making western agriculture more sustainable

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The energy crisis plus a shortage of phosphate fertiliser will change settlement patterns by forcing people to source their food from local farms.

Modern Western European agriculture is heavily dependent on services that often are taken for granted. However, if we are to discuss how it can be made more sustainable we need to consider all the support systems necessary for the entire field-to-table chain. This is seldom done although several authors (Odum, H.T., 1971; Odum, E.P., 1973; Huang & Odum, 1989; Pimentel et al., 1989). have explored the topic. In particular, the support services agriculture gets from ecosystems are often left out.

Current farming cannot produce food without the following:

- Cheap and continuous supplies of fuel.
- Phosphorus ores for fertilisers.
- A distribution system for fertilisers, animal feed, fuels and agricultural products that can function even if there are disturbances outside the agricultural system.
- A support infrastructure that can maintain machinery independently of the general industrial climate.
- The uninterrupted support of ecosystems to (1) bring forth and recycle nutrients, water, carbon and other essential production factors, (2) maintain the soil's structure and functions and (3) maintain a favourable climate and gas balance in the air.

- Specialist workers who are prepared to endure extended agricultural labour regardless of the low income and low status it brings them.

Some of these support systems are so vital that their failure would be disastrous for those who depend on the sector for their food. So how vulnerable are these systems to disruption and how can their reliability be improved?

THE DEPENDENCIES

Dependency on material and industrial energy support

Pre-industrial agriculture was a very local activity. Most equipment was made locally and agriculture was powered largely by different types of locally captured solar energy. Nutrients were collected by meadow plants and reached the arable fields (which were often situated within a few kilometers of the settlements in which their produce would be consumed) when hay was made from the plants, eaten by animals and released from the manure they had dropped when it was spread on the tillage land.

In contrast, the sun is not modern agriculture's main energy source. If the total inputs are considered, it is fossil energy of different types. This, coupled with its need for constant supplies of other inputs such as fertilisers, biocides, animal food, plastics for silage and drugs for treatment of animal diseases, gives modern agriculture a structure similar to any other throughput industry.

The higher yields produced by modern methods are not due to any enhancement of the crops' ability to capture more solar energy, but because some tasks formerly done by the crops themselves, such as extracting nutrients and warding off diseases and herbivores, are done for them by the farmer using fossil fuel inputs (Odum, 1971). This means that agriculture output levels cannot be maintained without industrial supplies. We consequently have to consider the sustainability of industry and infrastructure in any discussion of the sustainability of modern agriculture.

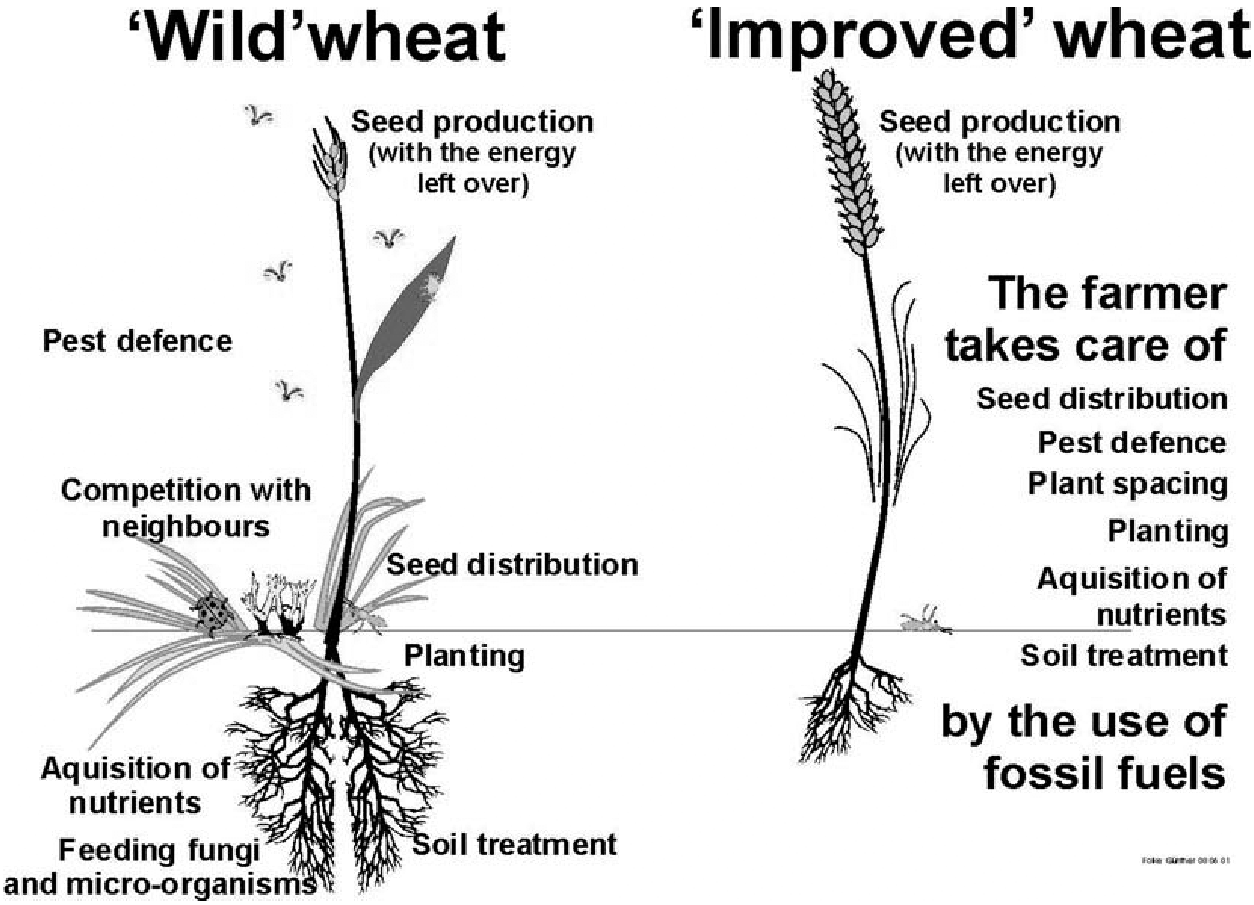

Figure 1 'Improvements' to domesticated plants and animals have often involved an increased dependency on fossil fuels.

