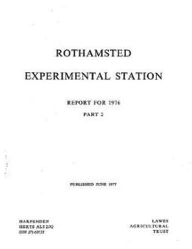
Rothamsted Experimental Station Report for 1976, Part 2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Full Table of Content

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Changes in Broom's Barn Farm Soils, 1960–75

A. P. DRAYCOTT, M. J. DURRANT, R. HULL and A. B. MESSEM

Introduction

Broom's Barn Farm (77 ha) was acquired in 1959 by the Lawes Agricultural Trust for the establishment of an experimental station for sugar-beet investigations. Laboratory and farm buildings were erected in 1959–61. These and the land were paid for, as is the work of the Station, from the Sugar Beet Research and Education Fund to which the sugar-beet growers and the British Sugar Corporation Ltd contribute equal amounts. When farming operations began in 1960, the farm-tracks were ploughed up and concrete roads laid along new field boundaries shown in the maps below. Land levelling commenced and old ponds and marl pits were filled in. Observations of the immediate previous husbandry of the farm suggested that yields had been small. To improve fertility, a five-crop rotation was introduced of sugar beet, followed by winter wheat, barley, ley or beans, and winter wheat. In general, each crop was given fertilisers, herbicides and pesticides consistent with good farm practice. The aim of the husbandry throughout the period 1960–75 was to improve fertility so that variations in yield within each field due to soil effects were minimised. This was considered essential for accurate field experiments with sugar beet.

All the soils of Broom's Barn Farm overlie at varying depth a layer of soft but flinty chalk. The chalk is completely covered with unconsolidated materials deposited during the Pleistocene and Recent periods. Soils on the northern part of the farm are formed in a light-coloured mixture of sand and chalk but towards the south, soils are formed in a deposit of heavier chalky boulder clay of increasing thickness. The soils of the farm have been examined several times by the Soil Survey of England and Wales but there is no published account. Copies of an unpublished report (Draycott, 1972) can be obtained from the Head of the Station.

In 1960 the farm was divided into approximately 100 × 100 m squares (5 chains) marked by permanent sockets set into concrete around the farm boundaries and internal roads. This allowed detailed soil sampling of each field in 1960; recently all the fields were resampled and the main object of the present paper is to describe the changes which have resulted from the 15 years of cropping. This is quite a short interval on the farming time scale, as it is likely that the land has been under cultivation since 1597 (Heathcote, 1965). Even so, some of the recent changes are of sufficient interest to warrant publication. In addition, it is opportune after this interval to examine how the farming and fertiliser practice is affecting crop yields, and nutrient offtake and balance in relation to changes in soil concentrations of nutrients.

Experimental methods

Soil sampling and preparation. Topsoil was taken from alternate 20 × 20 m squares and subsoil from the centre square of each 100 × 100 m square. Topsoil sampling depth was 0–23 cm which approximated to the ploughing depth from 1960 onwards; previously the land had been ploughed to about 18 cm. A cheese auger was used to take 25 cores from each 20 × 20 m square. Subsoil samples were taken from 24–46 cm, the topsoil 0–22 cm being first removed with a spade. The samples were air-dried at about 25°C and

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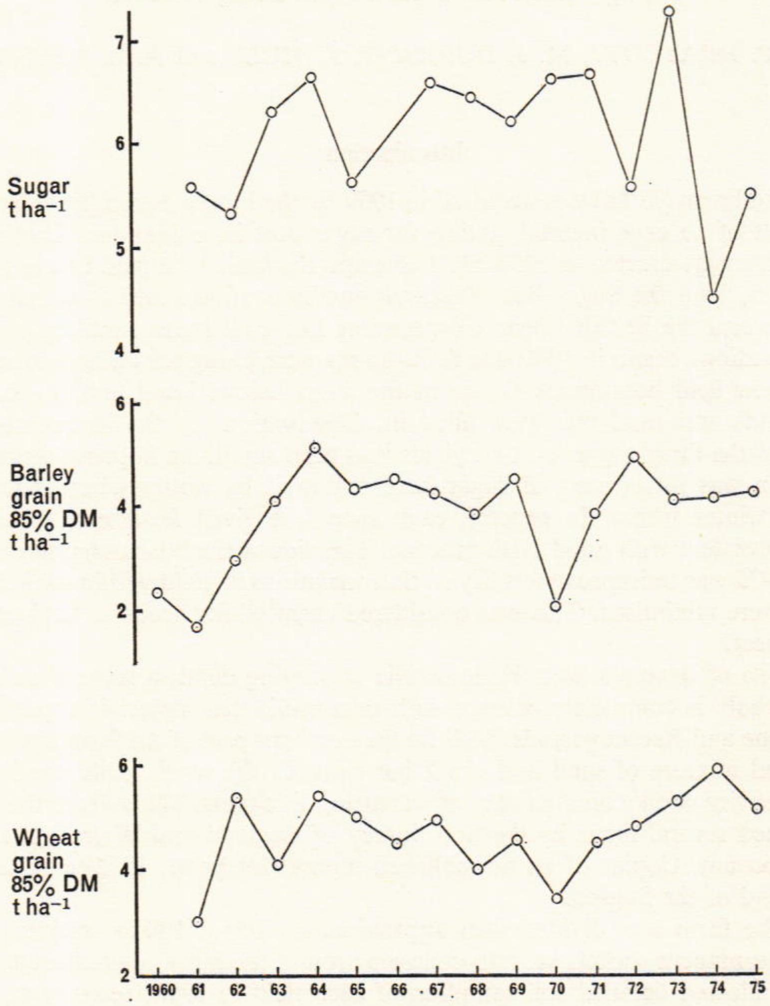

