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Waste of Fertilizers

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Waste of fertilizers

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Farmers do not use the available technical information sufficiently well to secure maximum efficiency of the fertilizers they buy. Animal and crop wastes contain most of the N, P and K in British crops and these should be used in recycling more efficiently than at present. The amount of nitrogen involved in soil–crop–livestock cycles appears to be twice as much as is taken up by the crops and grass grown annually, implying that there are large losses from U.K. farms. Much loss by leaching and denitrification of nitrate, and by volatilization of ammonia, is inevitable with present practices.

Much more P is applied to U.K. soils in fertilizers and animal wastes than crops contain. The surplus accumulates in soil and it seems that our farmers could save by purchasing substantially less phosphate than at present. The potassium supplied by fertilizers and animal wastes appears sufficient to maintain productivity. There is no evidence of waste by loss of K from the system.

The efficiency of the plant nutrients involved in U.K. agriculture could be improved by greater care in choosing and using fertilizers, and in handling and applying animal wastes. Further improvement should result from more research on the farming cycles involving plant nutrients and particularly on nitrogen.

Introduction

The fertilizers used in United Kingdom in selected years between 1939 and 1975 are shown in table 1. (Phosphorus and potassium fertilizers are reported as P_2O_5 and K_2O as this is common usage for international and U.K. statistics on fertilizer use; elsewhere in this paper these nutrients are reported as elements (P and K).) The use of all fertilizers was greatly increased during World War II because we needed to produce more food. The use of N and K was roughly trebled and P doubled in the 10 years from 1939 to 1949. In the next 11 years the P used increased slightly to a figure that was maintained until comparatively recently; the K used also increased to roughly 430000 t K_2O, and likewise maintained until recently. The N used more than doubled between 1949 and 1960 and had doubled again by 1971. Increases in use of N continued until checked in 1973 by rapidly increasing prices.

No statistics are yet available for fertilizers used in 1975/6 but it is reasonable to assume that they were roughly as shown in table 2. This table also gives the approximate costs to farmers, using prices quoted for October 1976 (Anon. 1976). The total spent on fertilizers was about one eighth of total farm expenditure listed as 'inputs' in statistics from the Ministry of Agriculture, Fisheries and Food (1976). Of the total, N accounted for half, P for a third and K for an eighth. It is important that this large expenditure should be used to best advantage and without avoidable waste. (Roughly half of farm expenditure is for animal feedstuffs, machinery costs are about equal to fertilizer costs, no other 'input' approaches these figures.)

Direct waste of fertilizers occurs when:

(1) more is applied than the crop needs;

(2) the correct amounts of nutrients are applied but (*a*) at wrong times, or (*b*) in the wrong place and (*c*) in forms not suited to crop and/or soil.

Indirect waste of plant nutrients occurs in several ways:

(1) leaching through the soil (NO_3^-, Ca^{++}, Mg^{++}, SO_4^{--} are lost in drainage water from all soils, K^+ only from sandy soils);

(2) soil erosion (all nutrients are removed in eroded soil);

Table 1. Fertilizers used in the U.K.

years (ending in June)	N kt	P_2O_5 kt	K_2O kt
1939	61	173	76
1949	188	426	199
1960	410	462	434
1970	796	470	438
1973	947	482	435
1975	984	395	397

Table 2. Approximate amounts of fertilizers used in the U.K. in 1975/6 and their total costs

nutrient	amount kt	cost £M
N	1000	160
P_2O_5	400	110
K_2O	400	40

(3) reaction to chemical forms that are useless to crops (in some soils phosphates are precipitated as chemical compounds, or adsorption complexes, which are very slightly soluble in the soil solution);

(4) volatilization (ammonia is lost to the air when ammonium salts are applied to calcareous soils and when organic manures lie on the soil surface (they should be buried); N_2 and nitrogen oxides are released from soil to the air by denitrification processes);

(5) failure to return crop and animal wastes (which all contain plant nutrients) to soil in ways which avoid loss;

(6) failure to make full use of soil reserves of N, P and K and of the N that can be supplied by biological fixation processes.

These causes of waste are not considered in detail but they are the background for the overall assessment of fertilizer and plant nutrient efficiency given in this paper.

