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Fertilizer trends in relation to biological productivity within the U.K.

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Technological developments in plant and animal breeding, pesticides, veterinary products and animal nutrition, together with the use of more sophisticated machinery, have all contributed to the outstanding progress in productivity achieved by U.K. agriculture since World War II; however, the predominant factor associated with increased arable crop yields, milk and meat production from grassland has been the steady rise in N fertilizer usage. For example, wheat in 1950–52 receiving 32 kg N ha^{-1} yielded 2.71 t ha^{-1}, whereas in 1977–9 the N rate was 125 kg ha^{-1} and the yield 5.21 t ha^{-1}. Comparable figures for barley were a 1950–52 yield of 2.51, rising to 4.22 t ha^{-1}, with N rates of 25 and 84 kg ha^{-1} respectively.

Winter wheat yields of over 10 t ha^{-1} are currently being achieved in experimental work and by some farmers in favourable seasons. Such yields, which require a total of 200 kg N ha^{-1} to be available from soil and fertilizer sources, have been made possible by the introduction of improved varieties. The current average farm yield of wheat, however, is only 5.21 t ha^{-1}, i.e. about half the potential yield. A similar situation exists with other arable crops.

Similarly, the potential productivity of our grasslands is much higher than is being achieved on a national scale. N fertilizer usage on grass averages only 120 ka N ha^{-1} whereas experiments and practical experience have shown that the optimum economic rate is in the range 200–400 kg N ha^{-1}, depending on whether the enterprise is based on sheep, beef cattle or dairy cows.

Biological productivity is unlikely to limit the growth of U.K. fertilizer use in the near future. Economic and political factors, such as how to use, or avoid, E.E.C. food surpluses, are likely to impose constraints long before the biological potential of crops in the U.K. is fully exploited.

Introduction

In this paper the pattern of fertilizer use over the period 1950–79 is examined in relation to changes in agricultural land use and to increased agricultural intensification and productivity.

The potential for the profitable use of fertilizers to continue to increase in the future is discussed. Constraints imposed by economic, political and other non-biological factors are also outlined.

Changes in land use from 1950 to 1979

The areas of the main categories of crops for this period are given in table 1. It can be seen that the total area devoted to cereals has increased by 16% since 1950, but within this total area barley has increased threefold and wheat by one-third, whereas other cereals have declined to less than one-third of their former area.

Areas of potatoes, fodder crops and horticultural crops (including fruit) have been reduced to a very marked extent; sugar beet area has increased by 23% and, within the last 10 years oil seed rape has become an important crop. Rough grazing is now about one-tenth less than in 1950, permanent grass has remained the same and temporary grass has been reduced by 15%.

Changes in fertilizer usage

Consumption of N, P and K fertilizers in the U.K. over the last 40 years is shown in table 2. During this period the growth in the total use of fertilizers has continued although the importance of P and K in relation to N has diminished, the former nearing peak consumption

Table 1. U.K. areas (millions of hectares) devoted to agricultural crops

	1950	1960	1970	1979
wheat	1.003	0.851	1.010	1.371
barley	0.720	1.363	2.243	2.343
other cereals	1.624	0.890	0.460	0.159
potatoes	0.500	0.335	0.271	0.204
sugar beet	0.174	0.176	0.188	0.214
fodder crops	0.611	0.490	0.301	0.245
horticultural crops (incl. fruit, flowers, nursery, glasshouse crops)	0.561	0.467	0.303	0.284
oil seed rape	—	—	0.004	0.074
other crops (incl. lucerne)	0.095	0.074	0.029	0.031
bare fallow	0.109	0.078	0.098	0.072
grassland < 5 years old	2.238	2.746	2.292	1.903
grassland, 5 years and over	5.168	5.184	4.944	5.127
rough grazing	6.921	7.406	6.693	6.328
totals	**19.724**	**20.060**	**18.836**	**18.355**

Reference: Central Statistical Office (1951–1981).

Table 2. Fertilizer usage (kilotonnes) in the U.K.

year (June–May)	N	P_2O_5	K_2O
1939–40	61	173	76
1949–50	229	468	238
1959–60	410	458	430
1969–70	796	470	419
1979–80	1268	440	444

References: M.A.F.F. (1955–1970); Fertiliser Manufacturers Association (1959–1979); Cooke (1980); S. J. Challinor (personal communication 1981).

by 1950 and the latter by 1960. With phosphate the main reason for this is that the phosphate status of most soils is considered to have been built up to a reasonable level by the regular use of basic slag and other phosphate sources in the past and, except for such crops as potatoes that need fresh supplies of phosphate for each crop, the manuring policy has been to apply sufficient of the element to replace what the crop removes. With K, it has become less common in recent years to find fields that are deficient in this element, and manuring, as for phosphate, tends to be on a crop removal basis.