FIG. 1. Average farm yields of sugar, barley and wheat grain at Broom's Barn, 1960–75.

milled to pass a 2 mm sieve and stored in polythene bags in cardboard boxes for future examination.

In 1960, all the fields were sampled; when they were re-examined more recently, the task was spread over three winter periods. The fields Dunholme, Marl Pit and The Holt were sampled in 1973, Flint Ridge, Bull Rush, Brome Pin and Hackthorn in 1974 and Little Lane, White Patch, New Piece and Windbreak in 1975. The location of each field is given on the plan on page 52.

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Analytical methods. All the soils taken in 1960 were analysed for pH, organic matter, available P and exchangeable K, Na and Mg. Together with the recent samples, they were re-analysed in 1973–75 using current methods except where otherwise stated below.

pH. For the determination of pH, 10 ml of air-dried soil were mixed with 25 ml of distilled water. Having been left to equilibrate (> 1 h), pH was read with a glass electrode and pH meter.

Organic matter. Soil organic matter was oxidised by boiling with chromic acid, obtained by mixing potassium dichromate, sulphuric acid and phosphoric acid. After cooling, excess chromic acid was determined with ammonium iron II sulphate and barium diphenylamine sulphonate indicator (Tinsley, 1950).

In 1960, the soils were analysed by the method of Walkley and Black (1934). The heat of reaction between dilute potassium dichromate and concentrated sulphuric acid was utilised to effect oxidation. This method was modified by Tinsley, the soil/acid mixture being boiled for 2 h under reflux. The Tinsley method was used on the 1973–75 soils and in the re-analysis of some 1960 soils. To avoid complete re-analysis of the 1960 samples, a selection was analysed by both methods to give a conversion factor.

Phosphorus. Originally the phosphorus in soil samples taken in 1960 was extracted using acetic acid/acetate solution (Morgan, 1937). However, since extraction with 0·5 M sodium bicarbonate solution at pH 8·5 (Olsen *et al.*, 1954) is more closely related to the soil phosphorus available to sugar beet (Draycott, Durrant & Boyd, 1971), all soils were analysed by this method.

Potassium, sodium and magnesium. These cations were extracted with M ammonium nitrate (Draycott & Durrant, 1970; ADAS, 1973). The concentration of K in the extract was read directly, using flame emission photometry. The Na was also read without dilution, using atomic absorption spectrophotometry. The Mg concentration was determined after dilution with strontium chloride solution, again using atomic absorption spectrophotometry.

Nutrient balance

Yields. Individual field yields are recorded in Rothamsted Report for each year and are not repeated here. Cereal grain yields (Table 1 and Fig. 1) were obtained from the farm weigh-bridge. Straw was not weighed but bales were counted in most cases and yields calculated from the weight of sample bales. Yields of sugar beet were averaged over both the fields in the crop each each year and the total weight obtained from the tarehouse returns from the local factory. Average sugar percentage from the returns was used for calculation of sugar yields. Sugar-beet yields comprise the produce from experimental plots, guards and larger areas of crop usually on parts of fields inadequately uniform for field experimentation. Yields from the ley were estimated for the silage cut and calculated from numbers of bales for the hay cut.

Nutrients applied. The quantity of N, P, K, Na and Mg applied was calculated from the weights of fertiliser given to each field each year and the concentration of the elements on the statutory statement of analyses from the manufacturer (Tables 2 and 3). Nutrients applied in lime and farmyard manure were not included in the balance sheets as there was no measure of their availability (analyses of the farmyard manure for the period 1965–70 were reported by Draycott, 1972).