Cheap fossil energy?

Today's agriculture is heavily dependent on fossil fuels. In developed countries, the input of fossil fuel energy to agriculture equals, or surpasses, the output of energy in the food supplied for human consumption (Hall et al., 1986; Folke & Kautsky, 1992; Hoffman, 1995). This is why industrial agriculture has been described as a black box for converting fossil fuel energy into edible food energy .

The implicit assumption underlying this conversion is that fossil fuel and the other necessary inputs will always be so cheap that they will not increase food prices beyond what the public can afford. This assumption can be questioned, however. As Colin Campbell has shown, (see his paper in this book), around half of the world's reserves of crude oil has already been used up and the remaining reserves can be expected to require more energy to be used for the extraction of each unit of energy they produce than those being exploited already. In other words, the energy yield per unit of energy (YPE) used in the extraction will fall.

Energy price is hard to calculate. The price for, say, petrol at the filling station changes on a daily basis. The salary of the person who buys it changes too. The best way of saying whether the energy is ‘cheap’ or ‘expensive’ is therefore to calculate how long a person has to work in order to get a certain amount of energy. The result of such a calculation is demonstrated in *Figure 2*, where the price for gasoline in Sweden is divided by the salary of a ‘general’ worker. It shows that the working time needed to purchase one kWh of gasoline in 1995 has fallen to about a tenth of the time needed in 1920. In other words, the availability of the energy to the worker has increased ten times.

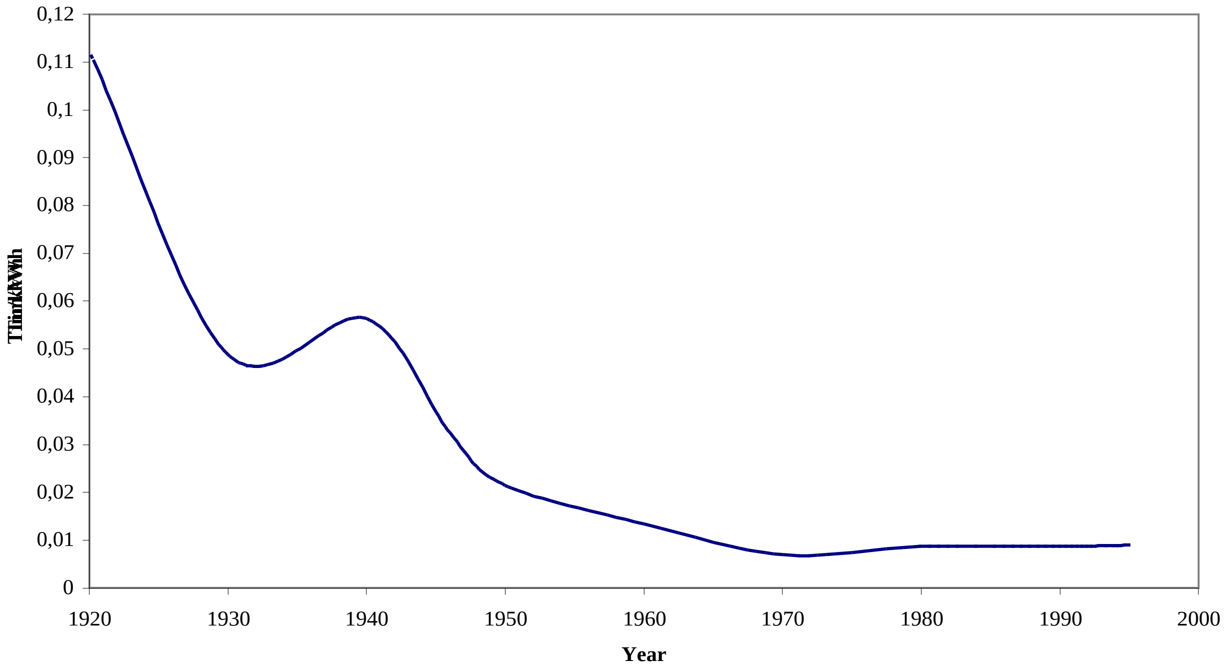

Figure 2. The working time needed to purchase one kWh of gasoline fell by about 90% between 1920 and 1995. Note the increase during World War II. The ‘energy crisis’ during the 1970s is barely noticeable.

The extraction of fossil fuels is energy intensive because to make the energy in fuels available energy must be used for drilling, prospecting, building an industrial infrastructure, etc.. The YPE for fossil fuel extraction decreased globally during the last century. In the lower 48 states of the US, the YPE of oil production is expected to fall below 1:1 about 2005 (Hall & al., 1986; Cleveland, 1991). At this point, the oil will not be able to be considered an energy source, even if it is still extracted for other reasons.