It will be seen in table 2 that in the decade from the beginning of World War II, fertilizer N usage nearly quadrupled. In each of the next two decades there was an approximate doubling of the amount used, and in the 10 years up to 1979 N fertilizer consumption increased by 60%.

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It is probably more informative, however, to view the increases in N consumption as an absolute amount in each decade because the fertilizer goes on to virtually the same total area of land each year. To view these increases in practical light we should examine N fertilizer usage on a crop basis over the same period (table 3 and figures 1–5). The heavy demand of potatoes, sugar beet and many market garden crops for nitrogen has long been recognized by research

Table 3. Fertilizer N usage (kilograms per hectare) on crops

(Average applied to main crops and grass, England and Wales.)

	winter wheat	spring barley	potatoes	sugar beet	temporary grass	permanent grass
1943–5	19	21	79	92	4	4
1950–2	33	25	117	113	16	6
1962	74	56	157	154	54	23
1970	90	82	166	161	108	53
1980	145	87	181	146	167	93

References: Cooke (1980); S. J. Challinor (personal communication 1981).

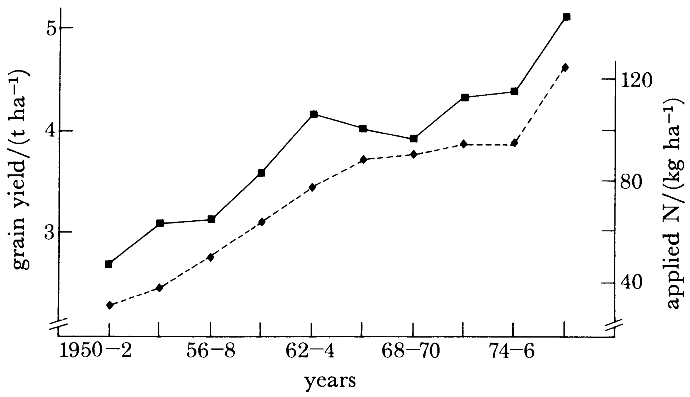

Figure 1. U.K. wheat grain yields (■) and N fertilizer rates (◆); 3 year means, 1950–2 to 1977–9.

workers and farmers, and these crops have, ever since fertilizers became readily available, been given amounts of N, P and K that were closer to economic optima than in the case of either cereals or grassland. In recent years, with the advent of stiff-strawed, lodging-resistant varieties, farmers have tended to apply N fertilizer dressings that are closer to the economic optimum. On grassland, however, farmers in the U.K., unlike their Dutch counterparts, have been reluctant to apply anything like the amounts of N fertilizer that have been proved, for many years, to be economically sound.

The recent very marked increase in the amounts of N fertilizer used on wheat and barley is associated with the rise in grain prices and with the introduction of improved varieties that have a higher yield potential than those that were previously available.

Sugar beet is one crop that, at least on the strength of available field trials evidence, is given too much N fertilizer by farmers. The downturn in usage in recent years (table 3 and figure 4) is presumably in response to technical advice to cut back because, in field trials, rates about 125 kg N ha^{-1} have seldom resulted in higher yields and tend to depress juice purity and extraction percentage (Draycott 1974).

Changes in productivity

Table 4 shows the change in output of the major arable crops that took place between 1950 and 1979 and table 1 gives the areas involved. In 1950 4.3 Mt of grain was produced by the combined wheat and barley area of 1.723 Mha. By 1979, productivity had increased such that 16.7 Mt of wheat and barley grain was harvested from 3.714 Mha. In other words, nearly four times as much was produced from just over twice the total area.

Table 4. Quantities of crops (megatonnes) produced in the U.K.

	1950	1960	1970	1979	percentage increase since 1950
wheat	2.6	3.0	4.2	7.1	173
barley	1.7	4.3	7.5	9.6	464
potatoes	9.7	7.3	7.5	6.5	—
sugar beet	5.3	7.3	6.4	7.7	45
fodder crops	16.1	12.6	9.8	9.2	—

Reference: Central Statistical Office (1951–1981).

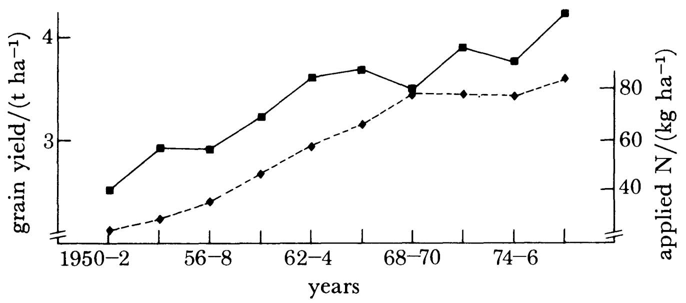

Figure 2. U.K. barley grain yields (■) and N fertilizer rates (◆); 3 year means, 1950–2 to 1977–9.

