2.9	2.2	2.9	0	5.3	2.7	2.7
Energy for tractor (MJ ha^{-1})	3139	3474	3265	1544	3395	3265	3014
Energy for machinery (MJ ha^{-1})	893	1058	990	529	1235	990	949
Other energy need (MJ ha^{-1})	1778	1537	1544	1062	238	1566	1288
Total energy use (MJ ha^{-1})							5251
Conventional animal production (B)	Barley	Grass clover	Grass clover	W-wheat	Sugar-beet	Peas	
Yield (Mg dry matter ha^{-1})	4.7	9.0	9.6	4.7	8.0	3.2	6.5
Energy for tractor (MJ ha^{-1})	3028	3937	3722	3772	5900	2972	3889
Energy for machinery (MJ ha^{-1})	734	1955	1894	960	1766	714	1337
Other energy need (MJ ha^{-1})	2759	1722	1709	3078	7340	4160	3461
Energy for N fertiliser (MJ ha^{-1})							5544
Total energy use (MJ ha^{-1})							14231
Organic animal production (C)	Barley	Grass clover	Grass clover	W-wheat	Sugar-beet	Peas	
Yield (Mg dry matter ha^{-1})	3.3	5.4	7.7	3.4	5.9	3.2	4.8
Energy for tractor (MJ ha^{-1})	3649	2594	3289	3329	4536	3174	3429
Energy for machinery (MJ ha^{-1})	1456	1040	1715	887	1463	788	1225
Other energy need (MJ ha^{-1})	1790	1459	1456	1666	5443	3424	2540
Total energy use (MJ ha^{-1})							7193

[a]Yields of sugarbeet are expressed as dry matter assuming a water content of 80% (yield x 0.2) in order to be comparable with grain crops. Yields of grass/clover and other crops are also presented in terms of dry matter.
[b]The energy use for N fertiliser production was assumed to be 42 MJ kg^{-1} N.

A field study located at three sites in southern Sweden (Scania) representing different soil fertility levels was monitored over two six-year rotations starting in 1987 (Ivarson and Gunnarsson, 2001). The study consists of five systems managed according to best agricultural practice, of which four were included in this evaluation:

A. Conventional crop production
B. Conventional with leys and manure (simulated animal production)
C. Organic with leys and manure (simulated animal production)
D. Organic crop production

Yield data for the experimental period are given in Table 1. Energy calculations of the systems for the period 1993-1997 made by Törner (1999) are also included in Table 1.

In the following we distinguish between crop production systems without animals (A and D) and animal production systems with leys and manure (B and C), as circulation of nutrients and the possibilities for symbiotic nitrogen fixation differ greatly between the two system categories. In line with what has been discussed in Chapter 3 (Kirchmann et al., 2008) and also stressed above, it is necessary to use total production over a rotation instead of crop-wise yields in the analysis.

3.1. Calculations of energy use and their limitations

As mentioned above, a common way to evaluate energy utilisation in crop production is to calculate the specific energy use, i.e. the energy required to produce a unit of product. According to Table 2, the specific energy use was higher in the conventional system (A) than in the organic system (D) using mean yields over a rotation, 2.1 and 2.0 MJ kg^{-1} harvested dry matter yield, respectively. However, when the green manure year was omitted and crop-wise yields were used for the calculation, the energy use for the organic system decreased to 1.6 MJ

Table 2. Interpretation of energy use for conventional and organic crop production as influenced by choice of input data. The data used are taken from Table 1

Choice of input data	Conventional system	Organic system	Organic/ Conventional
	MJ kg^{-1} dry matter yield[a]		(%)
Total yield or crop-wise yield			
Total yield (organic = 54% of conv.)	2.09	1.97	94
Crop-wise yield (organic = 67% of conv.)	2.09	1.60	77
Energy use for machinery for non-harvested crops			
Included	1.90	1.61	85
Excluded	1.90	1.31	69
High and low energy consumption for N fertiliser production			
50 MJ kg^{-1} N instead of 42	2.27	1.97	87
38 MJ kg^{-1} N instead of 42	2.01	1.97	98

[a]The energy content of common crops varies between 15 and 18 MJ kg^{-1} dry matter (Fluck, 1992) and we used the lower value of 15 for all calculations.

kg^{-1} dry matter yield. This is significantly lower than for conventional production and similar to the figure reported by Corré et al. (2003), indicating better efficiency of organic systems.

