Sustainability in Agriculture

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Definition For our purposes, it is hard to better the definitions provided by Webster's 3rd New International Dictionary (p2304) viz., *Sustainable*: capable of being sustained. And *Sustain*: (from *tenere* to hold) - (2) to supply with sustenance - nourish; (3) to keep up especially without interruption, diminution or flagging; (6) to endure.

General context:

The trouble with 'sustainability' is that it has become a fashionable term. Worse! It is politically correct! As a result the term is used to qualify and justify courses of action or policies that are thought subjectively to be desirable for other reasons. It has become a term that is forced to mean any one of many things and, when used by some people, can change meaning within the course of a single speech or article.

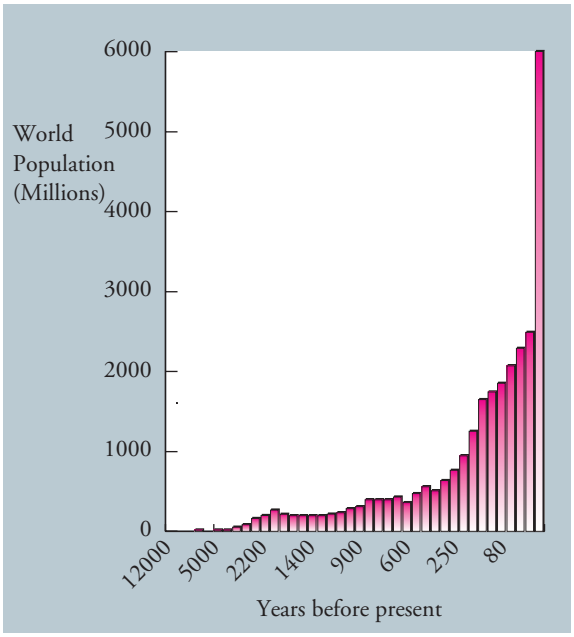
The quality of being sustainable is so attractive to us in our world where we have a nagging realisation that our current practices cannot be continued indefinitely, that the concept has generated a huge academic and pseudo-academic literature, full of large words and abstruse arguments but with little effect on the real world. Sustainability is a term that is used in the hope of conferring general acceptability on policies or actions that are seen by their proponents as being desirable for other reasons, many of which have little or nothing to do with sustainability. These include sustainable growth, development, and consumption. Examples include the UN, the World Bank, the UK Department of Trade and Industry[1], and even the Royal Society[2]. There are even periodicals on the issue of 'sustainability' e.g. Sustainable Development UK[3]. In the course of a conference on 'Sustainable Consumption'[2], organised by a group of European Academies of Science in March 2000, questions were raised on the unsustainability of certain agricultural systems. The issue spread readily into wider concerns for biodiversity, quality of surface and ground waters, and the consequences for woodlands whether timber is seen as a source of fuel, fibre, or construction material.

These opinions of ours may seem to be cynical but the purposes of this short review are simple. They are to step back and consider what is sustainability. In other words, to get off the bandwagon and walk round it, kick the tyres, really look at it and then suggest a coherent and simple (if possible) definition / description of what is sustainability. Is it necessary, is it even desirable? Can it be recognised in advance by asking what are the qualities and characteristics of agriculture that will allow it to be 'sustainable', and can one suggest those characteristics that make for unsustainability. Are there really such things as 'indicators of sustainability'; can one establish some simple guiding principles? And it is our purpose to do these things in a simple and direct language.

In a sense, and in the long run, nothing is sustainable. Not even life. To deny that is to deny the laws of thermodynamics. So! When we say or write 'sustainable' we should have at least an outline idea of the boundary conditions for our statements[5].

The world's population is estimated at 1-10 million people 10,000 years ago, between 170 and 400 million in the time of Christ, 250-350 million 1,000 years ago, ~1 billion in 1800 and 1.5-2 billion in 1900. Today, it is in excess of 6 billion and climbing – rapidly! The 20th century was not one of unparalleled fecundity, merely an era when many more children survived to adulthood and to reproduce. That trend will continue in the 21st Century with populations exceeding 10 billion by 2050. What can be held to be sustainable against such a background? Possibly the never failing ability of human beings to reproduce but certainly little else in the biosphere; exceptions will be animals and plants that live in harmony with human activity such as rats, mice, cockroaches, and *E. coli.*

There is evidence that mankind in low numbers, 10,000 years ago and before, had considerable and usually undesirable impacts (from a modern viewpoint) on his environment[4]. For instance, the extinction of many large animals around the world coincides exactly with the first appearance of man. Thus, the disappearance of hippos, elephants and deer, often in pygmy form, and other even more unusual animals from the islands of Crete, Cyprus, Corsica and Sardinia in the Mediterranean coincides almost exactly with the first signs of colonisation by hunter-gatherers. There is some debate about whether all such extinction was due directly to predation or indirectly to man-made alterations of the local environment but it easy to see the attraction that barbecued pigmy hippopotami might have had for our forefathers! If primitive man in his small numbers could have such effects, what of us in our billions - mining, logging, hunting, farming and just generally getting by.



Is the ability to last 10 years enough for a system or a practice to be called 'sustainable'? Or must something be able to last 100 years? Or 1000 years?

Some people have the idea that for a system to be sustainable it must be in some kind of balance or equilibrium. That is a superficially plausible idea but is it one that can stand close scrutiny? We doubt it and will examine the concept later. We can find agricultural systems that are more fertile now than they were formerly. How has that come about? These systems have developed because inputs were greater than outputs. That is, they were not in balance during that development.

Even a (living) system in an almost static equilibrium - if we can think of one, a remote non-eroding island perhaps - requires at least the input of energy from the sun.

We will explore the boundaries that need to be set before a discussion on sustainability can be meaningful. One such, that we will use from here on, is that we will consider sustainability of agriculture. Sustainability in fishing, motor manufacture, or candlestick making are outside the scope of this paper. On the other hand, such enterprises may attract a mention where they can be seen clearly to make agriculture unsustainable.

Agricultural context:

The government of the UK, the EU and indeed the whole of the developed world are exercised to achieve 'sustainability in agriculture'. See, for example, the web site http://europa.eu.int/comm/agriculture/foodqual/index_en.htm on the future of agriculture and food in Europe, which asks:

"What does our society expect from the agricultural sector and from the food we eat? How can EU policy enhance economic, environmental and social sustainability in agriculture? What does food quality mean and how does quality relate to price?

"According to a recent Commission poll, for EU citizens the priority of the CAP should be to ensure that agricultural products are healthy and safe, promote the respect of the environment, protect medium or small sized farms and help farmers to adapt their production to consumer expectations.

"The aim is transparency, quality and safety and a farm sector in tune with the environment and animal welfare. We need to develop an even more sustainable farm and food sector for the future."

In this short example alone we see confusion in meanings and a blurring of issues.