Inefficient use of fertilizers by farmers

Farmers tend to use fertilizers inefficiently when they are cheap in relation to other inputs. This was particularly noticeable in the 1960–70 period. Fertilizer prices increased by only about 12 % from 1956 to 1971, while in the same period other costs (e.g. machinery, labour) increased much more. The increasing efficiency of farmers, which resulted in larger yields in this period, was against a background of nearly constant prices for farm products, but of rising costs and an inflating currency. In efforts to maintain profitability many farmers spent much

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time in bargaining for lower prices of fertilizers, effort that would have been much more rewarding if devoted to using the fertilizers bought in ways that secured the maximum return.

Advice on the use of fertilizers for farm crops given by Agricultural Development and Advisory Service (A.D.A.S.) is based on a bulletin issued by the Ministry of Agriculture, Fisheries and Food (1973). These recommendations show how to allow for previous cropping and previous weather, type of soil and the amounts of soluble P and K in particular soils. Surveys of fertilizer practice made by A.D.A.S. and staff of the Fertiliser Manufacturers' Association, and coordinated by Church (1975), record how farmers use the fertilizers they buy. All recent surveys show that most farmers do not use fertilizers as efficiently as they should and many do not obtain, or do not heed, the advice that is readily available from A.D.A.S.

Table 3. Average amounts of fertilizers used on farm crops in England and Wales in 1974

	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
winter wheat	89	45	38
spring barley	73	39	39
potatoes	176	184	246
sugar beet	148	92	182
temporary grass	132	35	29
permanent grass	66	23	15

Table 3 gives the average amounts of fertilizers used on four important arable crops and on grassland in England and Wales. The data are from the 1974 survey reported by Church (1975). Average use on wheat, barley and potatoes is close to *average* recommendations. Sugar beet receives more N and P than is recommended. The K used on sugar beet is also excessive. Much of the K taken up by beet can be replaced by sodium salts which are cheaper; the surveys show that little more than half of our sugar beet crops receive sodium. The average nitrogen dressings used on temporary and permanent grass are no more than a third of the amounts that are now used profitably by skilful farmers.

Many criticisms of the way farmers use fertilizers have been published (e.g., Boyd 1961; Cooke 1964, 1967, 1971*b*), and only some important points are made here. At present farmers apply P and K fertilizers at fairly constant rates for a particular crop; analyses of the survey data suggest that farmers do not allow for differences in the reserves of these nutrients in the soils of their arable land. There is also little evidence that farmers allow for differences in the way that grassland is used. Grass that is cut or grazed five or six times in a year tends to receive the same amounts of P and K as that which is used only two or three times. Similarly no distinction is made on most farms between manuring for grazing or cutting systems. Grazed grassland receives in excreta most of the P and K in the herbage eaten; when grass is cut and removed all plant nutrients are taken from the field and much more fertilizer is needed than in grazing systems. In arable cropping it is important to fit the N fertilizer applied to the local conditions which determine how much N the soil can supply. These conditions are mainly previous cropping and the use of animal manures; in addition the amount of rainfall in the previous winter determines how much of the reserve is lost by leaching. Fifteen years ago Boyd (1961) used results of earlier Surveys of Fertiliser Practice to draw attention to the need to adjust fertilizing to local conditions. He concluded 'large differences in manuring from farm to farm bear little relation to those factors...shown to affect fertilizer response – kind of soil, previous rotation and manuring, use of farmyard manure and nutrient status of soils. Indeed it is difficult to believe that the greater part of the variation in fertilizer practice from farm to farm has any rational basis.' It is regrettable that similar criticisms can still be made. Data from recent surveys show that dressings of N on particular crops vary so little that the adjustments in fertilizer dressings needed to fit them to known variability in supplies of N from the soil cannot have not been adequate.

Table 4. Published prices of common fertilizers

	ammonium nitrate	superphosphate	muriate of potash
	£/t	£/t	£/t
1971	35	19	26
1973	39	23	37
1975	56	58	67
1976	53	51	65

Prices given relate to October of each year.