Another significant difference between the organic and conventional cropping system can be caused by the exclusion of energy used for machinery for non-harvested crops (e.g. Horne et al., 2003). When machinery was excluded for non-harvested crops and crop-wise yields were used in the calculation, the relative energy use of the organic system only amounted to 69% of that in conventional production, which in reality is 85% (Table 2).

A central input for the interpretation of energy analysis is the consumption of energy for N fertiliser manufacturing. Technical improvement of fertiliser plants to increase the efficiency has reduced energy demand for N fertiliser production in recent years. This has significant implications on energy calculations for agricultural systems (Table 2). Jenssen and Kongshaug (2003) reported that an energy use of 38 MJ kg^{-1} N is most appropriate for modern fertiliser plants. Applying this figure instead of the 42 MJ kg^{-1} N that is commonly used reveals that there is no difference in energy use between the conventional and organic systems (Table 2).

3.2. Other energy calculations

Although energy use per kg product is a well-defined and a common estimate for agricultural systems, it provides insufficient information as it is an efficiency parameter. The lower the value, the more efficient is the system. This seems clear enough but the examination of agricultural systems on the basis of energy use is misleading. The limitation of the efficiency term energy use per kg product becomes obvious through the following example.

If the aim is to reduce energy consumption per unit product as much as possible, not only N fertilisers, but also energy consumption by farm machinery should be excluded and the human or animal-powered alternative should be chosen. Energy consumption per kg of wheat would then be reduced by 95%, which would result in a situation similar to that on many African smallholdings. On the other hand, crop production would also be reduced, sometimes by as much as 80%, but this would not be reflected in the energy efficiency term. This clearly shows that energy data must be expressed in relation to the amounts of energy produced as crop yields in order to understand the energy characteristics of agricultural systems. Calculations of total or net energy production describe the amounts of energy gained and illustrate the land

Table 3. Further energy parameters derived from Table 1. Values are based on dry matter yields from crop production systems and no removal of crop residues

Energy parameter	Pure crop production	
	Conventional	Organic
Energy use (MJ kg^{-1} dry matter yield)[a]	2.09	1.97
Energy use (MJ ha^{-1})	10258	5251
Gross energy production (MJ ha^{-1})	73500	40500
Net energy production (MJ ha^{-1})	63242	35249
Energy productivity (Output/input ratio)	7.2	7.7

[a]The energy content of common crops varies between 15 and 18 MJ kg^{-1} dry matter (Fluck, 1992) and we used the lower value of 15 for all calculations.

requirement to produce the same amount of energy.

The data in Table 3 (based on Table 1) show that net energy production - total energy produced minus energy input - was almost twice as high in the conventional Swedish long-term cropping system as in the organic. The energy productivity (output/input ratio) shows that the energy return was 7-8 times higher in crop products than in inputs and that it was slightly higher in the organic system. In other words, crop production has a highly positive energy balance due to photosynthetic activity, whereby solar radiation is transformed into biomass. This also shows that minimising inputs and thus saving energy is not necessarily a successful strategy since a high energy input leads to higher returns, which can be well justified.

3.3. Findings from other organic field studies

Pimentel (2006) calculated the efficiency of energy use in agriculture in the USA. Compared with European conventional agriculture, energy use is often high and yields are low under USA conditions. The results from one experimental site in Pennsylvania (Rodale), where yields of organic maize were similar to those of conventional maize in a maize-soybean rotation due to large inputs of animal manures (see Chapter 3 of this book; Kirchmann et al., 2008), had a major impact on the conclusions drawn in the report. Such relations are not common in Europe, where yields of organically grown crops are consistently lower than those of conventional crops due to much lower nutrient inputs. Output/input ratios reported for major US crops were also very low (2.2), while European studies (Refsgaard et al., 1998; Dalgaard et al., 2001; Brentrup et al., 2004b) report, for instance, at least 6.5 for winter-sown cereals, similar to the data in Table 3.

