Energy use in crop production on danish mixed farms: Systems modelling of data from farm studies.

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12 pages
3 tables

Abstract
The problems of balancing agricultural production methods against environmental concern cannot be solved by focusing on single activities of livestock farming and experimental knowledge alone because of interactions between herds and crops and between the production system and the manager. An alternative method based on studies in private farms is proposed to evaluate the effects of the production intensity on pollution and resource efficiency. Energy use and crop yield in grain and grass-clover crops registered on conventional and organic mixed dairy farms were analyzed in order to facilitate modelization of energy efficiency in different production systems on different danish soil types. The energy efficiency was higher in organic crops on all soil types with the smallest difference on irrigated sandy soils. Yields were highest in conventional crops receiving large indirect inputs of energy from fertilizers. The yield response was not sufficient to give the same energy efficiency as in organic crops. Combined with an earlier analysis of nitrogen surplus and efficiency on the same farms the results indicate that high efficiency in use of both nitrogen and energy can be achieved by reducing intensity of production in mixed dairy farming. The need to include the farmers value orientation in the farming systems analysis is discussed.

key words:
Dairy farms - energy use - farm studies - interactions - manager - organic farming - production intensity - systemic modelling.

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Introduction

The two-faced situation of european agriculture with overproduction at one side and problems with the effects of intensive agriculture on the other calls for solutions that take into consideration non-economic values connected to farming. Examples are the size of pollution from nutrient loss and CO_2 emission and effect on wild flora and fauna and landscape aesthetics. This have been discussed in relation to two different perspectives of agricultural development: Separation and intensification vs. integration and extensification (Weinschenk 1986, de Wit et al. 1987). The question is whether the problems are best solved by *either*
-allowing further intensification of production in the most competitive areas and accepting the marginalization af large areas with the poorest conditions for agriculture and thereby give place for ecological refuges and extensive use of land, *or*
-attempting to limit production by promoting less intensive farming systems in general, which could ease environmental concern and secure the survival of agriculture also in less endowned regions.

We believe there is a great need to study ways of balancing production and economy against environmental concern and use of resources in livestock farming systems. This however, cannot be done with experimental knowledge alone. The nitrogen (N) loss, for example, from mixed farms having both animal and crop production cannot be attributed to single activities like fertilization or feeding practices because of interactions between animal and crop production and between the production system and the manager (Bacon et al. 1989; Halberg et al. 1994a). Analyzing N loss from 30 danish mixed dairy farms Halberg et al. (1994a) found significant differencies between organic and conventional farms. Main explanations for lower N surplus and higher N efficiency on organic farms were lower stocking rate and better crop N utilization due to lower fertilization levels and yields. It was concluded that substantial reductions in N loss from conventional mixed dairy farms probably is unlikely without accepting lower production intensity (yield/ha and/or stocking rate). Efficiency of use of energy is interesting because of direct impacts of CO_2 emission and indirectly through the intensification of farm practices (Refsgaard 1994a). The intensity in use of N affects both yield and N surplus (Halberg et al. 1994a). The relationship between N input and product yield affects energy efficiency in kg product per MJ input. Therefore it is not obvious how energy efficiency will be influenced by a reduction in production intensity with the aim of reducing N loss. The effects of changes in energy inputs to a system can best be assessed by establishment of a model (Spedding & Walsingham 1975).
The purpose of this paper is to
-demonstrate how studies in private farms can describe the interactions between livestock and crop production and farm management and help finding possibilities to balance production against environmental aspects and
-propose a method for generalizing results from farm studies.

Materials and Methods

Study Farms

The data was obtained from 30 private dairy farms affiliated with the National Institute of Animal Science. The registration period occurred during the 4 year period May 1, 1989 until April 30, 1993. While the farms had dairy production as the main enterprise, all had grain production. Fourteen of the farms met the Danish organic regulation prohibiting the use of chemically-produced fertilizers and pesticides. Non-organic fodder, only of Danish production, was limited to 15% and animal manure was applied from maximum 1,4 livestock units (LU) per ha/year.

There were some differences as regarding the type of land, crops and cattle within the two main groups (i.e. organic and conventional farming systems), Table 1. While the average number of cows/farm was nearly identical, the organic farms had slightly more land, a higher proportion of Jersey cows, and little fattening bull calf production, thus the number of livestock units per hectare was 40% greater on the conventional compared to organic farms. The acreage of permanent pasture and grass-clover in rotation was nearly identical for the two farming systems (11-13%). Acreage with fodder beets and whole crop silage from small grains was higher on conventional farms, whereas the organic farms had more rotation grass-clover including 9% alfalfa. The crops on the remaining area were different types of cereals (including about 10% winter cereals) and other cash crops as potatoes and rape seed. The total acreage of crops with a long growing season was 80-85% in both groups.

