

# Environmental Science FACT SHEET



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## Energy efficiency of food production systems

### Introduction

Three factors are important in deciding on a food production system:

1. **Economic:** Farmers have to be able to make a profit. Thus, the cost of their inputs must be less than the money they receive from selling their outputs – the products. But in most countries, the farmer cannot control the cost of the inputs or the price that they receive for their outputs.

In the UK, farmers have protested in recent years about the cost of diesel, which itself is influenced by the price of oil which, in turn, is influenced by events in the Arab countries that possess huge stocks. Thus, war in the Middle East may result in farms being sold in Cumbria. Throughout Europe, the most significant economic impact on agriculture is the level of government support through subsidies and direct payments. One of the reasons that organic farming is increasing throughout Europe is that the European Union provides financial help to farmers converting from intensive to organic production.

2. **Ethical:** Unsustainable systems - i.e. those that are totally dependent upon finite fossil fuels - are unethical because we are compromising the ability of future generations to produce sufficient food. Systems that require destruction of valuable habitat reduce biodiversity, which is likely to be essential for future ecosystem stability. Intensive animal systems, e.g. battery chicken farming, may be deemed unethical on animal welfare grounds.
3. **Environmental:** Those systems reliant upon fossil fuel input are unsustainable and cause, directly or indirectly, air, water and soil pollution and habitat loss. One of the key questions that is now being asked is "Who should pay for cleaning up pollution, and the damage to landscapes and wildlife caused by agriculture?"

All three of these factors really highlight the same issue. *Are agricultural systems sustainable?* This Factsheet addresses this question by looking in detail at the energy efficiency of agricultural systems.

### Energy Efficiency of Agricultural Production Systems

In the developed world, the way in which we grow crops and raise animals has changed dramatically over the last century. We now have a range of farming systems (*Table 1*).

These systems overlap. For example, many commercial systems use an intensive approach. The question of which system is best is the subject of fierce debate.

The key issues are:

- *Millions of people still do not have sufficient food.*
- *World food production is increasing but per capita food production is stagnant because world population is increasing quickly too.*
- *Increasing food production has resulted in greater reliance on mechanisation and the use of artificial inputs such as fertilisers and pesticides.*
- *Because they are based upon fossil fuels, these all represent 'hidden' energy inputs or an energy subsidy. The problem in the long term is that fossil fuels will run out.*

Thus, the key question concerns the **sustainability** of agriculture.

It is useful to consider which aspects of modern farming systems are not sustainable (*Table 2, page 2*).

**Table 1. Agricultural Production Systems.**

Type	Description	Inputs	Energy Efficiency
Subsistence	The food produced is just sufficient to feed the population. No surplus production for sale.	Manual labour.	High.
Commercial	Surplus food is sold for profit.	Manual, machinery, chemicals. May be intensive, extensive, organic or reliant upon artificial chemicals.	Very varied, depending particularly upon form and level of energy inputs such as N-fertilisers.
Intensive	Uses high energy inputs per unit area of land to try to obtain large outputs for commercial reasons	Manual, machinery, chemicals.	May be low if all of the energy inputs are taken into account.
Extensive	Uses relatively low inputs per unit area of land because the land area involved is large.	Manual, machinery, chemicals.	Very variable, depending upon the form and level of energy inputs.
Organic	Food is produced without the use of artificial fertilisers or of pesticides.	Manual labour, machinery, natural organic wastes and naturally occurring pesticides.	May be high and usually higher than intensive.

**Table 2. Unsustainable Practices.**

Practices	Why does it occur?	Problems
Keeping too many animals on one piece of land.	More animals = more product.	Overgrazing leads to soil erosion, which leads to low fertility.
Increased mechanisation.	Faster, easier and can work in all weather conditions.	Fossil fuels will become more expensive as they run out – and they will run out!
Increased reliance on artificial (man-made) fertilisers – ammonium nitrate, for example, Increased reliance on pesticides.	Supplies nitrogen quickly – essential for crop growth. Pest epidemics would otherwise occur, particularly in monocultures	Require huge amounts of fossil fuels to make, transport and apply them. This is polluting and is reliant upon a finite resource.
Use of genetic monocultures.	Easier to plant, grow, harvest and sell.	Reduces genetic diversity. If a pest strikes, there is no in-built variability in terms of resistance. If one plant dies, they all will.
Excessive use of irrigation.	Allows crop growth in arid areas.	Salinisation can lead to a permanent loss of soil fertility.