Hülsbergen and Kalk (2001) presented a detailed energy assessment of long-term field studies in Germany showing that less fossil energy was used per hectare in the organic systems but that the energy yield was reduced because of lower yields compared with conventional systems. Similarly, Mäder et al. (2002) reported results from a 21-year experiment in Switzerland with organic farming systems and concluded that organic production consumes less energy per unit product. Yields were on average 20% lower (potatoes 40%). The relatively small yield reduction in the organic systems in that study may be explained by the high animal density, 1.2-1.4 animal units per hectare, and the results are thus not generally applicable.

In a comprehensive review by Corré et al. (2003), it was concluded that: (i) organic agricultural systems require less energy but more land than conventional; (ii) the highest energy use efficiency in agriculture would be achieved by intensive conventional farming including the production of energy crops; and (iii) the composition of the human diet has a larger effect on energy use than the type of agricultural system.

4. INTERPRETATION OF ENERGY DATA IN MIXED ANIMAL-CROP PRODUCTION

Production involving livestock (the Swedish systems B and C) means growth of leys, removal of straw and beet tops, and addition of manure. An important condition at the Swedish site is that the manure addition to each system was adapted to the productivity of each site and corresponded to roughly one animal unit per hectare.

The organic livestock system produced on average 74% of yields over all crops compared with the conventional animal system (system B vs C, Table 1). The energy characteristics (Table 4) indicate that the organic livestock system was more favourable than the conventional. The energy use per unit product was significantly lower in the organic system and the output/input ratio was larger than in the corresponding conventional system (Table 4). This may be explained by the fact that growth of leys in the beef/milk producing system increased the N

Table 4. Energy parameters for animal production systems derived from Table 1. The values are based on dry matter yields

Energy parameter	Mixed crop-animal production	
	Conventional	Organic
Energy use (MJ kg^{-1} dry matter yield)[a]	2.18	1.49
Energy use (MJ ha^{-1})	14231	7193
Gross energy production (MJ ha^{-1})	98000	72500
Net energy production (MJ ha^{-1})	83769	65059
Energy productivity (Output/input ratio)	5.9	9.0

[a]The energy content of common crops varies between 15 and 18 MJ kg^{-1} dry matter (Fluck, 1992) and we used the lower value of 15 for all calculations.

input (N_2 fixation) in combination with the return of N through manure and the higher N input led to somewhat higher yield levels than in the crop production system without animal manure. Furthermore, leys in the conventional system require more N fertiliser than other crops and the energy input to the conventional livestock system was thereby higher than that to the conventional crop production system (Table 1).

Despite the lower efficiency of the conventional system, net energy production was considerably larger in that system. As the amount of energy produced is of the utmost importance in sustaining animal production, lower amounts of energy produced must be compensated for. Maintaining the energy production for organic animal husbandry would require an expansion of the area used for agriculture (e.g. Cederberg and Mattsson, 2000; Casey and Holden, 2006). In other words, high input agriculture requires less land per unit energy and this fact must be fully evaluated.

5. DOES BIOLOGICAL INSTEAD OF ARTIFICIAL NITROGEN FIXATION SAVE ENERGY?

The high energy demand and use of fossil energy for production of N fertilisers is often pointed out in arguments against the use of artificial N fertilisers in organic agriculture. In fact, if N fertilisers are replaced by biological nitrogen fixation, a major proportion of the fossil fuels used for plant production can be saved (see Table 1). The argument for not being dependent on fossil fuels for N fertiliser production and thus saving energy has gained wide-spread acceptance. Biological nitrogen fixation through legumes is seen as the given, sustainable alternative.

A realistic way to assess the energetic value of N fixation is to compare two similar cropping systems where legumes are an integral part of the organic system and N supply in the conventional system is based on fertiliser N. An isolated single crop comparison would not be convincing, since crops other than legumes must also be produced through organic farming. Such energy analysis of conventional and organic crop production systems does not support the argument that saving fossil fuels for N fertiliser production is beneficial. This may be difficult to accept, as saving means less consumption, but although N fertiliser production is energy-demanding, the much higher energy yield of the conventional system greatly compensates for