As oil gets scarcer, its price can be expected to rise in relation to other commodities. If it increases on average by only 5% a year, its price will rise by a factor of twelve within fifty years. Swedish agriculture uses over 110 litres of fuel oil per hectare[5] directly (SCB, 1994), plus perhaps 50% more for the production of pesticides, fertilisers, machinery etc., and for the electricity used on farms. Consequently, if the energy intensity of the food system does not change, the price of the sector's energy requirements will be very much higher (Table 1).

Table 1. Assuming a 5% annual increase, the price of fossil energy will rise twelvefold within 50 years

Years from today	0	15	25	50	75
Fossil energy price assuming 5% increase per year (SEK/kWh)	0.45	0.95	1.57	5.48	19.13
Direct fuel cost *per hectare* agriculture, assuming the same fuel use as 1994, SEK	495	1,045	1,727	6,028	21,043

Moreover, a lot of fossil energy is required to process food and to transport it to the consumer. These requirements, which are substantial, will be discussed later in this paper. However, it is not too bold to assume that the total cost of the energy required to grow food, process it and deliver it to the consumer could become more than the present food production system could bear.

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Phosphorus ore availability

Modern agriculture also needs a steady supply of nutrients to survive, at least as much as it loses when its products leave the farm. It is possible to use leguminous plants to fix nitrogen from the atmosphere but potassium and phosphorus have no such gaseous phases and must be made available in the soil in a soluble form. Potassium is a quite common element and scarcity is therefore rare. Phosphorus, however, is often a limiting element for plant growth, so a constant supply of it is vital to any type of agriculture exporting produce if the nutrient content of the produce is not recycled. As modern agriculture rarely recycles its nutrients, it has to import phosphates if they are leaving the farm with the products.

Guano, the polite name for bird droppings, was used to restore phosphorus losses in 19th century agriculture until the supply was exhausted after about 30 years (Brundenius, 1972; Gutenberg, 1993). Today, rock phosphate from countries like Morocco is the main phosphate source but resources of it are limited. Estimates differ but one literature survey (Pierrou, 1976) estimates the available amount of mineable phosphorus as being in the range of 3,140 - 9,000 Tg. If we assume Pierrou's constant extraction rate of 12.6 Tg/year, this gives the resource a life-time of 249 - 714 years. However, later estimates indicate smaller resources and higher rates of extraction. Smil (1990) estimates the amount of phosphorus in the reserves to be around 2,600 Tg. and says that they are being used at the rate of about 20 Tg P a year. This means that the resource may have a lifetime of only about 130 years.

Evidently, there is great uncertainty about both the amount of mineable phosphorus ore and its average phosphorus content. What is certain, however, is that extracting phosphorus from the ore is an energy-intensive process requiring between 18 and 32 MJ of energy per kilo of phosphorus, depending on the product (Smil, op.cit.). Moreover, the yield per unit of energy used in the extraction falls, just as it does in fossil fuel extraction, as lower-grade ores have to be used. (Hall & al., 1986). This could lead to a resource trap in which phosphorus reserves which could be exploited today and are therefore included in the above estimates become unavailable in the future because of the shortage of energy for extraction. Cleveland (1991) discusses this.

Phosphorus costs about 15 SEK/kg today, and the cost of the energy required for its extraction is 3 SEK. If energy prices rise at 5% per year in real terms and the amount of energy required rises at 3% a year because of the poorer ores, the energy cost for extraction will exceed 400 SEK/kg within 75 years, an increase of two powers of ten (Table 2). This is clearly an unsustainable situation worth further consideration. It is probable that such a cost would significantly limit the current method of phosphorus use.

Table 2: The energy price/YPE trap in the case of phosphorus mining, assuming 5% annual increase in petroleum prices

Years ahead	0	25	50	75
Price for industrial energy, SEK/kWh	0,45	1,6	5,5	19
Price for the extraction of phosphorus, assuming a 3% annual decrease in YPE., SEK/kg	3,13	34	119	415

Transport dependent centralisation

Fossil fuel-based industrialisation and the infrastructural development which accompanied it made it possible to produce food far from the consumers and transport it cheaply to them despite the long distances. This enabled populations to congregate in urbanised - industrialised areas. There seems to be a close connection between the availability of cheap energy and urbanisation. Certainly, without cheap energy, large cities cannot be sustained,as the extraction, refinement and transport of their requirements would otherwise be too expensive. Any recycling of nutrients would also be impossible(Günther, 1994a).

Far more energy is currently used to supply a typical family's food in Sweden than is used to heat its house or run its car. Moreover, it would be possible to save more energy in its food production and distribution than on its heating or motor fuel. A normal house for a family of four, built according to the1980 Swedish building standards, can be assumed to use about 17 000 kWh each year. However, energy conservation measures changing the house to an ‘eco-house’ could cut this figure to below 10 000 kWh. The potential for increasing energy efficiency in the building is thus about 8 000 kWh/year.

Assuming the family's car travels 15,000 km/year and uses between 0.6 - 1 litre of gasoline per 10 km, the annual energy requirement would be about 9,000 kWh for the more efficient car and about 15,000 kWh for the other one. The potential saving from switching from a less efficient car to a more efficient one is therefore about 6,000 kWh/ year, the same sort of saving that could be made on heating the house

Food is another matter. The energy used for transportation and handling of food is to a large extent unrecognised part of the total per capita uses of energy. In Sweden the use of direct energy for transport and handling of food is conservatively estimated to be at least 10 % of the total annual energy use (Olsson, 1978). Indeed, Nils Tiberg (LuTH, pers. comm.) puts the figure at about 60 TWh, or 13 % of the total energy use. In Great Britain the equivalent figure was estimated to have been between 16 and 21 % in 1976 (Leach, 1976) while in the US, the energy used in the food distribution and handling system is estimated to be at least 16.5 % of total energy use (Booz, 1976).

