Low input agriculture — Is it sustainable?

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Introduction

Since the 1940s the goal of agriculture worldwide has been increased production. The driving force for nations closely involved in the Second World War was maximum production from their own land; other nations have appreciated the extent of the market for agricultural produce in the industrialised countries. Increased production has been achieved as the agricultural industry has utilised, with the help of its advisory services, the results of research and development in nutrition, breeding and pest and disease control for both crops and livestock.

Present concerns

Today, although many go hungry for a variety of reasons, agricultural production is in surplus worldwide. Such surpluses are bad for farmers because they keep down prices but in industrial nations they encourage cheap food policies which are often favoured politically. However, over production has recently come under attack from two very diverse sources. First, in the European Community the operation of the Common Agricultural Policy led to considerable financial penalty as surplus production was brought into intervention and the taxpayer complained. The second attack has come from those people in the industrialised nations who have become increasingly concerned for the environment. Although threats to the environment and ultimately ourselves are the cumulative effects of many industrial and social practices, agriculture has all too frequently been made the butt of adverse media criticism. Thus large scale pollution, as with acid rain; major accidents, as at Chernobyl; destruction of important habitats, as in the Amazonian rain forests; the wasteful exploitation of the world's mineral and biological resources because of a lack of desire to recycle; and global problems, such as the greenhouse effect are often acknowledged but are thought to be too immense for individual action. On the other hand a vocal minority complain about those aspects of current agricultural practices which they believe are dangerous or objectionable, such as: pesticide residues in soil, water and foodstuffs; increasing nitrate concentrations in many ground and surface waters; landscape changes from simplified cropping patterns resulting in diminishing wildlife habitats; soil erosion and degradation; and animal husbandry systems perceived to be unnatural or degrading. In addition, there are those who believe that much of our food is of unacceptably poor quality. Many detractors of current agricultural practice believe that the ready availability of inorganic fertilizers and of agrochemicals used to control pests and diseases has made possible the systems they distrust. But they fail to accept that specialised, high input farming has increased agricultural production so that it has been possible to feed many more people than could have been supported on the practices of the 1930s and 1940s. They also fail to appreciate that any farming has some environmental impact. The present concern should be whether current practices cause unacceptable environmental change. This issue involves judgement of benefits and costs, but decisions are often based on political expediency rather than available scientific facts and understanding.

Future possibilities

The well orchestrated concerns noted above have coincided with declining profitability on many farms and increased direct and indirect subsidy payments by central governments. There is, therefore, interest in viable, alternative agricultural systems and many have been proposed. Many of these recent developments have been initiated by farmers themselves as they respond to economic pressures. For example, one of the first moves was a return to organic farming with no inputs of soluble inorganic fertilizers and agrochemicals. This is viable for some growers because the current premiums paid for organically-grown produce range from 25 to 100%.

At present besides organic farming, there are low input, reduced input, sustainable and regenerative systems being proposed. In the United States the concept of low-input, sustainable agriculture (LISA) is being widely debated. Little is gained by debating definitions, but it should be remembered that terminology is often vitally important to the lay public's perception as to how a system functions. In addition it must now be recognised by national research and advisory infrastructures that these changes require soundly based research programmes which take into account both short-term financial problems and the long-term need to maintain soil fertility.

Sustainable agriculture

Perhaps the best concept of sustainability is as defined by the World Commission on Environment and Development ("The Brundtland Commission"). This envisages a moral obligation "to meet the needs of the present without compromising the ability of future generations to meet their needs". Thus society must decide how to conserve limited global resources, of which agriculture still consumes a very small proportion, for the benefit of future generations.

Against this background of current change and the above concept of sustainability this paper assesses the effects of decreasing some of the current inputs to arable agriculture based on research at Rothamsted Experimental Station in England.

A nation's assets

A country's two most important natural assets are fertile soils and a wholesome water supply. To be sustainable agriculture must focus on the protection, care and maintenance of agricultural land, with emphasis on preventing loss of fertility, especially through soil erosion and degradation, careful husbandry of all resources and concern that agricultural activity does least damage to other ecosystems. Equally important, however, is that such stewardship must be economically viable and ready to meet the demands of an increasing world population for an adequate standard of nutrition.

The World Health Organisation has set standards for water quality and within the European Community these, or stricter standards, are being enforced for water supplied for human consumption. In many situations water used for public supply has passed through or over agricultural land where soluble substances have been taken into solution. Currently there is concern over the concentrations of both nitrate and pesticides in some supplies. One aspect of low input agriculture is an attempt to decrease the quantities of nitrogen fertilizers and pesticides applied to cropped land. For pesticides this is leading to the concept of biological and/or integrated pest control. For nitrogen attempts are being made to use biologically fixed nitrogen in arable rotations. Both require research and development.

