ROTHAMSTED RESEARCH

Report for 1974 - Part 1

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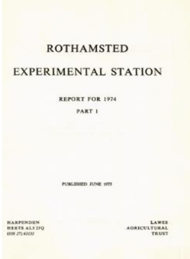
ROTHAMSTED

EXPERIMENTAL STATION

REPORT FOR 1974

PART 1

Chemistry Department

G. W. Cooke

G. W. Cooke (1975) *Chemistry Department* ; Report For 1974 - Part 1, pp 75 - 92 **- DOI: https://doi.org/10.23637/ERADOC-1-131**

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Introduction

In the 12 months from November 1973 the prices that British farmers paid for nitrogen and potassium fertilisers rose by 50% and phosphate prices doubled. These changes have been caused by the large increases in prices of oil and other fuels (which have affected nitrogen fertilisers particularly), by the four-fold increase in the world price of phosphate rock and by the removal of the remainder of our subsidies on nitrogen and phosphate. Prices of wheat and barley are nearly twice those of two years ago and compensate for larger fertiliser costs in cereal growing, but the value of other arable crops has not increased so much and the returns from animal products are certainly insufficient to repay the greater cost of fertilisers used on grassland. There has also been much public concern about the energy used (as oil, gas or coal) to make nitrogen fertilisers. Calculations suggest that as much as a third of all the energy involved in some modern intensive agricultural systems is needed to make the nitrogen fertilisers used.

https://doi.org/10.23637/ERADOC-1-131

Consideration of 'costs' in both financial and energy terms emphasises the need to make nitrogen fertilisers as efficient as possible by avoiding loss and wasteful use and by making the maximum use of nitrogen reserves in soil and fixed by biological processes.

Slow-release fertilisers have been suggested as a way of diminishing losses of nitrogen by leaching or volatilisation and of avoiding pollution of natural water by nitrate. The materials proposed are intended to release inorganic nitrogen at rates which match the needs of crops. The latest slow-acting fertiliser offered in Britain is sulphur-coated urea. In the work we have done, this product has had no advantages in terms of crop yields, or nitrogen uptakes, over ordinary fertilisers. Inferior results in field and pot experiments suggest that it shares with uncoated urea the liability to lose part of its nitrogen to the air.

Nitrogen fertiliser and fungicide for barley. Greater efficiency of nitrogen fertilisers is more likely to be achieved by the cumulative effect of many small improvements than by a major 'breakthrough' in research. One such example is this year's account of a series of experiments on three varieties of barley, testing different amounts and timings of nitrogen fertilisers, and also a fungicide (benodanil) against brown rust. The fungicide had its largest effect on yield of barley given large dressings of nitrogen, and particularly when the nitrogen was given late (in May) to diminish the risk of loss by leaching. Under such conditions the fungicide increased the return from the nitrogen fertiliser, particularly where it was applied to a rust-susceptible variety.

Nitrogen for wheat. In some European countries top-dressings of nitrogen fertiliser are given to wheat after the ears have emerged to increase yield and protein content. We have tested foliar sprays of calcium nitrate solution; applied at growth stage 6 ('early stem extension') small dressings diminished yields but larger amounts of N increased them. Spraying these solutions later (stages 10 and 11.1 ('boot' and 'milk' stages)) damaged yield seriously. In other work with wheat we have shown that more nitrate was taken up from surface than from subsoil and periods of particularly rapid uptake occurred at tillering, and again at growth stages 6, 10 and 11.1.

Fertilisers and quality of crops. Fertilisers affect the composition of crops and these changes may affect the suitability of products for particular purposes.

Wheat. The suitability of wheat for milling and breadmaking depends partly on its protein content (which is usually expressed by multiplying % N in grain by 5·7). We report preliminary findings from an examination of the effects of nitrogen fertilisers, organic manures and previous cropping on the nitrogen content of wheat in experiments with modern shorter strawed varieties done at Rothamsted and Woburn and on some commercial farms during the last 20 years. Other publications suggest that if British wheat is to comprise one-third of the grain used in bread flour, it must have 10% of protein in flour or about 1·9% N (at 85% dry matter) in grain of soft wheat such as Cappelle-Desprez. This value has been achieved in Cappelle-Desprez wheat grown on Broadbalk from 1969 to 1972 where the continuously-grown crop was treated with the maximum amount of N (192 kg N ha^{-1}) or where only half as much N was given to crops which also received farmyard manure or were grown after beans. Other experiments show that protein content is raised by nitrogenous residues left in soil by heavily fertilised potatoes and by leguminous leys. Often, however, to achieve 1·9% N in grain has entailed using so much nitrogen fertiliser that yields have been diminished; in at least one long-term experiment it proved impossible to achieve this % N even where farmyard manure and large nitrogen dressings had been applied.

https://doi.org/10.23637/ERADOC-1-131

Grass. Severe deficiency of nutrients other than nitrogen upsets the protein metabolism of ryegrass and results in large accumulations of certain amino acids in the non-protein nitrogen fraction of the plant. These effects have been investigated previously in ryegrass deficient in potassium and magnesium. This year we found that phosphorus deficiency also results in very large accumulations of some free amino acids. The work has also been extended to the very old pasture herbage on the Park Grass experiment where soils are acid due to long continued application of ammonium sulphate and are very deficient in potassium where none has been applied for 120 years. Both lime and potassium fertiliser greatly diminished the accumulations of free amino acids which occurred in grass grown on acid and K-deficient soil.

Organic matter in light soil. The practical worth of the organic matter accumulated by growing leys or green manures, or applying farmyard manure, straw, or peat for six years on the loamy sand soil at Woburn has been measured by growing potatoes followed by wheat. Potato yields were considerably and consistently increased by residues of organic matter left by most of the treatments. The effects were not simply due to the extra nutrients supplied by the organic manures since extra amounts were supplied by fertilisers on the plots receiving only inorganic manures. The results showed that, even if more nitrogen had been given, yields on plots given only fertilisers would never have reached those from soils containing organic residues. These results are not easy to explain and point to the need for more investigations of the ways in which organic matter increases potato yields.

The effects of organic residues were not so marked on yields of wheat grown three to four years after the 'organics' had been applied. The largest benefits were following clover leys and grass leys treated with N fertiliser. Residues of peat had no effect on wheat and the benefits from straw and farmyard manure were much smaller than they were on potatoes.