The amount of *direct energy* used to transport and handle a single person's annual food supply in Sweden is estimated to be between 5 625 and 7,500 kWh. while the annual amount of energy that the food has to supply for that person's growth and maintenance is about 900 kWh. From these figures, the efficiency of energy delivery in conventionally handled food in Sweden could be computed to be about

7 : 1. However, including the energy expenditures in agriculture, which in round terms can be estimated to about 1:1, the total energy efficiency would have been about 8:1 in 1976. The figure may be higher today in view of the changes in society. Hall & al. (1986) estimates the figure for an average western society to be about 9.5 : 1. It can thus be estimated that about ten energy units are spent in growing, transportation, handling, packaging, shop maintenance, and so on for each energy unit delivered to the dinner table. A conclusion from this is that for a normal family, needing 1,000 kWh of food energy per person per year, the largest single energy use is that for food management and handling!

The vulnerability of agriculture

Industrialised agriculture is as dependent on general services from the surrounding society as any other industrial activity. Economic pressures have tended to increase the size of the industrial units delivering these services during past decades and to cut their number. The number of dairies and slaughterhouses has been reduced, for example. In Sweden, the total number of diaries declined from about 400 to 58 between 1960 and 1993 (SCB, 1994). 56% of the total milk production is produced in Southeast Sweden (Skåne and Halland) (SCB, op. cit.). Beside the effects of increased transportation which will be discussed later, this tendency leads to an increasingly vulnerable structure. Any malfunction of any of the larger units - perhaps as a result of disease, a strike, an electrical breakdown, problems with the delivery of supplies - will have a much more serious effect on the food supply of the population than if a smaller unit had been in trouble. The resilience (Holling, 1973) of the system has been reduced.

The same thing has happened on the farms themselves because technologies have changed and the production of their inputs - animal feed, fertilisers, seed grain, spare parts for machinery, frozen sperm for insemination and so on - has become more concentrated. About 90 % of the cows in Sweden are artificially inseminated (SCB, 1994), which means a change from farm-produced to transported services. Likewise, about 80% of the Swedish milling capacity is situated in the far south-east part of Sweden today (Jordbruksverket, 1991).

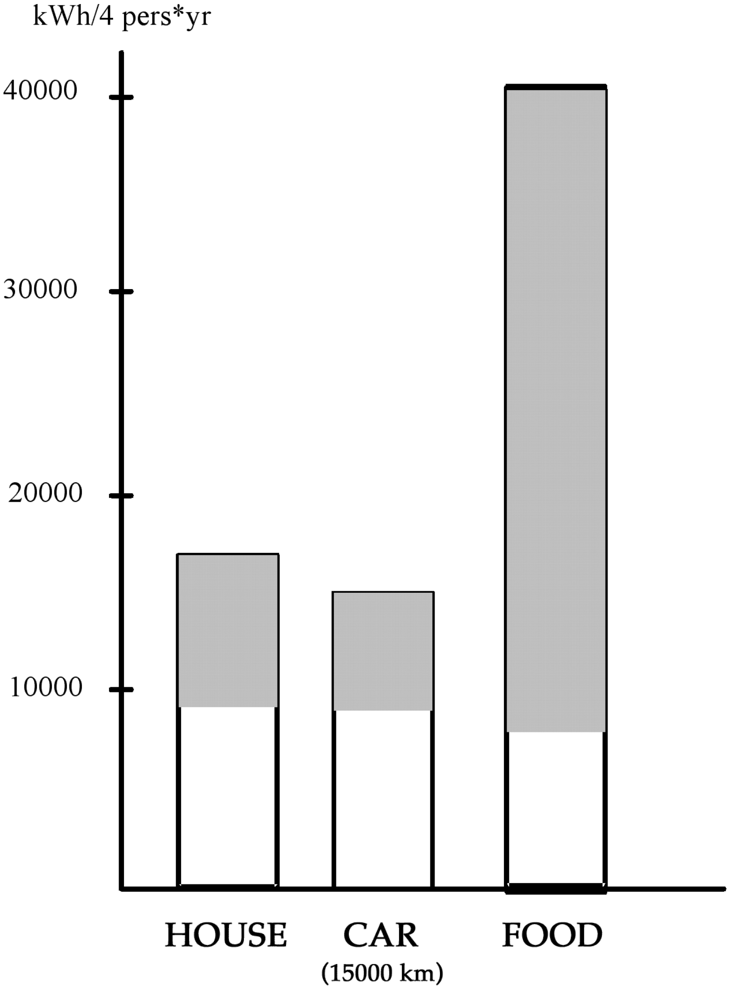

Figure 3. A rough breakdown of the energy use of a family of four in Sweden..The single largest energy user is the food system which is where the largest potential for increased energy efficiency (grey part of the bars) to be found.

The diversity of agriculture in any given area is usually reduced when the farms there become more specialised. Half a century ago, it was still common for farms to grow a large part of the feed for their animals and to keep a wide range of them. Cows, pigs, horses, geese and chicken could be found on the same farm, together with a variety of crops and processing procedures. Today, this situation is very rare. Farmers have been forced by the increased cost of their inputs and the lower price for their output to specialise on products that can be produced in large quantities at a low unit cost.. Rather than managing the land, a farmer now runs a company. State subsidies, together with the entrainment (Rosser & al., 1993) of firms into a new infrastructure, have intensified the specialisation which has lead to a decrease in diversity, reduced resilience and, consequently, to an increase in vulnerability of the food delivery system as a whole.

