THE FERTILISER SOCIETY

THE INFLUENCE OF THE CHANGING PATTERN IN AGRICULTURE ON FERTILISER USE

by

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CONTENTS

INTRODUCTION

I first wish to thank the Council of the Fertiliser Society for the opportunity to give a lecture on the influence of the changing pattern in agriculture on fertiliser use. This is a vast and somewhat speculative subject and, therefore, some restrictions will be made. I am only speaking about agricultural conditions in Western Europe and most data refer to the Netherlands and United Kingdom. In this context I acknowledge the useful discussions with colleagues in these two countries during preparation of this paper.

The first section deals with fertiliser use and efficiency in present farming which has to face increasing costs and diminishing profits. In the second section fertiliser policy in modern cropping systems is discussed. The impacts of increasing crop yields by improved farming practices and of increasing livestock numbers on fertiliser use are briefly reviewed in section three and four rsepectively. The possibilities of recycling nutrients in domestic waste are mentioned in section five.

1. FARMING ECONOMICS AS RELATED TO FERTILISER USE AND EFFICIENCY

1.1. Land

There is a tendency for farms to increase in size and to decrease in number, see Table I (Anonymous, 1971a; CBS/LEI data). However, average size is still 10 ha or less on at least 50% of the farms* in the Netherlands, Western Germany and Italy.

TABLE I. Farm size in various countries of Western Europe (percentages of total number of farms); (CBS/LEI data 1960-70).

	Netherlands		France		W. Germany		Italy		U.K.	
	1960	1970	1960	1970	1960	1970	1960	1970	1960	1970
1– 5 ha	38	26	30	24	47	39	67	65	30	22
5–10 ha	27	24	22	19	25	22	18	19	12	12
10–20 ha	23	32	25	26	19	24	9	10	17	24
20–50 ha	11	17	18	24	8	13	4	4	21	21
>50 ha	1	1	5	7	1	2	2	2	20	21

*Although the farmers remaining will probably have more know*ledge about responses to fertiliser and more capital, it is unlikely that this will promote fertiliser consumption. By contrast, it can be reasoned that smaller farms are operated more intensively, substituting fertiliser for land as it were. This may be profitable with current prices and interest rates (Table II; Anonymous, 1971a), especially with respect to grassland where large responses to nitrogenous fertiliser can still be obtained. This will be discussed later (section 4.1.1.). As capital grows the acreage may be increased.

It is certain, although exact figures are not available, that re-allotment (in the Netherlands 350,000 ha since 1925) and the

*Including small holdings with horticulture.

TABLE II. Price indices for farming in the Netherlands (1966-1968 = 100); ("Stikstofnieuws", March, 1971).

	Wages	Machinery	Feeds	Fertiliser	Interest	Rent
1959/60	47	80	86	98	77	66
1964/65	75	92	93	96	86	83
1968/69	108	103	100	97	103	103

construction of roads to make parcels more accessible, has stimulated fertiliser consumption. In some countries re-allotment might more than compensate losses in farm land resulting from expanding towns and industries or increasing recreational areas. Such losses amounted to 100,000 ha in the Netherlands and 160,000 ha in the U.K. in the past ten years.

1.2. Labour

Diminishing labour is typical for farming in Western Europe, see Table III (CBS/LEI data). Cooke (1970a) mentions a loss of half a million workers in the U.K. in twenty years' time.

TABLE III. Workers in agriculture as a percentage of the total labour force (CBS/LEI data 1960-1970).

	Netherlands	France	W. Germany	Italy	U.K.
1960	11	27	15	30	5
1970	7·7	15·5	10	23·2	2·9

Acute labour shortage leads to increasing investments for machinery and, consequently, to an increasing need for contractor services. The investments per labourer in various German industries and in agriculture (Mengel, 1969) are shown in Table IV.

TABLE IV. Investments per labourer in various industries and in agriculture in W. Germany (in D.M.); (Mengel, 1969).

Electronical	Machinery	Textile	Chemical	Agriculture
17,800	20,300	28,600	55,600	78,000

1.3. Machinery

Machines tend to become bigger and the use of heavy machinery may easily result in soil compaction. Therefore, traffic should be kept at a minimum, especially in the planting season, but also when harvesting. As heavy machines cannot operate on wet (loam) soils good drainage is a prerequisite for modern farming.

1.4. Fertilisers

1.4.1. Amounts used per ha

Production costs diminish and profits increase with increasing crop yields per ha. This is because rent and interest rates are not affected and labour and machinery costs rise less than proportional. In many cases the cheapest way to obtain higher yields is the use of fertiliser (and lime), accounting for only a small portion of total farm expenditure. In the U.K. this is only 8% (Fertil. Statistics, 1970) and in other countries of Western Europe the percentage is probably of the same order.

TABLE V. Fertiliser applications in kg/ha agricultural land (excluding rough grazings); (Fertiliser Statistics, 1969 (1970).

	1955/56			1967/68		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Netherlands	80	48	72	153	47	57
France	13	25	20	39	52	39
W. Germany	33	33	59	69	59	81
Italy	16	26	3	29	29	11
U.K.	23	31	26	61	39	26

Fertiliser consumption has greatly increased especially after the second world war (Cooke, 1968, 1970a), as illustrated in Table V (Fertiliser Statistics, 1969). However, there are striking differences for the various nutrients. From the mid 1950's nitrogen applications doubled to trebled in most countries but increases in phosphorus and potassium were less spectacular. In the U.K. phosphorus and potassium dressings have been roughly stable and in the Netherlands there was even a decrease in recent years. Apparently, in these countries the phosphorus and potassium status of most soils is adequate and (large) responses to these nutrients are not to be expected. On the other hand, there is also an increasing substitution of animal excreta for inorganic fertiliser, especially on grassland, as will be discussed in section 4.3.

1.4.2. Changes in nutrient concentrations

Costs of marketing, shipping, storage and distribution may constitute up to 80% of the price of the fertiliser if low analysis materials, like ammonium sulphate (20% N) or normal superphosphate (18 % P_2O_5), are used (Araten, 1968). Therefore, there is a marked tendency towards the production of high-analysis materials, with the U.S.A. as the leading country. Table VI (Ibach and Mahan, 1968) clearly demonstrates the substitution of high-analysis fertilisers, like urea (46 % N) and anhydrous ammonia (82 % N), for low-analysis materials like ammonium sulphate, ammonium nitrate and sodium nitrate.

TABLE VI. Nitrogen fertilisers used in the U.S.A. (in 1,000 tons N); (Ibach and Mahan, 1968).

	Amm. sulphate	Amm. nitrate	Sodium nitrate	Amm. phosphate	Urea	Anh. ammonia	Aq. ammonia	N solutions
1950	37	187	100	22	8	70	2	5
1960	107	416	73	118	62	581	77	195
1966	163	610	39	327	204	1,607	194	712

A similar tendency is shown for phosphorus fertilisers (Table VII; Ibach and Mahan, 1968), concentrated or triple superphosphate (48 % P_2O_5) taking the place of normal or single superphosphate (18 % P_2O_5).

TABLE VII. Phosphorus fertilisers used in the U.S.A. (in 1,000 tons P_2O_5); (Ibach and Mahan, 1968).

	Normal superphosphate	Conc. superphosphate	Amm. phosphate
1950	335	126	34
1960	103	183	217
1966	93	412	670

In the U.S.A. concentrated superphosphate was exceeded by ammonium phosphates in the last decade, viz. monoammonium phosphate (11-48-0), diammonium phosphate (16-48-0) and ammonium polyphosphate (15-62-0). The latest product, ammonium polyphosphate, contains monoammonium orthophosphate (H_3PO_4), tri-ammonium and tetra-ammonium pyrophosphates ($H_4P_2O_7$) and smaller quantities of higher condensed phosphates ($H_5P_3O_{10}$).

In Western Europe changes in fertiliser types are much less spectacular than in the U.S.A., mainly because of the shorter transport lines (Saalbach, 1970). However, the importance of high analysis materials as ingredients both for solid and liquid compound fertilisers will, no doubt, grow. According to Cooke (1968) there is already a pronounced rise in the concentration of total nutrients in solid compound fertilisers as shown in Table VIII. It is also noteworthy that nitrogen concentrations increase much faster than phosphorus and potassium concentrations.

TABLE VIII. Trends in nutrient concentrations of compound fertilisers (Cooke, 1968).

	% N	% P_2O_5	% K_2O	Total
1952/55	6·7	10·4	10·6	27·7
1959	8·4	10·7	13·3	32·4
1963	11·3	11·1	13·5	35·9
1967	14·7	12·0	13·6	40·3

1.4.3. **Compound versus straight fertilisers**

The use of labour-saving compound or multinutrient fertilisers has greatly increased in recent years, as shown in Table IX (Fertiliser Statistics, 1969; Anonymous, 1971a).

TABLE IX. Proportions of total nutrients applied in compound fertilisers in various countries (Fertiliser Statistics, 1969 (1970)).

	EEC		U.K.		Netherlands	
	1958	1966	1958	1966	1958	1966
N%	14	30	63	60	14	17
P_2O_5% (soluble)	15	50	91	98	26	55
K_2O%	12	56	85	92	8	41

In the U.K. the fast change from straight to compound fertilisers was earlier than in other countries. According to Cooke (1968) in the 1940's already 50% of the nitrogen, phosphorus and potassium was applied in compounds. By contrast, in the Netherlands the consumption of compound nitrogen fertilisers remained low.

There are some limitations in using nitrogen containing compound fertilisers. Autumn application is precluded as most of the nitrogen is lost by leaching. Large single applications just before planting or sowing may easily cause germination damage resulting from excess salt in a dry top-soil. Split applications are often recommended therefore. On intensively used grassland several nitrogen dressings are required whereas phosphorus and potassium are either applied once or not at all.

Compound fertilisers also have an acidifying effect, as opposed to conventional fertilisers like ammonium nitrate limestone, normal superphosphate and potassium chloride, which do not alter the base status of the soil. Sluijsmans (1966) arrived at the following formula expressing the amount of lime (in kg. CaO) needed to neutralize the effect of 100 kg. of a (compound) fertiliser: lime requirement = $-1{\cdot}0 \times CaO - 1{\cdot}4 \times MgO - 0{\cdot}6 \times K_2O - 0{\cdot}9 \times Na_2O + 0{\cdot}4 \times P_2O_5 + 0{\cdot}7 \times SO_3 + 0{\cdot}8 \times Cl + \underline{n} \times N$. CaO, MgO etc. represent the percentages of these ingredients in the fertiliser, the factor $\underline{n}$ for nitrogen equals 0·8 for grassland and 1·0 for arable land. It is evident that compound fertilisers containing little or no calcium, magnesium and sodium have an acidifying effect, especially those with high percentages of nitrogen and phosphorus.

1.4.4. **Liquid fertilisers**

The following (nitrogenous) liquids can be distinguished: high-pressure anhydrous ammonia, low-pressure aqueous ammonia (with addition of ammonium nitrate/urea), no-pressure ammonium nitrate/urea solutions (with addition of phosphorus and potassium materials), nitrogen/phosphorus/potassium suspensions.

Liquids with pressure must be injected into the soil to prevent nitrogen losses and, therefore, require heavy and expensive machinery for application. High application costs and other disadvantages such as soil compaction on arable land and sward damage on intensively used grassland (Van Burg, 1969) may offset the advantages of the low price of these materials. The rapid development of these liquids in the U.S.A. (cf. Table VI) had little impact on sales in Western Europe (with the exception of Denmark), accounting for only 2% of the total nitrogen consumption. High investments in solid fertiliser factories not yet written off also put a brake on liquid fertiliser production.

No-pressure solutions, to which fungicides and herbicides may be added, are easy to handle (by pumping) and to distribute uniformly in the field. Application presents no special problems, but the spraying equipment is subject to corrosion. Exposure to frost during storage should be prevented as the solutions may "salt out", especially those containing phosphorus and potassium in addition to nitrogen. Concentration of total nutrients in nitrogen/phosphorus/potassium solutions is low (less than 30%) because of the low solubility of the potassium chloride component (Hignett, 1968). In suspensions a higher analysis is obtained but handling is more difficult. Addition of clay is necessary to increase viscosity and to prevent settling.

1.4.5. **Micronutrient fertilisers**

Application of micronutrients alone, either by a foliar spray (manganese sulphate) or a soil dressing (borax, copper sulphate, ammonium molybdate, zinc sulphate, iron chelate), is costly if other fertilisers are to be given separately. Moreover, uniform distribution of soil applied materials is difficult as the amounts used are small. Incorporation of inorganic micronutrient sources in macronutrient (compound) fertilisers is hampered by chemical reactions lowering their solubility (Mortvedt and Giordano, 1970). Borax does not react with the components of compound fertiliser. Possible carriers for the trace elements are: ammonium nitrate (copper), ammonium polyphosphate (zinc and iron), monoammonium phosphate (manganese). Several nitrogen solutions also proved promising carriers for several micronutrients. As in Western Europe experience with these materials is scarce preference will be given to conventional (straight) micronutrient fertilisers for the time being.

1.4.6. **Fertiliser efficiency**

For obvious reasons, fertiliser manufacturers are aiming at materials easy in handling, storage and distribution and not subject to leaching losses.

Granulation is common practice now for most compound and straight fertilisers; appropriate granulation processes for water-insoluble materials like lime and basic slag are being developed. Granulated liming materials were found to be less efficient than powders in the year of application, as demonstrated by soil pH and spring barley yield (Sluijsmans and Loman, 1969). However, in the third year following application there was no significant difference between the two forms. The pH on the plots given granulated lime remained constant after the second year and that on the plots with powdered lime decreased because of leaching losses. The effectiveness of granulated basic slag as a source of phosphorus was found to depend on granule size, affecting the distribution pattern, and its ability to disintegrate in water (cf. Van Burg, 1963). It is postulated that granulation of such products will become common practice in the near future, the somewhat lower initial effectiveness being more than counterbalanced by the greater ease in handling.