The goal of data collection was to describe the farms' flow of energy, nutrients and money. Information was collected at farm level and on herd and crop level. Data were collected during biweekly visits on fodder consumption over a 24 hour period, stocks assessments and farm purchases and sales and the input in the crops. A detailed description of each farm's production system and yield during the working years was presented in yearly publications (Østergaard 1990; Østergaard 1991; Kristensen & Østergaard 1992; Kristensen 1993).

Calculation Methods

The use of energy in crop production and differences in yield between the systems have been analyzed separately. The idea was to establish standard estimates of energy use and yield in crop production in organic and conventional dairy farms on danish soil types to facilitate modelization of energy efficiency in different production systems.

The indirect energy input with f.ex. fertilizers and pesticides was calculated for 1990 and 1991 on the basis of average consumption in relevant manufacturing firms (Refsgaard 1992). The quantity of direct energy input relates to the actual use on the farms in 1990 and 1991. Individualized standard coefficients were used to distribute the total quantity to the different enterprises of the farm according to registered operations (Refsgaard & Halberg 1994). The farm data were subsequently used to modelize energy use in conventional and organic grass-clover and grain crops on clay soils and on sandy soils with and without irrigation. The energy items were tested statistically for effects of system and soil type.

Crop yields from all four years were analyzed statistically to test dependency of farming systems, soil types, and a regression variable expressing climatic factors with one observation per crop and farm per year (Halberg et al. 1994b). Farm and crop specific values of the regression variable was estimated using a crop growth simulation model to simulate potential yields on each farm and year. This way differences in water supply (precipitation and soil water retention capacity), temperature and radiation between farms and years were corrected (Halberg et al., 1994b). From the regression equations organic and conventional crop yields were predicted for clay soils and for sandy soils with and without irrigation using simulated potential yields. Energy efficiency was calculated as kg product (grain or feed units) per MJ input of energy.

Results

On average the farms used 47 % more diesel than expected from the standard coefficients. This unexplained consumption varied between 0 and 100 % between farms but there was no clear correlation with system or soil type. Therefore the modelized diesel consumption for soil preparation, manuring and other machine operations were multiplied by the factor 0.47 to give the item "diesel not accounted for" in Tables 2 and 3.

Organic grass-clover crops recieved more manure than conventional and a larger part was harvested for silage (Table 2). Conventional grass-clover crops yielded more than organic and diesel was used to spread fertilizer. Therefore the direct use of energy was almost equal in the two systems on the same soil type. Indirect use of energy in the form of fertilizers composed 47-73% of total energy use in conventional grass and grass-clover crops with no significant difference in the fertilizer level between soil types. Total energy use in conventional grass crops on clay and unirrigated sandy soils was 3-4 times higher than in organic crops. Electricity used for irrigation almost tripled the total energy use in organic crops on sandy soils. Because the yields were only 12% higher on irrigated compared to unirrigated sand, the energy efficiency was less then half of the efficiency on unirrigated sandy soils (Tabel 2). Conventional grass yields were ca. 15% higher than organic with a tendency to a greater difference on irrigated sandy soils. Energy efficiency calculated as yield divided by input was higher in organic crops on all soil types with the greatest difference on clay soils.

Diesel use per ha in spring sown grain crops was higher than in grass due to the soil preparation and higher levels of manure supply (Table 3). The fertilizer supply in conventional grain crops was not significantly dependant on soil type and was the main reason for a higher total energy use compared with organic grain crops. Though the yields were 700-1100 kg/ha (21-25%) higher in conventional grain yhan in organic the energy efficiency was lower on all soil types with the smallest difference on irrigated sandy soils.

Discussion

Energy efficiency in crop production depended on farmer decisions concerning use of input and their effects on output. In conventional farms a large part of energy input indirectly came from fertilizers. On clay and sandy soils regularly supplied with manure the yield response was not sufficient to give the same energy efficiency as in organic crops. The fertilizer levels varied between farms and the average 93 kg Nitrogen/ha spring sown grain used in the models probably more than secures most of these crops against lack of Nitrogen (N) (Halberg et al. 1994a). The level of fertilizer use (and thereby indirect energy input) may be changed in the models but the uncertainty of the N response curve must be considered. A large part of energy input in organic crops came from handling of manure (including aerating slurry, composting dung).

Irrigation increased energy input equally in organic and conventional crops but since yield increase compared to unirrigated sandy soils was highest in conventional crops, the difference in energy efficiency between systems was smaller on irrigated sandy soils. Halberg et al. (1994b) found that the difference between organic and conventional grain yields was larger on irrigated sandy soils than on clay soil. The high potential yields on irrigated soils assuming unlimited plant nutrient supply were better utilized on conventional farms with access to mineral fertilizers including the micro nutrients that often are lacking on sandy soils.