Soil fertility

Soil fertility is a complex interaction between the biological, chemical and physical properties of soil, and in whichever discipline we work we diminish the contribution of our research if we fail to integrate our results with those from other disciplines.

Biological properties are largely controlled by the vast population of minute living organisms, the soil microbial biomass. In temperate soils the carbon content of the biomass is often less than 5% of the total carbon in soil organic matter yet the survival and function of some of these organisms is crucial for the maintenance of soil fertility. The biological breakdown of organic debris deposited on or in soil removes this debris and cycles nutrients, principally nitrogen, phosphorus and sulphur. Microbial activity is dependent on both soil moisture and temperature and most importantly on having a supply of readily available carbon as a food source.

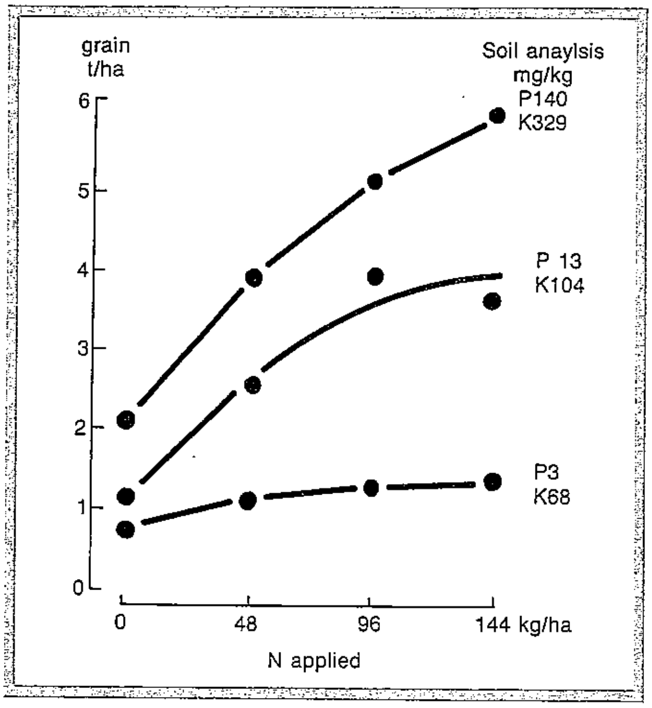

Fig. 1. Response of spring barley to nitrogen on soils with different amounts of readily soluble P and K, Hoosfield, Rothamsted

An important physical property is the pore structure of soil. The balance between air- and water-filled pores controls the development of roots and therefore their exploitation of applied nutrient inputs and their residues.

The weathering of rock minerals imparts important chemical properties on the clay fraction of soil, especially the overall electric charge on these particles. An understanding of these properties and those of soil organic matter is necessary to appreciate the effects of decreasing chemical inputs on soil fertility.

When discussing soil fertility it is essential to separate long-term aspects, which provide a "structure" on which production systems can be developed, from short-term effects which determine the level of production. Soil acidity, phosphorus and potassium status and organic matter content would be considered long-term aspects because they change slowly over time. The application of nitrogen fertilizers and the use of agrochemicals to control pests and diseases determine the level of production in the short-term. Fig. 1 and Fig. 2 provide useful illustrations; Fig. 1 of the need to get the correct fertility "structure" and Fig. 2 of the interactions between short-term factors.

Fig. 1 shows the response to nitrogen by spring barley on three soils with different levels of readily soluble P and K. The short-term effects of nitrogen were fully exploited only on soils with most P and K; where there was little P and K only the smallest application of nitrogen was justified.

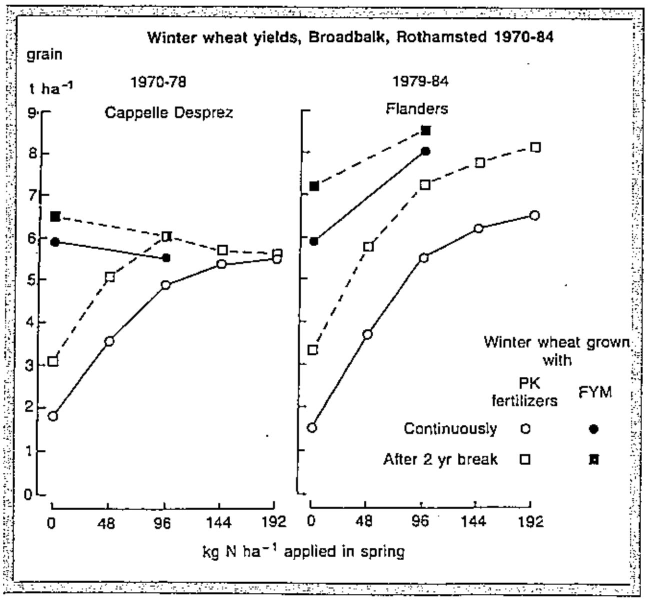

Fig. 2. Relationship between the yield of two cultivars of winter wheat and spring-applied fertilizer N during two periods on soils with two levels of organic matter, Broadbalk, Rothamsted