In December 2002, the UK government launched its strategy for farming and food in England [6, 7] in which it set out how industry, government and consumers could work together to secure a profitable and internationally competitive future for our industries, whilst contributing to a better environment, improving nutrition and public health and prosperous communities. *Is that what is meant by sustainability or is there more to it? Or less to it?*

The government plans to develop a scheme to pay farmers to farm in a more sustainable way, a core recommendation of the Curry Commission [8 †]. *That presumes that we know what is sustainable.*

The strategy combines a complex of measures: Continued expansion of rural and environmental schemes like Countryside Stewardship; a new 'whole farm' approach to management and regulation, helping farmers plan their business as a whole to meet commercial and regulatory needs; an audit- based approach to identify a farm's strengths and weaknesses as a basis for cutting red tape and the number of inspections required *(Is not that more red tape?)*; a new Agricultural Development Scheme intended to improve competitiveness and marketing, and to spread 'best practice'; assistance to small regional food producers; extra support for skills and training to make a profit while 'respecting the environment'; a network of demonstration farms to share best practice and experiences; a new animal health and welfare strategy; a Food and Health Action Plan; and other

† Farming & Food – a sustainable future. "The Curry report" - The Policy Commission on the Future of Farming and Food was set up by the Prime Minister in August 2001. The Commission was chaired by Sir Donald Curry. The Curry Commission report was presented to the Government on 29 January 2002.

features. *Most, or even all, are generally thought desirable but do they comprise sustainability? Are they both necessary and sufficient for sustainability?*

What is Sustainability in Agriculture?

'Attempts to define sustainability miss the point that, like beauty, sustainability is in the eye of the beholder ..' A. Campbell [9]

We tend to test 'sustainable agriculture' against a notion, perhaps ill defined, of long-term behaviour that neither depletes the resources of the land nor accumulates products to a toxic or pollutant level. Thus, adding an organic manure such as seaweed to land would be sustainable unless you were seriously worried that you would either wipe out the seaweed population and that which it sustains, or that you would deplete the sea of its mineral reserves(!). Additionally, we would consider it sustainable if the principal effect of that practice were to increase the organic matter content of the soil without increasing the levels of minerals that might be leached. We offer these ideas simply as a starter and to indicate our own leanings but we recognise that the issue is wider than that.

The population of the world is greater than ever and growing faster than ever and it appears to be outstripping the Earth's ability to feed it. Paradoxically, many no longer consider that intensive, western-style agriculture with high levels of inputs to support high yields is an appropriate model on which to base the agriculture of developing countries with burgeoning populations. Some even question that it is appropriate for Europe and North America. Yet the highest yields of most staple crops are achieved in intensive systems whether industrialised as in Europe or based on high inputs of labour and tight re-cycling of nutrients as in the traditional cultivation of rice in south east Asia. Sustainable agriculture is the Holy Grail of our times. However, sustainability is a complex and contested concept and it is important to clarify what is being sustained (Pretty, 1995) [5]. The popularly accepted meanings implied by the term 'sustainable agriculture' are that levels of yield should be maintained and also that the ability of the land to continue to grow food should not be impaired. These are sensible interpretations to make but some individuals and governments may tack a range of other ideas onto that basic pair.

Debates on issues such as the use of external inputs such as fertilizers, [10] tend not to resolve the issues but to illustrate how the judgmental values of the debaters can seriously affect their conclusions and recommendations, e.g. on the significance of soil erosion. However, to be sustainable, agriculture must provide the farmer with a living. Not just in the future, but now, and in between as well, or the farmer will not reach the future as a farmer. The idea of sustainability must distinguish between, yet be required to accommodate, both 'ecological' or 'biological' or 'environmental' sustainability and 'economic' sustainability, or it is not a useful concept.

The pursuit of efficiency in farming can, potentially, sidetrack one's thinking on sustainability. The requirements for ecological / biological / environmental sustainability have little to do with efficiency. These aspects of sustainability hinge, principally, on effectiveness – how well the job is done. Consider the use of water. Water Use Efficiency, the production of dry matter per unit of water evaporated, is generally recognised to be greatest where water is in short supply [11]. – Indeed this is true of any commodity, including money. But, in the right conditions, an irrigated crop will yield far more than an unirrigated one. This is an example where lower efficiency in the use of one resource – water – leads to greater production because the irrigation enabled the crop to increase its use of other resources e.g. sunlight. Efficiency – the output expressed as a fraction of the input – is really only relevant to the economic sustainability of the system. And the economics of agriculture are influenced by many non-agricultural factors, including politics.

As stated earlier, whatever the definition of 'long-term' sustainability, a sustainable agriculture must allow or enable the farmer to survive now, and in each succeeding 'now' between the present and the future target date for sustainability. Farming must be profitable if it is to be sustained.

Yet the products of our agriculture are sold in commodity markets that are increasingly open to global competition. That competition is usually based on price alone and, with the principal buyers being relatively few and large, these buyers are able to maintain a continuous downward pressure on prices.

Under a global free-market, production will move to (or survive in) areas where the climate is benign, soil suitable, and land and labour are cheap. What enables this global economy is the relative cheapness of fuel. – Transport over long distances appears to be hardly a consideration.

As long as these conditions obtain, UK agriculture is scarcely sustainable; not because it uses fossil fuels but because others do. But these conditions, themselves, may not last. When they change, when fuel becomes more expensive, the measure of sustainability in UK agriculture will change also – and possibly change for the better.

Since 1973, agricultural productivity in the UK has increased by 36% and the key factor has been labour productivity, which has doubled since 1973 [12 (at Indicator 13)]. (That is almost entirely accounted for by the fact that staffing has reduced by a third - see box) [12]. Yet DEFRA says that it is committed to making food production 'more sustainable' and that part of restoring economic sustainability will be making farm diversification easier. – In other words, enable farmers to spend less time on food production and do other things instead. – This is an example of the juxtaposition of two ideas, each of which seems laudable but which simply cannot co-exist.

Time 1: Produce 120 units using 3 men.
Productivity = 40 units / man.
Time 2: Produce 120 units using 2 men.
Productivity = 60 units / man.
Labour productivity has risen by 50%

The real cost of food has declined since 1973 [12]. One reason stated is greater efficiency in the food chain [*sic*]. – They really mean the supply chain but that point will be considered later. The principal reason, not mentioned, is that farm-gate prices have been kept low and pushed even lower, e.g. for potatoes, a crop grown without any subsidies, the prices over-winter in seven of the ten years 1979 –88 were within the range of the average prices over-winter in the years 2001/02 and 2002/03. That is, they are as low now as they were twenty years ago. The challenge is seen to be keeping food cheap while keeping production sustainable. This is a perversion of priorities. Household expenditure on food is decreasing (see box) and while people are spending less and less on food they are being manoeuvred into spending more and more on mortgages, consumer durables, not-so-durables, and entertainment.

The proportion of household expenditure that is spent on food (excluding catering) has fallen from 12.4% in 1989-91 to 9.7% in 2001. The proportion spent on alcohol has increased to 5.9%. [13, 14]

Industrialised Agriculture European agriculture is industrialised in that it is mechanised and is dependent on fossil fuels for machinery, fertilizers, and agrochemicals. These practices cannot be sustainable in their present form in the sense that they cannot go on forever. Supplies of petroleum are finite. However, it is neither useful nor realistic to suggest that agriculture should abandon the use of these products while they are available. A more practical question to ask would be whether it is sustainable to raise livestock on grain feeds, particularly on grain produced in other regions, even other continents. (This is discussed under 'Farming animals').

However, it is salutary to consider how arable agriculture would perform without the use of fossil fuels for machinery or some other sources of energy that might be devised. Consider how much land a horse can cultivate then consider how much more land it takes to feed and maintain that horse – probably between one and two hectares when allowance is made for grazing, hay, grain and bedding.