Sulphur from the air. In industrial countries such as Britain the rain supplies much sulphur—in fact more than crops need even when fertilisers supply none. Recently evidence has accumulated in several countries that extra quantities of sulphur are deposited directly in particles falling on soil and that sulphur dioxide is absorbed from the air; this phenomenon is called 'dry deposition'. At Rothamsted we have found sulphur was deposited in 1969 and in 1974 at rates roughly equivalent to 28 kg S ha^{-1} annually; a similar amount is present in rainfall.

Soil acidity. The damage that acid soil does to crops is associated with the aluminium present. Aluminium is toxic to some species; other species tolerate high aluminium concentrations and effects of aluminium on their growth appear to be due to interactions with the uptake of phosphorus and potassium. Small aluminium concentrations promote growth of some species by releasing other nutrients from soil, but large concentrations of aluminium decrease yields. However, both with crops which accumulate aluminium (e.g. tea), and those that do not (e.g. legumes), we have found uptakes of aluminium and phosphorus are consistently and closely correlated.

Experiments with nitrogen fertilisers

Sulphur-coated urea. The use of insoluble fertilisers that release nitrogen at rates which match uptake by crops has been suggested as a means of making fertilising more efficient and of reducing losses of nitrate to surface waters. The most recently introduced material is sulphur-coated urea (SCU) and we described preliminary work in last year's Report

https://doi.org/10.23637/ERADOC-1-131

(p. 52). This year we have followed movement of N from this and other sources down the profile of Rothamsted soil in the field during winter and have done more pot experiments.

Movement of nitrogen in soil in winter. Calcium nitrate, ammonium sulphate, urea and SCU, all supplying 100 kg N ha^{-1} were applied to bare soil (of pH 7·7, on Harwoods Piece) in October; on some plots the fertilisers were worked in with a power harrow. Nitrate concentrations in surface soil 0–13 cm deep which had received calcium nitrate declined to very small amounts during 101 days when 164 mm of rain fell; rate of movement was proportional to rainfall. Concentrations in the 13–26 cm deep layer increased to a maximum during the first 66 days (with 69 mm of rain); afterwards they declined to very small values. Working the fertiliser in speeded these changes.

Nitrate in the upper layer of soil receiving ammonium sulphate increased (and ammonium declined) for the first 24 days; afterwards concentrations declined to very small values by 101 days. In the deeper (13–26 cm) layer nitrate increased for the first 66 days but declined thereafter. Urea hydrolysed quickly to form ammonium-N which then behaved like N from ammonium sulphate. SCU maintained smaller nitrate concentrations in both layers of soil for the first 101 days. A deep sampling of the profile was done in March, 153 days after applying fertiliser, when 294 mm of rain had fallen. None of the plots given ordinary fertilisers contained more nitrate in the top 26 cm than untreated soil, but all contained more in the 26–52 cm layer of soil. Plots given SCU contained more nitrate in both upper and lower layers of soil than untreated plots, perhaps because nitrate was still being formed. Whether the fertilisers were worked in or not made no difference at the end of the experiment.

The residual value of the autumn dressings was tested by growing barley without any further dressings of N; it was harvested green after ears had emerged. Percentage recoveries of the N applied in October were:

From	
calcium nitrate	28
ammonium sulphate	35
urea	20
sulphur-coated urea	22

Sulphur-coated urea was similar to urea and both were less efficient than nitrate- or ammonium-nitrogen. These results suggest that: (a) barley recovered some nitrate which may have leached below 52 cm from calcium nitrate and ammonium sulphate, (b) SCU was inefficient because some N was lost to the air after hydrolysis or that some remained undissolved in the granules. (Addiscott and Cox)

Experiment on ryegrass. In a pot experiment on ryegrass a single dressing of SCU was compared with ammonium nitrate and urea applied as single dressings and dressings split for the first five cuts. Best yields were from split dressings of ammonium nitrate and urea; SCU mixed with soil and the single dressing of ammonium nitrate were intermediate, worst yields were from SCU applied to the soil surface or the single dressing of urea mixed with the soil. Most nitrogen was however recovered from the single dressing of ammonium nitrate; SCU mixed with soil and split ammonium nitrate dressings were intermediate; least N was recovered from SCU applied to the surface and from urea however it was applied. Adding sulphur to urea-treated pots did not affect yield or uptake of N. SCU was more effective when mixed with soil but it did not seem to be a genuinely-slow acting fertiliser as most of the N it supplied was recovered by the first two of the nine cuts; this supports recent incubation work similar to that reported last year. (Cox)

Adsorption of ammonia by soil. In last year's Report (pp. 53–54) we described adsorption isotherms of ammonia gas. The method for measuring these has now been applied to adsorption of trimethylamine (NMe_3) gas by two soils (Bromyard and Speller series). With both soils, the Li, Ca and Mg-saturated forms gave one isotherm and sorbed more gas than the Na, K and tetramethylammonium (NMe_4)-saturated forms, which gave another. (At relative pressures >0·01, Na and K-saturated Speller soil sorbed more NMe_3 than did the NMe_4-soil.) Trimethylamine, unlike ammonia, cannot form hydrogen bonds to oxygen atoms at the soil surface. The difference between the amounts of NH_3 and NMe_3 sorbed by these soils therefore enables an estimate to be made of the amounts of NH_3 sorbed in this way, when allowance is made for differences in the saturation vapour pressures of the two gases and the surface areas occupied per gas molecule. (Ashworth)

Times and amounts of nitrogen for barley at Saxmundham and the effects of fungicide. The experiments begun in 1967 on Grove Plot were continued; their purpose was to test factors that might explain the large differences in grain yield that occurred there from year to year. Results from 1967–71, summarised in the *Rothamsted Report for 1971*, Part 1, 56–57, should be read in conjunction with this report. Table 1 shows that the mean yields of Midas barley (a variety susceptible to brown rust (*Puccinia hordei*)) were similar to those given by Julia barley (*c.* 4·5 t ha^{-1}). Thus the small grain yields of Midas and Sultan (2·5–3·3 t ha^{-1}) in 1970 and 1971 could probably be explained by the severe attacks of brown rust in these two years as the disease was far less abundant in 1973 and 1974. Each year the barley followed barley; three rates of nitrogen, 50, 100 or 150 kg N ha^{-1} were tested, applied either at sowing (in late March) or in May. Table 1