The specialisation of the agricultural units combined with their increase in size and decrease in number (Figure 4) and the decrease of the number of service system units has brought about not only increased delivery distances for each unit, but meant that a malfunction in one support unit can affect several large production units that in turn produce a large part of the public’s total product requirement.

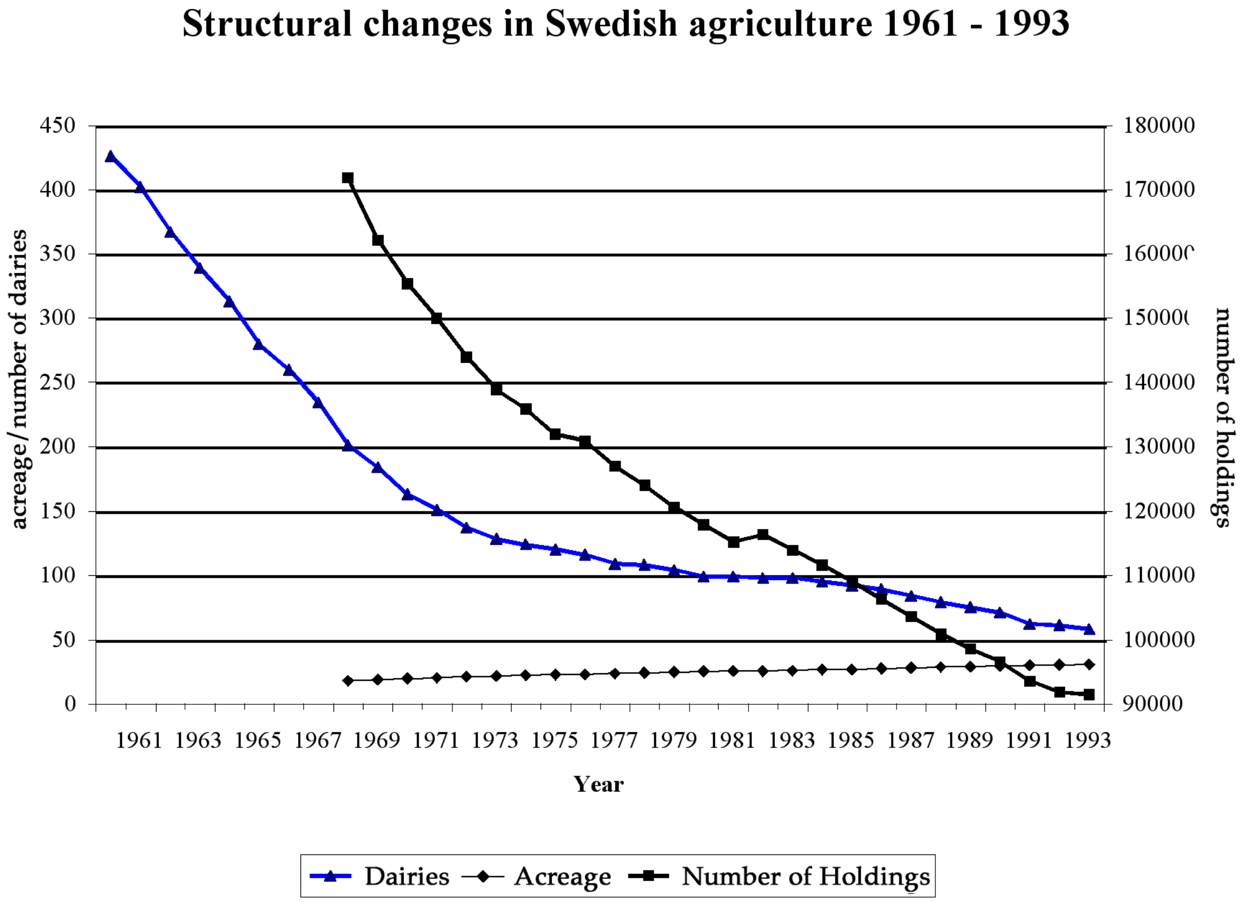

Figure 4. An increase in vulnerability can be expected as agricultural units become more specialised. This graph shows that as the size of Swedish farms increased, the number of dairies serving them fell.

With the decrease in number of production units and support units, the importance of the distribution system increases. Transportation lines are longer and the need for a safe and constant delivery of cheap energy and a well-functioning transportation infrastructure grows. Such a system is not only more likely to fail than one with shorter transportation lines and more self-sufficient production units, but the effects of the failure will be much more severe.

POTENTIAL SOLUTIONS

If we ignore changes to the agriculture itself such as organic farming or agroecology on the grounds that these have already been discussed extensively in the literature (e.g., Altieri, 1987; Pimentel, 1989), what can be done to reduce the unsustainability and potential instability of the food supply system?

1. Minimising energy use in transportation

We have seen that farming's heavy dependence on transportation is due to three factors:

- Fertilisers and other inputs are produced off the farm, and often at great distances from it.
- Farms may be a long way from the people who will eat the food that they produce.
- Animal feed may be produced in a different part of the country, or even abroad.