Effects of price increases

As a result of large increases in prices of the hydrocarbon fuels needed in nitrogen fixation processes, British prices for N are about 50% higher than in 1972. Prices of rock phosphate have also greatly increased and in 1975 prices of phosphate fertilizers were three times greater than in 1971. Similarly potassium fertilizer prices have also increased $2\frac{1}{2}$ times. Price changes for three common products are shown in table 4. Table 1 shows that British farmers reacted to these higher prices by using less P and K and slowing the rate of increase in use of N. Customer reaction is further reflected in the small decrease in prices quoted in autumn 1976 as compared with the year before. We hope that in restricting the amount of fertilizers applied, farmers are using them more logically and taking full account of their farming systems and the reserves in their soils; evidence that they are doing so *may* be provided by the 1976 Survey of Fertiliser Practice which is not yet published.

Plant nutrient cycles in U.K. agriculture

I now intend to examine the relations between plant nutrient inputs to agriculture through fertilizers and feeding-stuffs, the outputs of nutrients in crops, and the balance retained in the soil or lost by leaching or volatilization. This survey is for the whole of the U.K.

Nutrients in crops

Table 5 shows estimates of the amounts of N, P and K in U.K. crops grown in 1973. The data are based on published yields of arable crops, estimates of yield of grassland and average compositions of British crops. The grass grown in any one year contains at least twice as much N, P and K as do arable crops. In considering nutrient cycles, the fate of the crops is important. The nutrients in crops for human consumption are mostly lost to agriculture; a small proportion of the N and P appears in sewage sludge which *may* be used on agricultural land, but much of the N, nearly all of the K and some P, is discharged to rivers in purified sewage effluent. A considerable proportion of the arable crops grown (notably much of the barley), and all the grass, is consumed by stock on farms. Livestock excrete practically all of the K ingested together with most of the P. The amount of N retained varies with type of stock; fattening cattle retain little, dairy cattle return some N in milk.

Animal wastes are the medium for recycling most of the nutrients taken up by our crops. Crop wastes and by-products are important too. About 9 Mt of cereal straw are produced each year, containing 50, 10 and 100 kt of N, P and K respectively. About half is used for bedding and feeding and the nutrients are recycled through farmyard manure (f.y.m.). Of the remainder, most is burned and the N and S are lost to the air, P and K remain in the ash. Sugar beet tops contain about half of all the N, P and K in the crop, some are used as animal feed, but most are ploughed in (but Widdowson (1974) found that the nitrogen beet tops contained had little value for following crops). The value and use of organic manures was discussed fully by Cooke (1975).

Table 5. Nutrients in U.K. crops grown in 1973

	N/kt	P/kt	K/kt
arable crops	460	75	500
grass	1100	170	1000

Table 6. Nutrients in excreta of livestock on U.K. farms in 1973

	N/kt	P/kt	K/kt
cattle	600	150	540
sheep	150	30	120
pigs	30	6	10
poultry	60	12	20
(estimate of total amounts dropped on grassland	500	120	450)

Nutrients in livestock excreta

Table 6 shows estimates of the N, P and K in excreta of U.K. livestock calculated from animal populations and published data for amounts of nutrients excreted annually. Excreta contain twice as much K as is in K-fertilizers bought annually, more P than is bought in fertilizer, and four fifths as much N as fertilizers supply. In a predominantly livestock farming country, as is the U.K., the amounts of nutrients available for recycling through excreta must be taken into account in planning fertilizer policy. This has been emphasized by Smilde (1972) for the even more intensive agriculture of Netherlands where the large amounts of imported concentrated feeds used supply much N, P and K. On average in Netherlands livestock excreta supply as much P as is needed by crops, four fifths of the K and half of the N; on small densely stocked farms surplus manure has to be sold.

All the excreta voided by sheep is dropped on farmland. I assume about two thirds of cattle excreta also falls on land and give in table 6 a rough estimate of the total nutrients that are made available directly for recycling by animals at pasture. The remainder is voided indoors by pigs, poultry and cattle housed in winter; whether it is fully used to recycle nutrients depends on the efficiency of processes on the farm for making f.y.m. and handling of slurry. Nutrients are easily lost from animal manures. When f.y.m. is stored out of doors N is lost by volatilization of ammonia and both N and K are lost by leaching; further losses of N occur after spreading unless the manure is immediately ploughed into the soil. To save transport and handling costs farmers often spread slurries at undesirably large rates on small areas of land near to buildings. These dressings supply more nutrients than crops need; surplus N and K may be lost by leaching and surface run-off; water courses and springs may be polluted by N, P and organic matter. Some poultry droppings are recycled by being used in ruminant feeds, but the quantities are too small to affect nutrient balance calculations for the whole country.