The effects of disease and its control on the response to nitrogen by winter wheat are shown in Fig. 2 using data from the Broadbalk experiment started in 1843 at Rothamsted. During 1970-84, wheat was grown continuously (solid lines) or after a 2-year break (dotted lines) to minimise the effects of soil borne pathogens which decreased yields appreciably. The wheat was also grown on soils with two levels of organic matter, about 1,7% (open symbols) and 5% (closed symbols). The extra organic matter had accumulated from annual applications of farmyard manure over the last 130 years. Both soils contained much readily soluble P and K. *Cappelle Desprez* was grown in the first period, 1970-78. Grain yields did not increase above 96 kg N/ha on the less organic soil, and on the more organic soil applying fertilizer nitrogen decreased yields. *Flanders* was grown in the second period, 1979-1984, and grain yields responded to all amounts of fertilizer nitrogen tested even on the soil with more organic matter. However, the yield potential of *Flanders* was only a little greater than that of *Cappelle Desprez*. The different response to nitrogen was because fungicides were used effectively in the second period to control foliar pathogens. Thus green leaf area was maintained, extending the grain filling period and hence increasing yield.

Soil acidity

In Britain the beneficial effects of liming arable soils have been known since Roman times. However, the first experimental work started only in the 1870s on the Royal Agricultural Society of England's experiment farm at Woburn in Bedfordshire, now under Rothamsted's management. The pH (in water) of this sandy loam soil was about 6,0 in 1876 when experiments testing the effects of N, P and K fertilizers on the yields of winter wheat and spring barley were started. Nitrogen was applied as either ammonium sulphate or sodium nitrate. Where ammonium sulphate was used soil pH declined rapidly and yields of spring barley decreased drastically (Table 1). Yields of winter wheat were not affected so seriously. Tests of liming quickly showed beneficial effects. Today in England and Wales farmers are advised to maintain arable soils at pH 6,5 and grassland soils at 6,0 (in water).

It is a salutary lesson that in the period of agricultural depression following the First World War many farmers failed to lime their soils and by the early 1930s increasing acidity was adversely affecting yields of many arable crops. In fact the situation had become so serious that pressure was put on the Government to subsidise the liming of agricultural soils (Johnston & Whinham, 1980). Lime subsidy payments were introduced in 1937. Farmers who responded quickly gradually improved the pH of their soils during the next few years and were able to increase their production in the early years of the Second World War as supplies of imported food dwindled.

Today more reasons are known why it is important to maintain soil pH. At low pH aluminium and manganese are mobilised and decrease crop growth, and many soil-applied agrochemicals are less effective. Many plant breeding programmes, perhaps unwittingly, have produced cultivars which yield more on slightly acid or neutral soils simply because these were the soils on which assessments of yield potential were made. In addition, the acidity of subsoils is important because if they are very acid root growth is diminished, and this may decrease the ability of the plant to benefit from water stored in the subsoil. Even in climates like that in Britain this can be important because crops like winter wheat take up appreciable quantities of water from soil at 1 to 2 m depth during the latter part of the growing season. Table

Table 1. Effect of increasing acidity, from the use of ammonium sulphate, on the yield of spring barley and winter wheat, grain t/ha, on a sandy loam soil, Woburn 1877-1906

		Period	
Spring barley:	**1877-86**	**1887-96**	**1896-1906**
Ammonium sulphate*	2,57	2,10	0,44
Sodium nitrate	2,73	2,42	2,14
Unmanured	1,33	1,03	0,82
Winter wheat:			
Ammonium sulphate	2,04	1,94	1,68
Sodium nitrate	2,12	1,94	1,67
Unmanured	1,11	0,93	0,78

** Both nitrogen fertilizers supplied the same amount of nitrogen and were applied with PK fertilizer*

Table 2. Effect of 'natural' acidifying inputs on soil pH at three depths, Geescroft Wilderness, Rothamsted

		Year		
Horizon cm	**1883**	**1904**	**1965**	**1983**
0-23	7,1	6,1	4,5	4,2
23-46	7,1	6,9	5,5	4,6
46-69	7,1	7,1	6,2	5,7

Table 3. Effect of soil pH and past K manuring on the percentage of added K which remained exchangeable in soils which were alternately wetted and dried

Past K manuring	Soil pH	Exchangeable K, mg/kg, in unamended soil	Percentage added K remaining exchangeable
None	5 to 6	80	70
None	7 to 8	140	40
Fertilizer K	5 to 6	200	90
Fertilizer K	7 to 8	360	60

Table 4. Amount of K added, kg/ha, and exchangeable K, mg/kg at four depths in two soils of contrasted texture