Bulk handling of fertilisers, saving the costs and disposal of plastic bags, is gaining in interest but some technical problems (caking) remain to be solved.

The method of fertiliser application has been amply discussed in the past (Prummel, 1957). With an increase in fertility level the advantages of placement over broadcasting diminish (Fig. 1), ploughing down the fertiliser to where the soil is mostly moist remains important though (Nelson and Hansen, 1968).

Fertiliser efficiency is also affected by the time of application. Autumn or winter application is not only attractive in reducing labour and traffic in the planting season, but may also favour fertiliser efficiency. Early incorporation into the soil of non-mobile elements like phosphorus is advantageous except on calcareous and phosphate-fixing soils (Prummel, 1962). Application of potassium fertilisers in autumn or winter reduces the risk of salt damage (potassium, chloride), but some loss may occur on sandy soils (Prummel, 1956). Early dressing of nitrogen fertilisers is precluded by the ease of leaching. Separate application in spring involves extra labour which creates a need for high-analysis straight nitrogen fertilisers that can be uniformly distributed (e.g. solutions).

The efficiency of nitrogen fertilisers is low (50% recovery by the plant), losses occurring by leaching (nitrate), denitrification (gaseous nitrogen), volatilization (ammonium) and, temporarily, immobilization in soil organic matter. Ammonium-nitrogen moves

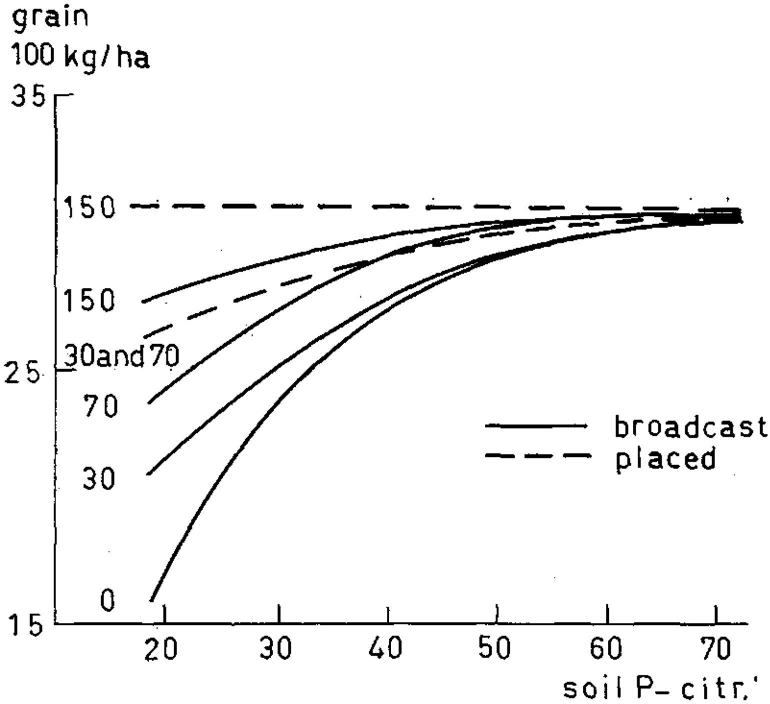

FIG. 1. *Maize yields with placed and broadcast phosphate fertiliser on a sandy soil at different levels of citric acid-soluble soil phosphorus* (*Prummel*, 1957).

little in the soil but is subjected to volatilization on calcareous soils. By nitrification it is converted via nitrite to nitrate which is easily lost both by leaching and denitrification. Chemicals that inhibit nitrification have been developed, "N-Serve" (2-chloro-6-(trichloro) methyl-pyridine) belonging to the more effective ones (Gasser, 1970). However, in experiments with winter wheat autumn-applied ammonium sulphate + "N-Serve" proved less effective than spring-applied dressings. Gasser concludes that more specific inhibitors are required to meet the efficiency needed in practical agriculture.

Partial sterilization of the soil with DD (a mixture of 1, 3 dichloropropene and 1, 2 dichloropropane), a common practice to control nematodes, prevents nitrification of mineralized soil nitrogen (ammonium). The amount of soil ammonium in spring varies according to the time of DD injection in the preceding autumn with an optimum application time around mid October (Kolenbrander, 1969; Fig. 2).

Injection in August or September is less effective because of DD volatilization in a relatively dry and warm soil, the nitrification process being restored some six to eight weeks afterwards. When

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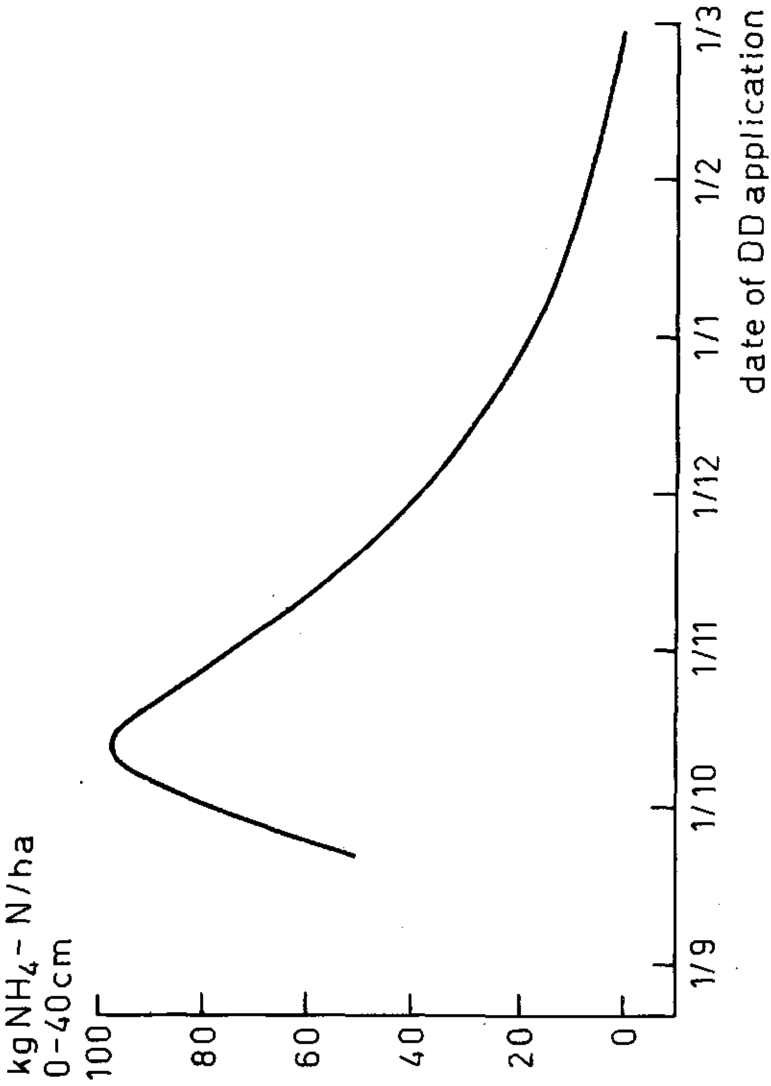

FIG. 2. *Amount of ammonium in a sandy soil on 1 March as dependent on the date of DD-injection in the preceding autumn* (*Kolenbrander*, 1969).

applied late, part of the mineralized nitrogen or added ammonium is already lost by leaching before nitrification is stopped. It is important that in fertiliser recommendations allowance is made for the effect of soil fumigation. On an average, about 30 kg. N/ha can be saved, 10 kg. accounting for the flush after partial sterilization and 20 kg. for the amount of nitrogen prevented from leaching.

In research on the improvement of nitrogen (ammonium) fertiliser efficiency, control of the volatilization process is also aimed at. This is particularly important for urea either used straight or as a high-analysis nitrogen component in compound fertilisers. Actually, ammonium losses following decomposition (hydrolysis) may occur if the material is not worked into the soil. Therefore, on grassland the effectiveness of urea is variable, also depending on temperature and rainfall distribution. Addition of urease inhibitors has only been partly successful as yet (Tomlinson, 1970a). Further research aiming at increased effectiveness of this material is needed.

1.4.7. Slow-release nitrogen fertilisers

With the present fertilisers it is difficult to cover the plant's nitrogen requirements over a long period by one single dressing. High salt concentrations in the soil may easily damage crops at the seedling stage. By contrast, excessive leaching may induce deficiencies. For these reasons, splitting the nitrogen dressings is often practiced now, even though certain leaching losses cannot be avoided. To meet these shortcomings, slow-acting nitrogen fertilisers have been developed which will certainly gain in interest if available at competitive prices. Slow-release of nutrients is being tried to attain chemically, by condensing urea with various aldehydes, or physically, by coating the fertiliser granules (e.g. sulphur-coated urea) or by developing inorganic materials of low solubility (e.g. magnesium ammonium phosphate).

The most common urea condensation products are: ureaform (Church, 1968), crotonylidene diurea (Jung and Detmer, 1968) and isobutylidene diurea (Hamamoto, 1968). The rate of nitrogen supply is characterized by the cold- and hot-water-(in)soluble fractions. Cold-water-soluble fractions (ammonium, nitrate and free or slightly condensed urea) are directly available to the plant as opposed to the higher condensed hot-water-(in)soluble fractions which first have to undergo mineralization (hydrolysis). The latter process is mainly microbiological in nature, except in isobutylidene diurea, and, therefore, temperature and moisture dependent. Details on some products (De Haan, 1970) are shown in Table X.

In pot experiments with perennial ryegrass using ammonium nitrate as a standard, the dry matter yields as presented in Table XI (De Haan, 1970) were obtained.

In the first four to five cuttings the yield level of ammonium nitrate was not attained but in later cuttings it was exceeded. Nitrogen recovery by the crop (nitrogen yield) showed a similar pattern. Total nitrogen uptake as a percentage of the quantity of nitrogen supplied amounted to 83, 30, 43, 54, 70 and 69% for ammonium nitrate, ureaform, crotonylidene diurea, crotonylidene diurea NPK 20-5-10, isobutylidene diurea and isobutylidene diurea NPK 20-5-10 respectively. It was found to be closely related to cold-water-soluble nitrogen. These data support those given by Jung and

TABLE X. Charactertics of some slow-release fertilisers. Nitrogen fractions are expressed as percentages of total-N (De Haan, 1970).

	% total-N	NH_4-N	NO_3-N	Urea-N	CWS-N*	HWS-N†	AI‡
Ureaform	37·0	0·4	0·0	7·0	28·6	56·8	39
Crotonylidene diurea	27·7	0·7	9·0	7·2	40·1	99·6	99
idem in NPK 20-5-10	20·5	11·7	12·2	7·8	54·6	99·5	99
Isobutylidene diurea	29·0	1·0	6·7	9·0	36·9	100·7	101
idem in NPK 20-5-10	19·3	14·0	18·6	6·7	70·0	99·5	98

* CWS = cold-water-soluble N
† HWS = hot-water-soluble N
‡ AI = activity index = $\frac{(100 - \text{CWSN}) - (100 - \text{HWSN})}{(100 - \text{CWSN})} \times 100\%$

Detmer (1968) in that crotonylidene diurea is more effective than ureaform, but less effective than isobutylidene diurea, neither product equalling ammonium nitrate in nitrogen recovery. However, when

TABLE XI. Dry matter yields of perennial ryegrass; for ammonium nitrate in g./pot, for slow-release fertilisers as percentages of the yields with ammonium nitrate (De Haan, 1970).

	Cutting				
	1	3	5	7	1-7
Ammonium nitrate	9·5	13·4	4·7	0·8	45·4
Ureaform	79	21	39	192	43
Crotonylidene diurea	74	34	84	285	60
idem in NPK 20-5-10	89	52	99	288	74
Isobutylidene diurea	87	84	129	218	92
idem in NPK 20-5-10	90	80	105	170	86

subject to leaching (irrigation) these authors found crotonylidene diurea to be far superior to ammonium nitrate. The same can be said with respect to plant tolerance when applied at excessive rates.

In general, without denying the interesting qualities of the urea condensation products, their pattern of nitrogen release remains difficult to predict. As these products cost three to five times more than conventional fertilisers their use is restricted to high-value (container-grown) ornamental plants, public turfgrass areas and private lawns. Moreover, the present state of research does not justify application in agriculture (Kilmer and Webb, 1968; Saalbach, 1970). In our opinion the coated nitrogen fertilisers are more promising for universal use, but the extra charge should not be more than 30-50% of the price of conventional types. Preliminary results by Dilz (unpublished) showed that on grassland nitrogen recovery was generally higher and re-growth after cutting quicker with coated (single dressing) than with conventional fertilisers (split application). In arable crops the pattern of nitrogen release can be controlled by the thickness of the coating. A nitrogen supply covering a long growing period (potato) could be obtained by one single dressing and late nitrogen application (cereals) would be unnecessary.

2. CROPPING SYSTEMS AND FERTILISER POLICY

2.1. Crop rotation

To keep the farmer's investments within reasonable limits, the present tendency to simplify the cropping system is likely to continue (Mengel, 1970). The farmer will specialize in crops adapted to his soil and climatic conditions and requiring little or no manual labour. The need to rotate crops is now being disputed as control of weeds and soil-borne diseases and maintenance of soil fertility and soil structure can be achieved by other means. Actually, narrow rotations or monocultures of cereals are being practised already, e.g. maize in the U.S.A., wheat-maize in France, barley in the U.K. Some permanent pastures with only one or two species of grasses in the Netherlands also belong to this category.

Some reports in literature, discussed by Kupers (1970), suggest that cereals in monoculture, if grown at high nitrogen levels or after soil fumigation, may have almost the same yield potentialities as cereals in rotation with other crops.

This was verified by this author in field experiments with winter wheat, either grown in monoculture or in rotation with spring barley or sugar beet (or potatoes). Additional nitrogen dressings were given to plots supporting winter wheat after winter wheat or winter wheat after spring barley, as continuous cereal cultivation increases the need for these nutrients. Treatment with chlorocholine chloride was included to prevent losses by lodging. Some results are presented in Table XII.