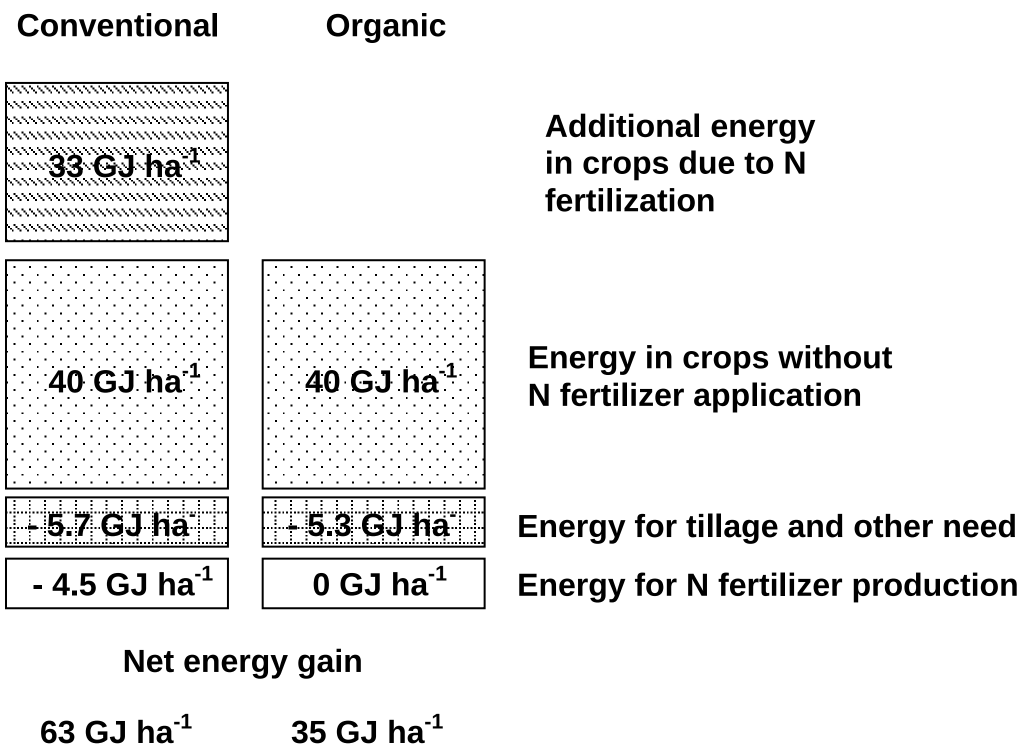

Figure 1. Energy input in relation to energy gain through crops and residues in the conventional and organic crop production systems. Data derived from Tables 1 and 3.

the energy demand for production of N fertiliser. For example, the energy production in the Swedish conventional crop production system (A) was 73 GJ ha^{-1} compared with 40 GJ ha^{-1} in the organic system (D) (see Table 3), but the energy input for N fertiliser was only 4.5 MJ ha^{-1} (see Table 1). Thus, even though the use of inorganic N fertiliser is the largest item in the energy budget of conventional crop production, it is also true that correct use of N fertiliser produces far more energy than is required for fertiliser production. Nitrogen fertiliser acts as a boost to solar energy capture by crops. In fact, crop production is associated with a positive energy balance and not many energy investments in society give such high energy returns. The energy yield through crops and residues is actually 6-15 times larger than the energy required for N fertiliser production (Ratke et al., 2002; Brentrup et al., 2004b).

In Fig. 1 (data from Tables 1 and 3), the input and output items of energy for the conventional (A) and organic crop production system (D) are compared. The extra energy yield obtained by use of fertiliser N was 7-fold higher than the energy required for N fertiliser production. This highly positive balance needs to be fully recognised. The use of energy for N fertiliser production has clearly no negative effect on the energy balance. Still, one may argue that the fossil energy needed to produce N fertiliser is non-renewable and the positive energy balance does not help to conserve fossil resources in the long-term. However, this argument is in fact not applicable for N fertiliser production. The raw materials needed for ammonia fertiliser production are air, water, and energy of almost any kind. If oil and gas reserves were to become depleted and/or very expensive, renewable or remote energy sources could be used instead because of the positive energy balance. In fact, less than 20 years ago, large N fertiliser factories were actually run on hydro-electricity in Glomfjord, Norway. As ammonia is easy and cheap to transport in large tankers, remote energy sources may be the basis for ammonia factories serving the world without competing with other energy demands. In other words, oil and gas depletion may become a global problem but it is not decisive for the production of N fertilisers. Sustainable production of artificial N fertilisers can be achieved using hydrogen produced through electricity or gasification of biomass. In an energy-scarce situation, fertilisers will be needed to create more bio-energy and improve sustainability. Furthermore, the entire global fertiliser industry currently uses less than 2% of global energy consumption (IFA, 2006).