These would all change if consumers lived nearer the farm and the traditional balance between animal and plant production on the individual farms was restored.(Granstedt and Westberg, 1993). We've also seen that about 10,000 kWh is used per person per year for food delivery. Is it unreasonable to think that this figure could be cut to 2,000 kWh if agriculture and human settlements were more closely integrated and there was a strategy for local food management? If this was possible for only 50% of the Swedish population, the amount of energy saved would be about 50 TWh annually, which equals the electricity produced by 10 nuclear reactors.

Naturally, energy use could also be cut by technological changes on the farm itself but since the total amount of fossil energy used on Swedish farms is about 18 TWh (Hoffman, 1995), the scope for savings in this area is more limited, besides being beyond the scope of this article.

2. Increasing nutrient circulation

In modern agriculture, the replacements for nutrients lost by the export of produce from the land come from mineral ores (P, K), or from industrial processes (N). The need for these replacements increases the vulnerability of the food system to breakdown because of the potential for problems in the mining and processing industries and because of the decline in resource availability and in the yield per energy effort we mentioned earlier.

Mature ecosystems meet their essential nutrient requirements in two ways: For elements that have volatile phases (e.g., N, C, O, S and H) they are transported in the atmosphere and captured when needed. For elements that in practice have no volatile phase, repeated cycling solves the problem. Advanced ecosystems have the ability to eliminate the leakage and export of nutrients almost completely (Stark and Jordan, 1978; Odum, 1973, 1985; Kay, 1994).

Advanced self-organising systems are capable of homeostasis and exert a dynamic balance, a characteristic of open systems far from thermodynamic equilibrium. In such a system, material circulation is a necessary consequence of the structural changes associated with the increased capability to secure solar exergy in some form and convert it to low grade thermal radiation. This combined fulfilment of increased exergy degradation (Schneider and Kay, 1994) and material circulation is called the *regenerative cycle* (Günther and Folke, 1993; Günther, 1994b). This seems to be a general principle of any self-organising system. If the elements used for re-charging exergy into the system are tapped off, the system will lose its power to recharge and eventually vanish. Examples of this are the bleeding of an animal or the constant export of nutrients from a farm.

In order to increase sustainability, it therefore seems a good idea to imitate the strategies of long-term surviving self-organising systems. One of the most important of those strategies seems to be the cyclic charging - discharging process of simple elements, the regenerative cycle referred to above. These elements are either volatile (N, C, S, O, H) or non-volatile (P, K and trace metals). The limiting non-volatile elements and the volatile ones that carry a heavy energy investment, as the nitrogen oxides, are carefully recycled in such systems (Stark and Jordan, 1978; Odum 1973, 1985; Kay 1994). To do the equivalent on a modern farm, two changes are needed (Figure 5).

Animal feed has to be produced on the same farm, or in the vicinity, allowing the manure to be returned to the land where the feed was produced. By this practice, 60-90% of the nutrients, at least the non-volatile ones, can be circulated (Granstedt and Westberg, 1993). Nutrients with volatile phases, e.g. nitrogen, can be conserved by anaerobic storage or other means. When applied to farmland, they should be immediately covered with soil.

The nutrients actually exported as human food should be returned as uncontaminated as possible, preferably as human urine and (composted) faecal matter. With the use of source-separating toilets, which do not mix urine with faeces, the urine, containing most of the phosphorus and the nitrogen excreted (Günther, 1994) can be reclaimed easily. Faeces can be composted out of reach of flies to eliminate pathogens and then returned to the fields.

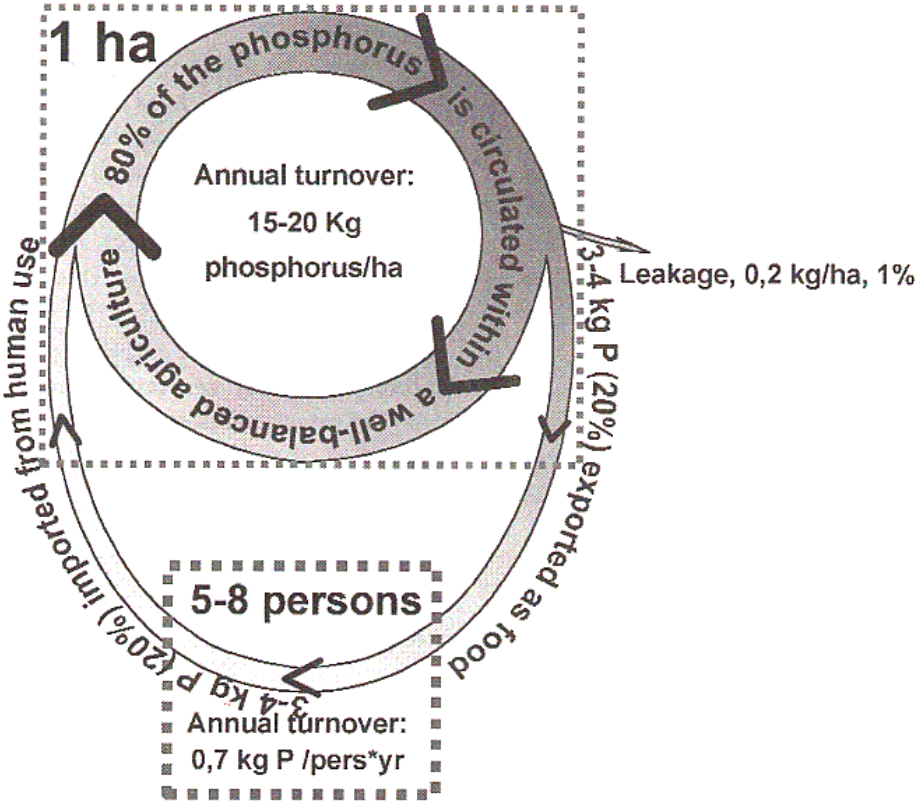

Figure 5. The phosphorus exported from a hectare of balanced agriculture (i.e. a farm producing food for its animals) equals the phosphorus content of the excrement from between five and seven people. This means that one person needs about 0.2 hectares of balanced agriculture for the production of his or her annual food needs.