TABLE 1

The effect of applying nitrogen, either early (to seedbed) or late (in May) for barley grown at Saxmundham from 1972–74

Yields of grain in kg ha^{-1} at 85% dry matter

	Yield		Effect of					
			Variety	Nitrogen		Time of N		Fungicide
Year	Average	Range	M-J	(N_2–N_1)	(N_3–N_2)	(E–(½E+½L))	(E–L)	(F–O)
1972	4·43	(3·7–5·3)	−0·42	0·56	0·08	—	0·50	—
1973	5·01	(3·9–5·8)	0·01	0·97	0·18	−0·11	−0·06	0·32
1974	4·62	(3·1–5·9)	0·03	1·03	0·32	0·16	0·78	0·22

M = Midas
J = Julia
O = No benodanil
F = Two sprays of benodanil

N_1 = 50, N_2 = 100, N_3 = 150 kg N ha^{-1}

E = All N to seedbed
½E+½L = ½ to seedbed; ½ in May
L = All N in May

TABLE 2

The effect of benodanil sprays (B) on brown rust (% area of 2nd youngest leaf infected at growth stage 11·1/11·2) on three varieties of spring barley

	Fungicide[a]			
	1973		1974	
	O	B	O	B
Julia	1·1	0·1	0·2	0·0
Mazurka	2·5	0·2	0·6	0·1
Midas	10·8	1·8	1·9	0·2

[a] Sprays of benodanil on 19 June and 10 July in both years

https://doi.org/10.23637/ERADOC-1-131

shows that 100 kg N ha^{-1} was enough in two of the three years, almost enough in the other. This N was best given early in years when springs were dry and leaching of N applied to the seedbed was minimal.

The 1973 and 1974 experiments included a test of the fungicide benodanil ('BAS 3170F'). Although rust was not severe in either year there was most on Midas and it was much decreased by the fungicide (Table 2). Mean increases from the fungicide were small in both years (Table 1), but the benefits were large enough to be significant on Midas. The fungicide most increased yield of barley given ample nitrogen (100 or 150 kg N ha^{-1}), especially when this N was given in May. The experiments demonstrated therefore that the damage done to spring barley by brown rust depended on (1) variety, (2) the amount of N given and (3) the timing of N. Thus one consequence of applying the fungicide was to increase the value of the N given, especially to the rust susceptible variety, and of that given late as a top-dressing. (Widdowson and Penny, with Jenkyn, Plant Pathology Department)

Nitrogen for wheat

Late dressings applied as foliar sprays. Tests were made of sprays supplying up to 90 kg N ha^{-1} as a 5% calcium nitrate solution (plus spreader) to crops which had received dressings of 'Nitro-Chalk' supplying 30 and 90 kg N ha^{-1} at tillering. The sprays were applied at Feekes scale growth stages 6, 10 and 11·1. When 30 kg N ha^{-1} was sprayed at growth stage 6 on wheat which had received also 30 kg N ha^{-1} in spring, yield was decreased, but spraying the larger dressing increased yields. Spraying extra nitrogen at stages 10 and 11·1 decreased yields seriously; the damage was most serious with stage 10 sprays presumably because the flag leaf was affected. (Page, Penny and Talibudeen)

Uptake by winter wheat on Broadbalk. Ion-selective electrodes were used to measure concentrations of soil nitrate by techniques established by Nair and Talibudeen (*Journal of Agricultural Science, Cambridge* (1973), **81**, 327–337). Measurements were made down to 25 cm in permanent sites and differences in nitrate concentrations between cropped and uncropped areas were used to determine when the crop took up most nitrate. On plots receiving no N fertilisers, amounts of soil nitrate depleted by crop uptake were too small to allow periods of maximum uptake to be identified. On nitrogen-treated plots depletion of soil nitrate by the crop was more with greater rainfall; more nitrate was taken from the 5 cm and 15 cm deep zones than from the 25 cm zone. Maximum uptake occurred at Feekes' scale growth stages 2 ('tillering'), 6 ('early stem extension'), 10 ('boot') and 11·1 ('milk'). On No. 2 plot, which is treated annually with FYM, soil nitrate was regularly taken up until growth stage 10; afterwards uptake was greater from the 5 cm and 15 cm deep zones of soil. (Page and Talibudeen)

Effects of nutrients on crop composition

Some factors affecting the percentage of nitrogen in wheat grain. Many of the experiments made at Rothamsted, Woburn and on commercial farms since the mid-1950s have grown the new shorter strawed varieties of cereals. The experiments have tested different rates, forms and times of application of nitrogen fertilisers on crops grown in different crop sequences. To find out which of the factors tested had influenced the protein content of grain, a survey was started this year of the results of all cereal experiments in which % N in grain had been determined; this includes about 100 winter-wheat and 50 spring-wheat trials. No general conclusions can yet be drawn but some pointers are provided by the five examples discussed below. In the tables that follow, N concentrations are given as

https://doi.org/10.23637/ERADOC-1-131

% N in grain at 85% dry matter. In publications concerned with the quality of wheat grain for breadmaking, the protein content is usually expressed as 5·7 × % N (Kjeldahl method) at 86% dry matter. If 10% protein (in flour) is regarded as necessary for 30% usage of home-grown wheat in bread flour, this implies a threshold value of about 1·9% N in the grain of soft wheat at 85% dry matter.

Broadbalk field at Rothamsted grew wheat continuously from 1843 to 1967 (Bawden, *Rothamsted Report for 1968*, Part 2, 7–11). Part of the field is still in continuous wheat, but part is now under a rotation of potatoes, beans, wheat. Table 3 gives average yields of grain and nitrogen concentrations for the four years 1969–72. On the plots without farmyard manure (FYM), yields differed between the two cropping regimes, with wheat grown in rotation needing less fertiliser to produce more grain. However, N concentrations were similar for the two regimes, ranging from 1·4% N without added fertiliser N to 1·9% N with the largest fertiliser dressing. Farmyard manure (35 t ha^{-1} annually) applied alone gave larger yields but smaller N concentrations than the largest amount of fertiliser N, but where 96 kg N ha^{-1} was applied in addition to FYM, % N in grain was the largest observed (though this was accompanied by a reduction in yield when wheat was grown after beans).

