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Energy and environmental burdens of organic and non-organic agriculture and horticulture

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Summary

Production of 10 major commodities in England and Wales was studied using Life Cycle Analysis (LCA). Organic and non-organic (contemporary conventional) systems were compared. Organic production was generally less energy consuming, except for poultry meat, eggs and tomatoes. Environmental burdens, such as global warming potential or eutrophication were often greater per unit of production from organic than non-organic systems.

Key words: Life Cycle Analysis (LCA), agricultural commodities, energy, environmental burdens, nitrous oxide

Introduction

There is increasing interest in the resource use and environmental burdens arising in agricultural and horticultural production. Environmental Life Cycle Analysis (LCA) provides a comprehensive and objective method of analysis that allows alternative production systems to be compared and it identifies where major consumption of resources and emissions to the environment occur, so highlighting where improvements in techniques are most needed. LCA can be used to quantify the resource use and environmental burdens arising for a range of agricultural commodities produced within both organic and non-organic systems. We therefore used this approach to analyse the environmental burdens of domestic production of ten commodities, providing the most comprehensive analysis of domestic production to date and also to compare organic and non-organic production systems.

Materials and Methods

LCA was applied to agricultural and horticultural production of ten key commodities in England and Wales (Williams *et al*., 2006, which includes all methods used). These were: bread-making wheat, potatoes, (oilseed) rape, tomatoes, beef, pig meat, sheep meat, poultry meat, milk and eggs. All commodities were quantified as functional units; typically 1 t fresh weight, with defined technical qualities. Tomatoes and potatoes are produced in various forms. These commodities were thus defined as *national baskets of products* including types such as loose and on-the-vine tomatoes, each included as their proportion of national production.

LCA analysis determines all the primary energy (e.g. crude oil) needed to produce each commodity. Abiotic resources used (ARU) were consolidated onto one scale based on relative scarcity.

Individual environmental emissions such as carbon dioxide (CO_2) and nitrous oxide (N_2O) were quantified and aggregated into impacts. The impacts are potentials for global warming (GWP), eutrophication (EP) and acidification (AP). Pesticide and land use were also quantified, including fertility building and cover crops in organic systems. Default values for all commodities are included in the working model, e.g. national proportions of main production systems and sub-systems; fertiliser application rates. In total, these represent the current balance of production methods in England and Wales.

The system boundary ended at the farm gate and included soil to a nominal depth of 0.3 m. Animal system boundaries included grassland, housing and contributory sub-systems of forage conservation, arable feed production, imports and processing. The LCA of each commodity included: all direct energy (e.g. tractor fuel); fertiliser extraction, manufacture and delivery; field machinery manufacture and maintenance; building construction and maintenance; producing, importing, processing and delivering animal feed crops. Functional relationships were used to connect parts of production systems, e.g. crop yields and supplied N; networks of animal production; milk yields and feed supply. These ensure that changes in one area are reflected in another. A long-term analysis (≥ 100 years) was used to ensure that nutrients were not allowed to build up in or be depleted from soils. Sufficient activities and inputs were also included to ensure weeds and diseases would not build up and that yields were technically sustainable. Organic production was always analysed, as well as variants of non-organic (= contemporary conventional) production.

Results and Discussion

Crop production

Non-organic production dominates current crop production (Table 1), so the results are effectively those of non-organic production. Care should be taken in trying to compare commodities as they are not equivalent. Potatoes can be eaten, wheat needs to be milled, and the 40% oil has to be extracted from rape. Potatoes superficially have the lowest burdens, but they contain 80% water. They incur higher burdens than rape on a dry matter (DM) basis and even more on an energy basis. Bread wheat incurs the least burdens on a DM basis, but this is equivalent to rape on an energy basis. The need for cold storage of maincrop potatoes accounts for over one third of the primary energy used for the whole commodity, whereas drying and storage is less than 5% of primary energy use for cereals.

Tomato production uses energy to extend the cropping season considerably and provide a fresh salad crop for much of the year, but the burdens are considerably higher than field crops. Tomatoes are, of course, not staple foods like bread or potatoes. About 97% of the energy is used for heating and lighting. Pesticide usage is lower than for field crops (e.g. 25% less than bread wheat) because biological control is possible in greenhouses. The high yields also mean that land requirements are one tenth of even high yielding potatoes. Because tomato production is dominated by energy use, which is almost identical for all production systems, the highest yielding tomatoes (non-organic, loose, classic or beefsteak) incur lower burdens than all other types of tomato. Specialist varieties (cherry, plum etc.) yield less than half of classic, thus more than doubling burdens.

The balance of global warming gas emissions and fossil fuel consumption is quite different from most industries. A *carbon footprint* inadequately describes agriculture; it has a *carbon-nitrogen footprint*. N_2O dominates GWP from field crops, contributing about 80% in wheat production (both organic and non-organic). The N_2O contribution falls to about 50% for potatoes as much fossil energy goes into cold storage. In contrast, CO2 from natural gas and electricity use in tomato production is the dominant contribution to GWP.

Animal production

Animal production is also dominated by the non-organic sector (Table 2) and burdens are all higher than for field crops, because much animal feed comes from field crops. Care is needed in comparing meats as they have different nutritional properties and fill different cultural roles.