Cereals

There has been a gradual improvement in annual average grain yields of wheat and barley grown in the U.K. since the days of longer-strawed varieties (figures 1 and 2). If one allows for the effect on yields of the dry summers of 1975 and 1976 it is apparent that there has been a marked upsurge of yields during the 1970s. The introduction of improved short-strawed varieties, coupled with the use of more N fertilizer, herbicides, fungicides, insecticides and plant growth regulators, have all contributed towards these increases in the national yield. It is not possible on a national scale to apportion the separate contributions of each of these factors, but on the basis of trials results it is clear that the potential of the newer varieties cannot be achieved without applying more N fertilizer than has been customary in the past. The effects of improved timeliness associated with the use of better farm equipment, better techniques generally and of the more comprehensive technical advice and services that are now available have no doubt also played a part in the attainment of higher yields.

Figures 1 and 2 show that N fertilizer rates to wheat and barley have been rising throughout the period but with a noticeable slowing-up in the rate of increase in the 1970s (possibly as a result of the oil crisis) followed by a sharp increase in 1977–9 in wheat, which may be associated with the knowledge that some of the newer varieties now available have an immense capacity for responding to N fertilizer. Examples of recent experimental results are presented in figure 6. Economic optima at current prices are indicated by the arrows.

Potatoes

Potato yields have been rising fairly steadily since the late 1950s except for a temporary setback caused by the dry summers of 1975 and 1976 (figure 3). N fertilizer rates have also been rising gradually during the same period.

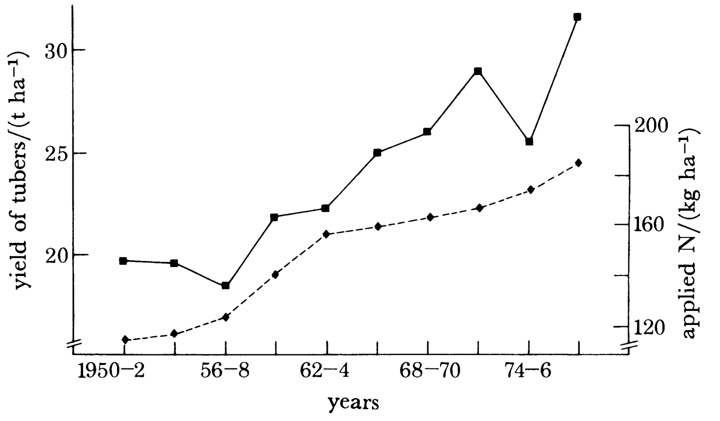

FIGURE 3. U.K. potato yields (■) and N fertilizer rates (◆); 3 year means, 1950–2 to 1977–9.

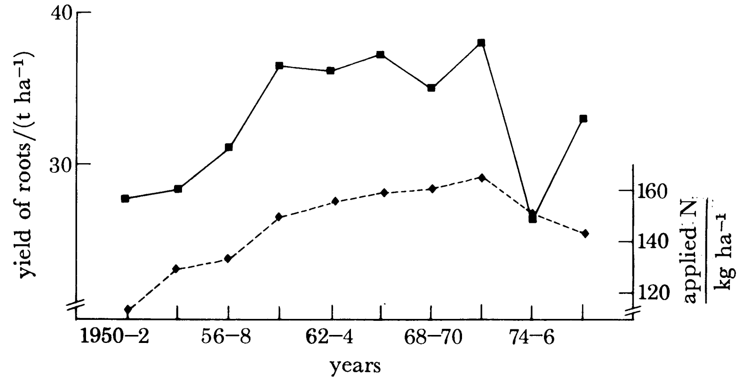

FIGURE 4. U.K. sugar beet yields (■) and N fertilizer rates (◆); 3 year means, 1950–2 to 1977–9.

Sugar beet

Although there was an upward trend in sugar beet yields during the 1950s and 1960s this has been abated by a sequence of bad years for sugar beet growing, including severe infestations of aphids, high incidences of virus yellows and the dry summers of 1975 and 1976 (figure 4).

Grassland

Most parts of the U.K., except parts of the drier eastern counties, are dominated by grassland or rough grazings. Together these two categories of land use cover 71 % of the total area devoted

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Table 5. Numbers of livestock in the U.K.