TABLE XII. Yields of winter wheat (kg./ha) grown in monoculture or in a rotation with spring barley or sugar beet (potatoes) since 1966. Additional N dressings at ear appearance (After Kupers, 1970).

	1969		1970	
	without CCC	with CCC	without CCC	with CCC
W. wheat monoculture (70 + 40 kg. N/ha)	4847	5288	4818	4989
W. wheat/s. barley (70 + 20 kg. N/ha)	4876	5635	4817	4880
W. wheat/sugar beet (70 kg. N/ha)	4424	5800	4935	5675

2.2. Cropping system and soil nutrient status

For nutrients like phosphorus which are strongly retained by the soil, the frequency of application becomes less important, particularly so with higher soil fertility levels (Cooke, 1968, 1970b; Nelson and Hansen, 1968). In the Netherlands, best financial results are mostly obtained when applying extra phosphate fertiliser to the more responsive root crops and none to cereals. Besides saving labour, this practice reduces the risks of yield losses from phosphorus deficiency in high-value crops. For potassium the picture is rather

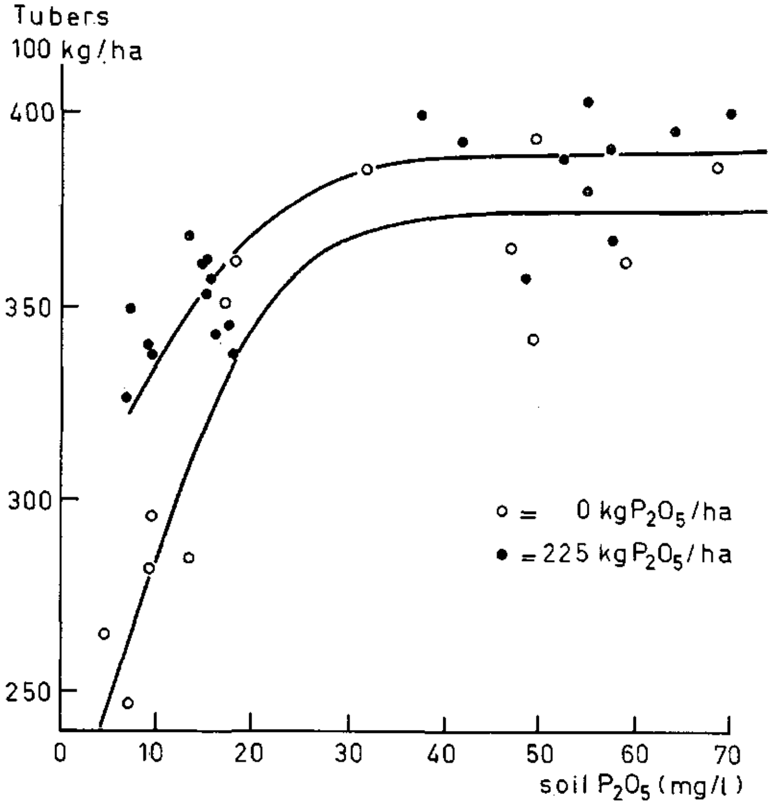

FIG. 3. *Potato yields as depending on water-soluble soil phosphorus (extraction ratio (v/v) 1 : 60, temperature 20°C.) and phosphate dressing on a marine loam soil* (*Prummel,* 1964*a*).

similar, except on sandy soils where leaching prevents building up reserves.

Soils rich in plant-available phosphorus and potassium often produce larger yields of responsive (root) crops than poorer soils given large fertiliser dressings (Cooke, 1968; Nelson and Hansen, 1968). This is also shown by Prummel (1964a, b, 1965), see Figs. 3 and 4.

Prummel (1969) also found K-content of potato tubers on marine loam soils to be more affected by soil potassium status than by fresh potash dressings (Table XIII).

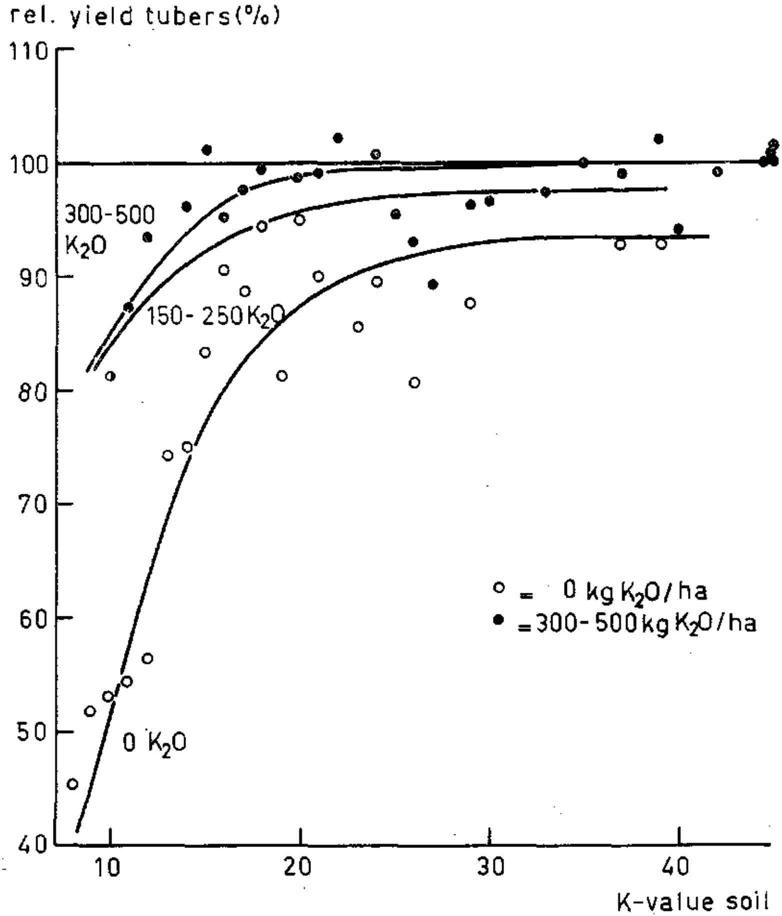

FIG. 4. *Relative yields of potato tubers as depending on soil potassium (K-HCl fraction, corrected for clay content) and potash dressings on marine loam soils (Prummel, 1964b).*

TABLE XIII. Influence of soil potassium status and potash fertilisers on K content of potato tubers (%) on a marine loam soil (Prummel, 1969).

	Soil K-status*					
	10	15	20	25	30	35
0 kg. K_2O/ha	1·10	1·49	1·77	2·03	2·24	2·41
150 kg. K_2O/ha	1·35	1·66	1·91	2·10	2·29	2·42
300 kg. K_2O/ha	1·49	1·77	1·99	2·21	2·40	2·53
500 kg. K_2O/ha	1·66	1·86	2·08	2·27	2·43	2·57

* K-HCl fraction corrected for clay %.

A high K-content (>2·3% K in dry matter) favourably influences tuber cooking quality in reducing its sensitivity to black discolouration (Vertregt, 1968).

In general, aiming at a high soil phosphorus and potassium status is profitable in rotations with a high proportion of root crops. However, on soils where these elements are easily fixed or leached (potassium in sandy soils) this practice is too costly.

To avoid depletion it is important to know how soil reserves are affected by cropping system and fertiliser policy. Table XIV shows the phosphorus balance sheet for cropping systems typical of major arable crop areas on loam soils in the Netherlands.

TABLE XIV. Phosphorus balance sheet for various cropping systems on loam soils in the Netherlands.

% Cereals	40	70	65
% Potatoes	25	10	15
% Sugar beet	25	7	15
% Other crops	10	13	5
Removed by crops annually (kg. P_2O_5/ha)	65	55	60
Added annually	75	55	60
Balance (kg. P_2O_5/ha)	+10	0	0

The calculation is based on current fertiliser recommendations for loam soils classified "sufficient", viz. 40, 120, 100 and 60 kg. P_2O_5/ha for cereals, potatoes, sugar beet and "others", respectively. The amounts of phosphorus removed by these crops are assessed at 50, 60, 100 and 50 kg. P_2O_5/ha, respectively.

The amounts of phosphate added and removed balance. On soils with a lower phosphorus status higher fertiliser dressings will be applied, resulting in a surplus. Conversely, soils with a higher phosphorus status will normally receive less fertiliser and the resulting deficit will diminish the soil reserve.

Analogous calculations can be made for potassium. Current fertiliser recommendations for soils of "adequate" potassium supply are 20, 230, 80 and 120 kg. K_2O/ha for cereals, potatoes, sugar beet and "others" respectively. The amounts of potassium removed by these crops are estimated at 90, 250, 300 and 80 kg. K_2O/ha, respectively. The balance sheet for potassium is shown in Table XV.

The amounts of potash added and removed do not balance. To avoid depletion of the soil potassium reserves, fertiliser dressings

TABLE XV. Potassium balance sheet for various cropping systems in the Netherlands.

% Cereals	40	70	65
% Potatoes	25	10	15
% Sugar beet	25	7	15
% Other crops	10	13	5
Removed by crops annually (kg. K_2O/ha)	180	120	145
Added annually	100	60	65
Balance (kg. K_2O/ha)	−80	−60	−80

should be higher than needed for "direct-action". In the rotation the additional potassium is preferably applied to potatoes or to other tolerant crops, but not to sugar beets as juice purity may be adversely affected.

When applying the above results, a simple fertiliser policy for the cropping system rather than for individual crops can be developed.

3. IMPACT OF INCREASING CROP YIELDS ON FERTILISER USE

There is a general trend for yields to increase as shown in Fig. 5 (Fertiliser Statistics, 1969). Even so, the national averages presented here are still far below potential yields. In long-term experiments at Rothamsted yields of 6,900 and 6,200 kg./ha were obtained for wheat and barley respectively (Boyd, 1968). Seventeen-year averages for maximum yields of winter wheat, potatoes and sugar beet at the experimental farm "Lovinkhoeve" of the Institute for Soil Fertility in the Netherlands are 5,800, 51,500 and 68,500 kg./ha, respectively. The yield increases are made possible by new varieties, improved farming practices, such as disease and weed control, irrigation, better soil drainage and tillage, and an increasing fertiliser use (mainly nitrogen, cf. Table V). These factors are inter-related, higher yielding varieties and improved farming practices often making fertilisers more profitable, and conversely.

3.1. New varieties

The example of hybrid maize, produced by crossing inbred lines, shows that yielding potential can be highly increased as a result of better genetic material.

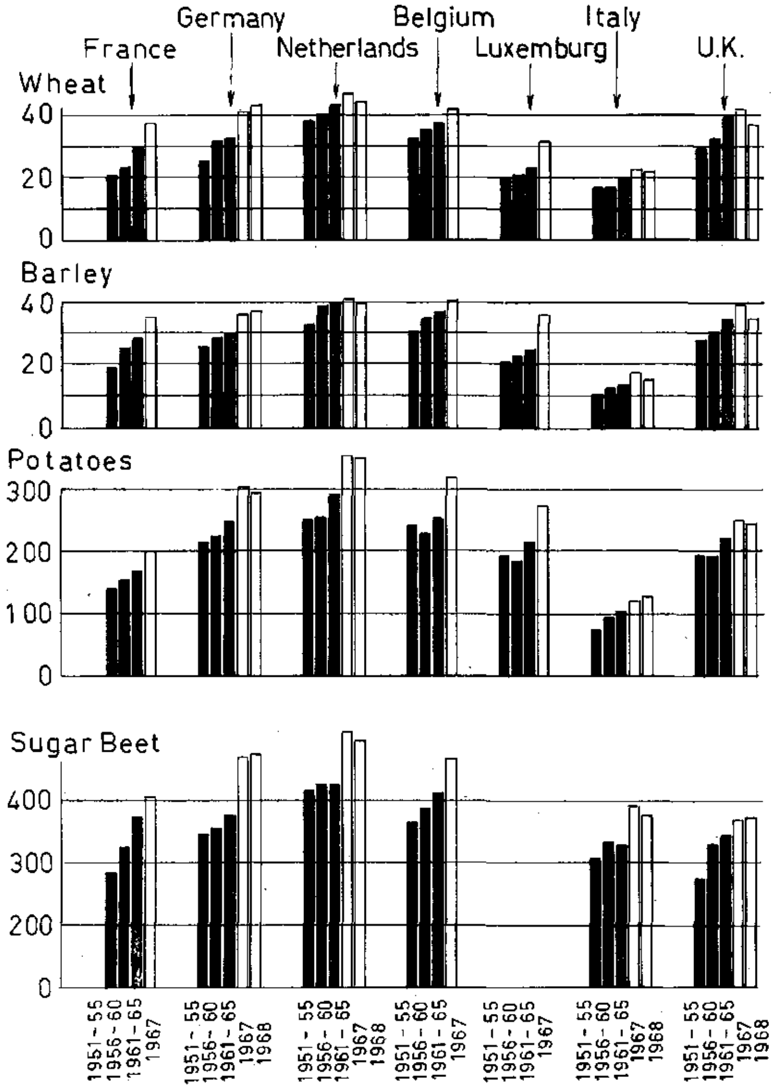

FIG. 5. *Average yields of arable crops in* 100 *kg./ha, trends* 1951-1967 (*Fertiliser Statistics,* 1969).

Many of these improved varieties are profitable only at high fertility levels (Hildreth and Williams, 1968). Economic production of hybrid wheat seed, facilitated by the discovery of cytoplasmic male sterility, is imminent now in the U.S.A. (Olson and Koehler) 1968).

In various (sub)tropical countries introduction of Mexican dwarf wheat resistant to lodging has raised yield potentialities enormously as compared with the local tall varieties (Swaminathan, 1968). However, for optimum utilization of these new types improved farming practices and fertilisers are essential, see Table XVI (Anonymous, 1966).

TABLE XVI. Wheat yields with and without improved farming practices (CIMMYT News, **1**(3), 1966).

Variety	Yield
Pakistan variety without improved farming practices	1250 kg./ha
Mexi Pak 65 without improved farming practices	1500 kg./ha
Mexi Pak 65 with improved farming practices	8000 kg./ha

Another striking example is the new rice variety IR 8 which yields more than the existing taller varieties only when given ample nitrogen fertiliser (Chandler, 1969).