It is difficult to assess the overall efficiency of the recycling of animal manures. Even in ideal conditions some N is lost in making and using f.y.m. Nutrients are lost in handling slurry and there is further effective waste through excessive application. Excretions fall on pasture in discrete patches so that excessive dressings of nutrients are given to small areas with much larger areas between which, in a particular year, receive none. N is volatized as NH_3 from faeces and urine patches; K may be leached from urine dropped on sandy soils. All of the P (and all of the K on medium and heavy-textured soils) is retained, and after a few years grazed grassland will have had dressings which may be regarded as uniform and as returning nearly all the P and K in the grass that was eaten. So it is reasonable to assume that nearly as much P and K as is shown in parentheses in table 6 is retained on our grassland; it is doubtful, however, whether even half of the N plays any part in producing more grass.

When livestock receive extra food that has been purchased, the farm is supplied, through their excreta, with extra N, P and K. With dense stocking the total nutrients available may be more than the system needs; P, and to a lesser extent K, supplies are particularly liable to be excessive. Problems in Netherlands, caused by over-supply of nutrients in excreta and discussed by Smilde (1972), have been referred to above.

The phosphorus cycle

A balance for P in U.K. agriculture is shown in table 7. Imported feeds supply about a quarter as much P as fertilizers do; sewage sludge (with P originating in human food and detergents) supplies a little. The total P supplied annually is more than our crops contain. This situation has occurred in each year since the late 1940s; furthermore, for at least a century the P supplied has been greater than is lost in sales of produce from farms (Cooke 1958). The surplus P has accumulated in our soils, particularly in the arable areas with a long history of using fertilizers. Tradition had it that this 'fixed' P was useless to crops and was therefore wasted. However, research done since 1955 and summarized by Cooke (1971*a*) and by Johnston *et al.* (1970), shows that reserves accumulated in this way are useful to following crops. The residues of P fertilizers which remain in soil are only very slightly soluble in water and are not removed by leaching; their small solubility means that the total stock cannot be used quickly. The effects on crops of the residues from a single small dressing of phosphate can rarely be measured with certainty in a field experiment but the residue from large dressings, or from a succession of small ones, enrich the soil so that larger yields are often obtained than from a soil without residues but receiving a dressing of fresh P (Johnston *et al.* 1970). A series of soils collected from farms involved in Surveys of Fertilizer Practice, and analysed by A.D.A.S., showed that only 15% of arable land was so deficient in soluble P that cereals were likely to respond to fresh P fertilizer. We have less evidence that P has accumulated extensively in our grassland soils. Since less phosphate has been applied in the past to grass than to arable land, residues are likely to be less but small average dressings are applied (table 3); on grazed grassland most of the P in the grass eaten will be returned in excreta.

The situation discussed above suggests that we could use much less P fertilizer on the overall 'national farm'. Land still deficient in P should be detected by soil analysis, and adequate dressings should be applied to these soils; elsewhere no more P is needed than is lost in the farming system. I believe that if these measures were carefully applied we could avoid purchasing a third to a half of the P now used in the U.K.

TABLE 7. PHOSPHORUS BALANCE IN U.K. FARMING, 1973

	P/kt		P/kt
inputs		outputs (in crops)	
fertilizers	210	arable	75
imported feeds	50	grass	170
sewage sludge	20		
totals	280		245

TABLE 8. POTASSIUM BALANCE IN U.K. FARMING, 1973

	K/kt		K/kt
inputs		outputs (in crops)	
fertilizers	350	arable	500
imported feeds	100	grass	1000
totals	450		1500

The potassium cycle

The amount of K supplied annually in fertilizers and feedingstuffs together is less than a third of the quantity taken up by our crops and grass (table 8). The balance (about 1 Mt of K) is annual supplied by reserves from soil plus that recycled in animal and crop wastes. Half of the K in crops reappears in animal excreta (tables 5 and 6); a serious obstacle to recycling this *on a national scale* is that most livestock are in the Midlands, North and West of Britain and the extensive areas of cash cropping (where most K is needed to replace that removed in crops that are sold) are in the East and South.

