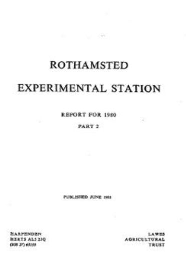
Rothamsted Experimental Station Report for 1980 Part 2


ROTHAMSTED
EXPERIMENTAL STATION
REPORT FOR 1980
PART 2

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A. E. Johnston, P. R. Poulton and J. McEwen

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The Soils of Rothamsted Farm
The carbon and nitrogen content of the soils and the effect of changes in crop rotation and manuring on soil pH, P, K and Mg

A. E. JOHNSTON, P. R. POULTON and J. McEWEN

Abstract

The recent cropping of Rothamsted Farm which was designed to make maximum use of land for experiments with a number of previous cropping options, is described, together with what is known of historic cropping.

Changes in manuring and liming during the last 20 years are described and their effects on readily soluble P and K in soil and soil pH are given. The major factor affecting the amount of soluble P and K is the frequency of growing potatoes which are generously manured and leave large residues of P and K in soil.

The present levels of soil carbon and nitrogen are related to historic cropping rather than recent changes.

Introduction

Lawes and Gilbert's field work on crop nutrition was done in large experiments laid down for many years on the same site; several of these, the Classical experiments, still remain. The rest of the Rothamsted estate was farmed commercially and the existing records suggest that a four- or five-course rotation was practised on the arable area.

The experimental programme expanded slowly from the early 1920s until the 1960s with annual and short-term experiments being made on the main arable crops. In the early part of this period it was usually quite easy to find suitable sites for any crop proposed because the land was still farmed on a four- or five-course rotation. However, in the late 1950s the rotation was lengthened by the inclusion of more cereals and it became increasingly difficult to find suitable sites, especially when cereal experiments required sites following non-cereals.

This paper discusses modifications in cropping made to give maximum use of land whilst retaining experimental sites with a number of previous cropping options. Changes in manuring and liming and their effect on soil pH and readily soluble P and K are given. The present levels of soil carbon and nitrogen are related to historic cropping rather than recent changes.

Present land use

The size of the Farm was increased when the Lawes Agricultural Trust purchased two fields, Whittlocks and Delafield, in 1955 and various other areas including Geescroft Wilderness and Road Piece in 1956. The acquisition of Scout Farm in 1965 added nearly 91 ha to Rothamsted Farm which now extends to about 330 ha, including woodland, of which 264 ha are farmed. Many of the fields, and something of their past cropping history, are listed in Table 1. Below we have described seven groups of fields according to their present use.

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TABLE 1

Area, cropping system in 1978/79 and cropping history of most fields of Rothamsted Farm

Field	Area[a] ha	Cropping: System[b] 1978/79	Cropping: In[c] 1623	Cropping: History
Appletree	6·1	PG	A	Grass; 1906–41 grass; 1942 oats; 1943–58 grass; 1959–61 arable; 1962–79 grass.
Black Horse I	9·3	OA	—	Unknown[d]; 1962–79 arable.
Black Horse II	6·7	OA	—	Unknown; 1962–64 barley/clover; 1965–79 arable.
Bones Close	6·0	PG	—	Reclaimed from woodland 1942–44; 1945–48 arable; 1949–79 grass.
Bylands	3·0	OA	—	Unknown; 1962–79 arable.
Claycroft	4·4	CD	A	Woodland since 1900?; reclaimed 1941–42; 1943–59 grass; 1969–79 arable; 1974–79 parts grass.
Delafield	2·6	SR	—	Orchard; 1959–79 arable.
Delharding	6·5	OA	A	Grass since 1870s; 1942–49 arable; 1950–57 grass/clover; 1958–66 arable; 1967–68 grass; 1969–79 arable.
Delharding S.W. Corner	—	RS	A	Grass since 1870s; ploughed 1941; 1942–79 fallow with occasional cropping.
Dell Piece	1·8	SR	W	As Bones Close; 1974–79 arable.
Drapers	5·1	OA	—	Unknown; 1966–79 arable.
Flint	7·1	PG	—	Unknown; 1966–79 grass.
Fosters Corner	1·0	SR	A	Arable; 1928–45 grass; 1946–48 arable; 1949–55 mixed ley; 1956–79 arable.
Fosters West	0·9	SR	A	Arable.
Furzefield	1·2	CD	W	Reclaimed from woodland 1941; 1942–48 arable; 1949–55 grass; 1956–79 arable.
Geescroft	1·4	SR	G	Possibly grass since 1623; 1941–51 grass; 1952–79 arable.
Great Field I	4·7	OA	A	Grass since 1870s; 1953–79 arable.
Great Field II	3·6	OA	A	Grass since 1870s; 1943–44 arable; 1945–51 grass; 1952–79 arable; 1959–61 parts in grass.
Great Harpenden I	5·1	SR	A	Arable; 1910–51 arable; 1952–56 uncertain; 1957–59 grass; 1960–79 arable; 1976–79 parts grass.
Great Harpenden II	3·6	SR	A	Arable; 1910–27 arable; 1928–40 grass; 1941–58 arable; 1959–67 grass; 1968–79 arable.
Great Knott I	4·0	SR	G	1909–28 arable; 1929–46 grass; 1947–79 arable; 1960–61 parts in grass.
Great Knott II	4·5	SR	G	1909–28 arable; 1929–41 grass; 1942–48 arable; 1952–55 grass; 1956–79 arable.
Great Knott III	5·1	SR	G	1909–79 arable.
Harwoods Piece	2·5	CD	A	1943–79 arable.
Highfield IV	2·0	SR	A	Grass since 1880s; 1900–50 uncertain; 1951–79 arable.
Highfield V	2·0	RS	A	Grass since 1700s; 1951–66 arable; 1967–70 grass; 1971–79 arable.
Highfield VI	2·0	RS	A	Grass since 1700s; 1951–66 arable; 1967–70 grass; 1971–79 arable.
Highfield VII, VIII & IX	9·5	PG/RS	G/A	Northern half grass since 1623; southern half since 1700s.
Highfield Drive	0·5	CD	A	Uncertain; 1951–79 arable.
Highfield Weighbridge Piece	1·5	PG	G	Grass since 1623.