As shown above, reduced susceptibility to lodging enables higher nitrogen fertiliser dressings with accompanying increases in yield. European wheats may also be improved by incorporation of dwarf characters and breeding programmes to this end are in progress now (Zeven, 1969). Another approach toward lodging resistance is application of growth regulators. In the Netherlands, an additional application of 40 kg. N/ha (basic dressing 80 kg. N/ha) with chlorocholine chloride sprayed at stage 5 (crop length 20-25 cm.) increased winter wheat grain yield by 450-1,100 kg./ha (Dilz, 1966). The results of one experimental field severely infected by eyespot (*Cercosporella herpotrichoides*) are presented in Table XVII. Chlorocholine chloride, in reducing the susceptibility to lodging, largely eliminated the damage caused by this soil-borne fungus.

3.2. Disease control

Diseases present another limitation to nitrogen response in crops. Examples are potato blight (*Phytophthora infestans*) causing premature decline of the foliage, and various diseases in cereals. The incidence of mildew (*Erysiphe graminis*), rust (*Puccinia graminis*) and glume blotch (*Septoria nodosum*) tends to become more serious in recent years. As shown by Dilz (1970), sprays with fungicides such as Calixin (against mildew) and Maneb (against diseases in ripening grains) were effective in improving nitrogen utilization and increasing yield of spring wheat. There was found to be a strong positive interaction between fungicides and chlorocholine chloride, either effect

TABLE XVII. Winter wheat yields (kg./ha) as influenced by nitrogen fertiliser and chlorocholine chloride (CCC) on a field infected by eye spot (Dilz, 1966).

	Without CCC		With CCC	
	Yield	Lodging index*	Yield	Lodging index*
0 kg. N/ha	2300	10·0	2160	10·0
40 kg. N/ha	3520	5·7	3760	10·0
80 kg. N/ha	4310	3·0	4720	9·7
120 kg. N/ha	4200	3·0	5180	9·3
160 kg. N/ha	3810	2·3	4850	7·7

* 10 = upright, 1 = flat.

being 150-200, but the combined effect 850 kg. of grain/ha (Fig. 6).

It is not certain as yet whether the overall effect should be attributed to disease control or to growth regulation. Kupers (1970) reports partial control of soil-borne fungus diseases in rye by frequent sprays with systemic fungicides (Benomyl).

Although disease control met with some success, for the time being it will remain a major limiting factor in fully utilizing yield potentialities of current and new grain varieties.

3.3. **Irrigation**

In arid regions where a shortage of soil moisture is the main factor limiting crop yield, using fertiliser is often unprofitable (Hildreth and Williams, 1968).

Irrigation, in increasing crop yield, creates a need for (higher) fertiliser dressings, especially nitrogen. In an experiment in Indiana (U.S.A.) the amounts of nitrogen required for maximum maize yield were 170, 225 and 280 kg. N/ha with 10, 19 and 24 cm. of water supplied respectively (Barber and Olson, 1968).

Interactions between irrigation and fertiliser effects have also been demonstrated in more humid climates. In a field experiment with potatoes in Western Germany (Pehl and Sturm, 1965) the effects of nitrogen and phosphorus/potassium dressings proved largest with applied water. Conversely, irrigation proved more effective at the higher nitrogen and phosphorus/potassium rates (Table XVIII). Similar effects were found in sugar beet.

Williams (1970), in irrigation experiments at Hurley, found grass to benefit from applied water in eight out of ten years, extra water increasing yields by 40-50%. However, there was no positive interaction between the effects of nitrogen and irrigation, except in years with long dry periods. He advises small amounts of water on grassland during dry periods to enable nutrient uptake from the top-soil.

The interest in irrigation of root crops and grass is likely to grow provided new devices make the equipment easier to handle and thus reduce labour. This may lead to an increase in fertiliser (mainly nitrogen) use.

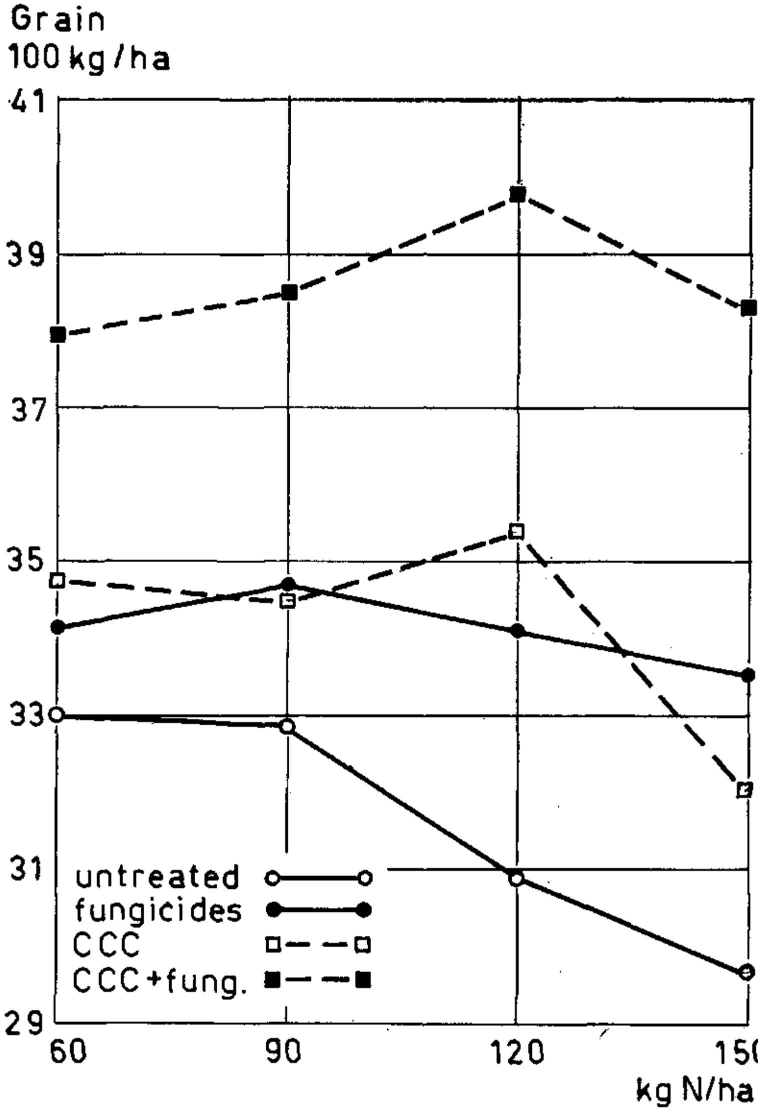

FIG. 6. *Grain yields of spring wheat (July) as affected by nitrogen fertiliser and treatment with CCC and fungicides (Dilz,* 1970).

3.4. Tillage practices

Urged by diminishing labour on farms there is now considerable argument on the merits of soil tillage. The reasons for ploughing and cultivating seem less obvious as their main objectives can be attained by other means. Most weeds are being effectively controlled by

TABLE XVIII. Effects of irrigation and fertilisers on potato yields (in 100 kg./ha), six-year averages (Pehl and Sturm, 1965).

	0 kg. N/ha	50 kg. N/ha	100 kg. N/ha
		Without irrigation	
Without P K	177	219	253
P_1K_1	182	230	259
P_1K_2	177	227	255
		With irrigation	
Without P K	261	335	377
P_1K_1	287	391	429
P_1K_2	297	393	426

chemicals. Crop residues from harvested crops and from "second" (cover) crops, now considered useful in protecting the soil from run-off and wind erosion, are killed with appropriate herbicides prior to sowing the new crop (by "direct-drilling"). Ploughing (heavy) soils to improve soil structure may increase rather than decrease soil compaction when carried out under adverse weather conditions (Cooke, 1970a; Kuipers, 1970).

Systems of direct drilling or minimum tillage, at this stage mainly experimental (Baeumer, 1970), are likely to become increasingly important. This may have some impact on nitrogen fertiliser consumption as there are indications that direct-drilled crops require more nitrogen than conventionally sown crops (Barber and Olson, 1968; Kupers and Ellen, 1970) especially so if accompanied by a higher yield (Bakermans and De Wit, 1970).

3.5. Quality aspects

It is beyond the scope of this paper to discuss the effects of nutrition on crop quality in detail. However one example, the effect of nitrogen on the baking quality of wheat, is worth mentioning. Most (soft) wheats produced in Western Europe do not meet the quality required for bread making and must, therefore, be blended with high percentages of imported (hard) wheats. In recent years considerable progress has been made in breeding wheats with a better baking quality (Cooke, 1970a; Mengel, 1969). Indigenous wheats can be improved by late nitrogen dressings increasing the protein content of grain and flour (Arnold, Meppelink and Dilz, 1971). An extra 50 kg. N/ha (basic dressing 100 kg. N/ha) given at stage 8 (appearance of flag leaf) raised grain protein from 11·4 to 12·7%, bread volume from 500 to 550 ml./100 g. flour when optimum amounts of flour ameliorants added, and sedimentation value from 21 to 26 (Table XIX). Similar results are reported by Mengel (1969).

Although the cost of the late nitrogen dressing is often more than repaid by the increase in grain yield, it is regrettable that payment by baking quality, which would certainly widen the prospects for wheat production, is not put into practice yet. For the

TABLE XIX. Effect of a late nitrogen dressing (50 kg. N/ha) at appearance of last leaf on baking quality of Manella winter wheat; basic dressing 100 kg. N/ha. (Arnold, Meppelink and Dilz, 1971).

	Without late N dressing	With late N dressing
Protein content grain (%)	11·4	12·7
Protein content flour (%)	10·3	11·5
Sedimentation value	21	26
Bread volume (in ml./100 g. flour) without ameliorants	427	435
potassium bromate added	512	554
ascorbic acid added	500	546

time being the increase in grain is the more important aspect of late nitrogen dressings.

Nitrogen requirements of malting barley are totally different. It was shown by Sluijsmans, Boskma and Wilten (1966/67) that dressings exceeding 60-70 kg. N/ha and late nitrogen applications which increase grain protein and decrease fermentable fractions, affected quality adversely.

4. IMPACT OF INCREASING LIVESTOCK NUMBERS ON FERTILISER CONSUMPTION

There have been large increases in livestock numbers in this century. In the U.K. cattle increased by 40% and sheep by 20% in the past thirty years (Cooke, 1970a, b) and trends are similar in other countries (Table XX, CBS/LEI data). Particularly the rise in the number of pigs is spectacular.

TABLE XX. Livestock numbers in various countries of Western Europe (millions) (CBS/LEI data 1960-1970).

	Netherlands		France		W. Germany		Italy		U.K.	
	1960	1969	1960	1969	1960	1969	1960	1969	1960	1969
Total cattle and calves (excluding sheep)	3·5	4·3	19·4	21·9	12·9	14·3	9·3	10·0	11·8	12·4
Pigs	3·0	6·2	8·5	11·7	15·8	21·2	4·1	9·2	5·7	8·1
Poultry	—	50	—	—	—	—	—	—	—	126

It is pertinent to distinguish between grazing stock (ruminants) and housed stock (non-ruminants). Production of beef, veal, mutton, lamb and dairy products depends on the area of grassland available and its utilization, and also on imported or home-produced concentrated (protein) feeds and roughages. By contrast, the produce of "bio-industry" (pork, ham, poultry, meat, eggs) are grassland-independent, although land may be needed for the disposal of animal excreta.

4.1. **Grassland productivity**

Grassland acreage (Table XXI, CBS/LEI data; Cooke, 1970a) did not keep pace with numbers of grass-fed cattle. To sustain the increasing stock numbers grassland efficiency had to be improved.

TABLE XXI. Area of agricultural land (excluding rough grazings) and percentage of grassland in various countries of Western Europe (CBS/LEI data 1960-1970; Cooke, 1970a).

	Netherlands		France		W. Germany		Italy		U.K.	
	1960	1969	1960	1969	1960	1969	1960	1969	1960	1969
Area of agric. land (million ha)	2·31	2·23	34·20	33·52	14·14	13·87	20·78	21·37	12·40	12·24
Permanent grassland (%)	55	58	38	42	40	41	24	26	43	40

4.1.1. **Fertilisers**

Nitrogen yield potential of the traditional clover-grass swards (6-8 tons of dry matter/ha) in Britain is only about half that of all-grass swards given sufficient nitrogen fertiliser (Cooke, 1970a). In experiments all-grass swards responded linearly up to about 400 kg. N/ha applied in a year. There is certainly scope for further expansion of nitrogen fertiliser use on grassland in the U.K. before the targets of 250 and 350 kg. N/ha for grazing and cutting respectively, that is more than three times the present dressings (Cooke, 1968), are reached. Experiments in the Netherlands (Oostendorp, 1964) demonstrated that there are limits to nitrogen dressings set by soil type and grassland use. On a fluvial clay maximum dry matter yields and optimum nitrogen dressings were about the same, for grazing and cutting. However, on a peaty soil the grazed plots yielded less and showed a lower nitrogen response (Figs. 7 and 8).

Heavy dressings of nitrogen, in decreasing the density of the sod, make it more susceptible to trampling. This effect is more important on peaty soils, especially those with impeded drainage, than on loam and clay soils.

After the winter period, when forage tends to become scarce, early grass growth is essential. Therefore, nitrogen should be applied as soon as the sward starts growing. According to Jagtenberg (1970) this is when accumulated temperatures after 1 January attain a value of 200°C. Van Burg (1968) found that the greatest gain in time in reaching the grazing stage of the sward (1·5 tons of dry matter/ha) was obtained with *heavy* nitrogen dressings applied early. Later application, though diminishing leaching hazards, made heavy dressings less profitable (Fig. 9). The silage stage of the sward (3 tons of dry matter/ha) was found to be less delayed than the grazing stage with late nitrogen application.