**Productivity and Energy Efficiency**

It is easy to confuse productivity and efficiency. Productivity refers to the amount of food we get per hectare. Productivity is certainly increasing; as a result of huge inputs of fertilisers and pesticides, the use of selectively bred or genetically modified crops and the use of hormones and growth promoters. **But this is not necessarily the same as greater efficiency.**

The energy efficiency (EE) of an agricultural system can be defined as:

**The ratio between the energy given out of the system (in terms of food) and the energy put in.**

$$EE = \frac{\text{Energy output (meat, milk, crops, etc)}}{\text{Energy input (labour, fuel, fertiliser, pesticide, etc)}}$$

The EE ratio is useful because:

1. It allows us to compare different types of farming or production system.
2. It is a good measure of how a particular agricultural system is using up the Earth's finite resources.

If the EE ratio is less than 1, the system is effectively using up the Earth's resources faster than they can be replaced and is therefore unsustainable.

**So how efficient are our agricultural systems?**

It is estimated that:

- In 1826 the EE of English agriculture was 40.
- In 1972 the EE of English agriculture was 2.

Thus, mechanisation and intensification have dramatically reduced efficiency (Table 4).

**Table 4.**

System	EE ratio
Slash and burn subsistence	28.00
Intensive wheat production	3.00
UK potato production	1.50
US rice production	1.30
UK intensive beef production	0.08

Organic farming systems are roughly twice as energy-efficient as intensive farming systems and this is despite the fact that output is considerably lower. We need to look in more detail at the energy inputs.

**Table 3 Agriculture - How it got like this.**

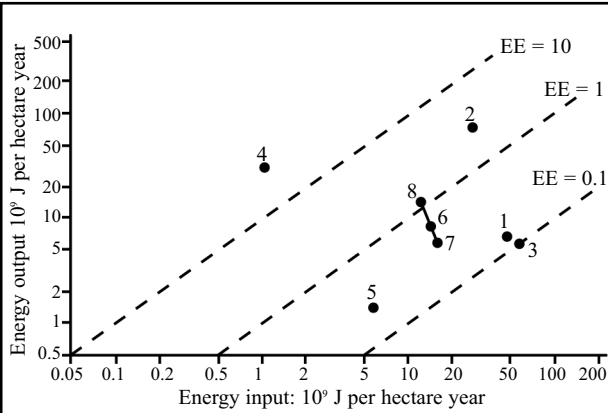
Energy Input = Labour	Hunting + Gathering	<ul style="list-style-type: none"> <li>• Low population density.</li> <li>• Small groups followed seasonal availability of nuts, plants and game.</li> <li>• Each group needed a very large area.</li> <li>• EE = 50 - 400</li> </ul>	TIME 
Energy Input = Labour	Cultivation + Hunting + Gathering	<ul style="list-style-type: none"> <li>• Population increase forced cultivation and then, as food production increased, this encouraged people to stay put or to develop shifting cultivation.</li> <li>• EE = 10</li> </ul>	
SELECTION OF CROPS AND ANIMALS - DOMESTICATION			
Energy Input = Labour and Animals	Annual Cropping	<ul style="list-style-type: none"> <li>• Developed through necessity as population continued to increase – they could not afford for land to be left fallow.</li> </ul>	
Energy Input = Fossil Fuels and Labour	Intensive Agriculture	<ul style="list-style-type: none"> <li>• Rapid population increase makes land a scarce resource, so pressure is on to grow as much food as possible on every hectare. Mexican shifting cultivation produces 1900kg of corn/ha. In Kansas, corn yields = 8500 kg/ha.</li> </ul>	

(Key: EE = energy efficiency)

**Typical Exam Question**

The graph (Fig. 1) shows the energy ratios on eight farms. The dotted lines indicate energy efficiency ratios (EE) of 10, 1 and 0.1.

**Fig. 1 Energy inputs and outputs per unit of land area in food production in the world.**



**Key:**

- |                                      |                     |
|--------------------------------------|---------------------|
| 1. Battery farm - egg production, UK | 5. Sheep farm, UK   |
| 2. Organic farm, Austria             | 6. } UK dairy farms |
| 3. Poultry production, UK            | 7. }                |
| 4. Shifting cultivation, Belize      | 8. }                |

- (a) Identify the most energy efficient farming system and explain why it is the most efficient. (3)
- (b) Comment on the relative efficiency of the organic system shown compared to the UK dairy farms. (3)