K added Depth cm	Silty clay loam			Sandy loam		
	None Exch K	16 700 Extra	28 800 Exch K	950 Exch K	6 400 Extra	11 800 Exch K
0-23	119	174	641	111	163	266
23-30	129	104	386	101	169	265
30-46	139	23	225	93	174	268
46-61	152	−2	152	83	143	226

2 shows changes in pH at three depths in a silty clay loam at Rothamsted under deciduous woodland during the period 1880-1980 (Johnston *et al*, 1986). Acidifying inputs were from "natural" sources — wet and dry deposition, nitrification of ammonium ions and biological processes. The pH of the top 23 cm horizon decreased from about 7 to 4 whilst even at 46-69 cm pH declined to about 6. The use of fertilizers would have enhanced this acidification.

Phosphorus and potassium

It is generally accepted that methods of soil analysis are needed to characterise soils according to observed crop responses to P and K. Only on very sandy soils do crop yields relate to the soils' total content of P and K. In England and Wales readily soluble P is ofter determined using Olsen's bicarbonate method (Olsen *et al*, 1959) and readily soluble K by exchange with either ammonium acetate or nitrate.

Manuring policies for P and K must be based on a knowledge of their chemistry in individual soils and how the concentration of the readily soluble fraction changes in response to cropping and manuring. For example in very acid soils phosphorus is readily precipitated as iron and aluminium phosphates which are totally unavailable to plants. At higher pHs plant available residues of P accumulate in soil (see later) — another good reason for maintaining soil pH above 6,0 (in water). More potassium tends to remain exhangeable in acid than in neutral soils (Table 3) and because a proportion of the exchangeable K is water soluble this can increase the movement of K into subsoils. Such leaching risk also depends on soil texture. Table 4 shows that the top 23 cm of the silty clay loam at Rothamsted has accumulated much more exchangeable K than the deeper horizons but on the sandy loam at Woburn all horizons down to 61 cm have been equally enriched. Such subsoils enrichment can only benefit deep rooted crops like lucerne, winter wheat and sugar beet.

The conclusions which follow are based on data obtained on soils in the pH range 6 to 8 (in water). The often expressed concern by many farmers that P and K applied to soil and not used by a crop is irretrievably lost is not supported by the data in Tables 5 and 6. During periods when residues were accumulating the increase in readily soluble P or K was only a fraction of the calculated P or K balance. (Balance equals amount of nutrient applied minus the amount removed in the harvested crop.) But during periods when no fertilizer was applied offtakes in the harvested crop far exceeded the decline in readily soluble P or K. The fixation of P and K in forms which are not readily soluble is reversible.

In the second half of the last century Lawes and Gilbert at Rothamsted were intrigued by the different residual values of nitrogen, phosphorus and potassium applied in organic manures and inorganic fertilizers. They modified many of their field experiments to test the magnitude and duration of these residual effects (Johnston, 1969). This was at a time when much agricultural land in Britain was farmed by tenants who could all too readily lose their tenancies. Lawes and Gilbert perceived that this could be a hindrance to tenants improving the fertility of their landlords' soils and they therefore proposed that tenants should be compensated for unexhausted manurial benefits when the tenant left the farm. Eventually legislation to enforce such compensation was enacted.

By the mid 1950s the continued application or withholding of P and K fertilizers to plots in the Rothamsted and Woburn long-term experiments had resulted in large differences in the readily

Table 5. Phosphorus balance, kg P/ha, and change in bicarbonate soluble P as a percentage of the P balance, Exhaustion Land, Rothamsted

Plot	Treatment	P balance kg/ha	$NaHCO_3$ soluble P in soil kg/ha			Change in $NaHCO_3$ soluble P as a % of P balance
Period 1856-1903			1856	1903	Change	
1, 2, 5, 6	None	−80	30	25	−5	6
3, 4	FYM*	+1 031	30	202	+172	17
9,10	PK	+1 217	30	197	+167	14
Period 1903-58†			1903	1958	Change	
1, 2, 5, 6	None	−193	25	20	−5	3
3, 4	FYM residues	−379	202	71	−131	35
9, 10	PK residues	−340	197	55	−142	42

* *FYM Farmyard manure*

† *FYM and PK manuring ceased in 1901*

Table 6. Potassium balance, kg K/ha, and change in exchangeable K as a percentage of the K balance, Garden Clover experiment, Rothamsted

Period	K applied each year kg/ha	K balance for period kg/ha	Exchangeable K in soil, kg/ha			Change in exch K as a % of K balance
			Start	End	Change	
1956-66	None	−246	171	194	+23	—
	136	+617	171	431	+260	42
1968-78	250	+1 667	375	1 065	+690	41
1979-83	125	−1 494	1 065	502	−563	38

Table 7. Effect of phosphorus residues on yields, t/ha, of spring barley, potatoes and sugar from sugar beet, Agdell, Rothamsted 1959-60