INTEGRATION OF AGRICULTURE AND SETTLEMENTS

Most of the problems pointed out in the first part of this paper can be ascribed to the unintentional separation of agriculture and settlements that has developed as a side-effect of the industrial revolution the last century. Re-integration of agriculture with settlements would be a way to solve the problems of increased vulnerability and decreased sustainability of the food system. Many of the environmental problems experienced today could also be alleviated by this strategy.

Micro-scale

Let's explore different scales of operation (Allen & Starr, 1982) to see how suitable each is solve the problems discussed earlier. We'll look first at a single agricultural unit and a small settlement of around 200 people.

1 . *Elimination of dependency for feed and nutrients*

Assume that the farm produces both animal and vegetable products. Suppose too that all the feed for the animals is produced in the area. This will reduce the need to import nutrients by 60 - 90 % (Granstedt and Westberg, 1993). However, the export of essential nutrients in food will still amount to 3-4 kg P/hectares/year. For the long-term survival of the system, this amount must be replaced. A human excretes 0.6 - 0.7 kg P/year in urine and faeces. This means that the phosphorus content of the excrement from 5-7 persons equals the losses of phosphorus in food from a hectare of a balanced agriculture (Figure 5).

From these figures, the area of a balanced agriculture needed to support one person is obtained. This area is between 0.23 and 0.15 hectares, which is in agreement with the figure of 0.2 hectare per person calculated from a typical person's food needs and a conservative estimate of the production capacity of an average Swedish farm(Günther, 1989). A 40 hectare agricultural holding can thus provide about 200 people with a large part of their needs.

Thus, if the farm's acute dependence on outside supplies of nutrients is to be cut, animal feed production and local human settlements must be integrated with the food producing system. This integration implies an increased diversity in local agriculture because of the increased diversity of products needed by the local population.

2. Elimination of leakage

The direct leakage of phosphorus from an agricultural unit is within the range of 0.2 - 0.4 kg/hectares/year (Brink & al., 1979). By planting buffer-strips beside streams, a large part of this leakage can be captured (Mander & al., 1991, 1994) in the vegetation and reclaimed.in the form of compost, biogas sludge or ash. Such buffer strips bring other advantages. The serve as windbreaks, increasing the yield 15 - 30 % within 15 meters of the vegetation strip. They also increase the number of predators against insect pests (Andersson, 1990) and the number of bumble bees for pollination (Hasselrot, 1960).

3. Economy

The extensive handling and transporting system between the producer and consumer is not only energy demanding, but also appropriates more than 75% (calculated from the figures in LES, 1991, 1993a, b) of the price paid by the consumer for food.. It is thus a factor in low farm incomes and the decreasing marginal returns in agriculture. Furthermore, most of the price paid to the farmer is swallowed up by the cost of the monetary and material inputs he or she has to buy. Calculations based on data from Augustsson and Andersson (1995) suggest that the proportion lost this way is about 85%. (Figure 5). This means that the net income to the farmer is not more than 3.6 % of the retail price in the shop

If farmers sold directly to consumers through a local market where the farmer would be paid half the price for food that is paid by the consumer in the shop today, his or her income would quadruple despite the fact that the cost to the consumer has been sharply reduced. (Both figures assume the current product price to the farmer is 25 % of the consumer price, which is somewhat high. The calculation goes like this.

	Today		Direct sale	
Consumer (4 pers family)	60,000 kr	100.0%	30,000 kr	50.0%
Distribution and trade	45,000 kr	75.0%	0 kr	0.0%
Producer price	15,000 kr	25.0%	30,000 kr	50.0%
Producer expences	12,000 kr	20.0%	18,000 kr	30.0%
Producer salary	3,000 kr	5.0%	12.000 kr	20.0%
Energy use, whole chain	40,000 kWh		8,000 kWh	