**Answers**

- (a) Shifting cultivation in Belize is the most efficient; Ratio = 34-38; i.e. for every joule of energy put into the system, the food output is 34-38j; energy input is mostly human labour/hand tools; no use of artificial fertilisers/pesticides, machinery;
- (b) Organic system more efficient; no use of artificial fertilisers/pesticides/antibiotics; ref. to legumes/biological control/manual techniques; dairy farms may use fertilisers to grow grass/ use herbicides to kill weeds/ antibiotics;

**Inputs**

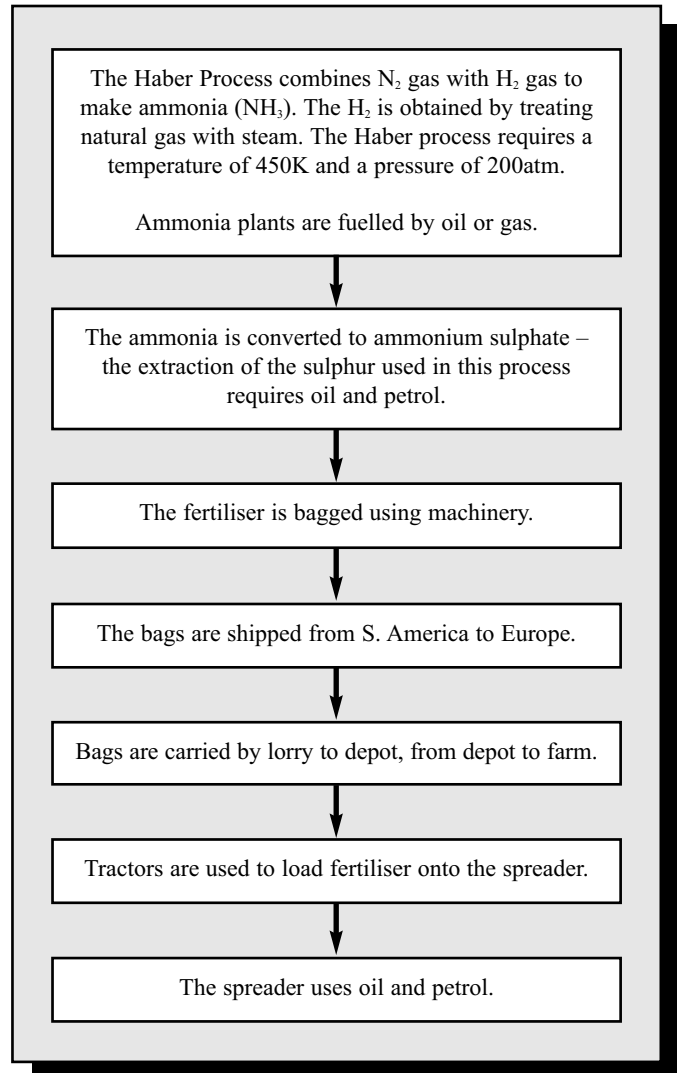
1. The Sun.
2. Human labour.
3. Dray animals.
4. Energy used to make tools and machines.
5. Oil and petrol used in machinery on farm.
6. Fossil fuels used to make fertilisers, pesticides and plastics.
7. Fossil fuels used in food processing and transport of food.

Analysis of the inputs often reveals that the single most important energy input in intensive cereal production is nitrogen. What this means is that the energy used to produce, transport and apply the nitrogen to the soil is huge. To the farmer and consumer, most of this is hidden, of course.

**Why does nitrogen represent such a huge energy input?**

Fig. 2 summarises the total energy inputs used in order for nitrogen to be applied to the soil.

**Fig. 2 The hidden energy input of N-fertiliser**



This is the main reason why the energy efficiency of intensive agriculture is so low.

**Why do we need to use fertiliser?**

1 ha of corn = 7000kg and of this, 40kg consists of nitrogen. This is removed from the field when the corn is harvested and must be maintained if fertility is to be maintained. If the soil is then immediately ploughed, 10 times this amount of nitrogen can be lost as the nitrogen – containing compounds oxidise and NO<sub>x</sub> is released into the atmosphere.

**Improving efficiency**

1. Use N-fixing cover crops in rotation.
2. Use sun-drying techniques.
3. Use rotation to minimise exhaustion of any particular nutrient.
4. Mimic natural ecosystems by planting a diverse range of crops and by recycling as many forms of wastes e.g. animal manure, as possible.