		Fresh P fertilizer applied, kg P/ha		
		0	14	56
Barley, grain:				
	Soils without residues	1,54	2,08	2,89
	Soils with residues	3,41	3,50	3,88
Potatoes, tubers:				
	Soils without residues	12,10	18,10	25,40
	Soils with residues	29,90	33,10	38,20
Sugar:				
	Soils without residues	3,38	3,99	4,79
	Soils with residues	5,77	5,87	6,00

Table 8. Effect of potassium residues on yields, t/ha, of spring barley, potatoes and sugar from sugar beet, Exhaustion Land, Rothamsted 1957-58

		Fresh K fertilizer applied, kg K/ha				
		0	16	32	63	126
Barley, grain:						
	Soils without residues	3,34	3,11	3,06	3,56	—
	Soils with residues	3,54	3,38	3,61	3,56	—
Potatoes, tubers:						
	Soils without residues	17,1	—	22,1	29,6	31,1
	Soils with residues	27,6	—	31,6	36,2	36,7
Sugar:						
	Soils without residues	4,87	—	4,98	5,90	5,67
	Soils with residues	6,15	—	5,85	6,01	5,43

soluble P and K contents of soils. We investigated whether yields on the impoverished soils could be raised to those on the enriched soils. Much to our surprise yields of many crops grown on impoverished soils and given generous applications of fertilizer could not be raised to those on enriched soils. Tables 7 and 8 show examples (Johnston *et al*, 1970). In retrospect this result was not surprising because it is difficult to thoroughly mix a small amount of fertilizer throughout the large volume of soil explored by roots during growth. Also shallowly incorporated P and K remains near the surface and once this soil has dried little or no nutrient will be taken up by the roots.

It was then decided to explore the response of crops to a range of readily soluble P and K levels in soil rather than the response to fresh applications of P and K fertilizer. Figure 3 shows the relationship between yields of potatoes and sugar from sugar beet and readily soluble P in soil (Johnston *et al*, 1985). For each crop the data are divided into three groups of years according to the maximum yield attained. This maximum was shown to be related to rainfall. Although yields differed by a factor of two, the point of inflection in the response curves was essentially at the same level of soluble P. Therefore allowing soils to decline below this level had a serious effect on yield in all years irrespective of the climatic factors which caused maximum yields to vary from year to year.

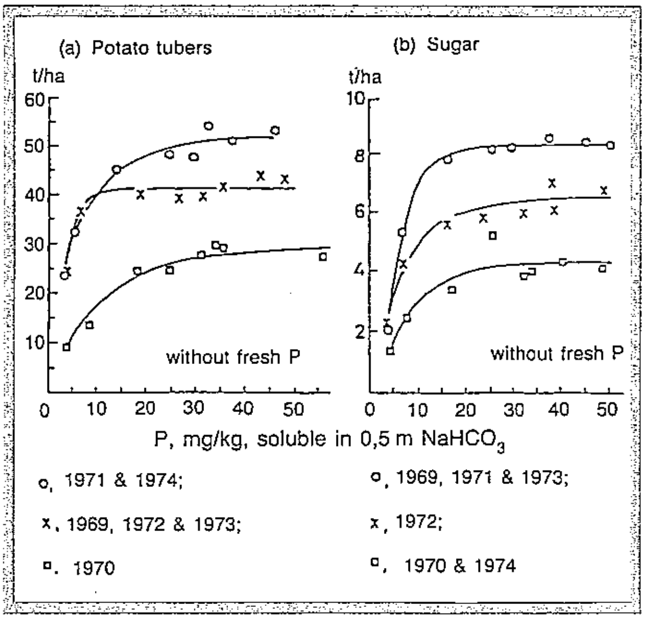

Fig. 3. *Response of potatoes and sugar beet to bicarbonate-soluble P in groups of years according to maximum yield*

Figure 4 shows that when the yield of winter wheat, given different amounts of nitrogen was related to readily soluble P, then using less nitrogen did not justify having less P in the soil. Using the

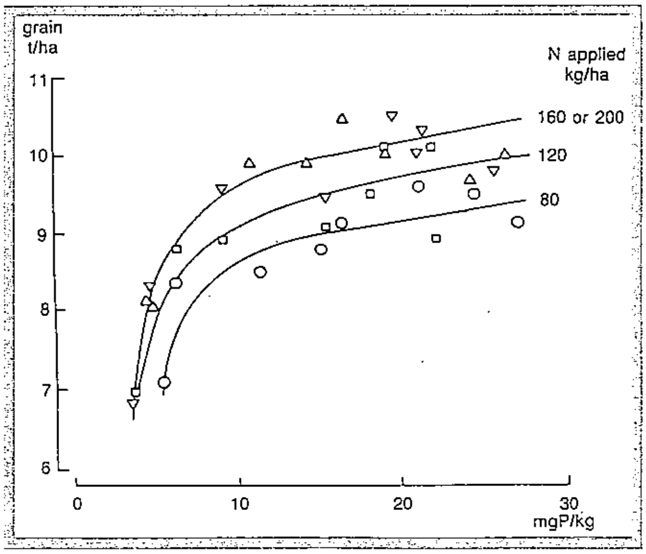

Fig. 4. *Effect of nitrogen on yield of winter wheat at different levels of bicarbonate-soluble P in soil*