Table 1. *The main burdens and resources used for field and protected crops in the current national proportions of production systems (with the current organic share shown in parenthesis)*

Impacts & resources used t^{-1}	Bread wheat, (0.7%0	Oilseed rape, (0%)	Potatoes, (1%)	Tomatoes, (3.6%)
Primary Energy used, GJ	2.5	5.4	1.4	130
GWP_{100}, t CO_2 (1)	0.80	1.7	0.24	9.4
EP, kg PO_4^{3-} (2)	3.1	8.4	1.3	1.5
AP, kg SO_2 (3)	3.2	9.2	2.2	12
Pesticides used, dose-ha	2.0	4.5	0.6	0.5
ARU, kg antimony	1.5	2.9	0.9	100
Land use (Grade 3a), ha	0.15	0.33	0.030	0.0030
Irrigation water, m^3			21	39

(1) GWP^{100} uses factors to project global warming potential over 100 years. (2) EP is eutrophication potential; PO_4^{3-} is phosphate. (3) AP is acidification potential; SO_2 is sulphur dioxide. (4) ARU are abiotic resources used; antimony is the element used to scale disparate entities.

Table 2. *The main burdens and resources used in animal production in the current national proportions of production systems (with the current organic share shown in parenthesis).*

Impacts & resources used t^{-1} of carcass, per 20,000 eggs (about 1 t) or per 10 m^3 milk (about 1 t dm)	Beef, (0.8%)	Pig meat, (0.6%)	Poultry meat, (0.5%)	Sheep meat, (1%)	Eggs, (1%)	Milk, (1%)
Primary Energy used, GJ	28	17	12	23	14	25
GWP_{100}, t CO_2	16	6.4	4.6	17	5.5	10.6
EP, kg PO_4^{3-}	158	100	49	200	77	64
AP, kg SO_2	471	394	173	380	306	163
Pesticides used, dose ha	7.1	8.8	7.7	3.0	7.7	3.5
ARU, kg Antimony	36	35	30	27	38	28
Land use (1)						
Grade 2, ha	0.04			0.05		0.22
Grade 3a, ha	0.79	0.74	0.64	0.49	0.67	0.98
Grade 3b, ha	0.83			0.48		
Grade 4, ha	0.67			0.38		

(1): Grazing animals use a combination of land types from hill to lowland. Land use for arable feed crops was normalised at grade 3a

Poultry meat production appears, however, the most environmentally efficient, followed by pig meat and sheep meat (primarily lamb) with beef the least efficient. This results from several factors, including: the very low overheads of poultry breeding stock (*c*. 250 progeny per hen each year *vs* one calf per cow); very efficient feed conversion; high daily weight gain of poultry (made possible by genetic selection and improved dietary understanding).

Poultry and pigs consume high value feeds and effectively live on arable land, as their nutritional needs are overwhelmingly met by arable crops (produced both here and overseas). Ruminants can digest cellulose and so make good use of grass, both upland and lowland. Much of the land in the UK is not suitable for arable crops, but is highly suited to grass. One environmental disadvantage, however, is that ruminants emit more enteric methane. This contributes to the ratios of GWP produced to primary energy consumed, being about 50% higher for ruminant than pig or poultry meats.

Comparison of organic and non-organic systems

About 27% less energy was used for organic wheat and rape production compared with non-organic, but there was little difference with potatoes (Table 3). The large reduction in energy used by avoiding synthetic N production is offset by lower organic yields, which increases the absolute contribution of energy for field work. Field work for combinable crops is always more for organic owing to the need for extra operations for weed control.

Table 3. *Ratios of the burdens of organically produced commodities divided by those of non-organically produced commodities*

Impacts & resources used	Bread wheat	Potatoes	Rape	Beef	Sheep meat	Pig meat	Poultry meat	Milk	Eggs
Primary Energy	0.7	1.0	0.8	0.7	0.8	0.9	1.3	0.6	1.1
GWP_{100}	1.0	0.9	1.0	1.2	0.6	0.9	1.5	1.2	1.3
EP	3.0	1.1	1.8	2.1	3.0	0.6	1.8	1.6	1.3
AP	1.1	0.4	0.6	1.5	4.1	0.3	1.5	1.6	1.1
Pesticides used	0.0	0.2	0.0	0.0	0.0	0.0	0.1	0.0	0.0
ARU	0.9	1.2	0.9	0.9	0.7	0.9	3.4	0.5	1.1
Land use	3.1	2.6	2.7	1.8	2.3	1.7	2.2	1.7	2.2

GWP is only 2–7% less for organic than non-organic field crops, reflecting the need for N supply to equal N take-off and the consequent emissions to the environment as nitrous oxide to air and nitrate to water. This reinforces the carbon-nitrogen footprint concept. Differences in AP and EP were more variable, being both lower and higher than non-organic. Pesticide use is zero for all organic field crops, except potatoes, where copper-based products for blight control are applied at 20% of the rate as non-organic.

Most organic animal production reduces primary energy use by 15% to 40%, but organic poultry meat and egg production increase energy use by 30% and 15% respectively. Despite the lower energy needs of organic feeds, this benefit is over-ridden by lower bird performance. More of the other environmental burdens were larger from organic production, but ARU was mostly lower (except for poultry meat and eggs) and most pig meat burdens were lower. GWP from organic production ranged from 42% less for sheep meat to 45% more for poultry meat.

Land use was always higher in organic systems (with lower yields and overheads for fertility building and cover crops), ranging from 65% more for milk meat to 160% for potatoes and 200% more for bread wheat, but the latter is a special case as only part of a crop meets the specified bread-making protein concentration. Organic tomato yields are 75% of non-organic. Thus, the lowest yielding organic, on-the-vine, specialist tomatoes incur about six times the burden of non-organic, loose classic.

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Reference

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