Little Knott I	2·0	OA	G	1912–24 arable; 1925–42 grass; 1943–78 arable; 1979 clover.
Little Knott II	2·4	PG	G	1912–24 arable; 1925–42 grass; 1943–73 grass?; 1974–79 grass.
Little Hoos	3·8	SR	A	1904–33 arable; 1934–41 arable?; 1942–79 arable; lucerne/cocksfoot intercropped 1959–62.
Long Hoos I & II	2·7	SR	A	1913–33 various; 1934–43 arable?; 1944–62 arable; 1963–66 mixed ley; 1967–79 arable.
Long Hoos III	2·5	SR	A	1913–33 various; 1934–43 arable?; 1944–79 arable.
Meadow	9·5	OA	—	Unknown; 1966 grass; 1967–79 arable.
New Zealand	5·1	PG	A	Arable; 1907–15 grass; 1916–28 arable; 1929–79 grass; 1944–45 arable; 1964–69 parts arable.
Osier	6·4	PG	—	Unknown; 1966–79 grass.
Parklands	7·3	PG	G	Parts possibly grass since 1623; 1906–79 grass; 1943 oats.
Pastures	6·1	SR	G	1909–39 various; 1940–49 grass; 1950–56 arable; 1957–63 grass; 1964–79 various.
Road Piece East	1·9	PG	—	Rough grass; 1969–79 grass.
Road Piece West	2·9	PG/RS	A	Grass since 1700s; 1906–42 grass; 1943–44 arable; 1945–79 grass; 1977 fallow.
Sawyers I S.W. Corner	—	RS	A	Arable; 1928–41 grass; ploughed 1941; fallow since 1950s.
Sawyers II	3·6	RS	A	Arable; 1928–39 grass; 1940–54 arable; 1955–60 grass; 1961–64 arable; 1965–73 grass; 1974–79 arable.
Sawyers III	3·6	RS	A	Arable; 1928–40 grass; 1941–54 arable; 1955–60 grass; 1961–68 arable; 1969–76 grass; 1977–79 arable.
Scout	5·5	OA	—	Unknown; 1966–67 grass; 1968–79 arable.
Stackyard	3·6	SR	G	1906–28 various; 1929–45 grass; 1946–79 arable.
Stubbings	1·7	SR	—	Unknown; 1966–79 arable.
Summerdells I	5·5	SR	—	Unknown; 1966–79 arable.
Summerdells II	6·0	SR	—	Unknown; 1966–79 arable.
Ver	1·9	PG	—	Unknown; 1966–79 grass.
Webbs	3·4	OA	—	Unknown; 1966–79 arable.
West Barnfield I	1·8	SR	A	1913–28 arable; 1929–45 grass; 1946–63 arable; 1964–66 grass; 1967–79 arable.
West Barnfield II	3·2	CD	A	1913–42 arable; 1943–48 grass; 1949–58 arable; 1959 grass; 1960–63 arable; 1964–66 grass; 1967–79 arable.
White Horse I	4·0	SR	—	Unknown; 1966–79 arable.
White Horse II	6·4	SR	—	Unknown; 1966–70 arable; 1971–73 grass; 1974–79 arable.
Whittlocks	7·7	SR	A	Orchard; 1959–79 arable.

(a) Areas may be approximate where field boundaries have changed.
(b) Cropping system 1978/79; PG—Permanent Grass; SR—Fields in Standard Rotation; CD—Cereal Disease fields; OA—Other arable fields not in Standard Rotation; RS—Restricted Sites.
(c) From a map of Rothamsted published in 1623. Some field boundaries have changed little; in 1623 these fields were in arable (A), grass (G) or woodland (W).
(d) Fields with 'unknown' cropping history before 1962–66 were those on Scout Farm purchased in 1965.

Fields in the Standard Rotation (about 84 ha). In the early 1960s it was decided to farm much of the arable land on a standard seven-course rotation of one break crop, two cereals, two break crops, two cereals. This rotation was introduced in 1966 and every effort is made to keep its essential features which are cereals following one- or two-year breaks, second cereals and reasonable intervals between the individual break crops to avoid their soil-borne diseases. The break crops include beans, oats, potatoes and, less frequently, one- or two-year grass leys. McEwen (1968) has discussed in detail the reasons for adopting this particular rotation. Occasionally the rotation has to be broken, usually only on a part of a field, to accommodate experiments which last more than one year and contain a sequence of crops not in the Standard Rotation.

Cereal Disease Fields (about 12 ha). In addition to the arable land brought into the Standard Rotation some fields were set aside for more frequent cereal cropping to aid studies on soil-borne diseases.

Restricted Sites (about 24 ha). In 1954 a number of fields were classified according to their usefulness for tests involving P and K and these fields eventually became known as the Restricted Sites. Some of these sites on both arable and grassland are maintained with restrictions on manuring and liming to provide sites where critical experiments on P, K and pH can be done. The low nutrient status of the soils on the arable Restricted Sites severely limits the range of crops which can be grown successfully.

Classical and Long-term experiments. These occupy all or much of certain fields. The Classicals include Agdell, the Alternate Wheat and Fallow, Barnfield, Broadbalk, Exhaustion Land, Hoosfield Continuous Barley and Park Grass. Notable amongst the Long-term experiments are the ley arable rotations on Highfield and Fosters and the liming experiment on Sawyers I. For most of these, detailed accounts of the effects of manuring and cropping on soil nutrient status have been given by various authors.

Permanent grassland. The old grassland fields are an almost irreplaceable asset because the development of a well-established permanent sward, and the level of soil organic matter associated with it, can take many years. Richardson (1938) was the first to show that it takes about 100 years to change from the equilibrium organic matter content of an old arable soil at Rothamsted to the equilibrium value under old permanent grass.

Small Plots land. Some fields are used only for small plot experiments and, as these are not managed in the same way as the rest of the farm, they are not discussed here.