There is no evidence that considerable areas of our arable land receives too little K to produce the yields desired. Neither is there any evidence that the K supplied as fertilizer is excessive. Any surpluses over current crop needs are retained in medium- and heavy-textured soils and these residues can be used by subsequent crops, just as P residues can be used. Accumulated residues of K raise soil productivity (Johnston *et al.* 1970). Only small amounts of K fertilizers are used on grassland (table 3). There is no satisfactory evidence from field experiments to show whether the amounts used on grazed grass (which benefits from K in excreta) are too little or too much. Surveys of Fertiliser Practice, however, show that cut herbage usually receives *much* less K than the grass removes.

On balance there is no evidence to suggest that serious waste of K-fertilizers is occurring in the U.K., or that the amounts used should be diminished. All crops take up large amounts of K (good crops of wheat (at earing) and potatoes (tubers) contain at least 150 kg K ha^{-1}) and general reductions in the amounts now given might lessen yields. The scientific work done on the K needed by grazed grassland is insufficient to provide a sound basis for using fertilizers on this important part of our farmland.

Nitrogen cycles

It is much more difficult to assess the efficiency of N involved in cropping systems. Lasting reserves of N are only accumulated in soil as a component of organic matter. Inorganic-N is ephemeral in soils. Ammonium-N is held in exchangeable form on soil colloids but is quickly nitrified and the mobile nitrate ion will then be lost by leaching. Ammonia itself is lost from ammonium salts or urea applied to calcareous soils as well as from organic wastes. Nitrate is also lost by denitrification processes which convert it to nitrogen gas or to nitrogen oxides.

TABLE 9. SOURCES OF NITROGEN IN U.K. AGRICULTURE, 1974

	N / Mt	average N contribution of each source / kg ha^{-1}
soil nitrogen	1.4	110
farmyard manure	0.3	25
fertilizers	1.0	70
animal excreta dropped on grassland	0.5	40

In spite of having to assess these diverse routes for loss of N, and the uncertainty of the size of losses to the air, it is important to try to estimate the components of a national nitrogen cycle. In our humid climate the supply of N governs the yields of all non-leguminous crops and we spend about £150 M a year on N-fertilizers. Table 9 shows estimates of the amounts of N derived from various sources; the data are all based on recent field experiments. The total N involved in producing our arable and grass crops is around 3 Mt, roughly twice the amount our crops contain (table 5). Is the N involved in U.K. agriculture only 50% efficient?

Nitrogen for arable crops

Table 10 shows that fertilizers and f.y.m. together supply less N than arable crops contain. A realistic assessment of the N fixed by biological mechanisms and released from soil organic matter is 370000 t annually – as important as the contribution from fertilizers. The average amounts lost annually by leaching from arable land are known roughly from NO_3-N concentrations in drainage water and the volume of drainage. Much of this large loss is inevitable since some nitrate is left in soils after harvest and much larger quantities are mineralized following autumn cultivations. These amounts are at risk since, on most arable land, no crop is present in winter to take them up. The amounts removed in drainage (and, conversely, the residues left to benefit a following crop) depend on the amount of winter drainage which, in turn, depends on the time when soil moisture is recharged in autumn and the winter rainfall that follows. Leaching losses also depend on soil structure – some nitrate is 'protected' when held in the finer pores within stable soil aggregates. In all it seems that our arable farming involves about 800000 t of N to produce crops containing little more than half as much. This figure for 50% efficiency of the N involved in arable cropping is similar to that found in arable field experiments where recoveries of N-fertilizers in harvested crops are measured.

Nitrogen for grassland

Because grass occupies land throughout the year, and can take up nitrate except when soil is very cold, losses of nitrate by leaching are small. Denitrification processes are believed to cause loss, but measurements have not been made in field conditions at enough sites to form reliable estimates of total loss. Much ammonia is lost from excreta. 'Natural' sources of nitrogen are from rain and by symbiotic fixation in swards containing legumes. Non-symbiotic fixation is believed to be important too (evidence from Rothamsted experiments suggests 70–100 kg N ha^{-1} may be added annually to permanent grass containing no legumes).