TABLE 3

Yield and % N of grain (at 85% dry matter) of Cappelle-Desprez winter wheat grown on Broadbalk, Rothamsted, 1969–72

'Nitro-Chalk' applied each spring (kg N ha^{-1})	Continuous wheat				Wheat after beans			
	No FYM		FYM		No FYM		FYM	
	Yield (t ha^{-1})	N (%)	Yield (t ha^{-1})	N (%)	Yield (t ha^{-1})	N (%)	Yield (t ha^{-1})	N (%)
None	1·90	1·44	6·13	1·65	3·44	1·38	7·05	1·84
48	3·96	1·36	—	—	5·41	1·39	—	—
96	5·28	1·60	6·42	1·96	6·19	1·57	6·08	2·06
145	5·39	1·81	—	—	5·86	1·77	—	—
192	5·70	1·87	—	—	5·61	1·93	—	—

Rothamsted Reference experiment. Winter wheat was grown as part of a five-course rotation of kale, spring barley, grass–clover ley, potatoes and wheat (FYM was given at 50 t ha^{-1} to potatoes and kale). Table 4 shows that over the 17-year period, yields decreased on plots with neither fertiliser N nor FYM but increased with FYM plus the

TABLE 4

Yield and % N of grain (at 85% dry matter) of winter wheat grown in the Rothamsted Reference experiment, 1956–72

N given each spring (kg ha^{-1})	1956–61		1962–67		1968–72	
	Yield (t ha^{-1})	N (%)	Yield (t ha^{-1})	N (%)	Yield (t ha^{-1})	N (%)
Without FYM						
None	5·08	1·66	5·01	1·48	4·38	1·24
75	6·04	1·84	6·38	1·64	5·86	1·30
151	5·50	2·06	6·21	1·92	6·60	1·58
With FYM						
None	5·65	1·74	5·87	1·55	5·07	1·29
75	5·67	1·96	6·29	1·66	6·49	1·44
151	5·71	2·14	6·04	1·92	6·17	1·62

Varieties: Koga II (spring wheat), 1956; Cappelle-Desprez, 1957–65; Champlein, 1966–70; Maris Nimrod, 1971–72

https://doi.org/10.23637/ERADOC-1-131

largest amount of fertiliser. By contrast, N concentrations in grain decreased consistently with time whatever the manuring; the varieties grown changed during the whole period and this prevents strict comparisons. Whereas during the first and second periods, when mainly Cappelle was grown, the largest dressings of fertiliser N produced grain with N concentrations up to or exceeding 1·9% N, the comparable figures for the third period (Champlein and Maris Nimrod) fell far short of it. Although FYM arrested the decline of total soil nitrogen (Williams, *Rothamsted Report for 1972*, Part 2, 86–101), it had hardly any effect on the decline of % N in grain.

Residual effect from N given to previous potatoes. Potatoes are a good preparation for wheat because they check cereal root diseases and leave residues from the large nitrogen dressings usually applied. The residual effects of fertilisers given to potatoes were tested on yields of wheat (Table 5). After a large dressing of N (208 kg ha^{-1}) given to potatoes, maximum yield of the following wheat was achieved with only 41 kg ha^{-1} of fresh N; where potatoes received much less N (41 kg ha^{-1}), the following wheat needed 82 kg N ha^{-1} for maximum yield. % N in grain was affected both by N given to previous potatoes, and by the fresh dressings applied to wheat; it increased steadily with residual and current fertiliser dressings—N in grain ranging from 1·67% with the smallest dressing to 1·97% with the largest.

TABLE 5

Relationship between nitrogen fertiliser given to previous potatoes and the yield and % N of grain (at 85% dry matter) of Cappelle-Desprez winter wheat at Rothamsted, 1968

	Winter wheat			
N to previous potatoes:	41 kg N ha^{-1}		208 kg N ha^{-1}	
N given to wheat[a] (kg ha^{-1})	Yield (t ha^{-1})	N (%)	Yield (t ha^{-1})	N (%)
None	4·20	1·67	5·14	1·74
41	5·43	1·66	5·68	1·81
82	5·80	1·74	5·60	1·87
125	5·52	1·84	5·40	1·97
Standard error	±0·096	±0·022	±0·096	±0·022

[a] In two spring top-dressings

Effect of three types of ley. Yield as well as % N in grain of winter wheat grown after different leys increased consistently in the order: grass ley, grass–clover ley, clover ley (Table 6). Similarly, both yield and N concentrations went up consistently with increasing

TABLE 6

Yield and % N of grain (at 85% dry matter) of Cappelle-Desprez winter wheat grown after three types of ley (clover, ryegrass, clover–ryegrass) at Rothamsted, 1962

	Winter wheat					
Previous ley crop:	Ryegrass		Clover-ryegrass		Clover	
N given to wheat[a] (kg ha^{-1})	Yield (t ha^{-1})	N (%)	Yield (t ha^{-1})	N (%)	Yield (t ha^{-1})	N (%)
None	4·10	1·28	4·66	1·31	5·94	1·38
63	5·67	1·33	6·09	1·38	7·02	1·51
126	6·76	1·53	6·86	1·56	7·22	1·70
Standard error	±0·065	±0·009	±0·079	±0·011	±0·112	±0·016

[a] In two spring top-dressings

https://doi.org/10.23637/ERADOC-1-131

fertiliser N given to the wheat. N in grain ranged widely between extremes of experimental treatments—from 1·28% N after grass ley with no fresh fertiliser N to 1·70% N after a clover ley receiving 126 kg N ha^{-1}.