Other land. Of the remaining land some is in arable cultivation outside the Standard Rotation, much of this being on the fields of Scout Farm, and some is woodland.

Soil surveys

The soils of Rothamsted Farm have been surveyed by members of the Soil Survey and a map showing the distribution of the various soil series published (Rothamsted Experimental Station, 1977). Detailed descriptions have been given of the soils of Broadbalk (Avery, Bullock, Catt, Ormerod & Weir, 1969) and Barnfield (Avery, Bullock, Catt, Newman, Rayner & Weir, 1972). A general description of the nutrient status of the soils has not been published previously although various surveys have been made.

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Early surveys. Very limited numbers of soil samples were taken and analysed in the 1920s and 1930s but little use can now be made of these data. In the early 1940s R. G. Warren sampled a number of fields in great detail, mainly to find sites suitable for tests of phosphatic fertilisers. Warren used 0·3N-HCl to extract readily soluble P from soil, but this extractant was replaced in the mid-1950s by 0·5 M-$NaHCO_3$. We have no satisfactory way of converting these data to 'bicarbonate values' so his results are only of historic interest. Warren also produced maps showing the variability of pH within the fields he sampled; these maps were of great value in showing an unexpected source of non-uniformity in experimental sites. Subsequently in the 1950s and early 1960s poor growth on fields other than those sampled by Warren was related to soil acidity.

Surveys in 1950–70. The realisation that patches of quite severe acidity had developed in fields where the soils were thought to be at least neutral or with small reserves of free $CaCO_3$, led G. W. Cooke to start surveys of all the farm fields. The first was organised by R. J. B. Williams during 1957–61 when a number of samples were taken from each field. The pH of each soil was determined and liming of a number of fields recommended. Nitrogen, carbon and P and K soluble in dilute acid were determined in most samples.

The second survey, which took 3 years, was started in 1966 when the Standard Rotation was introduced. It was organised by F. V. Widdowson. One of its aims was to see how effective the chalk dressings applied in the early 1960s had been in raising soil pH. Each field was divided into 1 acre blocks and the soils were sampled to plough depth. The pH of each soil was determined and any acidity within a field was corrected by applying suitable rates of chalk. Widdowson also initiated the present liming policy of regular chalking, details of which are given in the next section.

In 1967 Marie Blakemore made a less detailed sampling of most of the fields in the Standard Rotation and these soils were analysed for bicarbonate soluble P and exchangeable K.

The present survey. The 1978–79 survey was undertaken initially to see what effects the corrective and rotational chalk dressings had had on soil pH and how soil P and K status had changed with cropping and manuring now that the Standard Rotation had been in operation for some years. It was then extended to most of the Farm fields except those with Classical, Long-term and small plot experiments. Arable soils were again sampled to plough depth, which varies between 20 to 23 cm, whilst grassland fields were sampled to 23 cm. The larger fields were divided into eight approximately equal areas and the smaller fields into four or six. From each area a composite sample of 20 soil cores was taken with a 2·5 cm diameter semi-cylinder auger. After air-drying, the soils were passed through a 2 mm sieve and bicarbonate soluble P, exchangeable K, Mg, Ca, Na and pH in a 1:2·5 soil water suspension were determined on this sample. Nitrogen and carbon were determined on a subsample ground to pass a 44 mesh sieve. The results are in Table 2.

Liming and soil pH

Many of the soils of Rothamsted Farm were originally acid (Rothamsted Experimental Station, 1977). The arable fields were heavily limed, probably well before 1800, by small gangs of men who dug out the underlying chalk, carried and then spread it by hand (Gardner & Garner, 1957, p. 15). Unquestionably this hand work must have resulted in patchy distribution of the chalk especially on those areas furthest from the pits; details of the existing pattern of chalk in the topsoils of Hoosfield have been given by Warren and Johnston (1967) and Johnston and Poulton (1977).

Uneven distribution of the original chalk dressings coupled with natural leaching of

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TABLE 2

Carbon, nitrogen, pH, P, K, Ca, Mg and Na in soils of Rothamsted Farm 1978/79[a]

Field	pH in water	Total carbon % C	Total nitrogen % N	C/N ratio	$NaHCO_3$ soluble P mg kg^{-1}	Exchangeable cations, mg kg^{-1} K	Ca	Mg	Na
Appletree	6·6	2·95	0·288	10·2	25	132	3710	64	36
Black Horse I	7·2	1·69	0·173	9·8	26	111	4850	32	16
Black Horse II	7·3	1·77	0·188	9·4	22	128	4390	30	20
Bones Close	6·9	2·66	0·259	10·3	28	122	4020	52	23
Bylands	7·6	1·84	0·185	9·9	29	104	6470	31	18
Claycroft	7·7	2·16	0·227	9·5	29	230	7650	66	20
Delafield	7·0	1·16	0·138	8·4	74	302	2930	27	10
Delharding	6·4	1·82	0·204	8·9	18	142	3470	44	14
Delharding S.W. Corner	5·0	1·44	0·159	9·1	7	80	1770	48	10
Dell Piece	7·1	2·41	0·245	9·8	42	262	5040	85	17
Drapers	7·4	2·01	0·202	10·0	59	197	6370	49	12
Flint	6·7	6·11	0·588	10·4	54	279	5890	100	26
Fosters Corner	7·5	1·48	0·169	8·8	34	143	5290	35	15
Fosters West	7·1	1·35	0·153	8·8	46	138	3150	37	14
Furzefield	7·1	1·91	0·199	9·6	51	239	4570	52	13
Geescroft	7·3	1·47	0·160	9·2	35	169	3550	44	10
Great Field I	7·2	1·55	0·172	9·0	29	147	3500	40	15
Great Field II	7·1	1·65	0·180	9·2	24	122	3480	36	17
Great Harpenden I	7·1	1·42	0·156	9·1	57	177	3510	39	12
Great Harpenden II	7·3	1·62	0·179	9·1	39	162	3810	48	10
Great Knott I	6·8	1·57	0·175	9·0	68	319	3310	47	12
Great Knott II	7·4	1·68	0·185	9·1	50	221	6170	72	14
Great Knott III	7·4	1·67	0·175	9·5	68	244	4460	62	11
Harwoods Piece	7·6	2·26	0·205	11·0	46	203	7520	69	15
Highfield IV	6·7	1·63	0·178	9·2	26	136	2950	38	11
Highfield V	5·7	2·31	0·233	9·9	8	61	2700	47	18
Highfield VI	5·9	2·49	0·252	9·9	34	90	3260	57	17
Highfield VII, VIII & IX	5·8	3·80	0·383	9·9	15	194	3380	98	17
Highfield Drive	6·7	1·73	0·184	9·4	20	139	2960	59	13
Highfield Weighbridge Piece	6·6	3·65	0·356	10·3	78	293	4620	101	29