From time to time, one reads statements that several countries, notably those of central and Eastern Europe, could increase grain production and expand their exports if they would adopt economic policies to realize their full potential. Such calls imply the belief that the practices of modern Western agriculture are indeed sustainable, and ignore the eventual limitations imposed by the supply of fossil fuels.

What inputs are allowed to sustain the system?

NUTRIENTS. In the SCRI Annual Report for 1998-1999, the article on 'Organic' Farming [15] touched on sustainability in a few places and had a short section specifically headed 'Sustainability'. Here we précis part of that article:

> *It is easy to describe goals for a more sustainable agriculture, it is more problematic to define it. It can imply persistence and the capacity to continue for a long time. Applied to the environment, it involves actions that do not damage or degrade natural resources. In any discussion of sustainability, it is important to clarify what is being sustained, for how long, for whose benefit and at whose cost, over what area, and measured by what criteria. Answering these questions is difficult as it means assessing and trading off values and beliefs (Pretty, 1995)* [5].
>
> *What do we mean by sustainable? All the food and other products taken from the land represent an abstraction of resources. Unless these are replaced that land will become depleted and infertile. So, agriculture must*

look to what resources are drawn from the land and how these are to be replaced. (It must also look to what is lost inadvertently from the land through e.g. leaching and soil erosion, and it must consider changes brought about by its very operation e.g. soil compaction and changes in the abundance of associated species). *The principal commodities taken from the land are water, carbon, energy, and minerals. The first three of these are renewable although the energy balance has wider implications through the current dependence on fossil fuels.* (And the carbon balance is modified by agricultural practices). *The ability of plants to fix carbon and energy is dependent on the fertility of the soil and its physical properties. The organic matter in the soil influences these and so it is a legitimate concern that an adequate proportion of the assimilated carbon should be left in the soil. The supply of water as rainfall may be inadequate for maximum crop production, and then irrigation may be considered. Unless the irrigation water is drawn from on-farm reservoirs, filled by winter rain, the practice of irrigation is arguably not strictly sustainable; and this must be a consideration where water for irrigation or other purposes is drawn from ground water.*

The main concerns over sustainability must lie in the ability to replace the nitrogen and other mineral elements that are taken from the land in a crop. (Also consider any excesses of inputs over abstraction in the forms of crops or livestock). *Nitrogen and some other minerals are replaced from the atmosphere but not at rates that even approximate the rate of abstraction in a crop. So, the fixation of atmospheric nitrogen is in the order of 10 - 80 kg N / ha / y over most crops and 80 - 280 kg N / ha / y over a clover-rich sward. But a well-grown crop of potatoes (60 t / ha) takes 160 kg N / ha off the field in the tubers and a 5 t / ha crop of spring barley would remove about 85 kg N / ha in the grain and perhaps 40 kg N / ha in the straw. The minerals removed in a harvested crop are not readily replaced in rainfall (Allen)* [16] *and the growth of green manures only serves to cycle them.*

AGRO-CHEMICALS There is a common presumption that 'sustainable' farming will require a reduction of inputs, particularly those that are 'chemical'. Yet this is not a useful idea until such time as we can foresee synthetic chemicals becoming unavailable. The fundamental points at this part of the debate are that farmers use agrochemicals because they do the job e.g. controlling disease, and it is economic to use them. That is, the financial benefits outweigh the financial costs.

Late blight of potatoes, caused by the fungus *Phytophthora infestans*, is one of the most serious diseases of food crops and despite years of attempts to breed resistance into the crop, it is still controlled by the use of fungicides. The yield of potatoes in 'organic' systems where copper-based fungicides are used as protectants, are only 60% of those achieved by conventional agriculture. Leaving aside the point that copper itself is highly toxic and that approval for its use is now being withdrawn, the yield of organic potatoes without its use falls to 40% of conventional. [17]

That is only one example but it serves to pose the question, "Can the use of fungicides be sustained?" We do not know. But what we can say is that the world will be a far hungrier place without them.

Zandstra [18] described sustainability as a non-linear function of input levels of chemicals (Figure 1). He described systems in which excessive inputs degraded the system through accumulation while inadequate levels degraded the system through depletion. Between those extremes, the system is 'sustainable'. This contrasts sharply with the concept held dearly by the proponents of 'organic' systems in which sustainability is increased with reduced dependence on chemical inputs (Stinner & House) [19].

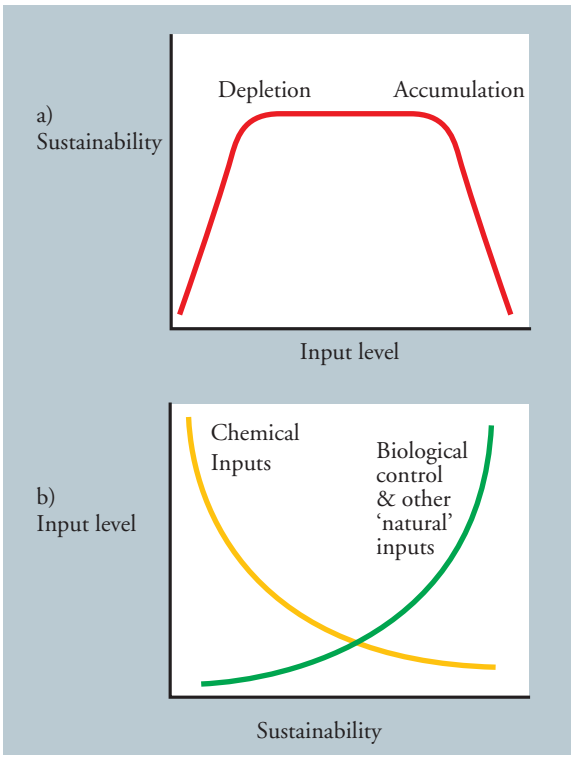


Figure 1 Sustainability a) after Zandstra[18] b) after Stinner & House[19].

ENERGY Can the inputs of synthetic materials be sustained? Providing only that regulations permit, it would seem that as long as the modern energy systems survive then chemical products can be synthesised. If the sources of energy collapse then a whole lot more than agriculture will be in difficulty, and agriculture is not a principal user of fuel.

Between 1985 and 2000, the consumption of energy, both direct and indirect (Indirect includes fertilisers, pesticides, manufacture of equipment and animal feeds), in UK agriculture dropped from 240 PJ to 192 PJ (PJ = PetaJoule = 10^{15} Joules) while the consumption per capita remained almost constant at around 345 GJ [14]. While such figures do not assure us of sustainability of agriculture, they do reveal both the dependence of agriculture on energy supplies and the small part it has (1%) in the national appetite for energy. We have sought comparable figures for other industries but have not been able to find them.