	1950	1960	1970	1979	percentage increase since 1950
(*a*) *total* (*millions*)					
cattle and calves	10.6	11.8	12.6	13.5	27
sheep and lambs	20.4	27.9	26.1	29.9	47
pigs	3.0	5.7	8.1	7.8	160
poultry	96.1	103.0	143.4	134.7	40
(*b*) *cows* (*thousands*)					
dairy cows	3014†	3165	3244	3288	
beef cows	753†	848	1300	1535	
totals	**3767**	**4013**	**4543**	**4823**	

† Estimates. Reference: Central Statistical Office (1951–1981).

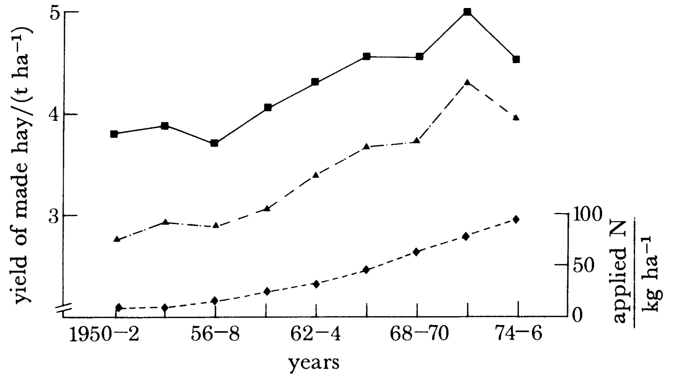

Figure 5. U.K. hay yields from temporary (■) and permanent (▲) grassland and average N fertilizer rates (◆); 3 year means, 1950–2 to 1974–6.

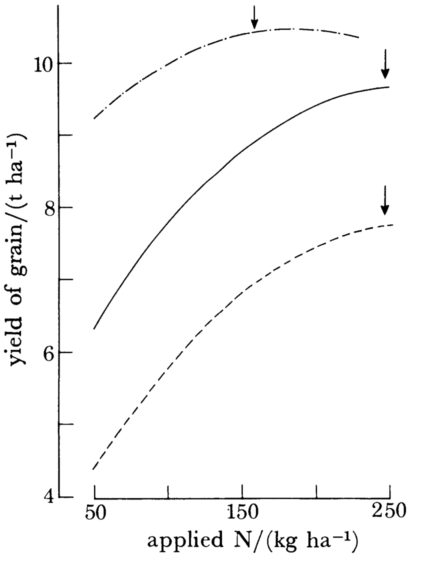

Figure 6. Examples of yield responses of a modern winter wheat variety (Hustler) to the rate of N top-dressing. –·–, Clay loam over London Clay (Berkshire), second wheat after grass ley; ——, clay loam over Boulder Clay (Lincolnshire), second wheat after peas; – – –, shallow loam over Upper Chalk (Berkshire), continuous cereals. The arrows indicate the economic optima at 1980 prices. All results are from 1980 harvest.

to agriculture (table 1) and support 13.5 million cattle and 29.9 million sheep (table 5). M.A.F.F. statistics up to 1976 show that yields of hay from permanent and from temporary grassland have increased steadily from the late 1950s onwards. Allowing for the temporary setback in the severe summer drought years of 1975 and 1976 it is clear that these increases can be fairly closely correlated with the use of progressively higher applications of N fertilizer (figure 5).

Livestock

Table 5 shows the changes in livestock numbers that have occurred over the period 1950–79. All categories have shown considerable increases since 1959; the numbers of cattle and calves have risen by 27 %, sheep and lambs by 47 % and pigs and poultry by 160 and 40 % respectively.

TABLE 6. U.K. PRODUCTION (KILOTONNES)

	1950	1960	1970	1979	percentage increase since 1950
beef	601	801	938	1046	74
veal	29	19	11	6	—
mutton and lamb	147	224	227	232	58
pork	63	422	623	695	1003
offal	101	141	143	152	—
poultry meat	n.a.*	328†	592	753	(130)‡
bacon and ham	195	180	251	212	9
sugar (from sugar beet)	554	779	851	1137	147
	1950–1	1960–1	1970–1	1979	—
Milk/Ml	9588	11115	12370	15364	60 %

* N.a., not available. † Figure for 1961. ‡ Since 1961.
References: Central Statistical Office (1951–1981); *Annual review of agriculture* (1951, 1963, 1972, 1980).