The Intensive Cereals experiment at Woburn is on a loamy sand containing very little organic matter. Wheat is taken in a rotation of ryegrass ley and potatoes before three consecutive crops of winter wheat which are compared with continuous wheat. The yields were considerably smaller than in most Rothamsted experiments. Table 7 shows that for the mean of five years (averaging crop sequences), the largest wheat yield was obtained with 188 kg N ha^{-1}, but the largest N concentration in grain was with 251 kg N ha^{-1}. The first crop of wheat after potatoes yielded best, the second crop was good too and both gave much more than the third crop or the continuously grown wheat. By contrast, N concentrations in grain varied little with crop sequence, though they increased very slightly with the length of the period the land had been cropped with wheat. (During the five years, interactions between crop sequence and N fertiliser treatments were small or trivial.) (Benzian)

TABLE 7

Yield and % N of grain (at 85% dry matter) of Cappelle-Desprez winter wheat grown in the Intensive Cereals experiment on Stackyard, Woburn, 1969–73

	Yield (t ha^{-1})	N (%)
N given (kg ha^{-1}) each spring		
Averaging crop sequence		
63	2·56	1·46
126	3·42	1·68
188	3·50	1·89
251	3·32	2·00
Wheat after break crop		
Averaging levels of N		
First	4·02	1·70
Second	3·19	1·75
Third	2·73	1·77
Continuous	2·84	1·82

The nitrogenous fraction of grass. In previous years we have reported the effects of potassium and magnesium fertilisers on the composition of the nitrogen-containing fraction of ryegrass grown in pot experiments. The work with potassium has now been extended to more practical conditions by analyses of samples of the mixed herbage treated with ammonium sulphate which is grown on Park Grass. This experiment provides a test of annual dressings of potassium fertiliser to very old pasture grown on very acid and less acid soils. Severe potassium deficiency has developed in the soils which have received no K fertiliser for at least 120 years. The effects of acute deficiency of soil phosphorus on the composition of the nitrogenous constituents of ryegrass has also been explored in a pot experiment.

The effects of potassium deficiency and acidity on the composition of pasture grasses. Nowakowski and Byers showed (*Journal of the Science of Food and Agriculture* (1972), **23**, 1313–1333) that the nitrogen metabolism of ryegrass grown on potassium-deficient soils in the glasshouse was greatly disturbed; free amino acids accumulated in the grass. We have now shown similar effects in grass grown on plots of the Park Grass experiment at Rothamsted which had received no K fertiliser (Warren & Johnston, *Rothamsted Report for 1963*, 240). Samples of grass, about 15 cm tall, were collected on 14 May

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from four plots (the species were mixed and were not identified). The sampled plots get fertilisers supplying N, P, Na and Mg annually. In addition Plots 9a and 9d get 220 kg K ha^{-1} annually, while Plots 10a and 10d have had no potassium since 1856. The annual dressing of 96 kg N ha^{-1} (as ammonium sulphate) had been applied on 5 April. The subplots 9a and 10a have had ground chalk, equivalent to 2200 kg CaO ha^{-1}, every fourth year since 1903; the other subplots 9d and 10d have never been limed. The effect of these treatments on the composition of the soil (0–23 cm depth) and the grass samples is shown below:

		Plot 9a with K limed	Plot 9d with K unlimed	Plot 10a without K limed	Plot 10d without K unlimed
Soil	pH in water	5·3	3·8	5·6	3·8
	exchangeable K mg kg^{-1}	390	220	80	60
In grass dry matter (%)	N	3·28	3·75	3·28	4·14
	K	4·35	2·76	0·81	0·66
	Ca	0·32	0·12	0·45	0·12

Table 8 shows the concentrations of some free amino acids in the grass; others were not affected by the treatments. Where lime had been given, K fertiliser had no effect on the percentage of protein N in the total nitrogen of the grass, but increased the concentrations of glutamic and aspartic acids. Where lime had not been applied and the soils were very acid (pH 3·8) K fertiliser increased protein N and the concentrations of aspartic and glutamic acids, whilst the concentrations of serine, basic amino acids (ornithine, lysine, histidine and arginine), asparagine and glutamine were all decreased. Irrespective of K manuring there was a large effect of liming. Where lime was not given and the grass contained only 0·12% Ca in dry matter, asparagine, glutamine and proline all accumulated in the plant, but the concentration of γ-aminobutyric acid was much less.

TABLE 8

Effects of potassium fertiliser and liming on free amino acids, protein N and total N in grass sampled on 14 May from the Park Grass experiment

	With K fertiliser		Without K fertiliser	
	Plot 9a with lime	Plot 9d without lime	Plot 10a with lime	Plot 10d without lime
Amino compound	μg amino acid per 1·0 g of dry grass			
Aspartic acid	784	625	234	495
Serine	878	1003	1027	1515
Glutamic acid	2826	3218	1001	2637
Proline	540	1349	654	1489
γ-aminobutyric acid	1568	833	1633	1072
Ornithine	31	33	42	166
Lysine	320	116	278	303
Histidine	314	129	143	242
Arginine	203	147	168	387
Asparagine	2406	4282	1768	7597
Glutamine	1718	5248	1670	8257
Protein N, as % of total N	87·3	86·2	88·4	81·3
Total N, % of dry matter	3·28	3·75	3·28	4·14

Grass from all four treatments contained only traces of nitrate. Larger concentrations of NO_3-N would have been expected in grass sampled so soon after the ammonium sulphate was applied and this suggests that the soils were so acid that nitrification was very slow.

Both K fertiliser and lime affected the yield of grass when cut for hay on 20 June. Yields of dry matter (t ha^{-1}) were 2·56 from plot 10d, 3·78 from plot 10a, 4·56 from plot 9d and 6·59 from plot 9a. (Nowakowski, Johnston and Lazarus)

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Effects of nitrogen and phosphorus fertilisers on the composition of ryegrass. Italian ryegrass was grown in a glasshouse experiment in pots containing P-deficient soil from Hoosfield Exhaustion land at Rothamsted ($NaHCO_3$-soluble $P = 5{\cdot}7$ mg P kg^{-1} of soil). Nitrogen was given at two rates (40 and 160 mg N kg^{-1} of soil) as ammonium nitrate and phosphorus at three rates (5, 25 and 100 mg P kg^{-1} of soil) as calcium tetrahydrogen diorthophosphate. Each pot received uniform dressings of K and Mg fertilisers. The grass was cut 30 and 51 days after sowing. Table 9 records yields and composition of the first cut of grass. Increasing the nitrogen increased grass yields only with the two larger rates of phosphorus. With both rates of N, the P fertiliser increased yields and P concentrations in the grass. Table 9 shows that in grass grown with little P fertiliser free amino acids (particularly glutamine, asparagine, ethanolamine, glutamic acid, serine and aspartic acid) and nitrate N accumulated. Increasing amounts of P fertiliser decreased all these compounds and increased protein N. With the small rate of N fertiliser, γ-aminobutyric acid decreased with increasing amounts of P given (irrespective of whether expressed as $\mu g\ g^{-1}$ of dry grass or as % of total N) but with large dressings of N, it increased, expecially when expressed as % of total N. (Nowakowski, Mattingly and Lazarus)