Sustainable use of the land Land has been farmed in Europe for several thousands of years. Over the centuries there has been a huge investment of effort and resources in the land to improve drainage, correct acidity using lime or chalk, which are plentiful, minimize flooding, and enable irrigation. That work has ensured, not only that European agriculture has been sustained but the level of productivity has been raised, and some soils can recover from a degree of misuse. [20, 21] In the earliest times, agriculture was very small scale and in some places shifting agriculture was practised - an indication of unsustainable, short-term exploitation of the nutrient reserves of a site and then moving to another place while the first site recovered. The developments of higher populations, more structured societies, and ideas of property were enabled by the combined practices of fertilizing land and of fallow (which, in essence, is really only a fractional equivalent of shifting agriculture). But where did the fertilizers come from? And was agricultural production sustained? In most cases if not all, arable land was fertilized with nutrients gathered from surrounding lands. The practice of grazing beasts on common land or 'outer toons' and bringing them in at nights worked to an extent, because it concentrated nutrients that had been deposited on a wider area than the cultivated land. But even these devices could not be guaranteed to sustain production. The practice of spreading 'night soil' from towns on the neighbouring farmlands not only solved a waste problem but also resulted in fertile soils in market gardens around most towns and cities in the country. The towns would have imported nutrients, not only from those gardens but also from further afield. Those nutrients were then applied to neighbouring land. In some rural coastal areas, seaweed was used to improve the soil with significant effect in many areas; again drawing nutrients from a wider source. Yet it is a matter of record [22] that agricultural production in Europe was nutrient-limited before the introduction of the first imported mineral fertilizers and later, manufactured fertilizers.

As reported in the abstract from 'Organic Farming etc. [15] harvesting a crop removes significant quantities of nutrients. These have to be replaced if the soil is not to degrade. Over the latest 50 years or so, applications of fertilizer in Europe have probably exceeded the 'off-take' in the crops. This is almost certainly true of nitrogen and phosphate, so that applications that are a bit lower can only have a beneficial effect on the environment and no adverse effects on the crops. That does not obviate the need to apply some fertilizer if yields are to be maintained and this focuses attention on what is meant by sustainability. If appropriate levels of fertilizers are not applied, current levels of yield are not sustainable. If fertilizers are used then there is every reason to believe that current levels of agricultural performance can be sustained. The manufacture of fertilizers, particularly nitrate, is dependent on supplies of energy, principally from fossil fuels. We can recognise that there must be a finite end to producing fertilizers as at present since fossil fuels are a finite resource. But should that mean that we should stop using these fertilizers? Certainly not. Which extra persons would be unfed because there is less grain in the world and it is more expensive? - The farmers among others. Should we avoid using fossil fuels to conserve these for future generations? No. These fuels would simply then be used for other purposes and any associated reduction in demand would provide only a marginal delay in the depletion of fossil fuels. And this leads us to the homily from the 'Brundtland' Commission [23], "meeting the needs of the present without compromising the ability of future generations to meet their own needs". While we should not squander resources and impoverish others whether in the future or the present, we must feed ourselves and others now, and we must do it next year and the one after. When the oil runs out it runs out. The needs of future generations will be their problems. (To be tackled by those same characteristics of acquiring and developing new technologies that has brought humanity and the world to their present condition).

There are plenty of examples where our society is indeed squandering irreplaceable resources for its present ease and gratification (see box) but agriculture is not among them. On the contrary, the most glaring example of ignoring Brundtland's dictum is in the destruction of good, and not-so-good agricultural land for urban and suburban building developments. Developers favour flat sites and sites near the edges of cities. These are frequently the very best agricultural land. If we wish to ensure that agriculture and its ability to feed and clothe us is to be sustained, then it is the planners and politicians who need to be re-educated, not the agriculturalists.

In 1988-1993, Dongguan, in China, converted 10.4% of its total land area into urban land uses. The city tried to maintain the best agricultural land by directing the large proportion of the expansion toward the area of less fertile land, but it is recognised that too much agricultural land was lost. [24]

Results of a remote-sensing-based survey of the tropical forests in Africa using high resolution satellite data of two dates, one close to 1980 and the other close to 1990, showed a compound annual rate of deforestation of 0.8% over the ten years. In Latin America and the Caribbean, and in Asia and the Pacific, the equivalent figures were 0.8% and 1.2%. [25]

In the UK the total area of arable land has declined 574,000 ha over the twenty years since 1981 [26]

Year	Area (1000 ha)
1981	5071
1991	5020
2001	4497

It is the politicians and planners who state that they want rural communities to thrive and be inclusive but then confuse such communities with urban communities in a rural setting. So it is that small rural villages are expanded, at the cost of arable land, into small towns from which the residents travel to neighbouring large towns or cities each day to work. It is this disconnected thinking that declares that we should reduce our use of the motor car for environmental reasons and then encourages families to commit themselves to the use of two or more cars.

We need to recognise that the loss of arable land is not sustainable – no more is being made – and so we should be very sparing indeed with approval for the change of land use from agriculture to domestic or industrial use. Houses are a once-only crop, only once-ever, even if they do pay the developer.

Beyond such an obviously unsustainable use of agricultural land, the real questions that we should address in assessing whether an enterprise fits with sustainable agriculture are: (i) Whether current levels of production are being achieved without 'consuming' the land and reducing its ability to serve the needs of present and future populations [20]. (ii) What are the levels of inputs required to sustain production at current, or other, levels and can those levels of inputs be sustained? (iii) What ecological side effects of modern agriculture will have adverse effects on current or future agriculture? (Notice that we did not write, 'what ecological effects will agriculture have?' We deliberately asked what ecological effects would rebound on agriculture).

Can cereal yields be increased further without damaging the environment? Remember that, within the genetic potential of a crop, the limits to yield are set by the limitations of temperatures on crop development and interception of radiation on dry matter fixation. It follows that simply increasing those inputs that have enabled the current levels of production will not increase production unless current levels are still limiting. If they are no longer the limiting factors, then increasing their inputs will prove uneconomic and so normal commercial constraints will operate.

There are ancillary questions concerning which inputs and outputs can be out of balance and for how long can they be out of balance. In the simplest case, it might be sufficient to attain balance within the period

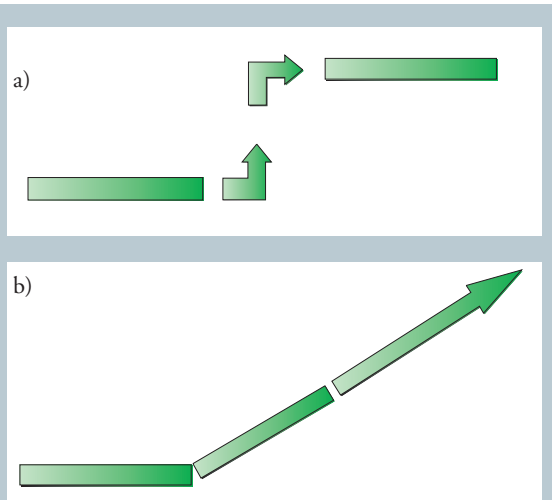


Figure 2 Sense and nonsense in 'sustainability', a) sustainability at two levels, b) 'sustained' development.

of a crop rotation and this leads to a consideration of equilibria.

Sustainability: a stable equilibrium or a dynamic equilibrium? The possibility of 'sustainable development' is a fashionable concept but a shallow one. Like acceleration, development cannot be sustained indefinitely. This does not mean that development is a bad thing or that it cannot take place, for a time. It is perfectly possible to conceive of a situation that is 'sustainable' (i.e. it could endure as it is) and that is then developed to another level that is, again, sustainable (Fig. 2 a) - or not as the case may be. It is the concept of sustained development that is a nonsense (Fig. 2b). An example of (a) might be levels of production before the 'improvements' of the 18th century such as drainage and liming. And still, development to new sustainable levels is possible, conceptually at least, in the 21st century.