larger amounts of nitrogen was a cost penalty below the point of inflection in the response curves. Equally the small increase in yield with increasing levels of readily soluble phosphorus would not justify on economic grounds the use of excessive amounts of phosphate fertilizer to rapidly increase soluble P in soil. However, the relationship supports the slow build-up of soluble P by ensuring that the P balance is positive each year.

Figure 5 shows that both the yield and K offtakes by potatoes and field beans (*Vicia faba*) increased linearly with readily soluble K in soil up to 200 mg K/kg. Unfortunately no limiting value for soil K could be determined for either crop. In another experiment the yield of spring barley was not increased by K levels above 80 mg/kg whereas that of sugar beet incresed up to an exchangeable K content of at least 200 mg/kg (Fig. 6). The scatter of values about the general relationship in Fig. 6 is probably because there was variation in the uptake of K from the subsoil. The variability of rooting patterns and K availability in subsoils should always be remembered when there are poor correlations between yield and readily soluble soil K. However, attempting to refine fertilizer recommendations on the basis of subsoil K would probably not justify the additional cost of sampling and analysis.

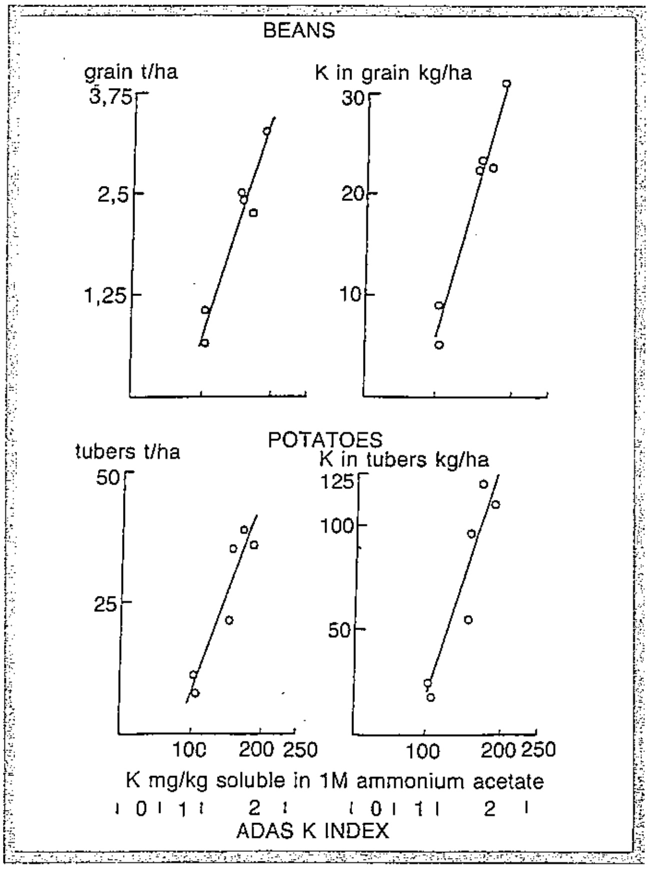

Fig. 5. *Relationship between yield of fields beans* (Vicia faba) *and potatoes and exchangeable K in soil*

The phosphorus and potassium fertility of a soil can therefore be defined in relation to the level of readily soluble P and K in soil below which yield of each of the more important crops there will be a loss in every year. Soluble P and K levels should be