TABLE 9

Effects of nitrogen and phosphorus fertilisers on yields, P concentrations, free amino acids, ammonium N, nitrate N, protein N and total N in a first cut of Italian ryegrass

	40 mg N kg^{-1} soil			160 mg N kg^{-1} soil		
Amount of P, mg kg^{-1} of soil	5	25	100	5	25	100
Dry matter, g pot^{-1}	2·78	3·84	4·41	2·86	5·74	7·99
P in dry matter, %	0·090	0·153	0·385	0·087	0·128	0·331
	μg amino acid per 1·0 g of dry grass					
Aspartic acid	977	435	311	1748	1279	670
Serine	448	175	147	1890	1047	490
Glutamic acid	952	431	289	2287	2054	756
Ethanolamine	631	131	132	1879	508	181
γ-aminobutyric acid	1475	1013	741	1458	1988	2102
Asparagine	2013	223	174	7279	4396	486
Glutamine	2749	326	264	15079	10 631	789
Ammonium N	112	65	65	272	201	89
Nitrate N	1406	156	62	7494	6520	935
Protein N as % of total N	83·4	92·1	91·8	59·6	69·0	90·2
Total N, % in dry matter	2·51	2·00	1·86	3·96	3·97	3·21

The effects of organic matter in Woburn soils on crop yields

The residues of organic matter applied to Woburn soils between 1965–70 (*Rothamsted Report for 1973*, Part 2, 98–151) were evaluated by growing potatoes (Pentland Crown) as first test crops in 1972 and 1973 and winter wheat (Cappelle-Desprez) as second test crops in 1973 and 1974. Half of the area, including the leys grown with clover or given nitrogen fertiliser since 1965, was ploughed up in autumn 1971; the other half, which was ploughed in autumn 1972, had grown winter rye in 1972 which was undersown with red clover as a green manure; no further additions of organic manures had been applied. On both potatoes and wheat a test of eight amounts of nitrogen was made (ranging from 0 to 350 kg N ha^{-1} for potatoes and 0 to 175 kg N ha^{-1} for wheat). Yields were good (up to 66 t ha^{-1} of potatoes in 1973 and 7 t ha^{-1} of wheat in 1974). Response curves for the nitrogen dressings were fitted to yields from each crop. Potato yields increased with all rates of nitrogen applied up to 350 kg N ha^{-1}. The curvilinear response was well represented by an inverse linear polynomial ($y = (A + Bx)/(1 + Dx)$), although for three treatments in 1972 (after the nitrogen-treated grass ley and the clover leys, and

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after fertilisers equivalent to the PKMg applied in farmyard manure) the curves were linear or concave, the yields increasing more rapidly at the higher than the lower rates of N applied. In all but one of the 16 treatment comparisons for winter wheat, split-line response curves (Boyd, *Proceedings of the 9th Congress of the International Potash Institute, Antibes, 1970*, (1971), 461–473) fitted the data satisfactorily. The effects of organic matter varied in different years and the results are discussed separately for the two crops in each year.

Potatoes. Yields in 1972 on plots previously given peat were larger than on plots given only equivalent amounts of fertiliser. The two response curves for N diverged and the benefits from peat increased with the amounts of N applied. Peat was inert in 1973; the results in 1972 probably reflect the better water-holding capacity of peat-treated soil in a dry summer.

Residues from straw had little effect on potatoes grown in 1972 but produced slightly more potatoes in 1973 than fertiliser-treated plots. In 1972 potatoes on plots which had grown green manures between 1965–71 outyielded the crop on plots given only fertilisers by 5–7 t ha^{-1} at all rates of applied N, a result very similar to that in 1967 (*Rothamsted Report for 1973*, Part 2,109–110). The benefits from green manures were negligible in 1973. Better yields of potatoes *can* be grown at Woburn in some years when they follow green manures than in an all-arable rotation; we do not know why the benefits are spectacular in some but not all years and further work is needed to establish how they act.

In both 1972 and 1973 yields of potatoes grown on plots containing residues from farmyard manure were greater by 5–10 t ha^{-1} and by 8–10 t ha^{-1} respectively than on plots that had received equivalent amounts of PKMg between 1966–71. Responses to applied nitrogen were linear in 1972 but diminished, with increasing amounts applied, in 1973.

Results after the clover ley were similar in both years to those after FYM. Yields were always more after the ley than on land which had received equivalent fertilisers but had not grown a ley. In 1973, following the ley, 49·0 t ha^{-1} were grown without adding any inorganic N; over 200 kg N ha^{-1} was required, on soils previously given equivalent fertilisers, to produce a comparable yield. Benefits from ploughing in the grass ley treated with nitrogen were somewhat less than from the clover ley, especially in 1972.

All organic matter treatments, except straw and the grass ley treated with nitrogen fertiliser (in 1972), and green manures (in 1973), produced 5–10 t ha^{-1} more potatoes than equivalent amounts of PKMg, even with the largest amounts of N applied to the crop (350 kg N ha^{-1}). In several cases (e.g. after peat and green manures in 1972 and after farmyard manure in 1973) the shape of the response curves suggested that, even with more nitrogen, yields on plots given only fertilisers would never have reached those from plots containing residues of organic manures. (The differences were unlikely to have been due to differences in PKMg supplies in the soil as liberal dressings were applied to the potatoes.)

Winter wheat. In both 1973 and 1974, residues from peat neither altered the total yield of the crop nor the optimum dressings of nitrogen, which were about 80 and 115 kg N ha^{-1} in the two years respectively. Residues from straw increased yields in 1973 (by 1·29 t ha^{-1}) but not in 1974 and green manures produced more wheat (+0·66 t ha^{-1}) in 1973 but not in 1974. The effects of farmyard manure residues were smaller in both years; yields from residues were slightly, but probably not significantly, greater than from equivalent fertilisers.