What can be used to indicate sustainability, and can such indicators of have any value to us? There have been a plethora of indicators suggested and tried, [7, 27, 28] just as there have been many interpretations of 'sustainability'. Many of those published reveal a mind set unchanged from the traditional 'growth' pattern, e.g. "producing … in a more efficient way", "greater efficiency of the food chain [*sic*]…", What is wrong with the present level of efficiency? Others are quite unquantifiable, e.g. "Improved landscape". Most ask for 'more' of good things and 'less' of bad things but few if any set a quantified target.

If 'indicators' of sustainability must be devised then they should be absolute and quantifiable otherwise they can never be attained.

Where a system is understood and certain aspects of the system are recognised to be key ones then it is conceivable that these could be used as 'indicators' of sustainability. Does that mean that, for as long as those parameters had values between certain prescribed limits the system in question could continue to function indefinitely. Surely not! A system might fail from some other cause not measured by the 'indicators'. Similarly, sustainability cannot be guaranteed by ensuring that all the so-called indicators lie within their prescribed limits - and for the same reason. Any set of indicators is simply a kind of model. It is an abstraction of reality and a simplification. The best that can be done is to recognise that if the values of the indicators go beyond the recognised limits, the system will not be sustainable. Whether a system will or will not be sustained over a period of time then becomes an exercise in probabilities. There have been several reports that explore this idea [29, 30, 31] but, of course, quantifying the probabilities is dependent upon data from the past, not the future.

To identify a few key indicators for a system and to set threshold values for acceptable levels of these indicators is a difficult enough problem and yet the idea implies a fairly low level of understanding of that system. It implies that the system in question is in static equilibrium (Fig. 3a). An alternative, more general, and more realistic model of an agricultural system is one that is in dynamic equilibrium (Fig. 3b).

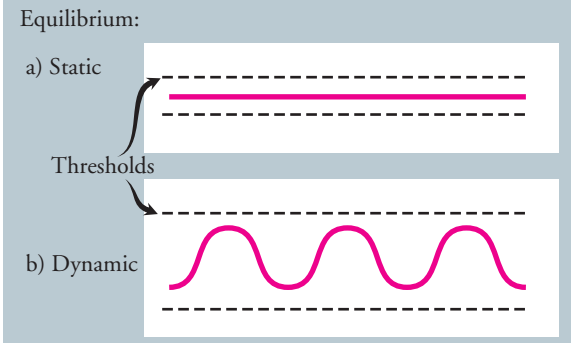


Figure 3 Sustainability - static (a) or is a dynamic equilibrium allowed (b).

The concept of a system in dynamic equilibrium makes additional demands on the choice of indicators and on identifying threshold values for them. Here, certain indicators are allowed to reach unsustainable levels just as long as their duration at those levels is limited and provided that they are followed by values that are on the opposite side of those required for sustainability so that the effect on a 'pool' of resources or waste products does not go beyond defined limits. So, not only must the required 'concentration' of an indicator be known, but the pool size must also be known together with acceptable rates of abstraction and return.

Essentially, this is what happens in any system of crop rotation. Each crop in the rotation moves the values of some factor or another, away from the 'average' for the rotation, be it soil organic matter, organic nitrogen, soil microflora or whatever. Succeeding crops shift other factors and allow the first to return to the average value. Equally, the fears over the sustainability of monocultural systems are exactly that they

might induce long-term trends that are not reversed or even, in extreme case, may be hardly reversible.

What is unsustainable?

INDICATORS - OF SUSTAINABILITY OR OF A SYSTEM OR PROCESS THAT IS NOT SUSTAINABLE?

What is to be indicated? (i) That no change is taking place? Is that necessary? And besides, changes may occur in other variables than the ones being monitored. (ii) That there is a wide biological diversity? That may indicate a certain flexibility for the future but at what level is the system not sustainable? (iii) That the imbalance in a variable is within tolerable limits? That will require understanding and suffers from the same drawback as in (i).

Should indicators of sustainability be positive (present = sustainable) or should they be negative (present = unsustainable)? Alternatively, would indicators of unsustainability be a better class of indicators if they can be devised? Would it be better to highlight these?

IS IT BETTER TO THINK OF GUIDING PRINCIPLES RATHER THAN INDICATORS? Yes. Presumably, indicators of sustainability show an impending unsustainability by their disappearance or appearance (depending on whether +ive or –ive). Whereas guiding principles should enable one to avoid unsustainability.

There have been attempts to take a firm, scientific view of the concept of sustainability. Hansen [29] considered the term to have both a philosophical meaning, as an approach to agriculture, and a quantifiable meaning, as a property of a system. He argued that sustainability could only be used as a criterion for assessing farming systems when it was used as a measurable property. Indeed, Hansen proposed that to be effective in guiding future development *"the characterization of sustainability should be literal, system-oriented, quantitative, predictive, stochastic, and diagnostic"*. That analysis was an excellent one yet did not define sustainability. Rather it revealed weaknesses in current and proposed approaches to achieving sustainability.

The approach taken by Hansen [29] and then by Hansen & Jones [30] was followed by McRoberts et al. [31] who focused on the stochastic aspects of indicators of sustainability. This drew attention to the difficulty of selecting indicators of sustainability. Critical thinking about the approach taken by Hansen and by McRoberts *et al.* suggests another difficulty, however, with this mathematical approach to sustainability. The difficulty lies with the requirement that sustainability should be considered as a stochastic (i.e. random) property of the system under study. That means that at any time, a system has a finite probability of failure. The simplest such assumption is that the instantaneous probability of failure is constant; value = p. For a cohort of N examples of the system (farms), the value for sustainability in Hansen & Jones' [30] simulation is approximately the expected value of Binomial[N,$(1-p)^t$] divided by the initial size of the cohort. Then the probability of a system being sustained declines exponentially over time. This ignores the possibility that a system that survives for one or for ten periods of time (years?) may be better, more sustainable, than one that fails, for reasons not considered in the definition of sustainability - Because of the character of the farmer, for example. McRoberts et al. [31] developed the ideas of Hansen & Jones to include a 'specificity' term that reduced the probability of failure successively at each time interval. That still showed sustainability to be increasingly unlikely over time. How can one provide inputs to a model that will predict a progression that is strongly influenced by factors outside the model?

These mathematical approaches do offer the potential to contribute to the idea of sustainability but that potential has not yet been realised.

One is reminded of the two academics debating how best to invest for the future and one says that he will invest in land. The value of land has increased progressively over the last two thousand years, he says. To which his colleague responds, "Yes. But do you really think that the last two thousand years were typical?"

Pearce [32] suggested that the amplitudes of cycles in system variables around their mean values could instead be used as indicators of loss of sustainability, that is of unsustainability. This idea is related to the one proposed earlier in this article that a dynamic equilibrium is acceptable as long as the excursions around the mean are not too large.

What is too large? An excursion from the mean that cannot be recovered is too large. But what the size of that excursion is will depend on the system and on the variable or indicator that is being considered. Then the resilience of a system or, rather, of the variables that define the system may offer indicators of sustainability. A unidirectional change from the mean will

suggest unsustainability. Increasing amplitudes in the deviations about the mean would suggest a chaotic system rather than one driven by environment and, again, one likely to be unsustainable.