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Little Knott I	7·3	1·61	0·179	9·0	36	203	3480	42	12
Little Knott II	6·9	3·65	0·370	9·9	32	185	4830	107	29
Little Hoos	7·7	1·30	0·159	8·2	33	133	5360	37	14
Long Hoos I & II	7·3	1·47	0·151	9·7	45	159	3510	53	10
Long Hoos III	7·0	1·51	0·151	10·0	63	234	3190	38	10
Meadow	6·9	2·30	0·237	9·7	31	153	3390	50	13
New Zealand	6·8	3·26	0·311	10·5	41	147	4680	67	19
Osier	6·8	4·30	0·422	10·2	48	328	4410	75	25
Parklands	6·6	3·68	0·356	10·3	45	260	4280	99	23
Pastures	7·4	1·53	0·171	8·9	44	181	3640	45	13
Road Piece East	5·9	3·23	0·329	9·8	12	150	2990	58	18
Road Piece West	5·4	3·38	0·323	10·5	17	112	2600	74	15
Sawyers I S.W. Corner	4·7	0·83	0·107	7·8	11	86	1100	38	5
Sawyers II	4·9	1·52	0·157	9·7	5	43	1420	35	—
Sawyers III	6·5	1·78	0·197	9·0	6	57	3150	35	10
Scout	6·7	2·24	0·220	10·2	26	199	2910	37	21
Stackyard	7·2	1·62	0·182	8·9	36	148	3880	45	10
Stubbings	7·0	1·83	0·202	9·1	31	170	6280	63	14
Summerdells I	7·8	1·79	0·188	9·5	28	158	6630	54	19
Summerdells II	7·4	1·53	0·170	9·0	20	135	4510	49	13
Ver	7·0	6·01	0·586	10·3	60	598	6750	132	18
Webbs	7·5	2·19	0·233	9·4	39	197	7860	59	15
West Barnfield I	6·5	1·33	0·155	8·6	38	176	2770	27	13
West Barnfield II	7·0	1·45	0·167	8·7	11	77	3560	36	15
White Horse I	7·9	2·08	0·229	9·1	23	224	8680	78	19
White Horse II	7·7	2·17	0·246	8·8	43	243	8890	64	23
Whittlocks	6·8	1·27	0·144	8·8	38	191	2760	34	12

(a) Analytical methods: pH was measured in a soil: water (1:2·5) suspension.
Total carbon (on soils <44 mesh) was analysed by the Tinsley method described by Bremner and Jenkinson (1960)
Total nitrogen (on soils <44 mesh) by Kjeldahl digestion using a Cu-Se catalyst. NH_3 in the digest estimated by distillation
Sodium bicarbonate-soluble P was measured, after extraction with 0·5 M-$NaHCO_3$ (Olsen *et al.*, 1954), on the Technican Auto-Analyzer (Salt, 1968)
Exchangeable cations were leached from soils with N ammonium acetate (Metson, 1956). Leachate evaporated to dryness, residue oxidised with 0·5 ml conc. HNO_3 and dissolved in 10 ml 0·5 N-HCl. K, Ca and Na were measured by emission and Mg by atomic absorption spectrophotometry

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calcium from the topsoils, enhanced by the use of ammonium sulphate, were all contributory factors to the development of patches of acid soils in some of the arable fields first shown in Warren's survey. Following Williams' more detailed survey in 1957–60 corrective chalk dressings were applied to the more acid soils. During 1966–67, 274 'acre plots' of Rothamsted Farm were sampled in Widdowson's survey, and of these, 106 had mean pH values below 6·5 and 46 below 6·0. Of 118 'acre plots' sampled on Scout Farm only 29 had a pH below 6·5. All the more acid soils received corrective chalk dressings before getting the standard rotational liming (Widdowson & Flint, 1971).

Widdowson suggested that the standard chalk dressing should be 3 tons chalk per acre (7·5 t ha^{-1}) once every 7 years. This dressing was based on an assumed annual loss of calcium equivalent to 8 cwt $CaCO_3$ per acre which was rounded up to 60 cwt for the total loss in 7 years. This chalk was applied to the stubble of the second cereal before the 1 year break. Subsequently the policy of applying this rate of chalk every 7 years was extended to all grassland and arable fields outside the Standard Rotation except the Restricted Sites.

The reason for adopting a policy of maintaining arable fields at about pH 7 was because large parts of many fields still had small reserves of free $CaCO_3$ and soil pH was near, or just above, 7. It was therefore preferable to lime to achieve soil uniformity near pH 7 rather than wait for soil pH to fall to perhaps pH 6·5. The 1966/67 survey had shown that the soils in only a few arable fields, Long Hoos III, Highfield IV and Furzefield, had