Since a large part of the diesel use was not accounted for -with great variation between farms-, there might be room for individual management, for instance by reducing the consumption by adjusting tractor engines or speed of field operations. The statistical analysis showed a tendency towards a higher proportion of diesel not accounted for on clay soil farms. The standard values do not take into account a probably higher power need for soil preparation on the heavier clay soils compared with sandy soils. These hypotheses needs further investigations.

Though the calculations presented apply to a limited number of farms and years the standardization of energy use (Refsgaard & Halberg 1994) and crop yields (Halberg et al. 1994b) allows for generalizing the results to other mixed dairy farms if correcting for potential yield. The next step will be to model utilization of energy in different milk production systems using the estimated energy budgets in crop production together with the results of a similar analysis of milk yield (Kristensen 1993) and energy inputs in imported feed plus operations in the stable (Refsgaard & Kristensen 1994). This type of systemic modelling (Sørensen & Kristensen 1992) might be a method to analyze the interactions between herd and crop production on a mixed dairy farm and thereby facilitate farm level generalization of detailed collected data from a limited number of farms.

Farm unit nitrogen (N) surplus, which is the potential loss of N from the farm, was analyzed for the same group of farms by Halberg et al. (1994a). There were significant differences in farm level N surplus between conventional and organic farms (average 242 kg N/ha vs. 124 kg N/ha respectively). N surplus was correlated to stocking rate and increased by 117 and 33 kg N/ha per livestock unit on conventional and organic farms. N input and surplus were correlated with yield and both N input and yield influence energy efficiency. Moreover, for these parameters there were interactions between herd and crop production. Therefore it is difficult to analyze relations between efficiency of nitrogen and energy utilization in dairy production from experimental knowledge alone. In this systems analysis both energy efficiency and nitrogen surplus and efficiency was found to be linked with the intensity of production in terms of input and yield per ha and stocking rate. Therefore it is assumed that there are basically no contradiction between goals of reducing pollution and increasing overall N and energy efficiency in danish dairy production by reducing input. Farming systems research might this way contribute to an evaluation of different perspectives of agricultural development.

Halberg et al. (1994a) believe that the rationality behind the current way of planning "the optimum fertilizer application" in conventional farming was an important reason for the higher N surplus. The calculation method is theoretically reasonable, but there are many uncertainties attached to finding the correct N level for a given crop and to estimate plant utilizable N supplied with manure and from soil N mineralization. Therefore in practice it becomes economically rational for risk adverse farmers to over apply manure and commercial fertilizer (Young et al., 1985; Halberg et al., 1994a). Moreover it can be assumed that farmers differ in their reaction towards these uncertainties. The fact that nitrogen surplus and also energy efficiency was very dependent on input and thereby on management have two implications: Firstly these interactions makes it necessary to include the farmer in the concept of the farm system as have already been recognized in research methodologies like Agroeco-systems analysis (Conway 1987) and some forms of Farming Systems Research (FSR) (Sands 1986; Bonnemaire 1993). Secondly there is a potential for finding solutions to the current problems among the existing variation in farming practice (Van der Ploeg 1993). Atypical cases can be useful for highlighting neglected possibilities (Hägg & Hedlund 1978). Aiming at balancing intensity of production and economic competitiveness against environmental concern organic farming might be feasible, critical cases (Pimentel 1993).

If accepting the idea of farming as a human activity system it becomes obvious to ask how the farmers personal standards (value orientation) influence the choice of production-methods and thereby the effect on the non-economic values of interest. Some sociological studies support the idea that differencies in the farmers value orientation can explain differencies in style of production and thereby in the effects on the environment (van der Ploeg 1993; Sauget & Balent 1993). This rises two questions:

I. How do we separate the effect of the farmers value orientation from the biological effects of the

chosen production method when we want to generalize from farm-studies?
II. How can the value orientation of individual farmers be incorporated in a process to develop farming systems and practices that are more in accordance with the expectations of the rest of society?

These problems will be attended to at NIAS in two research projects, running from 1993 to 1997 and initiated by the Ministry of Agriculture. Because the organic and conventional farms systematically differ in their use of pesticides and purchased fertilizer and feddstuffs the collected data can serve for modelling the effect of the intensity of production on the impact on environment as well as economic performance. It is expected that sociological studies of the value orientation of the particular farmers can contribute to explain the large differencies within the two groups. There is a lack of methods to evaluate the environmental and complex non-economic values of farming in relation to economic terms at farm level. Therefore an "ethical" accounts system will be developed as a tool for facilitating an aggregated description of many values attributed to a given production and from that the dialogue between farmer, consumer and researcher (Sørensen & Sandøe 1993). It is expected that the farmers will be able to use the ethical account as a strategic planning tool for changing the production-system in a desired direction.