TABLE 7. DAIRYING IN ENGLAND AND WALES

	1951–2	1960–1	1968–9	1979–80 (est.)
milk yield per cow/l	3305	3805	3769	4852
concentrates per cow/t	0.96	1.14	1.23	1.66
stocking rate/(g.l.u./ha^{-1})	1.0†	1.4†	1.56	1.75
fertilizer N/(kg/ha^{-1})				
dairy farms	n.a.	n.a.	108	180
all grassland‡	9	29	65	119

References: Milk Marketing Board (1952–1979); †, Green & Baker (1981) (for all stock on grass); ‡, S. J. Challinor (personal communication 1981).

The numbers of beef cows have risen by about 110 % since 1950 and dairy cows by about 9 %. In terms of the actual products of livestock farming, which are listed in table 6, the output of beef has increased by 74 %, milk by 60 %, and mutton and lamb by 58 %. Of the meat enterprises that are not directly dependent on land, the output of bacon and ham has increased by 9 %, poultry meat (since 1961) by 130 % and pork by a staggering 1003 %.

Milk yields per cow over the period under examination are given in table 7 along with concentrate usage, rates of N fertilizer and estimated stocking rates. Average milk yield per cow has been elevated from about 3300 l in 1951 to 4800 l in 1979. This 45% improvement in individual cow performance can no doubt be attributed not only to the feeding of more concentrates, which have to a large extent replaced fodder crops (such as mangolds, turnips and swedes) and straw and other arable by-products, but also to the contribution made by better cow breeding and selection and the use of more effective veterinary and pharmaceutical products. The use of more N fertilizer on grassland, on the other hand, has been accompanied by increases in the numbers of animals kept per hectare (table 7).

On a quantitative basis, U.K. home production as a percentage of all food consumed has increased from 47.2 in 1968–70 to 56.1 in 1979, and, as a percentage of that part of our food that could be grown here, from 59.7 to 70.9 over the same period.

Relative prices of fertilizer N and agricultural produce

In the 1930s nitrogenous fertilizers were a relatively expensive input to farming. For example the price paid by the farmer for 1 t of N as fertilizer was seven times the money obtained for 1 t of wheat in 1935 (table 8). Since 1950, however, the relative cost to the farmer of 1 kg fertilizer N has fluctuated between 2.0 and 3.3 times the prices obtained for 1 kg of wheat. Since 1971, despite the effects of the oil crisis of 1973, the relative cost of N fertilizer has been reduced even further if account is taken of the increased yield of wheat per hectare that has occurred in recent years.

Table 8. Prices of fertilizer nutrients (£/tonne) in relation to those of wheat, 1935–79

(Adapted from Cooke (1980).)

	N	P_2O_5	K_2O	wheat	ratio of prices N:wheat
1935	34	19	14	5	6.8:1
1950	50	32	23	25	2.0:1
1956	98	79	33	30	3.3:1
1971	101	104	42	31	3.4:1
1975	152	215	98	56	2.7:1
1979	266	234	129	100	2.7:1

Although wheat is taken as the example here, the same argument applies to other agricultural outputs. The cost-effectiveness of using N fertilizer has increased rather than decreased during the last 25 years.

Long-term effects of fertilizers

Most fertilizer experiments give only results on an annual basis, and control (no fertilizer) plots are likely to have received fertilizer dressings in previous years because they have been part of a normal farm crop. For a true picture of the long-term effects of fertilizer, or lack of fertilizer, one can do no better than to look at the results from the famous Broadbalk field at Rothamsted where winter wheat has been grown continuously since 1843 except for occasional years in fallow to control weeds. The grain yields in table 9 are taken from plots that were last fallowed in 1951 and which have grown wheat every year since then (Rothamsted Experimental Station 1952–1979).

These results suggest that, in the presence of effective weed control, the soil's nutrient reserves, supplemented by other natural sources such as rain, dry deposition and biological N fixation, contributed on average from 34 to 43 % of maximum yield. N, P and K fertilizers together contributed 57–66 % of maximum yield and, in the absence of N, P and K fertilizers, together contributed 7–8 %.

Table 9. Rothamsted Broadbalk Field Section 1/1A 1956–79: long-term winter wheat experiment

	plot 3			plot 5			plot 8		
fertilizer applied	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
amount/(kg ha^{-1})	0	0	0	0	80	108	144	80	108
mean grain yields/(t ha^{-1})									
1956–67		1.30			1.52			3.02	
1968–79		1.74			2.13			5.07	

Varieties: Squareheads Master each year from 1956 to 1967; Cappelle Desprez each year from 1968 to 1978; Flanders in 1979.

Hormone weedkillers were introduced in 1957 and mildew control in 1979.

(Results extracted from Rothamsted Annual Yields of Field Experiments.)