TABLE 3

Effect of chalk dressings on soil pH of various Rothamsted fields

	pH in	
Arable fields	1966/67	1978/79
West Barnfield II	6·6	7·0
Great Harpenden I	6·7	7·1
Great Harpenden II	6·9	7·3
Pastures	6·9	7·4
Stackyard	6·7	7·2
Fosters West	6·6	7·1
Harwoods Piece	7·0	7·6
Mean	6·8	7·2
Summerdells I	7·5	7·8
Summerdells II	7·2	7·4
Geescroft	7·2	7·3
Claycroft	7·4	7·7
Mean	7·3	7·6
Great Knott III	7·1	7·4
Long Hoos I & II	7·1	7·3
Mean	7·1	7·4
Long Hoos III	6·4	7·0
Highfield IV	6·2	6·7
Furzefield	6·4	7·1
Mean	6·3	6·9
	pH in	
Grass fields	1959/60	1978/79
Appletree	6·6	6·6
Bones Close	7·0	6·9
Highfield Weighbridge Piece	6·2	6·6
Little Knott II	6·6	6·9
New Zealand	6·6	6·8
Parklands	6·4	6·6
Road Piece East	6·4	5·9

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pH values less than 6·5 (Table 3). Although these soils were not acutely acid their pH was different from that on many other arable soils on the Farm. This difference could jeopardise the interpretation and comparison of results from experiments made on more than one field, especially if there was some unrecognised interaction between pH and one of the factors being studied.

The corrective chalk dressing and rotational liming were successful in maintaining soil pH. The recent survey found no very acid patches in any of the fields. Only on parts of Great Knott I, Delafield and Sawyers III were there areas of soil with pH values between 0·5 and 1·0 pH unit less than the rest of the field and corrective chalk dressings were applied to these in autumn 1980.

Soils which were at pH 6·8 in 1966/67 and which have received two standard dressings of chalk were at pH 7·2 in 1978/79 whilst soils at pH 7·2 are now pH 7·5 (Table 3). These changes in pH suggest that the current dressing is more than sufficient to maintain soil pH and a small amount of free calcium carbonate may have accumulated in these soils.

Liming the grass fields has maintained their pH values between 1959/60 and 1978/79 (Table 3) except for Road Piece East which became more acid because it was a Restricted Site given no lime.

When Widdowson calculated the standard dressing (7·5 t $CaCO_3$ ha^{-1}) there was less experimental evidence on loss of calcium from soil than exists today. On Park Grass, Warren and Johnston (1964) had shown that between 0·7 and 1·0 t $CaCO_3$ ha^{-1} was lost each year whilst on the Highfield Ley Arable experiment soil pH fell from 6·8 to 6·3 between 1956 and 1972 despite regular 6-yearly chalk dressings which supplied a total of 18 t $CaCO_3$ ha^{-1}. Subsequently Gasser (1973) summarised existing data on calcium losses and gave minimum, median and maximum losses at various pH values whilst Bolton (1977) gave a formula for calculating leaching losses based on data from Rothamsted and Woburn experiments. Both authors re-emphasised that calcium was leached from soil accompanying nitrate whilst Bolton stressed the additional effect of bicarbonate.

Using either Gasser's estimates or Bolton's formula for calculating losses of $CaCO_3$ from Rothamsted soil at pH 7·0 suggests that about 4·5 t ha^{-1} $CaCO_3$ might be lost in 7 years where there is little change in soil organic matter and no excessive residual nitrate from fertiliser dressings. Thus the present 7·5 t ha^{-1} dressing of chalk should be more than sufficient on most Rothamsted fields and recent increases in pH confirm this. Widdowson's estimate was based on data from soils with appreciably more organic matter than most Rothamsted soils, so that nitrate and bicarbonate from the mineralisation of organic matter could have played an important role in leaching more than average amounts of calcium from these soils.

Manuring and soil phosphorus, potassium and magnesium

There are few readily available records of the manuring of non-experimental fields in Lawes' lifetime. However it is almost certain that the generous P and K manuring tested from the start of the Classical experiments (74 kg P_2O_5, 108 kg K_2O ha^{-1} for cereals and 74 kg P_2O_5, 224 kg K_2O ha^{-1} for root crops and grass) was not used on the rest of the farm fields. In recent years, manuring (for rates see below) has usually been decided by the Head of Farms, except where N, P and K were tested, although sponsors of experiments have always been allowed to specify manuring. The limited quantity of farmyard manure available is applied once per rotation at most, ploughed down in autumn, usually before beans.

All soil samples collected in the 1978–79 survey were analysed for bicarbonate soluble P and exchangeable K, Ca, Mg and Na (Table 2). All but one of the fields in the Standard Rotation are now in ADAS P Index 3 and all are in ADAS K Index 2 or greater (MAFF,

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1979). Both soluble P and exchangeable K increased between 1966/67 and 1978/79 (Table 4) showing that P and K manuring was more than sufficient to replace the losses of these nutrients in the harvested crops. In 1967 some fields on Scout Farm, e.g. Summerdells I, Stubbings and White Horse II, contained much less P and K than other fields. However, because these fields have had standard Rothamsted cropping, including well-manured potatoes, soluble P and K has increased since we acquired them.

The large increase in both P and K in the soils of Great Knott I, White Horse II and Delafield (Table 4) was a result of sampling these fields in May and June 1979 soon after large dressings of compound fertiliser had been applied for potatoes. The amount of readily soluble P and K in the soil of these three fields during most of the rotation would be lower than the values given in Table 4.

TABLE 4

Readily soluble P, K and Mg in soil from some Standard Rotation fields Rothamsted 1966/67 and 1978/79

	Bicarbonate soluble P mg P kg^{-1}			Exchangeable cations, mg kg^{-1}			
				K			Mg
Field	1966/67	1978/79	Increase	1966/67	1978/79	Increase	1978/79
Great Knott II	20	50	30	124	221	97	72
Summerdells I	10	28	18	104	158	54	54
Great Knott III	24	68	44	128	244	116	62
West Barnfield I	11	38	27	84	176	92	27
Summerdells II	8	20	12	98	135	37	49
Long Hoos I & II	22	45	23	130	159	29	53
Stubbings	13	31	18	136	170	34	63
Pastures	17	44	27	108	181	73	45
Geescroft	14	35	21	128	169	41	44
White Horse I	16	23	7	194	224	30	78
Little Hoos	16	33	17	74	133	59	37
Stackyard	20	36	16	116	148	32	45
Fosters West	37	46	9	150	138	−12	37
Great Knott I	19	68	49	116	319	203	47
White Horse II	8	43	35	126	243	117	64
Delafield	19	74	55	164	302	138	27
Whittlocks	16	38	22	156	191	35	34
Fosters Corner	14	34	20	106	143	37	35
Highfield IV	13	26	13	112	136	24	38
Long Hoos III	22	63	41	130	234	104	38