Further nitrogen dressings should be adjusted to season and grassland use. As the growth rate of grass is higher in spring and early summer than in late summer, nitrogen is best utilized early in the season. The minimum amounts, based on an optimum nitrate

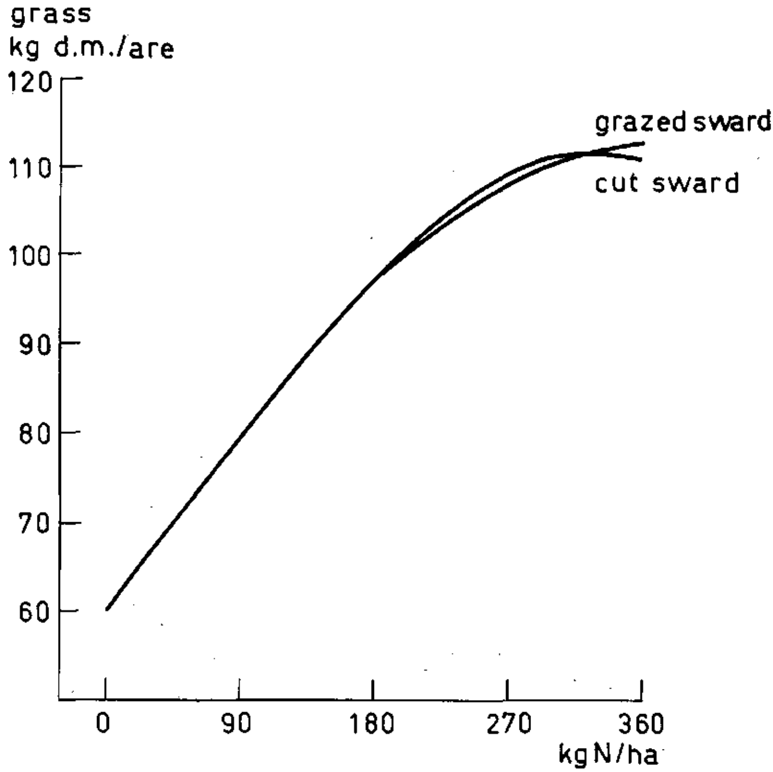

FIG. 7. *Annual grass yields at different nitrogen dressings on a fluvial clay soil* (*Oostendorp*, 1964).

content of 0·62% in dry matter, are 90 and 60 kg. N/ha for grazed swards and 125 and 80 kg. N/ha for cut swards (silage, hay,) in early and late summer respectively (Van Burg, 1965). If the sward is cut only once and grazed three times, as is customary in the Netherlands, this means a total of about 300 kg. N/ha in the year.

Phosphorus and potassium. As distinct from nitrogen, the use of phosphate and potash fertiliser on grassland is not likely to increase much and may even decrease in some countries. On grazed swards, most of the phosphorus and potassium in the herbage eaten is returned with the faeces although some allowance should be made for the patchy distribution. On cut swards these nutrients are removed and should, normally, be replaced. Purchase of concentrated feeds in intensive farming with large stocking rates further precludes the use of phosphate and potash fertiliser. In the Netherlands, for example, dressings of inorganic phosphate and potash

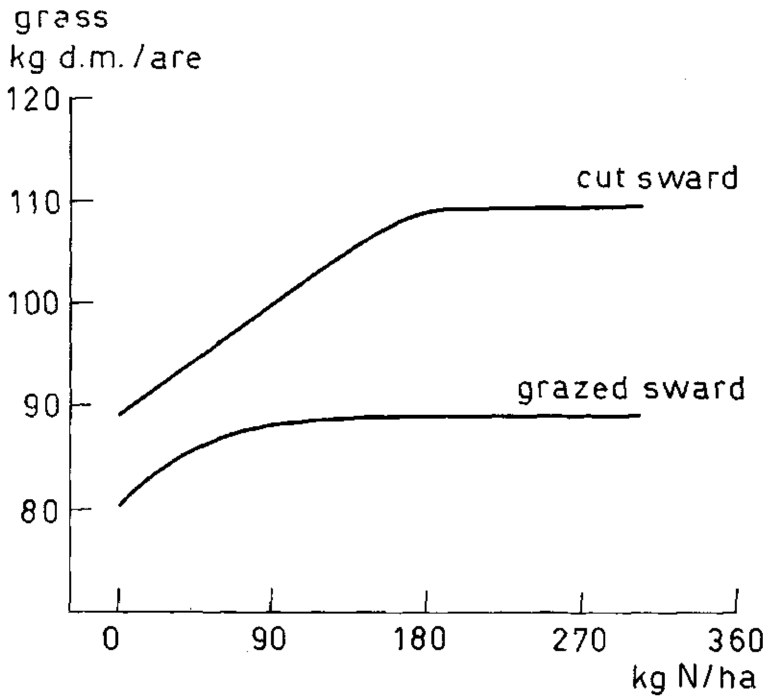

FIG. 8. *Annual grass yields at different nitrogen dressings on a peat soil* (*Oostendorp*, 1964).

fertiliser have to be disencouraged altogether in fairly large grassland areas.

Mineral composition. With the nitrogen rates recommended for maximum yields the nitrate concentration in herbage is not likely to reach levels associated with nitrate poisoning in cattle (Van Burg, 1965; Minderhoud, 1970).

Heavy nitrogen dressings in the presence of much potash predispose dairy cattle to hypomagnesaemia which may result in grass tetany. The resorption of dietary magnesium by the animal is reduced by both a high crude protein and a high potassium concentration of the herbage. According to Kemp (1960) blood serum magnesium is a function of herbage magnesium and herbage crude protein × potassium. The higher the product of crude protein × potassium the more magnesium herbage should comprise for obtaining an adequate magnesium level in blood serum (Fig. 10).

To safeguard a sufficient supply of magnesium to grazing dairy cattle, often oral supply (feeding cakes or top-dressing (dusting) the sward with magnesium oxide) has to be resorted to, as magnesium fertiliser may not be effective in raising herbage magnesium (Minder-

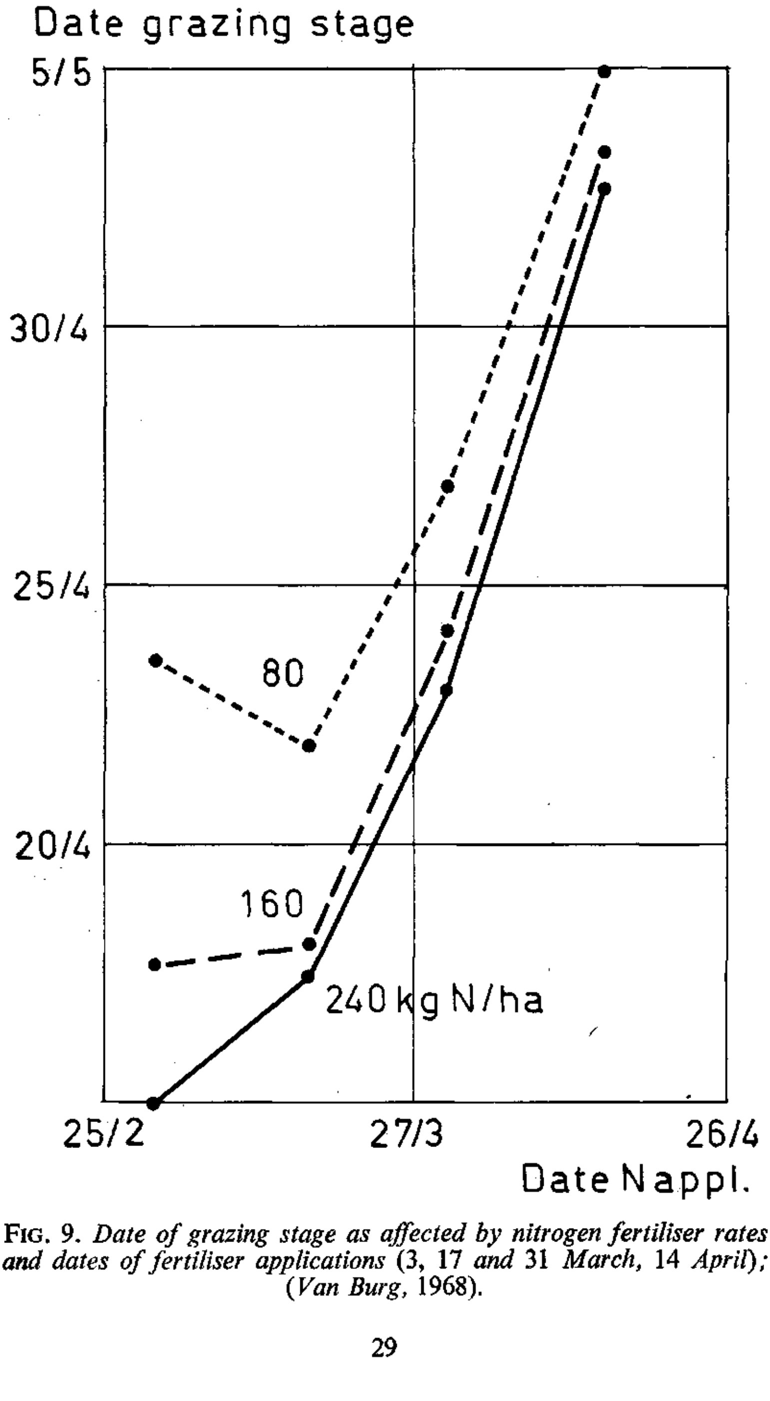

Fig. 9. *Date of grazing stage as affected by nitrogen fertiliser rates and dates of fertiliser applications* (3, 17 *and* 31 *March,* 14 *April*); (*Van Burg,* 1968).

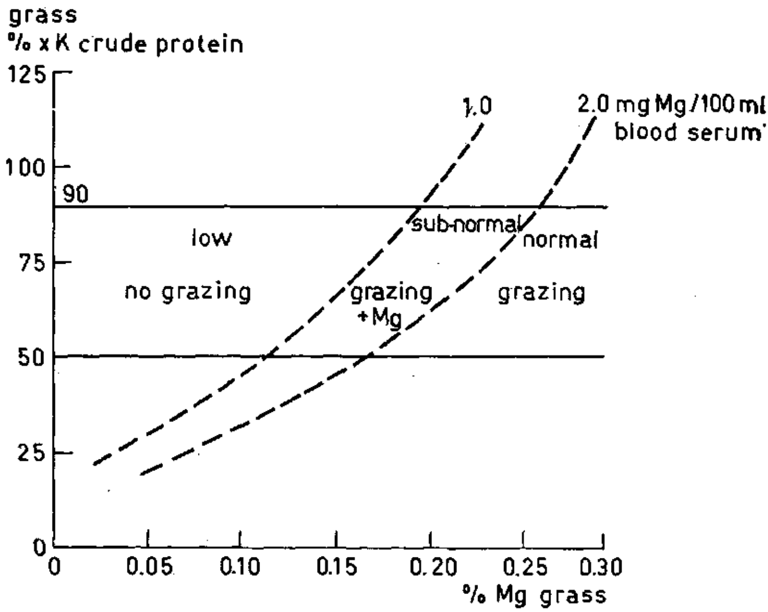

FIG. 10. *Safety limits for grazed swards indicating grass Mg.% needed at a given value for % K × crude protein to obtain (sub)normal serum Mg. levels (Kemp,* 1960).

houd, 1970), However, whatever the possibilities of magnesium supply may be, a sound fertiliser policy, keeping the potassium status of the grassland at a "safe" level, should receive priority.

4.1.2. Improved methods of handling livestock and herbage

As pointed out above, grazing involves wasting the herbage that is trodden or soiled by faeces. Therefore, in future grazing is likely to diminish as the herbage will be harvested and fed to housed cattle (Cooke, 1970a). To feed a cow herd, stored feeding may require only about half the acreage needed for conventional strip-grazing (Hildreth and Williams, 1968).

Better methods of conserving feed are clearly needed as conventional silage and hay making involves nutritive losses of 20 to 50% (Mengel, 1969). These losses are largely prevented by artificially drying young grass whose quality equals that of concentrated feed (Mengel, 1969). Other methods comprise drying hay in barns and using sealed silos (Raymond, 1968).

4.2. Rough and concentrated feeds

In intensive farming herbage alone cannot be relied on to feed large stocking rates. Mixed holdings may be self-supporting as far as rougbages (silage maize, fodder beets, cereals etc.) are concerned, but concentrated protein feeds, mainly imported, have to be bought. Production of high-protein grass by better conservation methods may lessen the need to import protein feeds, but large-scale substitution seems unlikely. With current prices replacing imported maize and sorghum by home-grown wheat and barley is not attractive. Prospects for maize growing depend on breeding early maturing high-yielding varieties. This seems to meet with some success as demonstrated by the increasing maize acreage in countries like Germany and the Netherlands. Alternative protein sources for ruminants may be found, e.g. urea which is metabolized to protein by the rumen flora (Cooke, 1970a).

4.3. Disposal of animal excreta

In most countries in Europe and in the U.S.A. disposal of animal wastes is a cause of growing concern, particularly in densely populated areas. Surpluses of animal manure occur where farmers try to raise the financial returns from a limited acreage by increasing the numbers of grazing and housed stock and purchasing concentrated feeds. In extreme cases this results in the pig and poultry "farm" without land.

TABLE XXII. Consumption of concentrated feeds in the Netherlands (million kg.); (De la Lande Cremer, 1971).

	1951/52	1960/61	1968/69
Home-produced	1600	2300	2000
Imported	750	3500	5900

Data for the Netherlands (Table XXII) show that there is a vast increase in consumption of concentrated feeds (mainly imported), housed stock accounting for three quarters of the total (De la Lande Cremer, 1971).

On the basis of present figures for imports and assuming a return of 70 to 90% via the faeces (De la Lande Cremer, 1970), it can be calculated that imported feeds alone supply 70,000 tons of P_2O_5 and 50,000 tons of K_2O, or 33 kg. of P_2O_5 and 24 kg. of K_2O per ha of agricultural land, annually. Estimates of total nutrients in animal excreta (De la Lande Cremer, 1971), nutrients supplied in fertilisers and average nutrient requirements are shown in Table XXIII.