Table 10

l.a.i.	respiratory loss (%)	potential grain yield/(t ha^{-1}) winter wheat	spring barley
8	40	11.4	9.8
12	40	12.2	10.5
12	35	12.9	11.1

Table 11

year	number of fields surveyed	mean grain yield / t ha^{-1}	number of fields yielding 10 t ha^{-1} and more
1977	669	6.3	5
1978	1110	7.0	27
1979	1027	6.9	16
1980	899	7.3	41
totals	3705		89
mean		7.0	

Potential yields of cereals

In calculating the potential photosynthetic activity that may occur in eastern England, assuming no lack of temperature, moisture and nutrients, Austin (1978) has estimated that grain yields of winter wheat and spring barley could be up to 12.9 and 11.1 t ha^{-1} respectively. His estimates were based on the assumptions shown in table 10 for maximum leaf area index (l.a.i.) and respiratory loss. Although these are theoretical calculations, yields approaching these levels have occasionally been achieved in practice. Current record field yields in the U.K. are around 12 t ha^{-1} for wheat and 10 t ha^{-1} for barley. Plant breeders are now producing material that is facilitating the attainment of such yields provided that the inputs, especially of nitrogen, pesticides, etc., are at the right level. With the varieties now in use, yields of 10 t ha^{-1} and above are becoming relatively commonplace in field trials and on farmers' fields. It seems highly likely that further improvements can be made in the yielding capacity of wheat and barley. I should not be surprised to see that photosynthetic rates and potential yields may be manipulated to an even greater extent than previously indicated, but the weather and our failure to predict the extent of its variability will limit farmers' ability to achieve abundant crops every year.

The I.C.I. 'Ten Tonne Club', which has been operating for the last 4 years, has confirmed that yields of winter wheat well above the average can be achieved fairly regularly provided that farmers pay sufficient attention to the essential ingredients such as adequate nutrient supply, especially N, judicious use of pesticides and other important aspects of crop husbandry, such as choice of variety, time of sowing and time of applying fertilizer. Table 11 is a brief summary of the results obtained in the I.C.I. 'Ten Tonne Club'.

Table 12. Grass swards: response to N fertilizer

(Data extrapolated from the literature cited.)

	(a) Jealott's Hill, Berkshire, 1963–8						
N/(kg ha^{-1})	0	100	200	300	400	500	600
d.m./(t ha^{-1})	5.2	7.5	9.5	10.9	11.9	12.4	12.5
d.m./(kg kg^{-1} N) (0–300 kg N ha^{-1})				19			
	(b) Henley Manor, Somerset, 1967–9						
d.m./(t ha^{-1})	5.1	8.5	11.2	12.9	13.4	13.8	14.0
d.m./(kg kg^{-1} N) (0–300 kg N ha^{-1})				26			
	(c) Hannah Res. Inst., Ayshire, 1967–9						
d.m./(t ha^{-1})	2.8	6.5	9.8	12.7	13.4	13.7	13.7
d.m./(kg kg^{-1} N) (0–300 kg N ha^{-1})				33			
	(d) Jealott's Hill, 1972–4						
N/(kg ha^{-1})				200			400
(i) *Melle perennial ryegrass*							
d.m./(t ha^{-1})				7.0			12.0
d.m./(kg kg^{-1} N) (200–400 kg N ha^{-1})							25
(ii) *Six other perennial ryegrass cultivars*							
d.m./(t ha^{-1})				7.0			10.0
d.m./(kg kg^{-1} N) (200–400 kg N ha^{-1})							15

d.m., herbage dry matter.

References: *Jealott's Hill guide to field experiments* (1964–9); Armitage & Templeman (1964); Reid (1972); Lee *et al.* (1977).

Austin (1978) has pointed out that attempts to quantify yield increases from the separate factors involved are unlikely to be worth while because the various factors interact with each other. By conducting carefully controlled field trials we can determine the separate effects of inputs such as N, P or K fertilizers and fungicides, and we can also, which is more important, determine their combined effects. The most important requirement in attempts to achieve yields near to the potential yielding capacity of crops is to ensure that nutrient supplies are adequate to satisfy the maximum needs of the crop at all stages of growth. This also requires a knowledge of the amounts of N, P and K removed by the crop, the amounts likely to be available in the soil and the likely proportion of fertilizer N that is likely to be taken up by the crop.