The effect of manuring for potatoes. It is very probable that the general improvement in the P and K status of the fields in the Standard Rotation is a result of the generous manuring for potatoes. During the last few years potatoes have usually received 195 kg P_2O_5 and 300 kg K_2O compared to 60 kg P_2O_5, 60 kg K_2O ha^{-1} for cereal crops. However, even large crops of potatoes (e.g. 50 t ha^{-1}) often remove less P than a good crop of wheat (e.g. 8 t ha^{-1}) and about as much P as a 6 t ha^{-1} barley crop (Table 7). Field yields of potatoes in recent years have often been less than 50 t ha^{-1} and consequently much larger P residues have remained in the soil after potatoes than after cereals. If areas of high and low fertility are to be avoided within fields then any field containing potatoes should receive basal P and K manuring as for potaotes even if some of the field is not planted with this crop. Table 4 shows that there has been only a small increase in bicarbonate soluble P on Summerdells II, White Horse I and Fosters West and these are all fields on which potatoes have not been grown for the last 12–15 years.

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The Cereal Disease Fields. Furzefield, Harwoods Piece, Claycroft and Highfield Drive, but not West Barnfield II contain adequate P and K for cereals (Table 2). West Barnfield II received a large basal dressing of P and K in autumn 1980.

Restricted Sites. Recently it has been decided to lessen the area on which P, K and lime dressings are restricted so that more land can be released for other purposes. In future the only field fully restricted for P, K and FYM will be Sawyers III and its pH will be raised and maintained at about pH 6·5. Small areas of Sawyers I, not already used for experiments, and Delharding south-west corner will also continue to be fully restricted for P, K and FYM; soil pH will be maintained at about pH 5. Highfield V, where manuring was fully restricted until recently, will now receive small dressings of P and K to maintain a small reserve of land at P and K Index 1 for experiments which require soils at low rather than very low P and K levels. Sawyers II and Highfield VI are no longer restricted and are being brought into the Standard Rotation after correction of nutrient and pH deficiencies.

Permanent Grass Fields. These fields, other than the Restricted Sites, contain adequate P and K. Because this old grassland is invaluable it has been decided that all of Highfield VII, VIII & IX should remain undisturbed in permanent grass but only the south-west third of this area should be restricted for P and lime. Road Piece West will remain permanently in grass without manurial restriction but, at the discretion of the Head of Farms, this can be ploughed and resown, if necessary, to maintain a good sward.

Exchangeable magnesium. Exchangeable Mg was included in the analyses of soils taken in 1978/79 because, in recent years, some potatoes on the Farm have shown typical symptoms of magnesium deficiency in leaves in June–July. Magnesium has never been applied routinely as a fertiliser dressing, except in the Classical experiments, although the occasional dressings of FYM contained some Mg. Results for the Standard Rotation fields (Table 4) show that these soils contain between 25 and 80 mg Mg kg^{-1}. The amount does not appear to be related to previous cropping, both arable and grass fields having the same range of exchangeable Mg values. There is a group of fields in the north-west corner of the Farm, Delafield, Whittlocks, West Barnfield I and Fosters West which all have less than 40 mg Mg kg^{-1}.

On the ADAS Classification the Standard Rotation soils are in Mg Index 1 and 2, 26–50 and 51–100 mg Mg kg^{-1} respectively. For soils at Index 1 Bulletin G.F. 1 (MAFF, 1979) recommends that magnesium is applied for potatoes and sugar beet. The Head of Farms has agreed that in future he will use a compound fertiliser containing Mg for all potato crops. If this does not prove sufficient to maintain soil Mg levels then it may be necessary to supply additional Mg as kieserite or use magnesian limestone instead of calcium carbonate as a liming material.

Carbon and nitrogen

Jenkinson and Johnston (1977) discussed changes in the organic matter content of the Hoosfield Barley experiment soils from 1852 to 1975. From their data it can be inferred that recent fertiliser dressings will have had little effect on soil organic matter. Annual dressings of 35 t ha^{-1} FYM appreciably increased soil carbon on Hoosfield after 100 years but this quantity of FYM greatly exceeds that used on the rest of the farm which, at most, now provides for a dressing of 50 t ha^{-1} every seventh year. Therefore, differences in %C and %N in Rothamsted Farm soils (Table 2) have most probably been caused by differences in past cropping. Table 5 summarises some of the data in Table 2 for fields on

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TABLE 5

Percentage C and N in soil in 1978/79 from various Rothamsted fields grouped according to their previous cropping history

Group and cropping history	Field	% C	Mean	% N	Mean	C/N ratio of mean C & N values
1 Grass before 1800:						
(a) still in grass	Parklands	3·68		0·356		
	Highfield Weighbridge Piece	3·65	3·71	0·356	0·365	10·2
	Highfield VII, VIII & IX	3·80		0·383		
(b) with very occasional short periods in arable	Road Piece West	3·38		0·323		
	Appletree	2·95	3·17	0·288	0·306	10·4
(c) ploughed 1950s then mainly arable with some leys	Highfield V	2·31		0·233		
	Highfield VI	2·49	2·40	0·252	0·243	9·9
2 Grass in 1870s or 1880s:						
(a) ploughed early 1940s then mainly arable with some leys	Delharding	1·82		0·204		
	Great Field II	1·65	1·74	0·180	0·192	9·1
(b) ploughed early 1950s then continuous arable	Great Field I	1·55		0·172		
	Geescroft	1·47	1·51	0·160	0·166	9·1
3 Arable:						
(a) with long leys	Great Harpenden II	1·62		0·179		
	Great Knott I	1·57		0·175		
	Great Knott II	1·68	1·63	0·185	0·179	9·1
	Sawyers II	1·52		0·157		
	Sawyers III	1·78		0·197		
(b) with short leys	West Barnfield I	1·33		0·155		
	West Barnfield II	1·45	1·39	0·167	0·161	8·6
4 Continuous arable:	Little Hoos	1·30		0·159		
	Fosters West	1·35	1·33	0·153	0·156	8·5
5 Mixed previous cropping, continuous arable for past 15 years	Fosters Corner	1·48		0·169		
	Long Hoos I & II	1·47	1·48	0·151	0·160	9·3
6 Old woodland, reclaimed early 1940s						
(a) 7 years arable, 7 years grass then arable	Furzefield		1·91		0·199	9·6
(b) 3 years arable, 26 yrs grass, 6 yrs arable	Dell Piece		2·41		0·245	9·8
(c) 3 years arable then grass	Bones Close		2·66		0·259	10·3
7 Old orchard until 1958 then continuous arable	Delafield	1·16		0·138		
	Whittlocks	1·27	1·22	0·144	0·141	8·7