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TABLE 1

Average farm yields of crops commonly grown at Broom's Barn, 1960–75

	Barley		Wheat			Sugar beet			
	Grain t ha⁻¹	Straw	Grain t ha⁻¹	Straw	Beans Grain t ha⁻¹	Root yield t ha⁻¹	Sugar %	Sugar yield t ha⁻¹	Ley Dry matter t ha⁻¹
1960	2·35	1·51							
1961	1·64	1·00	3·00	2·76		35·6	15·7	5·58	13·2
1962	2·96	1·87	5·38	5·13		32·3	16·5	5·33	8·9
1963	4·13	2·60	4·14	3·77		36·9	17·1	6·31	19·4
1964	5·09	3·22	5·40	4·99		36·3	18·3	6·64	17·7
1965	4·33	2·74	5·02	4·60		33·8	16·6	5·61	—
1966	4·47	2·85	4·51	4·11		42·9	16·1	6·91	17·5
1967	4·22	2·65	4·97	4·60		40·9	16·1	6·58	13·1
1968	3·81	2·38	3·97	3·63	1·57	40·7	15·8	6·43	20·5
1969	4·51	2·81	4·54	4·07	2·95	34·4	18·0	6·19	40·9
1970	2·02	1·24	3·46	3·13	2·00	37·7	17·5	6·60	35·4
1971	3·81	2·43	4·45	4·13	1·76	38·9	17·1	6·65	39·0
1972	4·94	3·95	4·81	4·29	3·14	30·9	18·0	5·56	34·4
1973	4·04	2·87	5·27	2·84	3·76	43·9	16·5	7·24	31·3
1974	4·13	2·11	5·90	3·99	3·02	28·5	15·7	4·47	37·4
1975	4·21	3·61	5·15	5·34	2·13	33·3	16·5	5·49	34·8
Mean	3·79	2·49	4·66	4·09	2·54	36·5	16·8	6·11	26·0

Grain and straw yields at 85% dry matter

TABLE 2

Total amount of nutrients, farmyard manure and lime applied to each field

Field	Period	N	P	K kg ha⁻¹	Na	Mg	FYM t ha⁻¹	Lime
Dunholme	1960–72	1322	317	722	266	25	25	8
Marl Pit		1388	284	906	354	78	50	6
The Holt		1266	325	850	236	50	50	0
Brome Pin	1960–73	1520	268	959	502	107	58	22
Bull Rush		1340	315	1086	472	138	58	18
Flint Ridge		1518	360	994	236	50	50	25
Hackthorn		1488	325	966	354	75	25	5
Little Lane	1960–74	1636	360	836	414	90	45	0
White Patch		1882	371	1024	236	50	25	0
New Piece		1488	360	1093	413	94	25	11

TABLE 3

Average amount of nutrients applied to each crop

Crop	Number of crops	N	P	K kg ha⁻¹	Na	Mg
Spring barley	46	84	18	35	0	0
Winter wheat	38	104	21	38	0	0
Sugar beet	28	127	30	157	121	26
Grass	17	169	35	87	0	0
Beans	7	0	21	41	0	0
Oats	2	70	17	33	0	0
Spring wheat	1	99	18	34	0	0

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Nutrients removed. The quantity of P, K, Na and Mg removed from each field each year were calculated from the yields and the average nutrient concentrations (Table 4). These concentrations were obtained from long-term experiments at Broom's Barn (Draycott *et al.*, 1972a, b). Where straw was burnt it is assumed there was no loss of mineral elements. Sugar-beet tops were ploughed in.

TABLE 4

Analysis of plant material used in the calculation of nutrient uptake

Crop		Dry matter %	P	K	Mg
			% of dry matter		
Barley	Grain	85	0·35	0·40	0·12
	Straw	85	0·09	0·56	0·06
Wheat	Grain	85	0·36	0·44	0·12
	Straw	85	0·09	0·72	0·06
Sugar beet	Tops	15	0·34	3·10	0·24
	Roots	20	0·15	0·80	0·11
Grass		12·5 (silage) 80 (hay)	0·30	2·25	0·12
Beans	Grain	85	0·61	1·16	0·12
	Straw	85	0·08	0·55	0·07

Offtake and balance. Total offtakes of P, K and Mg were calculated as the sum of each nutrient removed in the crops in the individual years for each field for the period 1960–72, 1960–73 or 1960–74, dependent upon the year of soil sampling (Table 5). Nutrient balance for each field was then calculated as the difference between the amount of each element applied in fertiliser and that taken from the field in the crop (also shown in Table 5). Windbreak field was not included as several crops were grown on it in the same year.

Results

Soil analyses

pH. The soil pH in 1960 and 1973–75 is shown for the farm in Fig. 2 and as averages of individual fields in Tables 6 and 7; Table 2 shows the amounts of lime given to correct acidity. Liming was based on field pH tests 18 months before sugar beet. Where soil pH was less than 6·5, lime was applied on a field or part-field basis. Some of the soils were naturally calcareous and never needed lime whereas some areas of the farm needed lime every time they were tested.

Overall pH increased only marginally from 7·7 to 7·8. There were larger individual differences, however, particularly on Brome Pin, Bull Rush, New Piece and The Holt. The pH of the most calcareous soils decreased by 0·5 unit but the majority of the soils had increased.