Potential production from grassland

The capacity of grass to respond to heavy dressings of N fertilizer has been known at least since the early 1950s and since then many field trials have been conducted throughout the country to determine the shape of the N response curve under different soil and climatic conditions. A summary of some of these results is given in table 12. The results of these trials show conclusively that, under a cutting régime, grass swards respond to N fertilizer applied at up to 400 or 500 kg N ha^{-1}. Economic optima, which may be less than this, vary with locality and type of stock used. Responses over the range 0–300 kg N ha^{-1} from the examples given are in the region of 19–33 kg dry matter kg^{-1} N. A G.R.I.–A.D.A.S. series of trials, in the most comprehensive experimentation of this type that has ever been carried out in the U.K., was

Table 13. Grass–clover swards: response to N fertilizer

(a) Jealott's Hill, Berkshire, 1950–3								
N/(kg ha^{-1})	0	100	200	300	400	450	500	600
d.m./(t ha^{-1})	7.9	9.3	10.6	11.8	12.5	12.9	—	—
average clover (% total d.m.)	48.9	14	13	12	7			
d.m./(kg kg^{-1} N) (0–300 kg N ha^{-1})				13				
(b) Hannah, Ayrshire, 1957–9								
d.m./(t ha^{-1})	7.0	8.8	10.6	12.4	13.5	14.2	14.2	14.3
average clover (% total d.m.)	20	18	18	18	11			
d.m./(kg kg^{-1} N) (0–300 kg N ha^{-1})				15				

d.m., herbage dry matter. References: Hood (1956); Reid (1972).

designed to determine the response to N fertilizer on pure grass swards on many sites throughout England and Wales (Morrison *et al.* 1980). These trials have demonstrated quite forcibly the magnitude of the yield variation that occurs between and within sites. The principal factors involved were considered to be local rainfall and the moisture-retaining powers of the soil. None the less, over all sites, potentially economic responses were considered to have been obtained from rates ranging from 260–530 kg N ha^{-1}, or 388 kg N ha^{-1} on average.

Other trials have shown that, when a sward contains a great deal of clover, response up to the 300 kg N ha^{-1} level is reduced to between 13 and 15 kg dry matter kg^{-1} N, which is nevertheless above the level of economic return (table 13). In practice, however, clover contents of more than 10% are seldom achieved (Green & Baker 1981), and therefore most fields are likely to produce more than 13 kg dry matter per kilogram fertilizer N applied.

In one experiment that lasted for 3 years at Jealott's Hill (table 12*d*), Melle perennial ryegrass averaged 25 kg dry matter kg^{-1} N between rates of 200 and 400 kg N ha^{-1}, whereas six other cultivars averaged only 15 kg dry matter kg^{-1} N. Although the results of this one trial have not been repeated elsewhere, the indication is that some grasses can probably be selected for greater responsiveness to N fertilizers and for higher yields of dry matter.

Agricultural production in 1979 at 1950 level of inputs

One way of putting a value on the changes that have occurred since 1950 is to consider what the position would have been if British agriculture had not advanced since 1950, i.e. assuming the areas devoted to grassland and to the main agricultural crops to be the same now as they were then, and that all inputs were also at the 1950 level, the amounts of indigenous-type foods shown in table 14 would have to be imported to make up the difference between 1950 and 1979 U.K. production levels.

The amount and value of the extra food that would have to be imported would be completely unacceptable in view of the effect that this would have on our balance of payments, on the livelihood of farmers and land-workers and on the national economy generally. An alternative method of calculating the value to the nation of the changes in agricultural practices, especially fertilizer N use, is to consider how much additional land would have been required to produce 1979 agricultural outputs using 1950 inputs and techniques. The land area required for the arable crops is shown in table 15. These calculations show that the increased agricultural inputs have 'saved' the equivalent of 3.214 Mha of land.

A similar calculation for ruminant livestock products is more difficult because of the influence of supplementary purchased feeds in addition to that of grass and the difficulty in calculating the true value of the two types of feed.

Table 14

	quantity			value/M£
wheat	4.5 Mt	—		374
barley	8.0 Mt	—		452
sugar	0.6 Mt	—		71
milk	—	5806 Ml		668
beef and veal	0.422 Mt	—		555
mutton and lamb	0.855 Mt	—		118
			total	**2238**

Table 15

	wheat	barley	potatoes	sugar beet
1950 production/Mt	2.7	1.7	9.7	5.3
area/Mha	1.003	0.720	0.500	0.174
1979 production/Mt	7.2	9.7	6.6	7.8
area required (at 1950 input levels)/Mha	2.675	4.111	0.340	0.256
actual area/Mha	1.371	2.343	0.240	0.214
extra area/Mha	1.304	1.768	0.100	0.042
total extra area required/Mha		3.214		

Discussion

It is clear from the facts presented above that the increased use of fertilizer that has occurred over the past 30 years could continue since there is ample scope to push current average crop yields nearer to the biological maximum. Whether this will continue to happen is more likely to be influenced by political, economic and environmental arguments about the effects of continued intensification of U.K. agriculture production rather than by any biological limitations.