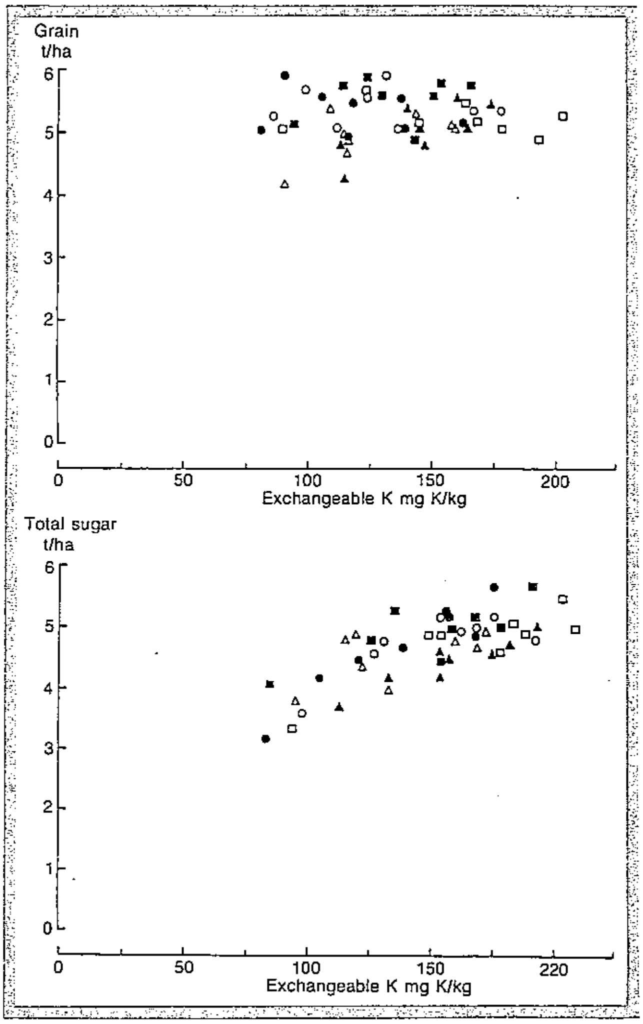

Fig. 6. *Relationship between yield of spring barley and sugar from sugar beet and exchangeable K in soil*

raised above the largest critical threshold for each nutrient by generous annual manuring over a number of years rather than excessively large dressings in one or two years.

Policies for P and K manuring should then be based on maintaining these levels of P and K. The simplest scheme to adopt is a balance sheet method. Namely replace all the P and K removed in the harvested crop. For this it is sufficiently accurate to use tables of average composition per tonne of produce removed from the field and a good estimate of yield. The success of such a scheme can be checked by periodically analysing the soil to follow changes in readily soluble P and K with time. When using soil analysis in this way it is essential that the sampling protocol remains unchanged; the method of analysis is less critical provided that it gives reproducible results.

Soil organic matter

The amount of organic matter in soil invariably moves towards an equilibrium value which depends on: (1) The amount of organic matter added each year and its rate of decomposition; (2) the rate of breakdown of existing soil organic matter; (3) soil texture; (4) climate. For soils of any one texture in a given climatic region, the equilibrium value depends on factors 1 and 2 which are directly related to the farming system practised. As farming systems have tended to polarise into intensive livestock or all-arable production systems, organic wastes have been a disposal problem in the former and of no concern in the latter. However, soil organic matter in arable systems is affected by inputs like fertilizers and agrochemicals, which besides increasing the amount of saleable produce also affect the size of the organic residues returned to soil each year. Although the return of these residues may result in only small gains in amounts of soil organic matter the benefits can often be greater than expected.

A good example are results from the Organic Manuring experiment on the sandy loam at Woburn (Johnston, 1986). During a six-year treatment period there were six contrasted cropping and organic manuring sequences intended to give a range of soil organic matter levels. In all treatments inputs and offtakes of P, K and Mg were carefully monitored, and at the end of the treatment phase four of the six soils had very similar amounts of readily soluble P, K and Mg, the other two treatments had more. In the test phase four arable crops were grown in rotation and eight amounts of fertilizer N were tested on each. The crops and range of N rates, kg/ha, were: potatoes, 0-350; winter wheat, 0-175; sugar beet, 0-280; spring barley, 0-175. In three of the four soils with identical levels of P, K and Mg soil organic matter at the start of the test cropping was: 1,18% in the all-arable rotation with all above ground residues removed, 1,58% in the all-arable rotation where a total of 45 t/ha cereal straw dry matter had been incorporated, and 1,58% following grass-clover leys for six years. Yields of all four crops, averaged over the four lowest and four highest rates of nitrogen were always larger on soils with more organic matter (Table 9).

There are a number of possible mechanisms through which organic matter can affect yields of arable crops; examples of three are given here.

First there is the release of nutrients by mineralisation at times and sites within the soil profile which allow plants to make maximum use of them. Although these residues accumulate from the use of fertilizers, their effect is difficult to mimic by fertilizer application. An example is the improvement in the protein content of small grains when grown on soils with more rather than less organic matter. Larger amounts of nitrate mineralised from the extra organic matter during grain filling are translocated to the grain.

Improved soil water holding capacity can be another benefit from extra organic matter. Table 10 shows yields of spring barley, potatoes, winter wheat and winter barley grown on soils with two levels of soil organic matter, again on the sandy loam at Woburn. Although mineral nitrogen from the extra organic matter increased yields of cereals when no fertilizer nitrogen was given, the best yields of barley and potatoes were achieved with the most fertilizer nitrogen on the soils with more organic matter. Yields of the two winter cereals were not affected by the amount of soil organic matter. Presumably the autumn-sown crops produced a root system in the deeper soil horizons which was capable of exploiting subsoil water. The shallower rooting spring-sown crops were more dependent on the water in the upper horizons of the profile where the quantity of water would depend on the organic matter content.