To calculate average nutrient requirements the following nitrogen rates were used: 80, 150, 130 and 270 kg. N/ha for cereals, potatoes, sugar beet and grassland respectively. For phosphorus and potassium the average recommendations for soils classified "sufficient" were used: 40, 100, 80, 45 kg. P_2O_5/ha and 70, 225, 160, 120 kg. K_2O/ha for cereals, potatoes, sugar beet and grassland respectively. The data presented indicate that if the phosphorus and potassium contained in livestock manure were distributed uniformly on the total acreage of agricultural land, no phosphate and little potash fertiliser would be needed. Nitrogen fertiliser use would still be high, particularly so as the organic source of nitrogen is less effective. Trends in the U.K. are rather similar, but less extreme as yet (Cooke, 1969).

TABLE XXIII. Estimates of total nutrients in animal excreta, nutrients supplied in fertiliser and average nutrient requirements per ha of agricultural land in the Netherlands (1970 data) (De la Lande Cremer, 1971).

	N	P_2O_5	K_2O
Amounts in all livestock excreta (million kg.)	234	118	225
Idem in kg./ha	106	54	102
Amounts in fertiliser in kg./ha	177	49	55
Average requirements in kg./ha*	220	50	125

*Arable land (cropping system 50% cereals, 25% potatoes, 25% sugar beets) = 1/3 of total acreage. Grassland (cut once, grazed 3 times) = 2/3 of total acreage.

A farmer should return livestock wastes to his own land for recycling whenever possible. Even then, handling difficulties may lead to uneven distribution, the nearby meadows receiving more than those further away (Minderhoud, 1970). With the data of Table XXIV (De la Lande Cremer, 1971) the carrying capacity of grassland for livestock can be calculated, see Table XXV.

Apparently, the carrying capacity of grassland is limited by the phosphorus contained in the excreta. However, the effects of excess phosphate on animal health are still largely unknown. When

TABLE XXIV. Estimates of excreta production and nutrients in excreta of grazing and housed stock (De la Lande Cremer, 1971).

	Production (ton)	Available N (kg.)	P_2O_5 (kg.)	K_2O (kg.)
Dairy and beef cattle (excluding sheep) per unit per housed period (slurry)	10	25	18	50(18)‡
One pig per housed period (slurry)*	0·52	2	2·1	2·1
100 laying hens per year (droppings)	4·0	30	70	35
100 broilers per housed period†	0·08	1·3	2·0	1·4

* 40% of annual production.
† 20% of annual production.
‡ urine excluded

TABLE XXV. Carrying capacity (numbers of animals) per ha grassland per year based on average nutrient requirements of 270 kg. N, 45 kg. P_2O_5, 120 kg. K_2O/ha supplied in the excreta (slurry for cattle and pigs, droppings for poultry).

	N	P_2O_5	K_2O
Dairy and beef cattle (excluding sheep)	10	2·5	2·4(6·7)*
Pigs per housed period	54	8	22
Laying hens	900	65	340
Broilers per housed period	4,150	450	1,700

* urine excluded

doubling the stocking rates, the tolerance level for potash is not exceeded and the herbage can still be considered "safe" from the grass tetany point of view. (This is not true for cattle slurry unless the urine is disposed of otherwise.) The carrying capacity of arable land for livestock can be calculated similarly. An example is given for potatoes (Table XXVI) using average nutrient requirements. The carrying capacity of land cropped with cereals is only half as large. Crop tolerance to animal wastes is mainly limited by the amount of nitrogen supplied, possible overdoses of phosphate and potash have to be accepted, but are less harmful generally.

TABLE XXVI. Carrying capacity (numbers of animals) for 1 ha of potatoes per year based on average nutrient requirements of 150 kg./N, 100 kg. P_2O_5, 225 kg. K_2O/ha supplied in the excreta.

	N	P_2O_5	K_2O
Dairy and beef cattle (excluding sheep)	6	5·5	4·5(12·5)*
Pigs per housed period	30	19	42
Laying hens	500	140	640
Broilers per housed period	2,300	1,000	3,200

* urine excluded

Surpluses of livestock manure that cannot be used on the farm should be sold or disposed of otherwise. It is evident that livestock manure cannot compete with the relatively cheap high-analysis inorganic fertilisers that are easy to handle. Even when farmers or growers are encouraged to use animal wastes, e.g. by supply and delivery free of charge, uniform distribution over the total acreage of agricultural land is unlikely to be ever attained. Other means of disposal like treatment in lagoons or sewerage plants, drying, incineration, sanitary landfilling, are very costly (De la Lande Cremer, 1970), or contribute to pollution and eutrophication. Some types of dried manure can be used in the recreation sector and as a feed for non-ruminants.

The problem of imminent surpluses of phosphate and potash contained in livestock wastes might be solved to some extent by replacing imported by home-grown concentrated feeds and encouraging the use of livestock wastes for recycling (decreasing the consumption of inorganic phosphate and potash fertiliser accordingly).

5. DOMESTIC WASTE

It is interesting to compare the supply of nutrients in livestock waste with that in household refuse (cf. Cooke, 1969). Estimates for the Netherlands (population 13 million) are shown in Table XXVII.

TABLE XXVII. Estimates of nutrients in livestock waste and domestic waste (million kg.) in the Netherlands.

	N	P_2O_5	K_2O
Livestock waste (see Table XXIII)	234	118	225
Solid domestic waste*	26	22·5	10
Fermented domestic waste (40% of total)	10·4	9·0	4·0
Digested sewage sludge (25% dry matter)†	1·0	1·0	0·1
Sewage effluent (to water courses)	52	36	30

* 0·52% total N, 0·45% acid-soluble P_2O_5, 0·20% water-soluble K_2O (Meded. VAM, 1971).
† (0·77% total N, 0·60% acid-soluble P_2O_5, 0·08% water-soluble K_2O (Riem Vis, 1970, 1971).

Solid domestic waste production is estimated at 5 million tons (380 kg. per person). It is assumed that 40% of the total is fermentable and could be used for recycling. However, present production of fermented household refuse amounts to only 10% of the potential. Estimates for primary undigested sewage sludge (5% dry matter) and digested sewage sludge (25% dry matter) are 195,000 and 116,000 cubic metres respectively (Verhaagen, 1967). About 90% of the nitrogen and phosphorus in domestic sewage (faeces, waste water, detergents) reaches the water courses. Actually, only one third of the household sewage is purified biologically, 70% of the nitrogen and phosphorus remaining in the effluent (Bayley, 1970; Kolenbrander, 1971).

The amounts of nutrients available for recycling in fermented household refuse and sewage sludge are negligible compared to those in livestock waste. The problems in handling and marketing these materials are much the same. It is unlikely that fermented household refuse and sewage sludge will ever be used to some extent in other than recreational sectors unless supplied and spread free of charge (Geering and Künzli, 1967; Geering, 1968).

Vast amounts of nitrogen and phosphorus now entering water courses would be available for recycling if the domestic sewage were treated chemically to remove these nutrients. However, the cost involved in reducing eutrophication are considerable and algae and weed problems might not substantially lessen (Downing, 1970).

Because of the growing public concern on pollution of water courses which might result in banning fertilisers or livestock manure, it is useful to compare the contributions of rural and urban areas to eutrophication. Data for the Netherlands have been collected by Kolenbrander (1971), see Table XXVIII.

TABLE XXVIII. Annual contribution of rural and urban areas to eutrophication of water courses in the Netherlands (kg./ha agricultural land) (Kolenbrander 1971).

	Rural (0·5 persons/ha)		Urban (5·5 pesons/ha)	
	N	P_2O_5	N	P_2O_5
Via the soil	32	0·6	—	—
Human faeces	—	—	21·2	5·8
Domestic waste water and detergents	0·1	1·0	0·8	9·4
Total	32·1	1·6	22·0	15·2

The average losses from the soil by leaching, erosion and run-off are estimated at 32 kg. N/ha (20% from inorganic fertiliser, 15% from organic manure, 65% from mineralized organic matter) and only 0·6 kg. P_2O_5/ha. Leaching of phosphorus is prevented by fixation and, therefore, losses are not directly related to the amounts applied to the soil. Domestic sewage accounts for 40% of the nitrogen and 90% of the phosphorus entering water courses. In the U.K. Tomlinson (1970b) arrived at similar conclusions.

Despite the nitrogen discharges to streams resulting from agricultural practices, there is no clear evidence (Kolenbrander, 1970) that the increase in nitrogen fertiliser consumption in the Netherlands in the 1920-1967 period (from 12 to 150 kg. N/ha) is directly related to the rise in nitrate content of water sources during this period (from 4 to 6·5 ppm NO_3). It is suggested that denitrification also occurs at greater depths during infiltration of the drain water.

It can be concluded that there is no reason to blame phosphorus fertilisers for eutrophication and nitrogen fertilisers contribute only to some extent. Proper timing of nitrogen dressings, for example no application of slurry during the wet winter period, should be encouraged to reduce the amounts entering water courses.

6. SUMMARY

Fertiliser use and efficiency are discussed in the light of diminishing labour and decreasing net profits typical of modern farming. Often the use of fertilisers (and lime) is the cheapest way to increase yield and, consequently, to reduce production cost. From the mid 1950's nitrogen dressings doubled to trebled in most Western European countries, but trends for phosphorus and potassium were less spectacular. Fertiliser manufacturers are aiming at materials easy in handling, storage and distribution, and not subject to leaching losses. There is a marked tendency towards the production of high-analysis materials either used straight or as ingredients for compound fertilisers. No-pressure fertiliser solutions will become increasingly important. More efficient nitrogen fertilisers, that cover the plant's requirements over a long period by one single dressing, will gain in interest if available at competitive prices.

Fertiliser policy in modern cropping systems is discussed.

The effects of increasing crop yields (by new varieties, disease control, irrigation), changing tillage practices, and quality aspects on fertiliser use are outlined.

Increasing grazing stock rates will promote nitrogen fertiliser use on grassland. By contrast, the use of phosphorus and potassium fertiliser is not likely to increase (much) further as the nutrients in the herbage eaten are recycled via the faeces. Purchase of (imported) concentrated feeds further precludes the use of inorganic fertiliser. Particularly the increasing numbers of housed stock create surpluses of excreta rich in these nutrients. Future trends in the overall phosphate and potash fertiliser consumption will mainly depend on the possibilities to use animal and, to a lesser extent, domestic wastes for recycling.

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PROCEEDINGS

CHAIRMAN, THE PRESIDENT: DR. MULCKHUYSE

THE PRESIDENT: Ladies and Gentlemen, may I open your second meeting of this year. I welcome you here, and am pleased that I can do it in a well lighted room. I especially welcome our Dutch guest speaker of today, Dr. Smilde. This afternoon Dr. Smilde will try to give a reply to a question which has far-reaching consequences for all aspects of our industry; where are we going with the use of fertilisers in Western Europe in the coming years, under the pressure of rising labour costs, increasing re-cycling of nutrients and high pressure of public opinion on matters of environmental pollution? I think the picture which emerges from his lecture is not altogether very reassuring for the fertiliser manufacturer. A lot of reorientation and adaptive thinking will be necessary, but this makes Dr. Smilde's lecture the more interesting.

Dr. Smilde graduated at Wageningen State Agricultural University in 1957, and was appointed research assistant in tropical crop husbandry at that university. In 1960 he was appointed research officer at the West African Institute for Oil Palm Research in Nigeria, and in 1964 he became senior research officer at the Institute for Soil Fertility in the Netherlands. Since 1967 he has been head of the division for fertilisation of arable crops and grassland at the same Institute.

I understand that we are in a "high risk" area and that there may be a power cut at about 3 o'clock, so I now invite Dr. Smilde to proceed with his lecture as soon as possible.

(*Dr. K. W. SMILDE presented his paper*).

THE PRESIDENT: Thank you very much, Dr. Smilde, and particularly for adapting yourself so easily to these romantic candle-lit conditions.

To make the "Dutchifying" of this afternoon complete, I will now give the Chair to my countryman and Council member, Dr. van Burg. Dr. van Burg was the sponsor of this lecture, and in view of his thorough acquaintance with the subject he is in a much better position to lead the discussion.

(*Dr. VAN BURG takes the Chair*).

THE CHAIRMAN: We have had a most interesting paper from Dr. Smilde. It is a pity he was not able to show all his slides, but I think he has adapted himself wonderfully to these conditions.

I will now ask Mr. Devine to open the discussion.

MR. DEVINE: Dr. Smilde introduced his subject this afternoon by commenting on its vastness and the need for restrictions. Nevertheless, he has covered a considerable area of diverse topics, which he obviously chose from the many he could have chosen as being of the greatest significance and importance. I am sure you will agree with me that he has presented these with conciseness and clarity.

The main message which I extract from the presentation is the continuing and perhaps growing urgency for farmers to utilise systems of management which will reduce labour demand and increase profitability—considerations which are very relevant to British agriculture just now and will be in the future.

Fertiliser practice can play an important role in this, assisted, I think, by the fertiliser industry. Dr. Smilde has pointed out the marked increase in fertiliser concentration in the last two decades. Currently much attention has been directed towards improved systems of fertiliser handling.

Table IV of Dr. Smilde's paper, which gives investments per labourer in various industries, is most illuminating in that it shows how very capital intensive agriculture is. In the extreme it is four and a half times that of the electronics industry. I presume that much of this is due to the inflated land values which we enjoy, or otherwise, depending on one's point of view. I think it might be interesting to know if agriculture is, in fact, at the top of the league, or whether some of the other related industries such as forestry and fishing come near in this respect.

In conjunction with his Table I, Dr. Smilde discussed the effects of re-allotment resulting in the amalgamation of farms into larger units. I understand there is another type of re-allotment in progress in parts of France and Germany, where the farms often consist of numerous small fields scattered over a wide area, and here the aim is to reduce the number of plots per farm and thereby ease the transport problems between the farm buildings and the land itself. I wonder if Dr. Smilde would care to comment on the effect of this type of re-allotment, always assuming it is successful, on fertiliser use?