**Practice Exam Questions**

1. Analysis Exercise: Organic farming is spreading rapidly through many European countries.

Using information in the following points, outline why organic agriculture is considered to be more sustainable than intensive agriculture. (10 marks)

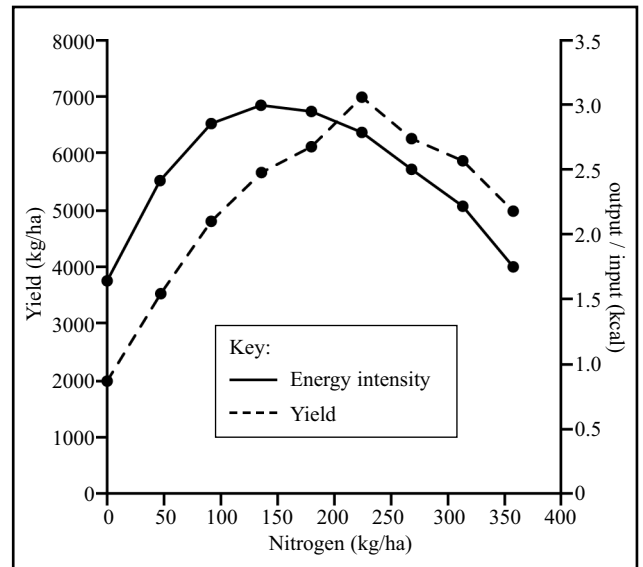
- Food is produced without using synthetic pesticides, inorganic fertilisers, ionising radiation, growth hormones, antibiotics or genetic engineering.
- Tries to incorporate natural processes, e.g. recycling, predator-prey relationships, natural N-fixation rather than external, artificial inputs.
- Uses crop rotation to minimise problems of weeds, pests or nutrient exhaustion.
- Weeds are suppressed by mulches, mechanical removal or by inter-planting different crops that do not compete for the same nutrients at the same time.
- Uses Integrated Pest Management in which biological control, naturally-occurring pesticides and cultural techniques such as rotation or careful timing of planting are employed.
- Tillage is used to conserve soil and water.
- Uses green manures, legumes and animal wastes to retain organic matter and nutrients in the soil.
- Organic fields have greater organic matter content, suffer less nutrient loss through leaching and have a greater number and diversity of invertebrates. For example, vegetables can be under-planted with Phacelia. Phacelia attracts Hoverflies. The Hoverfly larvae prey on aphids, which would otherwise feed on the vegetable crop. This is an example of biological control.
- Yield is usually lower than in systems that use artificial inputs.

2. The table shows energy inputs and outputs in US corn production

Inputs	Quantity/ha	Kcal/ha
Labour	10 h	4,650
Machinery	55 kg	1,018,000
Diesel	75 Litres	855,000
Gasoline	40 Litres	400,000
Nitrogen	152 kg	3,192,000
Phosphorus	75 kg	473,000
Potassium	96 kg	240,000
Limestone	426 kg	134,000
Seeds	21 kg	520,000
Irrigation	660,000 kg	660,000
Insecticides	2 kg	200,000
Herbicides	4 kg	400,000
Drying	660,000 kcal	660,000
Electricity	100,000kcal	100,000
Transportation	322kg	89,000
	<b>TOTAL</b>	<b>8,945,650</b>
Outputs		
Corn Yields	7,500 kg	<b>26,625,000</b>

- (a) Calculate the energy efficiency of US corn production. Show your working. (1)
- (b) Explain why nitrogen represents such a large energy input. (3)

3. The graph shows the effect of nitrogen application on the yield of corn in the US.



- (a) Summarise the data shown (2)
- (b) Estimate the optimum level of nitrogen input (1)

**Answers**

1. Pesticides, inorganic fertilisers, hormones etc use fossil fuels; In their manufacture/transport/use; Fossil fuels are finite; Organic systems use much less fossil fuels; Use natural cycles driven by solar energy; Credit example e.g. nitrogen cycle using legumes; Credit example e.g. crop rotation not fertilisers or pesticides; Credit example e.g. biological control using natural predators; Credit example e.g. mulches, mechanical removal not herbicides; Organic system less likely to suffer soil erosion; Organic matter levels higher so soil and water conserved; Because of time scale of formation, soil is a finite resource; Less need for irrigation;

(Any 10)

2. (a)  $26,625,000 / 8,945,650 = 2.97$
- (b) use of fossil fuels; ref to Haber process; mining of other elements; transport; application;

(Any 3)

3. (a) Between 0-225 kg/ha of N, as N increases, so does yield; Then declines;
- (b) 225 kg/ha

**Acknowledgements**

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