Soil organic matter can also effect soil structure. Table 11 shows the yields of barley, potatoes and sugar from sugar beet on silty clay loam soils at Rothamsted with two amounts of organic matter, 1,5 and 2,4% and a range of bicarbonate soluble P levels.

Table 9. Effect of soil organic matter on the yields of four arable crops, Organic Manuring experiment Woburn 1972-76

			Treatment 1965-71 and % organic matter in soil, 1971		
			Arable no residues returned	Arable straw added each year	6-year leys
Crop	**Years grown**	**N rate***	1,18	1,58	1,58
Potatoes, tubers	1972-73	Low	32,0	35,4	43,8
		High	43,8	47,4	49,7
Wheat, grain	1973-74	Low	3,22	3,60	5,14
		High	5,42	6,10	5,66
Sugar	1974-75	Low	2,11	2,40	2,83
		High	2,90	3,08	3,25
Barley, grain	1975-76	Low	2,96	3,45	3,56
		High	3,81	4,14	4,12

**Mean of four lowest and four highest rates of N tested on each crop (see text)*

Table 10. Effect of soil organic matter on the yields. t/ha, of four arable crops, Woburn 1973-80

% soil organic matter	Fertilizer N applied*			
	N0	N1	N2	N3
Potatoes, tubers 1973 & 1975				
1,3	25,7	35,6	41,7	43,2
3,5	27,1	40,6	50,7	59,0
Spring barley, grain 1978				
1,3	2,19	5,00	6,73	7,05
3,4	2,58	5,12	6,85	7,81
Winter wheat, grain 1979				
1,3	3,54	7,32	8,05	7,82
3,4	4,81	7,21	8,09	8,08
Winter barley, grain 1980				
1,3	3,05	6,01	7,32	7,83
3,4	3,57	5,92	7,00	7,98

**N0, N1, N2, N3: 0, 100, 200, 300 kg N/ha for potatoes*
0, 50, 100, 150 kg N/ha for cereals

Table 11. Effect of soil organic matter and different amounts of bicarbonate soluble P on yield of three arable crops, Agdell, Rothamsted 1970-72

Crop	% soil organic matter	P soluble in 0,5 M $NaHCO_3$, mg/kg				
		0-9	9-15	15-25	25-45	45-70
Barley, grain	1,5	—	2,71	3,29	4,21	4,61
	2,4	3,18	4,78	5,20	5,00	5,46
Potatoes, tubers	1,5	—	31,5	36,7	39,3	44,0
	2,4	26,6	43,0	45,3	46,4	47,8
Sugar	1,5	—	5,03	5,91	6,66	6,80
	2,4	2,45	5,92	7,06	6,73	6,85

In the range between 15 and 45 mg/kg bicarbonate soluble P, the yields of all three crops were much larger on the soils with more organic matter. It is probable that lack of organic matter adversely affects the structure of the Rothamsted soil with only 1,5% organic matter so that roots explore the soil for nutrients less effectively.

One other aspect of crop residue management important in many parts of the world is mulching to protect soil against erosion by rain and wind. Larger crops grown on fertile soil leave larger residues which properly managed help minimise soil erosion.

Summary

World population is increasing, but world production, on a *per capita* basis, of the three principal small grains, wheat, maize and rice, has remained static or has fallen slightly since 1984 (Brown, 1988). It is no part of this paper to discuss whether the expanding population can or should pay, directly or with subsidy, the full economic cost of food production, including the cost of maintaining or enhancing soil fertility. It is reasonable, however, to suggest that current inputs to agricultural soils should seek to meet the needs of the present without compromising the needs of future generations, i.e. soil fertility should be maintained. A fertile soil is a farmer's most important capital asset and the economic viability of each farming enterprise depends on making optimum use of this asset. This fertility arises from complex interactions between biological, chemical and physical properties and many facets of these properties can be manipulated only over time scales measured in years. Therefore, in times of economic stress some thought should be given as to which inputs can be lessened. Most cultivars of current agricultural crops require minimum conditions for soil pH, organic matter and available phosphorus, potassium and magnesium to achieve maximum yield. The appropriate critical threshold values must be determined by field experiments for the principal soil types and major climatic regions. Inputs needed to maintain soils above these thresholds should not be lowered. Inputs of nitrogen can be varied to give different levels of production to meet market demand. Lower yields will often decrease the need for other agrochemical inputs and the size of the maintenance dressings of P and K fertilizers. In extreme cases it is probably better to maintain high levels of production on a limited area of land. Surplus land should be kept under permanent vegetative cover to minimise the risk of soil erosion and build up soil organic matter. Such land can be brought back into production when the need arises.

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