The residues from the clover ley produced more wheat in 1973, at all levels of applied N, than was obtained from plots given only equivalent fertilisers. The difference in

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maximum yields (+1·5 t ha^{-1}) was highly significant but, surprisingly, the same amount of nitrogen (63 kg N ha^{-1}) was needed to produce these yields on both soils. In 1974, the maximum wheat yields were practically identical (6·6 t ha^{-1} after clover and 6·4 t ha^{-1} after arable cropping) but the residues from the ley supplied some nitrogen to the crop and optimum dressings of nitrogen were 75 and 120 kg N ha^{-1} for the ley and arable cropping sequences respectively. The residues from the grass ley given nitrogen behaved similarly and maximum yields (6·9 t ha^{-1}) were achieved by applying 87 and 120 kg N ha^{-1} to soils in the ley and arable cropping sequences respectively.

The benefits from organic matter were smaller for winter wheat, grown three to four years after peat, straw and farmyard manure were last applied in 1970, than for potatoes. The benefits from the clover ley and the ley given nitrogen, which were ploughed up in 1971 and 1972, were larger than could be explained by the nitrogen they released in 1973 but not in 1974, when only the nitrogen (30–45 kg N ha^{-1}) released from the residues of the leys had any effect. (Mattingly, with Sparrow, Statistics Department)

Sulphur supplied by dry deposition

For some time we have noted that the sulphate content of drainage water at Saxmundham and other stations is greater than the amount supplied by rain and fertilisers together. The explanation may lie in extra quantities deposited directly on soil as particulate material and SO_2 sorbed from the air. Measurements of this 'dry deposition' of sulphur on vegetation and on soil have been made by several workers (for example Bromfield & Williams, *Nature, London* (1974), **252**, 470–471). The possibility that 'dry deposition' accounts for this additional sulphate S was explored by two independent measurements made at Rothamsted in 1969 and 1974.

In 1969 the SO_4-S content of drainage water from the 20-in. deep one-thousandth acre drain gauge at Rothamsted was 58·4 kg S ha^{-1}. Subtracting S in rainwater for that year (33 kg S ha^{-1}) leaves 25·3 kg S ha^{-1} (Jenkinson's results (*Rothamsted Report for 1970*, Part 2, 113–137) show that less than 1 kg S would be released by mineralisation of organic matter in this soil; this quantity can be ignored.) In 1974 the increase of total S in soil placed in a dish inside a Stevenson meteorological screen for 60 days from mid-February was equal to 45·2 μg cm^{-2} of soil exposed. The deposition rate was $8{\cdot}72 \times 10^{-12}$ g cm^{-2} s^{-1} (which is near the annual mean given by Stevenson (*Quarterly Journal of the Royal Meteorological Society* (1968), **94**, 56–70). These results give an annual dry deposition of 27·5 kg S ha^{-1}. Agreement between the two methods of estimating the extra sulphur directly deposited is satisfactory and this fraction must always be measured when constructing balances for movement of sulphur from air to soil and into drainage water. (Bromfield and Williams)

The behaviour of exchangeable aluminium in acid soils

In previous work, we had assumed that the charge on hydrolysed aluminium ions in the adsorbed and solution phases of soil suspensions was the same and was governed by the pH of the soil (*Rothamsted Report for 1969*, Part 1, 65–66). However, when adsorbed aluminium ions were exchanged into solution using M-NH_4Cl solutions adjusted to the pH of the soil, the pH of the effluent solution was invariably more, e.g. 0·4 units at about pH 4 (*Journal of Soil Science* (1972), **23**, 163–176). This consistent observation lead us to suspect that adsorbed aluminium ions were more hydrolysed and, therefore, had a smaller positive charge than those in the equilibrium solution. This hypothesis was tested by adsorbing aluminium ions from mixed K + Al solutions of various compositions and pHs on NH_4^+-saturated soil (Batcombe series; pH 3·7) and equating the adsorbed K and Al ions to the NH_4^+ released. These calculations clearly demonstrated that even in

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the pH range 3·2–4·0, when >95% of soluble Al is in the Al^{3+} form, from 20 to 100% of the adsorbed Al was in the $Al(OH)^{2+}$ form and the remainder as Al^{3+}. (Lim and Talibudeen)

Effects on the growth of tropical legumes. Legumes are grown as cover crops between young stands of rubber and oil palm. Most of the soils are acid and exchangeable Al interacts with the uptake of potassium and phosphate. The effects of the K–Al interaction on *Pueraria phaseoloides* (a tropical legume of unknown Al-tolerance) and on *Macroptilium lathyroides* (an Al-tolerant 'temperate' legume) were compared in a pot experiment using a Batcombe series soil (pH 3·7). Small concentrations of Al ($<2{\cdot}5\times10^{-4}$M) stimulated growth of both species, maximum yield response being 15% for *Pueraria* and 35% for *Macroptilium*. As no specific nutrient effect has been established for Al such increases in yield can only be ascribed to added Al displacing K from exchange sites on soil, making it more readily available to roots. Similar yield stimulation of lucerne and trefoil by 10^{-5}M Al in soil was reported by Macleod and Jackson (*Canadian Journal of Soil Science* (1965), **45**, 221–234) and of tea by Sivasubramaniam and Talibudeen (*Journal of the Science of Food and Agriculture* (1971), **22**, 325–329). Aluminium concentrations $>2{\cdot}5\times10^{-4}$M decreased yields of both legumes, maximum yields being obtained at molar K/Al ratios of *c*. 1·5. As with tea, a significant and positive linear correlation was observed between Al and P uptake after ten weeks growth of both species, such that the molar Al/P ratio in the plant was *c*. 2. (Lim and Talibudeen)