WHERE SHOULD ONE LOOK FOR POTENTIAL CHANGES THAT MIGHT WARN OF UNSUSTAINABILITY?

The nature of agriculture depends heavily on the climate and on the soil. The climate defines the type of agricultural enterprises that are conducted; the weather defines the potential for production of crop or pasture; and the soil is the limiting source of nutrients and water that may constrain primary production within that potential. A sustainable agriculture, therefore, must be one that is compatible with the climate and that maintains or, even, improves the quality of the soil. – Or at least, any component enterprises of the agricultural system that reduce that quality must be offset by others that enhance it. That, after all, is the idea that underlies the use of crop rotations. Indicators of possible unsustainability, therefore, include the prolonged reduction of soil organic matter and the accumulation of mineral salts.

We suggest 'possible' unsustainability because some soils that are low in organic matter can be highly productive as long as the necessary inputs of water and minerals can be provided. The accumulation of mineral salts is normally only a problem in areas of low rainfall.

The indicators of sustainability must include economic factors such as simple profitability. Yet the current dependence of many farm enterprises on state subsidies threatens the sustainability of agriculture on political grounds. The issue of subsidies for agricultural commodities and for management of farming systems is too wide to be treated here. However, if profitability could be achieved coupled with the reduction and eventual elimination of subsidies then our agriculture would be well on its way to being both politically and economically sustainable.

Farming animals

The MAFF publication, *Towards Sustainable Agriculture. - A Pilot Set of Indicators* [27], included a five-point definition of sustainable agriculture that advocated keeping animals "in a welfare-friendly manner". Attending to animal welfare is good husbandry and is humane but it has little to do with sustainability. ….

Animal-based agriculture is an integral part of our systems for food production, with foods of animal origin representing about $^1/_6$ of human food and $^1/_3$ of human food protein [33].

The losses that are inevitable in the conversion of plant matter to meat makes meat-eating an inefficient way to use energy from the sun in feeding people (see box). However, this overlooks the fact that many animals, especially ruminants (cattle, sheep, goats) mostly eat food that is not suitable for humans. The traditional distribution of agricultural enterprises e.g. between arable and pastoral had much to do with the environmental resources and constraints of an area. For many reasons, soil-types, slopes, weather, most of the uplands of the UK are unsuited to arable farming but well-suited to raising animals. Similarly, in areas with more extreme environmental challenges – arctic tundra, semi-arid areas, food-production is animal-based.

In areas that are fertile, agriculture may be mixed between arable and animal and the balance between

Food-Chains [35, 36]

Higher plants that photosynthesise are the **primary producers** of all human food. Only they can manufacture food from inorganic raw materials. That food feeds herbivores, called **primary consumers**, and then **carnivores** that feed on **herbivores** are called **secondary consumers.** Carnivores that feed on other carnivores are **tertiary** (or higher) **consumers**.

Such a path of food consumption is called a **food chain.** Each level of consumption in a food chain is called a **trophic level.** So, the chains of: grass - grasshopper - toad - snake – hawk, and of: leaves – greenfly – ladybird – blackbird – hawk, each have five trophic levels.

Most food chains are interconnected. Animals typically consume a varied diet and, in turn, serve as food for a variety of other creatures that prey on them. These interconnections create **food webs.**

At each trophic level, net production is only a fraction of gross production because the organisms must expend energy to stay alive and there are substantial losses in net production as energy passes from one trophic level to the next. The ratio of net production at one level to net production at the next higher level is called the **conversion efficiency.** We can take 10% as the average conversion efficiency from producers to primary consumers. From primary consumers to secondary consumers (herbivores to carnivores) conversion efficiencies tend to be much lower, averaging about 1%.

So, when we eat fruit and vegetables we participate in a very short food chain. When we eat meat the chain is longer and we are making less efficient use of energy from the sun. Whether we are efficient or not with the nutrients depends on what we do with the wastes.

the two depends partly on environment (e.g. in the UK the wetter west has more animals) and always on economics.

Populations are high where arable agriculture can be practised (more food per unit area of ground) or, with the economics of modern transport, where the products of agriculture can be delivered.

We should recognise a difference between rearing animals using grazing and fodder from their farm and rearing them on grain or fodder that is bought in. Animal production from grassland has many characteristics of sustainability, relying on perennial plant species and long-term production cycles. [34] This does not immediately say that the other system is unsustainable, although it invites the question, simply that different issues are raised by the two systems.

Much is made of the idea that intensification of agriculture involves loss of micro-habitats and diversity of wildlife and there tends to be a presumption that 'sustainable' farming is less intensive than otherwise. That is a simplistic idea.

The wood / pasture systems of southern Europe involve grazing livestock on permanent pastures and among tree cover. At one time, they were characterised by what is known as transhumance – seasonal migration up and down the hills with livestock – but there is little if any of that these days. The cattle and sheep still graze but there are fewer grazing animals than before – because it doesn't pay. And the consequence is that what were once 'permanent' pastures are invaded by scrub, reducing the grazing (and the diversity of species) and farmers now periodically have to destroy some of the scrub mechanically. In the Transylvanian region of Romania, where traditional systems of farming were maintained until late 20th century, changes following the revolution in 1989 have meant a sharp decline in the level of grazing and a loss of biodiversity. [37]

On the other hand, studies by ADAS in Wales, where a trend to a monoculture of sheep has changed grazing pressure and the competitive balance between plant species, leading to a decline in the quality and quantity of heather, have suggested that reduced stocking rates have differing effects in the short- and long-terms. In the short-term, reduced stocking rates may lead to increased cover by heathers, increased availability of forage in late season, and an increase in the proportion of productive ewes, an increase in their live weight, and an improvement in their condition. Yet, in the longer-term, reduced stocking rates may lead to an increase in rough, undesirable grasses, decreased quality and quantity of forage, reduced flock performance and reduced weaning weights for lambs. [38]

The point is that there are appropriate stocking rates for each system. Further, there are other options for management besides simply raising or lowering the stocking rate. To argue for higher or lower stocking rates without knowing the circumstances of the place under consideration is to invite not just mistakes, but the collapse of the very things one wants to preserve.

FOOD-CHAINS AND SUPPLY-CHAINS We have explained the proper meaning of the term 'food-chain' (see box, previous page). A supply chain is the set of links from food producer (the farmer) to the consumer and so may include a wholesale merchant, a processor, another wholesale merchant, a retailer, and finally the consumer. Unfortunately, the biologically uneducated among us have pirated the former term and used it for the latter term.

The two kinds of chain have one thing in common. The longer they are the less efficient they are. In supply chains, each middle-man needs to take his 'cut' and so the shorter the chain the more nearly the consumer might expect to pay the cost of production. In a food-chain, each organism has a conversion efficiency of only a few percent.

So it is that while a shorter food-chain may enhance sustainability of food production by being more efficient with the use of primary food production, a shorter supply-chain would also enhance sustainability. In our current, energy dependent, industrial economy, supply chains may be lengthened in several ways, some obvious and some less so. The inherent inefficiency is obvious if one is eating strawberries flown from Chile – a short food-chain, you are eating the primary product – but a supply-chain that is thousands of miles long. The inefficiency is perhaps less obvious if you live in York and are eating ready-prepared Bubble and Squeak from your local supermarket. Again you are eating primary products, and the distance is probably short for both the potatoes and the cabbage, but the number of hands is considerable from farmer to potato processor, to food processor and packer, to retailer and then you, the consumer.