Table 10. Nitrogen economy of U.K. arable crops, 1974

	N/kt		N/kt
inputs		outputs	
fertilizers	370	in crops	460
f.y.m.	30	lost by leaching	120
totals	400		580
(extra from biological sources	370)		

Table 11. Nitrogen economy of temporary grassland in the U.K., 1974

	N/kt		N/kt		N/kt
nputs		recycled		outputs	
fertilizers	220	f.y.m.	70	in crop	440
natural sources	450	excreta	200	lost by leaching	10
totals	670		270		450
	940 (670 + 270)				

A nitrogen balance sheet for *temporary grassland* is in table 11. Fertilizers supply nearly as much N as appears to be recycled by f.y.m. and excreta. Calculations suggest that 'natural' sources (mineralization from soil, plus fixation) may provide as much as fertilizers and animal wastes together. The total N estimated to be 'available' is more than twice as much as the estimates of that contained in the crop.

Permanent grass occupies 5 million ha, two fifths of our farmland; a balance sheet for the N involved in its growth is in table 12. Half as much fertilizer-N is used per hectare as on temporary grass (table 3); f.y.m. supplies as much N as fertilizers do, and excreta more (though much of this must be lost by volatilization). 'Natural sources' are calculated to provide most N to our permanent grass (clovers are very important on the half of all the fields which receives no fertilizer-N in any one year).

There is less justification for treating our permanent grassland as a whole than there is for calculating national budgets for temporary grassland and for arable land; the latter tend to be fertilized and treated similarly in different regions. Permanent grass varies from intensively stocked and heavily fertilized lowland pastures to upland grass on acid soils where phosphate and lime are the first needs and where N-fertilizers are little used.

Nevertheless the figures in table 12 represent an average of conditions; they suggest that, as with temporary grass, twice as much N may be involved in the cycle as is harvested in grass

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eaten by cattle or cut by machine. Because 'available' N is ephemeral much must be lost. The largest losses are likely to be by volatilization of ammonia from excreta and f.y.m. dropped or spread on the soil surface. As drainage water from grassland normally contains little nitrate, except where stocking is very heavy, we consider little N is lost by leaching. In fertilizer experiments testing N on grassland, recoveries of applied N in the crop range normally from 50 to 85%, with an average recovery of 70–75% – considerably better than recovery by arable crops. Denitrification may, under pasture, be responsible for much of the losses not accounted for by leaching.

Table 12. Nitrogen economy of permanent grassland in the U.K., 1974

	N/kt		N/kt		N/kt
inputs		recycled		outputs	
fertilizers	200	f.y.m.	200	in crop	650
natural sources	540	excreta	300	lost by leaching	25
totals	740		500		675
	1240 (740 + 500)				

It is difficult to see how the N involved in grassland production may be made more efficient until we have the results of more intensive studies of N in the crop–soil system. In the meantime it must be stated that much more N-fertilizer than is applied at present could be used with profit, and advantage to the nation, on most of our grassland.

Conclusions

Any general summary must differentiate between arable and grassland. Much is known about the nutrient status of soils used for arable and ley-farming, fertilizers have been applied regularly for many years, and most arable crops now receive as much or more than is necessary.

Arable land. Better application of existing knowledge would avoid some waste. Fertilizers are very profitable, in spite of their high prices; farmers need to give more attention to technical aspects of using them efficiently, increased profitability will follow automatically. Most tilled land is well supplied with phosphate and on such soils there is no case for applying more than crops remove. It is likely that the amount of P now used could be diminished by 30–50% without loss of crop. Nitrogen fertilizer could be saved by adjusting dressings to farming systems, and to past rainfall, so that full allowance is made for reserves in the soil and for the amounts that crop residues and organic manures supply. Improved timing of dressings would reduce losses by leaching. All crops remove nearly as much K as N. Many of the crops grown for sale are sensitive to K deficiency which may develop quickly on light and medium soils where the produce is removed; therefore there is little scope for a general saving in K-fertilizer. Some economies may be made by better use of crop and animal wastes and by restricting dressings for soils where clay minerals release much K.