It seems to me that the situation regarding the effect of irrigation on the optimum fertiliser requirement of crops has not been wholly clarified. At Levington we obtained a positive interaction between irrigation and nitrogen in 1970, when we applied nine inches total irrigation, but the previous year, when irrigation was not required until later in the season and the total required was only four inches, we had no interaction. I think this is in line with the Hurley experience which Dr. Smilde quoted: that only when there is a long dry spell is there likely to be a positive interaction. In practice, I would suggest that this means the farmer uses the same rate of nitrogen whether he has irrigation or not. Without irrigation, he depends on the weather for the degree of efficiency or effectiveness of his nitrogen, whereas with irrigation he can always ensure a greater efficiency. If my interpretation has any substance, it seems to me that the increase in the use of irrigation will have very little effect on the increase in nitrogen requirement. I wonder if the West German experiments, in fact, suggest something different. I should certainly be very glad to have your comments, Dr. Smilde.

Regarding slow-release fertilisers, there is no doubt that a fertiliser which gradually and continuously releases its nitrogen sounds very desirable, but I must say that I am not sure in my own mind just how important are the advantages of slow-release nitrogen in agriculture. I stress the word "agriculture," because horticulture and more expensive crops are in a different category. But if nitrogen is applied according to the best practice we do get a high utilisation, certainly compared with other nutrients. Ammonium has in itself some excellent slow-release properties. Certainly in the United Kingdom, except for winter-sown crops, very little advantage, if any, has been obtained from late top dressings of nitrogen. Perhaps the most obvious place for slow-release nitrogen is on grassland where repeated dressings throughout the season are appropriate at present, but this means a loss of flexibility. In fact you do say, Dr. Smilde, "Fertiliser nitrogen should be adjusted to seasonal grassland use." Once upon a time we did have a fertiliser which farmers used widely which had slow-release properties, and this was called FYM. Then we felt that we were not getting responses quickly enough, so we introduced inorganic nitrogen to get a quick response. Now we seem to be wanting a change once more, or perhaps there is more to it than that. I am not passing judgement on slow-acting fertilisers, I am asking for information, and I would be glad—as you promised during your talk this afternoon, Dr. Smilde—if you would elaborate a little on the positive advantages which you see from slow-release nitrogen in agriculture.

Dr. Smilde suggested that grazing in the field will be replaced by indoor feeding. This practice is sometimes called zero grazing, and it is a practice which has not had very great popularity in this country although it has had many advocates. I would suggest that, in spite of what was said about the wastage of herbage by treading and soiling, with proper management grazing can be very efficient, and it does avoid heavy capital expenditure and also a slurry disposal problem. Perhaps a major use of zero grazing, in this country at any rate, might be in the predominantly arable farm where grass is introduced perhaps as a break from cereals, or to improve soil structure. It would be very interesting to have your views on this, Dr. Smilde.

There is very little doubt that one of the major problems of the intensive stock farmer today, and probably increasingly in the future, is disposal of animal excreta. It may be that the cheapest and best way to overcome this problem in the long run is to ensure that livestock production is sufficiently dispersed so that all intensive livestock units have adequate land for disposal of excreta. There are already restrictions of this type in Sweden, where a farmer must show that he has adequate land before he can expand livestock output. Similar requirements are included in the suggested code of practice prepared by the Department of Agriculture in Canada. If we adopt such a requirement in this country, it will undoubtedly have some influence on fertiliser practice.

As I said at the beginning, Dr. Smilde's paper is full of interest, and there are many points which I should like to take up with him, but I know that there are others here today who have the same enthusiasm to question Dr. Smilde so I shall take no further advantage of my privilege.

DR. K. W. SMILDE: Thank you very much for your questions. There were certainly enough to keep us going for some time.

First, you wanted to have some more information about the effect of re-allotment on fertiliser use. The term "re-allotment" is probably not a correct English term, I do not know, but what I mean by that is what you stated, to combine small parcels which are spread about everywhere into bigger units. Unfortunately, I could not find enough exact figures on this, but I am convinced that improved accessibility of land has promoted fertiliser use. In Holland, since 1925 350,000 hectares have been re-allotted, or roughly 800,000 acres, and although I could not find exact figures I am certain this must have increased fertiliser use because there were certainly parcels which never received any fertiliser whatsoever because you could not get there.

In Table IV, which gives you some figures about investments per labourer in various industries, I must point out that the figure under "Agriculture" includes buildings as well as machinery. Nevertheless, this figure is colossal, and in some countries such as Holland there is over-investment. The farmer is investing more than he can pay, in fact, and the machines are tending to drive the farmers from their farms because they cannot afford to spend more on investment.

On the question of irrigation, I agree with you that probably in the majority of cases, though not in all, there is no positive interaction between irrigation and nitrogen requirement. You probably know the results of the Grassland Institute here in England, which are that in eight out of ten years you get a positive effect of irrigation, but only when there are very long dry spells do you get positive interaction between nitrogen requirement and irrigation; so in most cases there is no positive interaction. Will the farmer use more nitrogen if he irrigates? I do not know. In the United States he certainly would. I have some figures here which show the amounts of nitrogen required for maximum maize yield were 170, 225 and 280 kg. of nitrogen per hectare with 10, 19 and 24 cm. of water supply; so I think in the United States the farmers are advised to use more nitrogen if they irrigate their land. But this is certainly not common practice in Holland, and it is probably the same in your country.

Slow-release nitrogen fertilisers; about a year ago the Fertiliser Society had a joint meeting with the Society of Chemical Industry and Dr. Winsor from the Glasshouse Crops Research Institute at Littlehampton gave a talk about slow-release nitrogen fertilisers. He was not very optimistic about them, and I more or less agree with him. Anyway, in horticulture there is no need for slow-release fertilisers because if you have a sprinkling system you can add nitrogen to your sprinkling system whenever you want, and up until now the prices have been so high—three to five times more expensive than normal—that it has been impossible to use them in practical agriculture. One of the advantages on grassland is that you can just give one application and get the same results, or even better results than with split application of normal conventional fertiliser like ammonium nitrate limestone. But what do the costs of spreading amount to? In total farm expenditure I think the costs of spreading fertilisers are negligible, so I do think that the importance of slow-release fertilisers has been a little exaggerated in some papers.

Another important aspect is the prevention of nitrogen losses by leaching, as a control of pollution.

Yes, farmyard manure was the first slow-release nitrogen fertiliser, but of course you get certain losses if you apply farmyard manure, poor utilisation of ammonia of course, and the product is fairly bulky; spreading causes difficulties and handling causes difficulties.

Just a few words about other possibilities of obtaining slow-release fertilisers. This was discussed in the meeting last year which I told you about. You can try to obtain slow-release or controlled release of fertilisers by combining urea with various aldehydes. You can also try to obtain this chemically by reducing the solubility of the product. Then you get products like magnesium ammonium phosphate. You can try to control your nitrogen release by coating and varying the thickness of your coating.

You say that indoor feeding is not exactly popular in your country, and I am afraid it is the same in my country because in solving one problem you create another. One of the biggest problems is livestock waste, which has to be distributed again on the field. Buildings are needed and there is a need for storage of excreta, and so on. I have seen some American figures stating that by indoor feeding you can double your productivity of grassland; in other words you can keep twice the number of animals per hectare by indoor feeding. I have been unable to prove this with figures from the Netherlands, but I may not have seen all the figures about it.

You need adequate land for disposal of animal excreta, and that is our problem. I was glad to hear that there are restrictions in Sweden already, and I think we shall get them within the next three or four years. Also, I think there will be restrictions on the use of farmyard manure, and that farmers will be encouraged not to use farmyard manure and slurry during the winter or autumn because there is no crop on the field and leaching goes on at a fairly fast rate.

MR. L. CARPENTIER: I should like to comment on Dr. Smilde's last statement about whether phosphate and potash fertiliser use will increase according to the development of cattle and livestock breeding in those countries. I think you are basing your statement on the case of Holland particularly, because in larger countries you see very large areas of arable land without any cattle whatsoever, or very little. In those areas which are the largest consumers of fertilisers they do not use any slurry or farmyard manure at all; they rely entirely on chemical fertilisers, and it seems likely that the consumption of phosphate and potash fertilisers in those areas will increase because the productivity of the land also increases, as new high-yielding crops are extended. In my own country the area occupied by a crop like maize is increasing rapidly, so that the use of phosphate and potash fertilisers is also increasing rapidly.

I would suggest that the statement you made in the last part of your conclusions is perhaps based on a special case. I do not think that it will, at least in the short term and perhaps in the medium term, influence the use of phosphate and potash fertilisers to a great extent.

DR. K. W. SMILDE: If you look at Table V on page 6, you can see that the potash and phosphate consumption in Holland and in England is almost stable, or even decreasing in Holland, so I agree with you that my last few sentences were mainly based on the situation in Holland. If you look at the figures for France and West Germany you can see that the consumption of phosphate and potash has almost doubled in the past twenty years, and is likely to continue to go up, especially with new crops like maize.

Unfortunately for us, the results with maize are not very promising. We need maize varieties, adapted to a short growing season, at present it is rather risky for us to grow maize. But I agree with you that I have been a bit pessimistic about potash and phosphate fertilisers as I was mainly referring to the situation in the Netherlands. But I should point out that in England they have also reached the stage of stabilisation in consumption of potash and phosphate, and according to Dr. Cooke it is not likely to go up in this country. Maybe others among you have a different opinion about it.

MR. H. SANDFORD: As phosphate and potash reserves are built up in the soil, and to a lesser extent nitrogen as well, one way for better utilisation of fertilisers would seem to be to recommend a policy for a rotation rather than for a specific crop. I am wondering whether Dr. Smilde would agree with this, and whether leading farmers in the Netherlands, or in other Continental countries, are practising this, because I think it would increase efficiency of utilisation.

Secondly, some years ago work in this country showed that with CCC it did not pay to put on extra nitrogen. I am wondering whether the results you have shown were from just a series of trials which do not have general application, or whether you are in fact recommending in the Netherlands that extra nitrogen be put on when CCC is used on cereals?

DR. K. W. SMILDE: On your first question, although not all the problems have been solved, there is a tendency to apply P and K for a rotation of crops, say three or four years. If large amounts of K are applied at once this may cause difficulties, however, especially in beets—a deterioration of juice quality, and things like that. If you apply large dressings of K_2O at once it may cause some difficulties, but in Holland we may omit application of P and K for cereals and give double, so to speak, for the root crops. That is possible, of course, because we have built up reserves of P and K in the soil, so our crops are not too dependent on the direct action of P and K. If you have a reasonable level of P and K in your soil it is not necessary to apply fresh P and K all the time. This will not apply to nitrogen generally.

Your second question was about CCC. I was just showing you some data which refer to many experiments in Holland. The basic application in this case was mostly about 60 to 80 kg. of nitrogen. If CCC is applied, at a certain stage when your crop is 20 to 25 cm. high, more nitrogen can be utilised, and it pays. You certainly get higher yields. In most cases the same results are not reached with a split application of nitrogen. We get better results with CCC than with a split application of nitrogen in general, and with CCC I think the risks are smaller, and you can use up to about 120 kg. of pure nitrogen per hectare. Of course you have to take into account the weather conditions. As you probably know, in Holland we have a system of encouraging farmers to use less nitrogen after a dry winter than a wet winter, the difference amounting to some 30 kg. of nitrogen per hectare. For instance, this year, following a dry winter, we advise using 20 kg. of nitrogen per hectare less than usual.

DR. S. LARSEN: In your lecture, Dr. Smilde, you mentioned in passing lime and liming. In this context I should like to raise a point which has worried a lot of people in this country, where the pattern is that lime consumption is falling off. At the same time, fertiliser consumption has increased drastically. There are two schools of thought here. One is that this is bad, and the second one to which I belong, is that when you increase consumption of fertiliser your need for lime falls off; in other words, the pH optimum for a well fertilised crop is lower than the pH optimum for a starving crop.

Now that we are gathered from all corners of the world, including Holland, I would like to hear what the pattern is in Holland. Is the lime consumption dropping off in Holland? I checked on the position in my native country, Denmark, where anhydrous ammonia is used on a very large scale, and the result of that, of course, is that this particular fertiliser, like other ammoniacal fertilisers, will make the soil more sour, and therefore this must be compensated for with increased lime consumption. But what is the position in Holland

and the rest of the Continent? Is lime consumption going down, and what views have you got in relation to fertiliser consumption?

DR. K. W. SMILDE: I do not think lime consumption is decreasing, although the farmer considers it as an investment as he does not see the profits immediately. That is the difficulty with liming. But I do not believe that a starving crop needs a higher pH. Although consumption of lime is not decreasing in Holland, I certainly do not think it is what it should be, so there is still a lot of propaganda to be done to increase the use of lime fertilisers.

As you will see from my paper, the use of compound fertilisers increases the need for lime. If you compare compound fertilisers with a product like ammonium nitrate limestone it is clear that you need, when using only compound fertilisers as nitrogen source, more lime to make up for the losses which occur by leaching. In fact, compound fertilisers have an acidifying effect, and the example you mentioned in Denmark, the injection of anhydrous ammonia, will certainly increase the need for lime. I do not know if the Danish farmers are increasing their lime consumption?

DR. LARSEN: They are.

DR. K. W. SMILDE: But I do not think what you said about these farmers believing that the pH optimum increases when the crop starves is correct. I think, on the other hand, it may increase with fertiliser consumption. But I wonder if lime application is optimum in Holland already.

DR. LARSEN: I think we have to agree to disagree there. The pH optimum goes down as the fertiliser consumption goes up.

DR. K. W. SMILDE: Is that correct? I wonder, I do not know.

DR. LARSEN: I know that for a fact.

DR. K. W. SMILDE: It depends on the type of fertiliser you use, of course. I mean, if you rely only on compound fertilisers I would say that an increase in the use of compound fertiliser would increase the need for lime application.

THE CHAIRMAN: I do not agree with you, Mr. Larsen. I think an increase in, for instance, N or NPK calls for a higher pH. At least, that is my feeling. If we want maximum production I think we have to go to the optimum pH.