Finally, correcting the argument against producing N fertilisers due to energy saving does not mean that use of N should be negligently. Like all powerful tools, fertilisers have to be used correctly and conservatively to enhance crop growth and maintain soil fertility (Carlgren and Mattsson, 2001). Use of fertilisers should not be an excuse for poor agricultural practices. Fertilisers may tempt the user to make shortcuts such as use of unsuitable monocultures and exhaustive tillage, but these are malpractices. The use of fertilisers should never been seen as replacing soil conservation measures, recycling of nutrients or growth of legumes. Fertilisers should be viewed as one important tool for crop production, not eliminating other necessary practices which enable agriculture to be sustainable.

6. ADDITIONAL BIO-FUEL PRODUCTION THROUGH CONVENTIONAL CROP PRODUCTION ON SET-ASIDE LAND

Bertilsson (1993) pointed out that high-yielding food production creates the least demand for agricultural land and thereby leaves more options for society for various other uses. Access to land is an important resource and a natural constraint that needs to be considered in energy analyses. In fact, the demand for land for food production may compete with the demand for land for bio-energy production (van den Broek et al., 2001; Connor and Mingues, 2006).

6.1. Combustion

In the comparison in Fig. 2 (data from Tables 1 and 3), the same amount of food is produced through conventional and organic crop production. The additional land area needed when organic production methods are applied can be used for bio-fuel production in conventional agriculture. Combustion of bio-fuels can replace use of fossil fuels for the production of heat in some processes and the need for the corresponding amount of fossil energy would then be reduced through direct substitution.

The energy input required for conventional food and bio-fuel production would amount to 22 GJ yr^{-1} (Fig. 2). This figure can be compared with organic production, which produces the same amount of food (4.9 Mg dry matter yield) on the same area and only uses 9.5 GJ yr^{-1} of fossil fuel, but provides no additional bio-energy.

Production of bio-fuel on ‘set-aside’ land amounts to at least 75 GJ. This amount exceeds by far the total energy input needed for production of food and energy crops (22 GJ). The net energy gain through additional bio-fuel (53 GJ) is of the same order of magnitude as the net energy production through food in the organic system (64 GJ) on the same area (Fig. 2). Thus, instead of saving energy through low-input organic agriculture, conventional agriculture increases energy productivity.

6.2. Ethanol production

In this example, the ‘set-aside’ area (see Fig. 2) is used to produce winter wheat for ethanol production in order to replace petrol for vehicles. We assumed a winter wheat yield of 5 Mg ha^{-1} and applied the following key data for the calculation: (i) the production of 1 Mg of ethanol requires 3.5 Mg of wheat to be fermented, which leaves 1.5 Mg dry matter in form of protein