Grassland. Every effort should be made to use animal wastes and manures so that the nutrients are evenly spread and losses of N are minimized – they cannot be prevented entirely. More research is needed on the nitrogen cycle in grassland soils, and in grass–legume associations. The objects should be to find management systems which make the most efficient use of

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purchased N and obtain the maximum contribution from N fixed by biological mechanisms. More study is needed on the amounts of P and K fertilizers needed to maintain productivity from grazed grassland and on the rôle of excreta and manures in recirculating these nutrients. It is possible that on heavily stocked grass the amounts of P and K now used are unnecessary. On the other hand, where grass is cut and removed farmers do not supply sufficient fertilizers to replace the nutrients taken from the field. Some upland pastures would certainly benefit from phosphate, particularly where none is now given.

More research is needed on the processes which cause loss of N and on the concentrations of P in soil needed by crops and grass. The main need, however, is for a fuller understanding of nutrient cycles in whole systems involving soils, crops, animals and wastes so that fertilizer use can be matched to the needs of farming systems. This background information is needed to show how to adjust fertilizing to secure the larger potential yields which will become possible through plant breeding and other advances in agricultural science.

An immediate improvement in efficiency could be obtained on many farms by using the advice on fertilizing available from A.D.A.S. Far too many farmers use one compound fertilizer for all their fields growing a particular crop. Often the fertilizer is chosen because of its price or by pressure from a salesman rather than by its suitability to soil and crop. All farmers should obtain advice that takes account of reserves of nutrients in the soil, the potential of the crop to be grown and the climate. Even on one farm, soils in different fields differ greatly in fertility because of differences in soil types and past treatments and fertilizer dressings should be varied accordingly. Nitrogen fertilizers are wasted when applied at times which do not match crop uptake. If applied too early or too late in the season, they are liable to be lost by leaching. The timing of dressings of nitrogen should be determined by the needs of the crop and by weather, and not by convenience in spring cultivations.

References (Cooke)

Anon. 1976 Market activities: fertiliser prices. *Journal of Flour and Animal Feed Milling* **159**, no. 9, September 1976, p. 43. (See issues in previous years.)

Boyd, D. A. 1961 Current fertilizer practice in relation to manurial requirements. *Proc. fertil. Soc.* no. 65.

Church, B. M. 1975 *Survey of fertiliser practice. Fertiliser use on farm crops in England and Wales.* Publication of Ministry of Agriculture, Fisheries and Food No. SS/SAF/14. (Earlier issues in this series should be consulted.)

Cooke, G. W. 1958 The nation's plant food larder. *J. Sc. Fd Agric.* **9**, 761–772.

Cooke, G. W. 1964 Nitrogen fertilizers: their place in food production, the forms which are made and their efficiencies. *Proc. fertil. Soc.* no. 80, 88 pp.

Cooke, G. W. 1967 Advice on using fertilizers, 1861–1967. *Jl R. agric. Soc.* **128**, 107–124.

Cooke, G. W. 1971*a* Value and valuation of fertilizer residues. In *Residual value of applied nutrients*, Ministry of Agriculture, Fisheries and Food Technical Bulletin no. 20, pp. 296–317. London: H.M.S.O.

Cooke, G. W. 1971*b* Fertilisers and Society. *Proc. fertil. Soc.* no. 121.

Cooke, G. W. 1975 *Fertilizing for maximum yield.* 2nd edn. London: Crosby Lockwood Staples.

Johnston, A. E., Warren, R. G., Penny, A., Mattingly, G. E. G. & Chater, M. 1970 *Rep. Rothamsted Exp. Stn for* 1969, part 2, pp. 5–112.

Ministry of Agriculture, Fisheries and Food 1973 *Fertilizer recommendations, agricultural and horticultural crops.* Bulletin 209, 102 pp. London: H.M.S.O.

Ministry of Agriculture, Fisheries and Food 1976 *Annual Review of Agriculture* 1976. Cmnd 6392. London: H.M.S.O.

Smilde, K. W. 1972 The influence of the changing pattern of agriculture on fertilizer use. *Proc. fertil. Soc.* no. 126.

Widdowson, F. V. 1974 Results from experiments measuring the residues of nitrogen fertilizer given for sugar beet, and of ploughed-in sugar beet tops, on the yield of following barley. *J. agric. Sci., Camb.* **83**, 415–421.