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Table 1. Some characteristics for the analyzed project farms.

System	Organic		Conventional	
Number of farms:	14		17	
Distribution regarding				
Soil type: sandy + clay	7+7		14+3	
Irrigation: yes + no	6+8		9+8	
Cattle type: heavy + light [1]	7+7		11+5	
	Average	(min-max.)	Average	(min.-max.)
Area, ha	71	(21 - 114)	56	(25 - 85)
- % permanent pasture	13	(1 - 32)	11	(4 - 51)
- % rotation grass/grass-clover/alfalfa	38	(25 - 55)	25	(14 - 60)
- % fodder beets	4	(0 - 11)	10	(0 - 25)
- % whole crop silage from small grains	10	(1 - 18)	13	(2 - 49)
- % grain for harvest	32	(15 - 50)	34	(16 - 53)
- % other cash crops	4	(0 - 13)	7	(4 - 26)
Cows per farm	59	(28 - 111)	58	(36 - 94)
Livestock units[2] per ha	1.06	(0.8 - 1.5)	1.50	(1.27 - 2.26)

1) Heavy types: Danish Frisian, Danish Red or Red and White. Light types: Yersey.

2) 1 livestock unit is equal to 1 dairy cow of approx. 550 kg.

Table 2. Estimations of energy use (MJ/ha) and grass yield (FU/ha[3)]) in organic and conventionel rotation grass-clover on three soil types. See text for further explanations.

Preliminary results based on modelization of collected data. Energy data from Refsgaard & Halberg (1994), yields from Halberg et. al (1994b).

Soiltype	Sandy, no irrigation		Sandy, irrigation		Clay	
System	Conv.	Organic	Conv.	Organic	Conv.	Organic
Electricity, irrigation, 142 mm			6218	6218		
Diesel, manure[1)]	301	427	301	427	301	427
Diesel, harvest[2)]	2007	1831	2316	2059	2260	2124
Diesel not accounted for	1085	1061	1230	1169	1204	1199
Sum, direct energy	3393	3319	10065	9873	3765	3750
Seeds	77	77	77	77	77	77
Fertilizers 225 N, 16 P, 105 K	9452		9452		9452	
Pesticides	72		72		72	
Sum, indirect energy	9601	77	9601	77	9601	77
Total energy, MJ/ha	12994	3396	19666	9950	13366	3828
Grass yield, FU/HA[3)]	6000	5200	7100	5900	6900	6100
Energy efficiency[4)] FU/MJ	0,46	1,53	0,36	0,59	0,52	1,59

1) Machine operations to composting and spreading of manure, 12 t/ha conventional, 17 t/ha organic farms

2) Other machine operations incl. harvesting of 44% of conventional and 51% of organic grass-clover and alfalfa yield

3) Scandinavian feed units per ha

4) Energy efficiency was calculated as FU grass per MJ

Table 3. Estimations of energy (MJ/ha) use and spring sown grain yield (kg/ha) in organic and conventionel grain crops on three soil types.

Preliminary results based on modelization of collected data. Energy data from Refsgaard & Halberg (1994), yields from Halberg et al. (1994b).

Soiltype	Sandy, no irrigation		Sandy, irrigation		Clay	
System	Conv.	Organic	Conv.	Organic	Conv.	Organic
Electricity, irrigation 60 mm			2628	2628		
Electricity, drying 2%	246	195	318	239	311	239
Diesel, manure[1]	853	795	853	795	853	795
Diesel, other[2]	2410	2241	2410	2241	2410	2241
Diesel not accounted for	1534	1427	1534	1427	1534	1427
Sum, direct energy	5043	4658	7743	7330	5108	4702
Seeds	358	459	358	459	358	459
Fertilizers	3799		3799		3592	
Pesticides	218		218		218	
Sum, indirect energy	4375	459	4375	459	4168	459
Total energy, MJ/ha[3]	9418	5117	12118	7789	9276	5161
Grain yield, kg/ha	3400	2700	4400	3300	4300	3300
Energy efficiency[4] kg/MJ	0,36	0,53	0,36	0,42	0,46	0,64

1) Machine operations to composting and spreading of manure, 33 t/ha conventional (95% slurry), 25 t/ha organic (5% stable + 55% liquid manure).
2) Machine operations from ploughing to harvesting.
3) Diesel straw not included.
4) Energy efficiency was calculated as kg grain per MJ.

Table 3. Estimations of energy (MJ/ha) use and spring sown grain yield (kg/ha) in organic and conventionel grain crops on three soil types.

Preliminary results based on modelization of collected data. Energy data from Refsgaard & Halberg (1994), yields from Halberg et al. (1994b).