Here there is an obvious conflict between the ideas of sustainability and value-adding employment.

Is biodiversity important or irrelevant?

Has 'biodiversity' got anything to do with sustainability or is it just a red herring? Nice, but red nonetheless? Does wild life have a role in a sustainable agriculture? Is it necessary and if not, is it tolerable?

Smith et al. [39] reported just 6 animal and 35 plant extinctions across Europe since early in the 15th century. But, even if correct, this gives a false impression of the effect of humanity on biodiversity in Europe. The greatest effect has been on local abundance of species with little effect of the regional species diversity in the strict sense. Whether these changes have had or will have a significant effect on sustainability of our agricultural ecosystems is unknown.

'Biodiversity' and 'wildlife' are terms that the public may interpret to mean higher plants, mammals, birds, and butterflies but which also include other less attractive insects, mosses, and moulds, fungi, and all the microflora and microfauna of the land. Their interactions with each other and with agriculture are complex and not properly understood. Particularly, the potentially overlapping functions in the biology of the soil are only now being appreciated and studied. It follows, therefore, that it must be unwise as well as being uncultured, to dismiss any organism as being insignificant or irrelevant. However, the survival of any organism is dependent, not just on its food supply but upon the survival of its whole environment. The major decline in biodiversity has occurred through loss of habitat. Following our proposition that the key to sustainability is to avoid making changes that are irreversible, we have to allow that biodiversity in its fullest sense should be encouraged, not just tolerated, even where the necessity for parts of that biodiversity are not recognised.

Tolerance is not enough. Extinctions can occur through indifference as well as through deliberate elimination and the biggest threat to the survival of any species is the loss of habitat. It follows, therefore, that in agriculture and in other human enterprises we should ensure that there are adequate areas of unmanaged land and that these should be more or less connected to allow movement of other organisms.

Where species are confined to a shrinking, and disjunct, non-agricultural habitat, it is tempting to think that although their loss is regrettable and from wider ethical points of view, may be unacceptable, they do not affect agriculture. But that would be a presumption based on ignorance rather than understanding. As a hypothetical example, consider a bird that eats insect pests on an agricultural crop during the growing season but that then, in winter, needs to feed on an insect species that lives exclusively on a woodland tree. Loss of that woodland would mean loss of the second insect species, loss of the bird, and so on. Unless we actually know everything we are unwise to dismiss any parts.

As suggested earlier, a sustainable system of agriculture is one whose attributes stay within an acceptable range of states – but a range not at a fixed level. These attributes vary with time and the patterns of variability within the system may change in scale and complexity. The drivers of the system may change and so the factors conferring sustainability are related to the diversity of system components and to the extent and consequences of their interactions. So, a diversity of species and habitats is desirable.

In the same way, a diversity of farm enterprises is desirable, too. If one weakens or fails there is another to tide one over. But each enterprise must potentially be capable of being both profitable (economically sustainable) and environmentally sustainable. If individual farms are able to follow this approach then there is a possibility that the wider agriculture will be sustainable.

Concluding Points

The 'Brundtland' Commission [23] defined sustainable development as, "meeting the needs of the present without compromising the ability of future generations to meet their own needs". This has been a definition of sustainable anything that has been most readily accepted by politicians and policy makers. We judge this quotation to be worthless, pious rubbish because it says nothing but allows those who use it to appear to be politically correct. Instead we propose the much simpler idea that to be sustainable, anything - agriculture, production etc. – should be capable of being continued for a long time and should not make irreversible changes.

There is a fundamental problem to be resolved over the approach to take when considering sustainable agriculture. One option is to think at the macro scale and proceed from the top down. - To consider the size of the human population and its growth, then to consider what it needs to feed itself and its increase; how much more food is needed to feed that population better; and whether that could be sustained. The difficulty with that approach is that one quickly gets lost in the unrealistic arithmetic of dividing produc-

tion in one part of the world by mouths in another part. It is all very well calculating that world production of grain, evenly distributed, could support 2.5 billion people at the American rate of consumption, five billion at a European level, or ten billion at an Indian level [2]. The underlying assumption is preposterous, the world supplies of grain are not going to be spread evenly for reasons of economy, limited resources for transport, etc., and it completely disregards what would be the consequent effect on the world's population in the succeeding years. So, it is better not even to start those sums.

A second option is to consider the problem from the bottom up. What can be done to ensure that current agricultural production, here, does not fail? If that is not possible, what must be done to change production practices to ensure that production is sustainable. Alternatively, are there changes that can be foreseen that would enhance production and would still allow production to be sustained at that higher level.

This second option must be the more rewarding one to take. First, the problems that are perceived are real and understandable. Then, they may be capable of solution. Any solution that is to be worked out at a macro scale must be implemented at the micro scale - the farm or the field. Given diversity in soils, weather, crops etc. it is evident that problems must be recognised and resolved at the local scale. If solutions are implemented then the sum of their effects can build towards the macro scale.

Urban-based cultural perceptions assume that old-fashioned agricultural practices and technology are, somehow, superior and more sustainable than their modern equivalents. In most cases, that is not so although they may offer guidance.

OVER WHAT INTERVAL OF TIME? Sustainable' should mean forever but it is not in our gift to see that far ahead. Rather we should consider that an operation or a system is sustainable if it does not lead to irreversible changes within the period that we can foresee. So, depletion of soil organic matter is not sustainable over a long period but an operation that causes that in the short-term is acceptable if it is to be followed by an operation that reverses that change.

WHAT OF CONTINUITY? Again, continuity is, or should be, a prerequisite of sustainable agriculture. However, this is not to be confused with an unchanged mix of farm enterprises. Indeed the mix of farm enterprises can be conceived as cycling over a longer period just as crops cycle in a rotation. Such changes would be slower because of the capital investment required in any new enterprise but, because true sustainability involves making only reversible changes, they would be manageable. A farm on which the farmer 'came out of' pigs or potatoes in the 1960s might well return to either if the economic conditions warranted it.

IS A BALANCE REQUIRED BETWEEN INPUTS AND OUTPUTS? We suggest that a system in which nutrients are balanced over a period are part of the sufficient conditions for sustainability – but only part, and that balance is not a necessary condition. A negative nutrient balance is clearly unsustainable over a prolonged interval but a positive nutrient balance might well be sustainable if the nutrients are locked into a non-labile form such as nitrogen in soil organic matter.

The important measures for assessing sustainability will be those that show how far one's system has moved from its mean condition, for how long one can continue, and how long it will take to recover. That is, measures to define permissible cycling in a dynamic equilibrium.

ECONOMIC POINTS Diversification from farming into other enterprises may be currently an economic necessity but it risks the farmer losing focus.

For agriculture to be sustainable the price that the farmer gets for his products must be related to the cost of production plus a margin. To insist that production be achieved within an arbitrary price limit is to condemn farming to failure.

The best philosophy for a sustainable agriculture is to use 'appropriate technology' and to use just enough of it. To eschew the use of modern products or techniques simply because they are not traditional is very short-sighted and makes the farmer dependent upon the goodwill and prosperity of special customers with a penchant for a particular philosophy.