The arguments for and against the U.K.'s becoming more or less intensive could be outlined as follows. Perhaps if we let other countries produce more of our food this could presumably reduce environmental problems here but would perhaps increase them elsewhere. It would help the economy of developing countries if they exported to us. This seems to be an unlikely development because most of these countries do not have enough food for their own basic needs. The decline of agriculture in the U.K. would release more land for amenity purposes and for afforestation, and the public might have access to more extensive areas than at present. There would presumably be fewer farmers and people working on the land and in the ancillary agricultural industries, agricultural research and in the food processing industries. The prosperity of the country would be reduced, food would be dearer; our balance of payments deficit would be enlarged because the decline in the agricultural industry is unlikely to be replaced by increased industrial production and efficiency. Unemployment would be at an even higher level. A reduction in food production self-sufficiency would make us more dependent on foreign sources of supply and therefore put us in a vulnerable position. This seems an unduly large price to pay for the uncertain achievement of a cleaner and questionably more desirable environment. Wholesale afforestation is not necessarily an appealing type of landscape, as has been found in certain parts of Scotland. In addition, forests replace people and livestock unless they are integrated with farming.

Farming in general is productive and profitable and provides work. Its suppression would leave a void that could not be justified on economic grounds. Any benefits to be derived from such a policy would therefore fall on the countries supplying us with food.

The U.K. could be more self-sufficient if more N fertilizer were used on grassland. Our grassland would need to receive an average of at least 100 kg N ha^{-1} more to allow our farmers to be as efficient and competitive as their Dutch counterparts. As shown in work at Jealott's Hill, the addition of this amount of N fertilizer would have little effect on our environment (Hood 1976).

As has been shown elsewhere in this paper, fertilizers, and in particular N fertilizers, are a substitute for land as they allow higher production per hectare; with grassland this carries with it the capacity for keeping more stock on a given area of land and producing more milk and meat from that land. The reduction in the farm labour force that has occurred in recent years has necessitated an increasing commitment to mechanization. Inflation has elevated the cost of labour and of new machinery and equipment at a faster rate than it has increased the prices currently received for many agricultural products, especially those of livestock origin. Management and investment incomes were generally less in 1979 than in 1978 except on some arable farms growing root crops. Nevertheless, it can be demonstrated that the cost–price squeeze can be counteracted by increasing output. On dairy farms this is less likely to result from an increase in yield per cow, which necessitates the feeding of more concentrates, than from relying more heavily on grass, which is by far the cheapest feed. Extra grass can be produced by using more N fertilizer, enabling stocking rates to be raised and proportionately more grass and grass silage to form the cow's ration.

On arable farms also, the best way to counteract the effects of rising overhead costs is to increase production per hectare by using the best available varieties coupled with the optimum economic N dressing (established from recent trials results) and with appropriate pesticides and growth regulators where required.

Conclusions

A number of factors have contributed towards the steady increase in agricultural productivity that has occurred in the U.K. during the last 30 years. Of these, the increasing use of N fertilizer, which provides probably 30–50 % of crop yields, has played a major role, aided and abetted by such essential inputs as improved crop varieties, and the use of plant protection and veterinary products. This trend of improving productivity is likely to continue because average crop yields and output of livestock products throughout the country are well below biologically achievable potentials. Those who would call a halt to the intensification of British agriculture appear to ignore the significance of such action on total world food supplies. Millions of the

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world's population now and in the foreseeable future will continue to be seriously undernourished, a situation that would be exacerbated if affluent nations were to cut back on agricultural effort and import more from developing regions. In addition, our own farmers would suffer because the only way to counter the effects of the cost–price squeeze is to strive for higher yields in order to reduce cost of production per tonne of output. This can only be done by employing the inputs essential for success, in particular the use of the optimum economic rate of N fertilizer application. The strides made by plant breeders, in particular of winter wheat, in the last decade have been quite spectacular and have made possible the realization of yields towards what is considered to be the theoretical potential. Further improvements still seem likely. With grasses too, some breeding improvements may be expected, but even without such a development the productivity of our grasslands could be improved linearly, at a rate of about 20 kg dry matter kg^{-1} fertilizer N applied, from the present average applications rate of 120 kg N ha^{-1} up to at least 320 kg N ha^{-1}, which would result in a total increase in yield of 4 t dry matter ha^{-1}. This would have the effect of increasing grass yields by anything from 50 to 100 %. The degree to which such intensification will be taken will depend on competition in milk and meat production from other farms and countries. The general level of N application after a period of, say, 20 years will therefore be influenced by the general economic climate, primarily within the E.E.C., rather than by the reaching of any biological barrier.

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