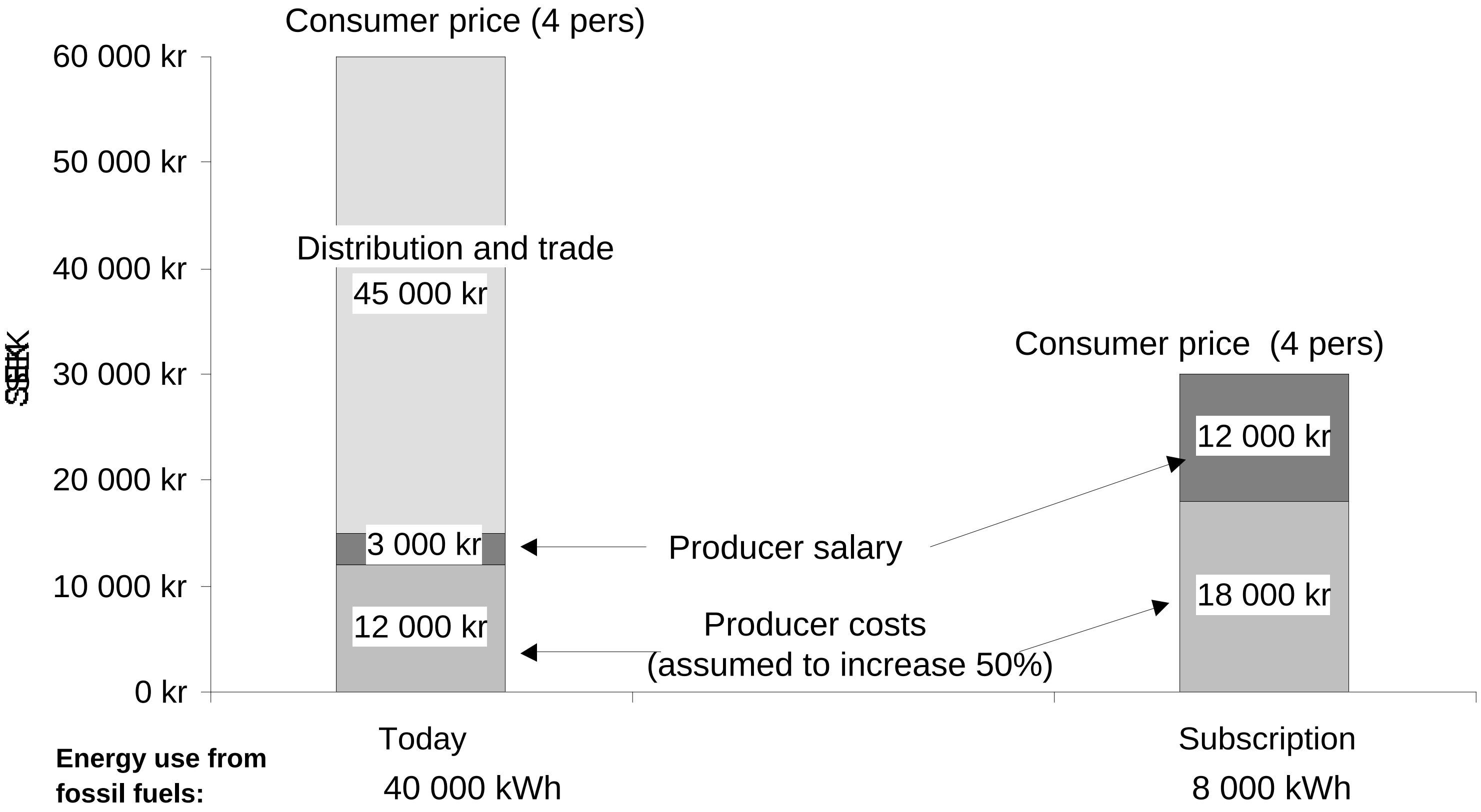

Figure 6. Direct co-operation between an agricultural unit and a near-by settlement would be economically beneficial to both the consumers and the farmer even if the production cost increased by 30%.

Medium scale

The implementation of the solutions proposed above is not incompatible with intermediate size settlements. Three or four settlements with their associated agriculture can form groups of 800 - 1,200 persons and an associated agricultural area of 160 - 240 hectares. Such a population size is large enough for a good deal of the usual social infrastructure like primary schools, small service business etc. It could be argued that this size of settlement is not enough for the cultural needs of people, and for employment etc., and that this may generate an increased need for transportation. For the sake of discussion, however, imagine an area where such settlement types cover the land. In such an area, ignoring the incidence of lakes, mountains etc., everybody would have close to 18,000 neighbours within 3.5 km.

LARGE-SCALE IMPLEMENTATION OF THE PROPOSED SOLUTIONS: RURALISATION

Nutrient recycling becomes increasingly expensive with increasing distances (Günther, 1994). The energy requirements for distribution of food also tend to increase with quantum leaps when the distribution pathways require extensive packaging and preservation of the products. Providing this energy from fossil fuels is risky and unsustainable; so, if the goal is to provide this security, energy requirements have to be cut to a minimum and met from renewable sources. Also, the methods used to provide agriculture with its 'ultimate' raw material, phosphorus, must be changed. To maintain a linear flow of phosphorus through the society over a prolonged time is both wasteful and insecure.

Therefore, to attain nutreint circulation at the same time as energy support needs are diminished in large societies, a different societal structure strategy in should be applied: instead of the current trend towards increasing agricultural specialisation combined with urbanisation of the population, a closer integration of farms and settlements would be the goal.

A name for such a strategy is *ruralisation*, as opposed to urbanisation. This development strategy implies that instead of building a new house on the same site as one due for replacement or extensive repairs, small settlements integrated with agriculture as outlined above would be created in the hinterland of the urban area.

CONCLUSIONS

In this overview, I have argued that agriculture has a lot of problems that cannot be alleviated by better agricultural methods since they are due to the way the whole society has developed. Among these problems are

- its dependency on industrial energy support
- the need for constant inputs of nutrients and other materials
- the inescapable loss of nutrients, which is in turn caused by
- the linearity of the food handling system
- the alienation of farmers and farm workers from the rest of society.

These problems are aggravated by the following factors:

- the probable increase in fuel prices
- an increasing dependency of cheap energy
- the increasing specialisation of agricultural units

- the decreasing population working in agriculture
- urbanisation.

I argue that such problems, and others, as ecological and psychological ones, could be alleviated by *a closer integration of agriculture and settlements,* thereby:

- minimising industrial energy dependency
- increasing nutrient circulation
- increasing the integration between agricultural practice and other social activities
- increasing and supporting the ecosystem services received.

The economic returns from such systems seem likely to be better than those from the current type of agriculture in view of the latter's vulnerability and the near-certiainty that its costs will rise sharply in the near future.

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