DR. LARSEN: Optimum, yes, but what you have just said now is what I call the conventional wisdom, and I doubt very much if that is right. I question the statement that the more fertiliser you use the higher pH you need in the soil, and I think there is good evidence to show that the pH optimum of the soil drops as the crop production increases owing to increased use of whatever fertiliser it is, nitrogen, phosphate, potash. There is one very simple reason for that: the need for trace elements like manganese increases. As a matter of fact, you can reverse the position. If you have a starving crop it might suffer from manganese toxicity, but if you fertilise and thereby double it or treble it, you can get manganese deficiency on the same soil. What about that?

DR. K. W. SMILDE: I assume you include manganese in your fertiliser recommendations?

DR. LARSEN: We are talking about NPK fertilisers.

DR. K. W. SMILDE: You should include manganese too, and provided your optimum level for *all* nutrients is correct I do not think it has much to do with your pH level. If you omit one of the elements, a trace element like manganese, I agree with you that increasing use of NPK will increase your need for manganese because, especially in compound fertilisers, you may tend to omit manganese and then, if you increase the pH, you will get into trouble with manganese deficiency. But I think when all your elements are optimum your pH level has little to do with the amount of fertilisers used.

THE CHAIRMAN: If you want to grow spring wheat on acid sandy soil, you have to apply quite a lot of magnesium, but if you increase your pH there is no need for such large amounts of magnesium.

MR. P. COX: I should like to quote a grass-seeding series of experiments that we conducted last season in relation to the point we are discussing. We made a basic dressing of phosphate and potash, and then we applied, over the season, 600 units of nitrogen as urea, sulphate of ammonia and CAN. The original pH of the plots was 6·3. No lime was applied. By the end of the season—this was after five cuts of hay or five assimilated cuts of silage—after only seven months the pH fell to between 4·8 and 5·3, from the original figure of 6·3. The resulting pH depended on the source of nitrogen. As you would expect, the sulphate of ammonia had the most acidifying effect.

DR. K. W. SMILDE: What was the proportion of the different nitrogen fertilisers?

MR. COX: These were applied separately to individual plots.

MR. D. M. RAMSAY: Dr. Smilde, you said the actual work of applying fertilisers was not a very serious problem. I do not think this applies when the holdings get bigger. When you have one man to 10 hectares the application of fertilisers may not be much of a problem, but when you have, as we have on some farms in this country, one man to 100 hectares—or in the United States and Canada there may be one man to 200 or 300 hectares—would you agree that it does then become important to try to avoid as much rush in the spring as possible, when you have a lot of other work to do, and that this may affect the pattern of compounds and straight nitrogen use?

DR. K. W. SMILDE: Yes, I agree, but I still think you have to apply your nitrogenous fertiliser in spring, whether it is slow-release fertiliser or not.

MR. RAMSAY: I was not necessarily disagreeing with that, but it could affect, for instance, the pattern of use of compounds; it could influence the moving of P and K out of spring into autumn, reversing what has happened in this country in the past.

DR. K. W. SMILDE: That is right.

MR. S. LAG: Dr. Smilde, you mentioned that compound fertilisers were not popular in the Netherlands, and you gave two reasons for that. The first reason which you gave was that you could not apply it in autumn, and you usually apply P and K in autumn, but do you not lose some potash by leaching in winter? Another reason you mentioned for compound fertilisers not being popular is that you need to apply the nitrogen several times in the season. I presume this was for grassland and pasture purposes. My question is: would it not be advantageous to split also the potash applications when fertilising grassland because of the relation between large amounts of Potassium and the frequency of grass tetany?

DR. K. W. SMILDE: I agree with you that in some conditions there may be losses of potash, especially on sandy soils. In our country these losses do not amount to more than about 10%, and we just apply a little more. We do not bother too much about it, but I agree with you that there are losses. But taking these into account I think the farmer prefers to apply his fertilisers in autumn. Particularly with fertilisers like P which you can easily work into the soil there is a better opportunity to do this in autumn than in spring because of the workability of the soil. I think if he has the choice he will apply his phosphate in autumn, although there are exceptions: on phosphate fixing soils you have to apply in the spring, but that is an exception.

Your second question was about the disadvantage of compound fertilisers on grassland. In our system, most grassland is only cut once and grazed the rest of the year, so in that case we apply only once P and K, and that is in spring. For the first application you could use a compound fertiliser, but the remaining applications over the summer are only nitrogen fertilisers, so there is no need to use compound fertilisers there. The first application could be a compound fertiliser, but the second, third and fourth applications are straight nitrogen fertilisers.

There is one thing I should point out: if the grassland use is different, that is if you cut it more than once for silage or hay, of course the system is different because the nutrients which are removed have to be replaced, so you have to apply not only nitrogen but also P and K several times during the summer. In that system of course it is useful to use compound fertilisers. It all depends on the grassland system.

THE CHAIRMAN: In your Table V you show that the yields are still increasing. Nitrogen consumption is increasing, but P and K are not increasing. This suggests that there is no interaction between nitrogen and P and K. Could you comment on that?

Secondly, in the United States they are seriously considering restrictions on the use of fertilisers in order to decrease pollution. Could you comment on that? Will it really decrease pollution, because one can imagine that if you want to continue farming you might have to import feeding stuffs, so it would not make any difference?

DR. K. W. SMILDE: Your question is that when increasing your nitrogen applications do you necessarily have to increase your phosphate and potassium applications, or maybe more proportionally, and if there are interactions between these elements. Interactions between nitrogen and phosphate and nitrogen and potash are certainly possible, but this is probably more the exception than the rule, judging by our experiments. If you produce higher yields per hectare, of course you have to replace the nutrients used by the crop; you have to make up for these losses, but I do not think your increase in phosphate and potash consumption should keep pace with your increase in nitrogen consumption. That is not our experience, though maybe in England it is somewhat different. I remember that in one of Dr. Cooke's papers he comments on this situation and complains that farmers are not using more P and K, because he says that as nitrogen goes up your P and K should go up accordingly. However, that is not our experience.

THE CHAIRMAN: You show in Table V that yields have increased quite considerably since 1955 but the P consumption is static. Would that mean that if you do not increase your use of P the soil phosphorus status will be decreasing.

DR. K. W. SMILDE: You must take into account the soil reserves which have been built up over the years. That is very important in this situation. The reason why we do not have to use more P and K in countries like the United Kingdom and the Netherlands is because we have built up our reserves already. In other countries like France or Germany they have not reached that stage, but they may reach it after ten or twenty years, and then their consumption will also be stable. In other words, you should take into account the residual effect of P and K applications in the past.

Your second question was about restrictions on fertiliser use in order to decrease pollution. I believe in the State of Michigan there are certain restrictions on fertiliser use. I do not know what the amounts are, but I think they only decrease pollution to a certain extent. That has been our experience, and also the experience of people in this country such as Cooke. It was found that the biggest contribution towards nitrogen leaching losses is made by soil organic matter, from which nitrogen is mineralised.

In our country, the losses of nitrogen from the soil by leaching, erosion and run-off are estimated at 32 kg. of nitrogen per ha, 20% comes from inorganic fertiliser, 15% from organic manure, and 65% from mineralised organic matter. So if you really want to decrease pollution you have to deplete your soil completely and use all the organic matter which is in it, but that will involve large imports of food, and in fact you do not gain anything because by importing foodstuffs you get the same situation.

I do not think restrictions on fertilisers is the solution. I think some restrictions can be made as far as the time of application is concerned—in other words, do not use slurry during winter or autumn—but I do not think a decrease in inorganic fertiliser will contribute much towards a decrease in pollution. Quite apart from that, importing foodstuffs for human consumption is very expensive, so I do not think this is the solution to the problem.

DR. LOW: On page 15 you write: "The need to rotate crops is now being disputed as control of weeds and soil-borne diseases and maintenance of soil fertility and soil structure can be achieved by other means." I am wondering what other means you have in mind for maintenance of soil structure.

DR. K. W. SMILDE: I mean the need to rotate crops as far as wheats are concerned by the application of weed-killers and so on. By "maintenance of soil structure" I was thinking about minimum tillage and things like that. There is a tendency to decrease the intensity of cultivation rather than increase it. However, this is not just my opinion. I agree with it to a certain extent, but not completely. In our experience, a narrow rotation of, say, wheat-barley always means a loss in production of up to 15%. To some extent this loss in production can be made good by high applications of nitrogen, but that is not always necessarily true: in other words, the losses due to narrow rotation may be rather heavy with no nitrogen applied and with nitrogen applied.

I just put that statement in for argument's sake, I do not necessarily agree with it.

DR. LOW: In the next sentence of the same paragraph you say, "narrow rotations or monocultures of cereals are being practised already," and you refer to barley in the U.K. Those of us who have tried to find much evidence for this have failed; in other words, there may be the odd field where they can keep up monoculture, perhaps for decades, but the system seems to break down on any scale. That at least is the evidence I have found.

DR. K. W. SMILDE: This was quoted somewhere, and I have not checked it. This is not common practice in certain areas in the United Kingdom?

DR. LOW: As far as my experience goes it is not, apart from the odd few hectares.

MR. D. H. THOMPSON: On page 10 you make a brief mention of bulk handling of fertilisers. I remember last year near Groningen seeing a number of silos which were part of an experimental farm appraisal. These contained about eight tons of fertiliser, sited on grassland farms, the theory being that the throughput would be six, seven or eight times the capacity each year and therefore this would be economic. I wonder whether I might ask you whether the results of that work were promising.

I understand from a discussion with a colleague of yours, Dr. Bakker, that pallet handling is being introduced in Holland on the larger holdings. As you know, pallet handling is becoming very important in this country for our larger farms. It is a thing which has snowballed rapidly over the last few years. I am speaking of farms where they use over 100 tons of fertiliser each year. We have a handling problem where farms are less intensive or smaller and the tonnage is something of the order of 50 tons a year, or possibly less. I wonder whether you could comment on the growth of pallets in the Netherlands, whether you see this continuing, and whether you can give us any guidance on how we might help our smaller farmers handle their fertiliser tonnages, particularly having regard to the fact that a large proportion of nitrogen in this country is supplied in the form of ammonium nitrate?

DR. K. W. SMILDE: I agree with you that the system with silos is certainly more profitable for the larger farms than for the smaller ones, and also for pure grassland farms rather than for arable farms. That is because on grassland you have to apply fertilisers several times a year, whereas for arable land your silo is empty most of the time; in other words, the investment is too heavy for arable land because you do not use it enough.

However, I think the system works, and the number of silos is increasing, but I would say it was mainly on the bigger grassland farms. I do not see that the system will work on a smaller farm. The smaller farms prefer to use bulk handling, that is handling fertiliser without bags, or pallet handling. If the farmer has a building with a concrete floor he can store his fertiliser there, and in most cases that is probably more economical than buying silos which are quite expensive.

Perhaps Dr. van Burg has another opinion about this.

THE CHAIRMAN: No, I agree. The silo system on grassland farms is expanding rapidly. I think some 100 silos were installed last year, as you saw at Groningen, and this coming season another 100 silos will be installed. Of course, you can use them as dual purpose silos, for fertilisers in spring and for concentrates in winter. The price of the silo, complete with concrete, etc., is about £350 for a 10-ton or 8-ton silo.

DR. L. J. WILKINSON: I should like to ask Dr. Smilde about the P and K use on grassland.

I think you mentioned the figure of 45 kg. per hectare of P_2O_5 and 120 kg. of K_2O. First, were those recommended amounts, or actual amounts used?

Secondly, I should like to ask your opinion on the recommendations in this country of between a half and three-quarters of a unit of potash for every unit of nitrogen used for grass for silage?

DR. K. W. SMILDE: Those figures, which can be found in Table XXV, are an average for loam soils and sandy soils, so the potash recommendation on sandy soils will be of the order of 140 and on loam soils of the order of 100. The average is about 120 assuming that the total acreage of loam and sandy soils is about the same. These figures are recommendations, based on soil tests. Actual consumption is probably higher if you also include organic manure. That can be seen in Table XXIII.

On the question of the relation between P and K and N, I cannot exactly answer that question. An increase in nitrogen application will increase to a certain extent the need for P and K, but we have not found a definite relationship. Of course, what is removed from the field should be replaced, and if yields are boosted by nitrogen you have to replace your P and K, but exactly what the relationship is between these I do not know.

DR. WILKINSON: I asked this particularly because there is a strong tendency in this country to use something like a 2 : 1 : 1 compound for grass which is cut for silage or hay, and sometimes even to use this for one cut and just straight nitrogen for the second cut, so we are obviously depleting soil potash considerably. I wondered if you did the same thing in Holland?

DR. K. W. SMILDE: We do exactly the same, I think. We do not apply much compound fertiliser on grassland, but if we did apply it we would use the same compound, 2 : 1 : 1, and then later in the year, for the second, third and fourth applications, we would use straight nitrogen fertiliser. Do we deplete our potash reserves in the soil? Looking at the figures for farmyard manure, I do not think it likely that we apply too little We must be careful because if you apply too much potash you get into trouble with diseases like grass tetany. We always try to keep the potash status of grassland soil at a "safe" level. But maybe our reserves are high, and perhaps it is different in your country.

THE CHAIRMAN: I am now going to close the discussion, I thank all those who have contributed towards it and I will hand back the Chair to the President for the rest of the meeting.

THE PRESIDENT: Thank you very much Dr. van Burg for your help and guidance.

I will now ask Mr. de Tarragon to present a vote of thanks.

MR. H. DE TARRAGON: I am very pleased to express, on behalf of the Council of the Fertiliser Society and the audience, my warm thanks to Dr. Smilde for his very interesting lecture.

The subject of his paper was of immense interest not only to all those involved in fertiliser manufacture and agronomy but also to the farmers, who are faced with changing patterns in their practical farming conditions.

The very wide and animated discussion we had proved the great interest in this subject, both now and for the future, and I thank Dr. Smilde for his lecture and for the excellent answers he gave to the questions.

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