similar soil types; data from fields on what was Scout Farm have been excluded. Seven groups of soils are distinguished in Table 5.

Soils with most organic matter, mean 3·71 %C, are those which were in grass probably from before 1800 and continuously since then (Group 1a, Table 5), whilst soils in continuous arable (Group 4) contain only 1·33%C. The C/N ratios in these two groups of soils are 10·2 and 8·5 respectively. Growing short leys in mainly arable cropping sequences has done little to increase soil organic matter, 1·39 %C in Group 3b soils, but longer leys have increased the carbon content of Group 3a soils to 1·63 %C.

Occasional or longer periods of arable cropping have appreciably decreased %C in soils which were in grass before 1800; 3·17 and 2·40 %C in Group 1b and 1c soils respectively compared to 3·71 %C in Group 1a soils. Fields which were grassed down about 1880 and had 70 or 80 years in grass before being ploughed about 1950 now contain 1·51–1·74 %C (Groups 2a and 2b), much less than the 2·40 %C in Group 1c soils which had a much longer period in permanent grass.

There is an interesting series of soils in Group 6 from fields which were reclaimed from old woodland in the early 1940s. Soil carbon now ranges from 1·91% in Furzefield, which has had the least number of years in grass, to 2·66 %C in Bones Close which has been in grass for all but 3 years.

Another interesting feature of these results is that soils with a long period of arable cropping, and probably with few long-term leys, Groups 3b, 4 and 5, all contain between 1·3 and 1·5 %C which represents appreciably more organic matter than the 0·9–1·0 %C in most of the unmanured or fertiliser only treated soils of the Broadbalk, Hoosfield and Barnfield Classical experiments. It is probable that yields on the Classical fertiliser treated plots were at least equal to those on non-experimental fields so that crop residues ploughed in each autumn could have been about the same in both cases. Extra organic matter may have been returned to the soils in the non-Classical fields both in occasional dressings of FYM and weed rubbish. These fields possibly received a dressing of FYM once per rotation when cropped and manured on a traditional four- or five-course rotation before the 1950s, and these dressings would have added some organic matter. Also, before the introduction of herbicides it is most unlikely that it was possible to maintain the high standard of weed control, which was a notable feature of the Classical experiments, on the rest of the farm. Therefore extra organic matter from weeds and probably less inter-row cultivation may account for some of the larger carbon content of these soils.

Soils with least organic matter (Table 5) are those on Delafield and Whittlocks (Group 7) and on these fields %C is closer to that on fertiliser-treated soils in the Classical experiments. These fields, purchased in 1955, have been in continuous arable since 1959 and before that they were small orchards of top fruit for many years. It is likely that both before and after purchase the return of organic matter was minimal.

The N and C contents of the soils of fields in the Standard Rotation and grass fields in 1959/60 (R. J. B. Williams data) are compared with 1978/79 in Table 6 where the groups used are the same as in Table 5. On both occasions N was determined by macro-Kjeldhal but for carbon Williams used the Walkley–Black method whilst we used a modified Tinsley method. The Walkley–Black carbons have been corrected by the conventional factor of 1·3.

Between 1959/60 and 1978/79 %N in permanent grassland soils increased by 13%, on average, with the largest increase, 31%, on Bones Close which had the least nitrogen in 1959/60 and was reclaimed from woodland in 1942. In most soils %C has changed little but this could be an artefact of the different methods of analysis rather than indicating that the carbon content of the soils had not changed.

In nearly all arable fields %N has declined between 1960 and 1978 because the organic matter content is still falling towards the equilibrium value for an arable soil under the

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TABLE 6

Percentage C and N in soil from some Standard Rotation and Grass fields Rothamsted, 1960 and 1978/79

			%C		%N		
Standard Rotation fields	Group in Table 5	Arable since	1960	1978/79	1960	1978/79	C/N ratio 1978/79
Geescroft	2b	1952	1·96	1·47	0·193	0·160	9·2
Great Harpenden II	3a	1968[a]	1·53	1·62	0·160	0·179	9·1
Great Knott II	3a	1956	2·07	1·68	0·200	0·185	9·1
Stackyard	–	1946	2·20	1·62	0·212	0·182	8·9
West Barnfield I	3b	1946	1·51	1·33	0·169	0·155	8·6
Great Harpenden I	–	—[b]	1·46	1·42	0·172	0·156	9·1
Little Hoos	4	1942	1·32	1·30	0·140	0·159	8·2
Fosters West	4	1900s[c]	1·52	1·35	0·170	0·153	8·8
Great Knott III	–	1909	1·53	1·67	0·172	0·175	9·5
Fosters Corner	5	1946[d]	2·11	1·48	0·210	0·169	8·8
Dell Piece	6b	1974	2·67	2·41	0·219	0·245	9·8
Delafield	7	1959	1·55	1·16	0·147	0·138	8·4
Whittlocks	7	1959	1·58	1·27	0·158	0·144	8·8
Pastures	–	—[b]	2·03	1·53	0·181	0·171	8·9
Highfield IV	–	1951	2·14	1·63	0·172	0·178	9·2
Grass fields							
Appletree			3·06	2·95	0·270	0·288	10·2
Bones Close			2·24	2·66	0·198	0·259	10·3
Highfield VII, VIII & IX[e]			3·75	3·80	0·328	0·383	9·9
Highfield Weighbridge Piece			3·64	3·65	0·320	0·356	10·3
Little Knott II			3·37	3·65	0·315	0·370	9·9
New Zealand			3·25	3·26	0·298	0·311	10·5
Parklands			3·64	3·68	0·303	0·356	10·3
Road Piece West			3·79	3·38	0·332	0·323	10·5