Boron in Woburn soils

Soils from the Woburn Organic Manuring experiment (*Rothamsted Report for 1973*, Part 2, 98–151) were sampled in September 1973 to a depth of 90 cm and hot-water soluble B in the soils was measured at each of six depths. Between 1965–70 the total amounts of boron applied in peat and farmyard manure to these soils were 1·23 and 1·25 kg B ha^{-1} and removals by the crops were 0·20 and 0·23 kg B ha^{-1} respectively. Negligible amounts were added in fertilisers and 0·18 and 0·19 kg B ha^{-1} were removed by crops from plots given amounts of fertilisers equivalent to the nutrients applied in straw + superphosphate or in farmyard manure. The largest amounts of water-soluble boron were in the 30–45 cm layer on plots given peat, farmyard manure or fertilisers and in the 15–30 cm layer in the plot given fertilisers equivalent to the nutrients in straw + superphosphate. The total amounts of water-soluble B, to a depth of 90 cm, were less on plots given peat or farmyard manure than on the plots given equivalent fertilisers.On this evidence, it seems that none of the boron applied in the organic manures has been retained by the soils in water-soluble form. (Chater and Mattingly)

Silicon in natural waters

Silicon is a universal constituent of 'natural' waters but is usually ignored. Nevertheless it may be important in studying eutrophication problems as it is an essential nutrient for some micro-organisms (particularly diatoms). Silicon concentrations in drainage water may also help to elucidate pedogenetic processes occurring in surface soils. Silicates occur in natural waters combined with alkali metal or alkaline earth cations in true solution; the range is from soft moorland water containing about 1 mg Si $litre^{-1}$ to hard waters from Chalk formations which average about 18 mg $litre^{-1}$ of Si. The automated method used for measuring Si concentrations in rain, drainage and river waters was that described by Wilson (*Analyst, London* (1965), **90**, 270–277).

Rainwater. Concentrations in samples from Rothamsted, Woburn and Saxmundham averaged 0·07 mg $litre^{-1}$ of Si (range 0–0·55).

Land drainage water from these three Stations and Broom's Barn contained, on average, 3–5 mg litre^{-1} of Si (range 1·4–13·4) but there was considerable local variation. At Woburn, drainage originating in Greensand formations had most Si (4–9 mg litre^{-1}), drainage from resorted Oxford Clay had least (2–4 mg litre^{-1}). Average concentrations in Broom's Barn drainage from heavier textured soils varied from 1·7–5 mg litre^{-1}. There was little difference in average silicon contents of drainage at Saxmundham from arable crops (3·0 mg litre^{-1}) and from grass (3·5 mg litre^{-1}).

Borehole water is supplied to Rothamsted and Woburn and both sources contain ten times as much Si as rainwater and nearly twice as much as is in land-drainage at these sites. Large concentrations (8–9 mg Si litre^{-1}) were found in borehole water at Rothamsted and Broom's Barn (both pump water from Chalk); Si in spring water from Greensand at Woburn was also large (11 mg litre^{-1}). (Williams and Messer)

Mechanical fractionation of potatoes

The purpose of work on the mechanical dehydration of potato tubers was explained in last year's Report (pp. 63–64). Further progress has been made in studies of methods of pressing water from potato pulp; evaporating the water takes about a thousand times as much energy as pressing it out. Fluid can be pressed from pulped potato tubers on a practical scale if they can be disintegrated enough to liberate juice without making a pulp that is too fluid to be contained in a press. A grooved roller works best but other arrangements were, and will be, tried. Pulp containing 32–33% dry matter can be made from pulp initially containing 21–23% by light pressing. Methods depending on suction are being tried. Partly dewatered pulp can be pressed to >40% dry matter in a belt press. It is then firm enough for pressing hydraulically to 50% dry matter. Without preservatives, the pulp would usually deteriorate within a few days but adding more than 0·3% propionic acid to pulp containing 50–60% dry matter prevented visible deterioration during more than three months storage in unsealed polyethylene bags at 20°C. Wetter pulp could be preserved using more propionic acid. Uses will have to be found for the soluble components in the juice which contains about one-seventh of the original dry matter of the tubers. (Pirie and Carruthers, with Lacey, Plant Pathology Department)

Protein in potato haulm. From the haulm of main crop potatoes, taken at the time when haulm is being killed, 0·2–0·3 t ha^{-1} of dry protein can be extracted. There is also 1–2 t ha^{-1} of fibre with the composition of good hay. Judging from the evidence we have collected so far, it would not be advisable to harvest potatoes early purely to gain more fibre and extracted protein—the loss of protein and dry matter, resulting from the diminished yield of tubers, is about as great. However, the fact that useful material can be made from the haulm should be borne in mind when the date of haulm killing is being decided, and tubers are more easily lifted when much of the haulm has been removed rather than killed. (Pirie and Carruthers)

Staff and visiting workers

A. R. Bromfield was seconded to the Ministry of Overseas Development to work on sulphur cycles in East African agriculture. Mrs. Maureen Broom, R. C. Flint and G. Panther left. The following workers were appointed: R. W. H. Brown (evaluation of plant nutrient residues), K. W. T. Goulding (cation exchange), Mrs. I. Jasko (analytical services) and G. J. Smith (radiochemical assays).

These visitors worked in the Department during the year: Mr. J. H. Ahmed (Bahrain), Mr. F. Cabrera (Spain), Mr. K. S. Chan (Malaysia), Mr. M. W. Fotyma (Poland),

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Dr. A. Hamid (Pakistan), Mr. M. C. Igbokwe (Nigeria), Mr. T. S. Lim (Malaysia), Mr. R. Mukuka (Zambia), Mr. S. Osafo-Kroffah (Ghana), Professor A. M. Posner (Australia) and Mr. K. Y. Tan (Malaysia). A. J. Sparkes was a sandwich course student.

Blanche Benzian attended a Symposium at Wageningen (Netherlands) on 'Stand Establishment' organised by the International Union of Forestry Research Organisations. She was also invited to visit the Department of Soil Fertility and Plant Nutrition of the Royal Veterinary and Agricultural University at Copenhagen; the visit was sponsored jointly by the Department, the Danish Societies of Soil Science and Forestry, and the British Council. J. Bolton attended the 7th International Colloquium on Plant Analysis and Fertiliser Problems at Hanover, Germany, in September with the help of a grant from the Agricultural Research Council. G. W. Cooke led the British Delegation to a CENTO Seminar on Fertiliser Analytical Methods, Sampling and Quality Control held in Lahore, Pakistan. Cooke also attended the 10th Congress of the International Potash Institute held in Budapest as a guest of the Institute.

T. S. Lim did a research project in the Department as part of a course at Reading University; he was awarded the M.Sc. degree.

Publications

Thesis

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https://doi.org/10.23637/ERADOC-1-131