The scarcest resource is our agricultural land. That should only be surrendered under duress.

FINALLY The idea of indicators of sustainability is not practicable. Rather there should be indicators of unsustainability and a set of guiding principles.

We have tried to set out some of these guiding principles in this article. – Maintenance of diversity both agricultural and biological and, principally, no irreversibility.

References

[1] Dept. of Trade & Industry (2001). Sustainable Development – Improving competitiveness through corporate social responsibility. T. Nash (Ed.) Director Publications Ltd., London. 80 pp. ISBN 1 901580 60 1.

[2] The Royal Society (2000). Towards sustainable consumption – A European perspective. B. Heap & J. Kent (Eds.) The Royal Society, London. 157 pp. ISBN 0 85403 537 0.

[3] Sustainable Development UK. Partnership Media Group Ltd., Manchester.

[4] Diamond, J.M. (1992). Twilight of the pygmy hippos. Nature, 359, 15.

[5] Pretty, J.N. (1995) Regenerating Agriculture. – Policies and Practice for Sustainability and Self-Reliance. Earthscan Publications Ltd., London. 320 pp. ISBN 1 85383 152 2.

[6] Dept. for Environment, Food and Rural Affairs (DEFRA) web site at: http://www.defra.gov.uk/farm/sustain/newstrategy/index.htm

[7] The Strategy for Sustainable Farming and Food – Facing the Future (2002). Defra Publications, London. 52 pp. Product Code PB 7751A. Also on DEFRA web site at: http://www.defra.gov.uk/farm/sustain/newstrategy/strategy.pdf

[8] Farming & Food – a sustainable future (2002). Report of the Policy Commission on the Future of Farming and Food. 140 pp. Also on the Cabinet office web site at: www.cabinet-office.gov.uk/farming /index/CommissionReport.htm

[9] Campbell A. (1994) Participatory enquiry: beyond research and extension in the sustainability era. In: paper for *International Symposium on Systems-Oriented Research in Agriculture and rural development*, 21 - 25 November 1994. Montpelier, France.

[10] Conway, G.R. and Pretty, J.N. (1991). *Unwelcome Harvest. Agriculture and Pollution.* Earthscan Publications Ltd., London. 645 pp.

[11] Jones, H.G. (1983) *Plants and Microclimate*. Cambridge University Press, Cambridge. 323 pp. ISBN 0 521 24849 3

[12] Dept. for Environment, Food & Rural Affairs (2002). Foundations for our Future. – DEFRA's Sustainable Development Strategy. DEFRA, London.

[13] Agriculture in the United Kingdom 2000 (2001). DEFRA, SEERAD, DARD(NI), NAWAD. The Stationery Office, London.

[14] Agriculture in the United Kingdom 2001 (2002). DEFRA, SEERAD, DARD(NI), NAWAD. The Stationery Office, London.

[15] MacKerron, D.K.L., Duncan, J.M., Hillman, J.R., Mackay, G.R., Robinson, D.J. & Wheatley, R.E. (2000). Organic Farming: Science and Belief. *Scottish Crop Research Institute Annual Report for 1998-99.* SCRI, Dundee. pp. 60 - 72.

[16] Allen S.E. et al. (1968) The plant nutrient content of rainwater. *Journal of Ecology* 56, 497-504.

[17] Zarb, J. et al. (2002). Control strategies for late blight in organic potato production. Extracted From: Powell et al. (eds), *UK Organic Research 2002:* Proceedings of the COR Conference, 26-28th March 2002, Aberystwyth, pp. 221-222.

[18] Zandstra, H. (1994). Sustainability and productivity growth: issues, objectives and knowledge needs. – guidelines for working groups. In *Reconciling Sustainability with Productivity Growth*. Report of a workshop, Gainesville, Florida, May 1993. University of Florida and Cornell University.

[19] Stinner, B.R. & House, G.J. (1987). Role of ecology in low input, sustainable agriculture: an introduction. *American Journal of Alternative Agriculture.* 2, 146 –147.

[20] Greenland, D.J. (2000). Land resources. In: *Towards sustainable consumption. A European perspective*. B. Heap & J. Kent (Eds.) The Royal Society, London. pp. 27 – 33. ISBN 0 85403 537 0.

[21] Greenland, D.J. & Szabolcs, I. (Eds.) (1994). Soil resilience and sustainable land use. CAB International, Wallingford.

[22] Russell, E.J. (1939). Soil Science in England 1894 – 1938. In: *Agriculture in the Twentieth Century.* Clarendon Press, Oxford.

[23] World Commission on Environment and Development 1987. *Our common future.* Oxford University Press, New York. (The 'Brundtland' Commission)

[24] Xia Li (1997). A sustainable land allocation model with the integration of remote sensing and GIS - A case study in Dongguan. *International Journal of Environmental Studies A & B*, 53, 325-348.

[25] Food and Agriculture Organization of the United Nations (1993). 1993. 1990 Forest resources assessment: Tropical countries. Food and Agriculture Organization of the United Nations, Rome.

[26] Agricultural Statistics United Kingdom (1972, 1982,1992). MAFF, DAFS, DANI, WO. Government Statistical Service, HMSO, London.

[27] MAFF (2000). Towards Sustainable Agriculture. - A Pilot Set of Indicators, pp. 1-72. MAFF Publications, London.

[28] Sustainable Farming and Food strategy: a framework for evaluation and monitoring (2002). Section 3 in: *Farming and Food's Contribution to Sustainable Development. – Economic and Statistical Analysis.* Defra Publications, London. 125pp. Product Code PB 7751B. Also on DEFRA web site at: www.defra.gov.uk/farm/sustain/newstrategy/econ/section3.pdf

[29] Hansen J.W. (1996) Is agricultural sustainability a useful concept? *Agricultural Systems* 50, 117-143.

[30] Hansen J.W. & Jones J.W. (1996) A systems framework for characterizing farm sustainability. *Agricultural Systems* 51, 185-201.

[31] McRoberts, N; Doyle, C J; Quinn, F; Smith, J (2000). Is predicting the sustainability of agricultural systems an impossible dream? *Aspects of Applied Biology*, 62, 159-164.

[32] Pearce, D.W. (1998). Measuring sustainable development: Implications for agri-environment indicators. In *Environmental Indicators for Agriculture*, vol. 2: Issues and Design, 29 – 42. OECD, Paris.

[33] Animal Agriculture and Global Food Supply (1999). Council for Agricultural Science and Technology, Ames, Iowa. 92 pp. Also on web site at: http://www.cast-science.org/pubs/anag_nr.htm

[34] Institute for Grassland and Environmental Research Annual Report for 1999 – 2000. IGER,

[35] E. P. Odum (1959). *Fundamentals of Ecology*, 2nd. ed., W. B. Saunders Co., Philadelphia.

[36] Food Chains at web site: http://users.rcn.com/jkimball.ma.ultranet/ BiologyPages/F/FoodChains.html

[37] *The Saxon Villages of Transylvania, Romania – A Future for the Medieval Landscape.* Kim Wilkie Associates. Mihai Eminescu Trust, Richmond Upon Thames. 2001.

[38] ADAS Pwllpeiran Research Centre, News. 2002

[39] Smith F.D.M. et al. (1993). How much do we know about the current extinction rate? *Trends In Ecology & Evolution* 10, 375-378.