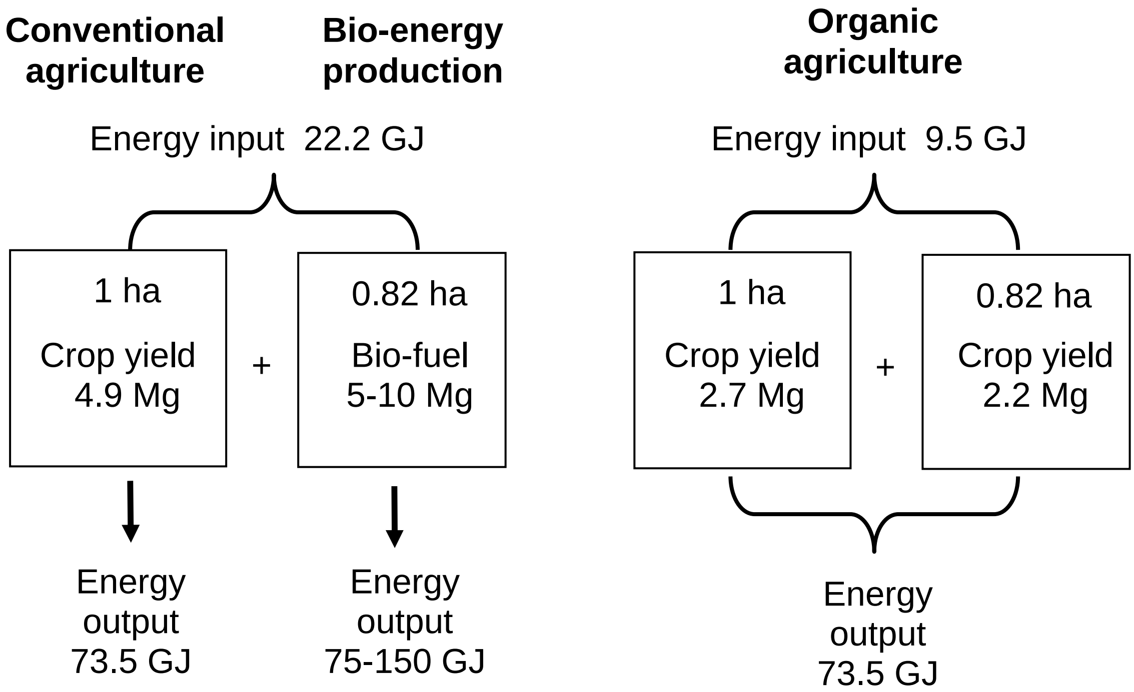

Figure 2. Energy output when the same amount of food id produced through conventional and organic agriculture. The boundary condition was access to the same area of land. Data are taken from Tables 1 and 3.

residues that can be used either as fodder or for combustion (Horne et al., 2003); (ii) the energy content of ethanol is 26.7 MJ kg^{-1} or 21.1 MJ L^{-1} and that of protein residues 15 MJ kg^{-1} dry matter; and (iii) the process energy required to ferment and distil 1 Mg ethanol amounts to 9.2 GJ.

According to these values, 5 Mg of grain produce 1.4 Mg of ethanol equivalent to an energy amount of 37 GJ. In addition to ethanol, 2.1 Mg protein residue dry matter containing 31 GJ are available for use as feed. Other more general figures derived from the calculation are that roughly 33% of the total energy in grain is transformed into ethanol energy, 43% remains in protein residues and 24% is required for the conversion and/or lost. The ratio between energy in ethanol and in protein residues is 44 to 56.

Based on this information, we calculated the number of cars that can be run on ethanol produced on ‘set-aside’ land if food is produced conventionally instead of organically. We assumed that an average Swedish car is driven 10 000 km per year using 0.1 L of petrol (32.6 MJ L^{-1}) per kilometre, which would be equivalent to 1000 L petrol per car and year. The equivalent consumption of ethanol would be 1545 L (21.1 MJ L^{-1}). Thus for each hectare of agricultural land converted to organic production, the additional land required to produce the same amount of food could provide fuel covering the annual consumption of an average Swedish car. As approximately 90 000 ha have been converted from conventional to organic cereal production (Andrén et al. 2008, see Chapter 8), fuel for 90 000 cars could be produced in addition to food if this area were converted back to conventional production.

7. CONCLUSIONS

The outcome of comparisons between organic and conventional systems depends on the original assumptions, the design of the study, the boundaries for the study, the use of data in space and time and, last but not least, the way of accounting for energy. Indeed, the same study can be used to demonstrate the superiority of either organic or conventional systems depending on how such factors are considered. In order to understand the energy characteristics of agricultural systems, it is necessary to calculate total or net energy production.

Production of agricultural crops, whether conventional or organic, results in a positive energy balance, with more solar energy bound than energy invested. The energy demand for N fertiliser production is the largest item in the energy budget of conventional systems, but the highly increased crop production when using N fertiliser results in a very positive energy balance, with at least a six-fold return on the energy invested for N fertiliser production. Growth of legumes for biological N fixation instead of artificial fertiliser production does not improve the energy budget of organic systems. It is a misunderstanding that exclusion of artificial N fertilisers means saving energy. The highly positive energy balance when using N fertilisers instead of biological N fixation needs to be fully recognised. Furthermore, the option exists to use renewable energy instead of fossil fuels for N fertiliser production.

As yields in conventional agriculture are about twice those in organic production, conventional methods allow both food and energy to be produced on the area of land required for organic food production alone. When bio-energy production is included in a comparison between conventional and organic systems, the more productive conventional systems are always preferable.

8. REFERENCES

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