(a) 8-year ley 1959–67
(b) Part in grass, part in arable
(c) Probably arable before 1900s
(d) 7-year grass ley 1949–55
(e) Highfield VII, VIII & IX now includes part of what was Road Piece West

climatic conditions at Rothamsted. However, a small part of the change may be because the plough layer was sampled in both surveys and this may have deepened slightly between 1959 and 1978.

The increase in %N in soil from Great Harpenden II and Dell Piece can be explained by their cropping history between 1960 and 1978. In 1959 Great Harpenden II was sown to grass which remained unploughed until 1968. Therefore %N would have increased for the first 8 years of this period to an unknown value before starting to decline once the ley was ploughed. Dell Piece was put down to grass in 1942 and was not ploughed until 1974. From 1960 to 1974 %N would have increased above the 1960 value and then between 1974 and 1978 the loss of organic matter was less than the accumulation under grass between 1960 and 1974.

Changes in %N in Group 4 soils are of interest. The small decline on Fosters West and the small increase on Little Hoos together with the very small change on Great Knott III all suggest that %N is changing very little from an average value of about 0·16 %N. This is larger than the 0·12 %N in the fertiliser-treated soils of Hoosfield (Jenkinson & Johnston, 1977) which has remained constant for the last 100 years. Assuming both values are correct then the input of organic matter must have been larger on the Group 4 soils than on Hoosfield. As suggested previously this extra organic matter could have come from occasional dressings of FYM, from weed rubbish or possibly less inter-row cultivation.

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Future cropping and manuring policy

During the last few years the number of experimental plots on the Farm has remained fairly constant, although the complexity of the experiments has increased. It has usually been possible to find acceptable sites, but in 1978 most of the suitable area of spring barley was taken up by experiments. This meant that experiments tended to follow one another with a more than desirable frequency, and whilst this situation continues to exist every effort must be made to keep the nutrient status of the soils as uniform as possible.

The present Standard Rotation is satisfactory although there are some problems with finding sites for early sown winter cereals after a break because we grow little oilseed rape or winter beans.

Liming once in the rotation has been satisfactory and recently there have been no problems attributed to acidity. Ground chalk will continue to be applied to the cereal stubble before the 1 year break. The amount applied, 7·5 t ha^{-1}, has increased the pH of all Standard Rotation fields and the size of the dressing could be reconsidered.

Two reasons for maintaining the current dressing are:

1. Nitrogen usage is tending to increase thereby increasing the residual nitrate which is leached from the topsoil thus enhancing calcium losses.
2. Slight overliming ensures that, within each field, small areas of soil with pH values less than the average remain within the desired pH range throughout the 7 years of the rotation.

The small quantities of FYM that are available for the fields in the Standard Rotation will continue to be applied to whole fields in autumn on a cereal stubble and ploughed in.

Dressings of P and K have always been applied to the seedbed before sowing or have been combine-drilled for cereals. This puts a considerable strain on the Farm's resources at busy periods and combine-drilling often diminishes the speed of drilling. Direct applications of P and K to grain crops can be replaced by larger dressings applied less frequently but at convenient points in the rotation now that our fields contain adequate reserves of P and K. This rotational manuring will aim to replace at least as much P and K as is removed in the crops. Estimates of P and K uptakes by average 'target' yields for the 1980s have been calculated (Table 7); the total P and K required in 7 years will be 440 kg P_2O_5 and 1015 kg K_2O ha^{-1}. This large dressing will be split and some applied to

TABLE 7

Target yields and estimates of P and K removals from Standard Rotation fields, Rothamsted

Year	Crop in Rotation	Field yield, t ha^{-1}[a]: Estimated range in recent years	Field yield, t ha^{-1}[a]: Target for 1980s	Removal, kg ha^{-1}, in target yield: P_2O_5	Removal, kg ha^{-1}, in target yield: K_2O
1	Beans/oats[b]	1–6[b]	5	55	170[b]
2	Winter wheat	5–6	8	80	110
3	Spring barley	3–6	6	60	110
4	Oats/beans[c]	4–6[c]	5	45	110[c]
5	Potatoes	20–60	50	60	295
6	Winter wheat	5–6	8	80	110
7	Spring barley	3–6	6	60	110
			Total	440	1015

[a] Grain at 85% dry matter, potatoes total tubers. In calculating offtakes in cereals a harvested grain straw ratio of 1 : 1 has been assumed.
[b] Beans assumed
[c] Oats assumed

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those cereal stubbles which will subsequently be ploughed for spring sown crops. This will allow some latitude in the timing of the applications in those autumns when the weather is less than favourable. The present proposals are to apply 200 kg P_2O_5 and 300 kg K_2O for potatoes (as a compound fertiliser with an N: P_2O_5: K_2O ratio of 10: 10: 15 which also contains 4·5 %Mg). This dressing will be applied in spring. The balance, 240 kg P_2O_5 and 715 kg K_2O, will be divided into two equal applications, one to the cereal stubble in the autumn of year 4 and one to the stubble in the autumn of year 2 (Table 7). It is intended to monitor the effects of this manuring policy on bicarbonate soluble P and exchangeable K and Mg by a spring soil sampling of those fields which are in year 4 of the rotation. This is about half way through the liming cycle (lime is applied at the end of year 7) and before the large P and K dressings are applied for potatoes. These calculations ignore any P and K applied in FYM because not all fields receive a dressing. They also ignore the K returned to the soil when straw is burnt because we do not often burn straw.

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