The effect of soil type on the pH of top soil is shown in the 1960 analyses (Fig. 2a) where a dry valley of alluvial sand corresponds to a strip of soil of low pH running from the west of Bull Rush field, across New Piece and Hackthorn and opening out into a large area of acidity on Dunholme field. Extensive acid patches were also found on sandy-textured areas on Brome Pin, Flint Ridge and Bull Rush field.

Organic matter. As would be expected during such a small interval, changes have been small but some effects were sufficiently consistent to be worthy of comment. Table 6 shows that, overall, the organic matter concentration in top soil decreased slightly from 1·92 to 1·88%. The changes within fields were all very small, only Little Lane, Marl Pit and The Holt showing differences of more than 0·1%. Of the 11 fields, three (Brome Pin,

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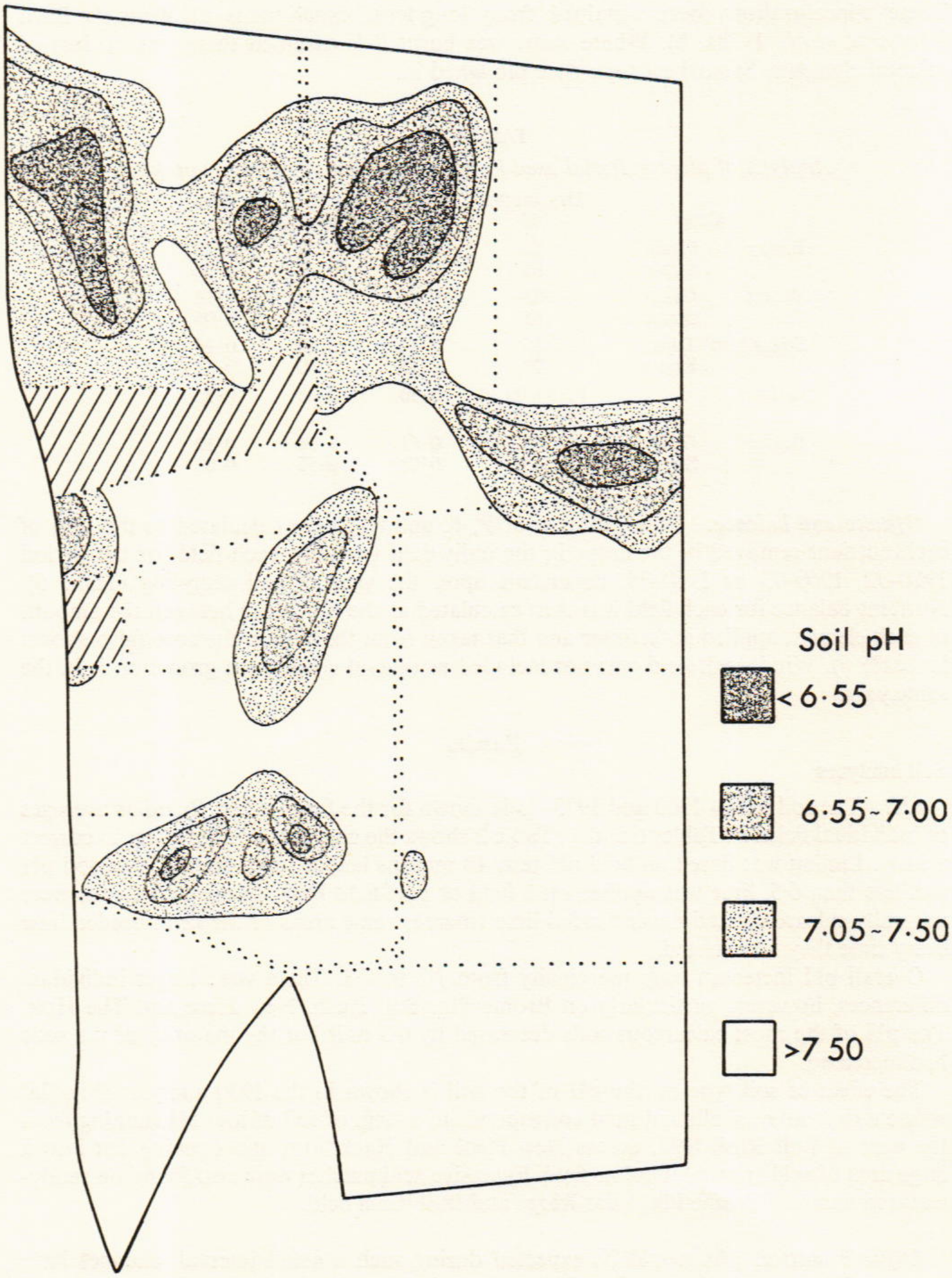

FIG. 2a. Topsoil pH on 1960.

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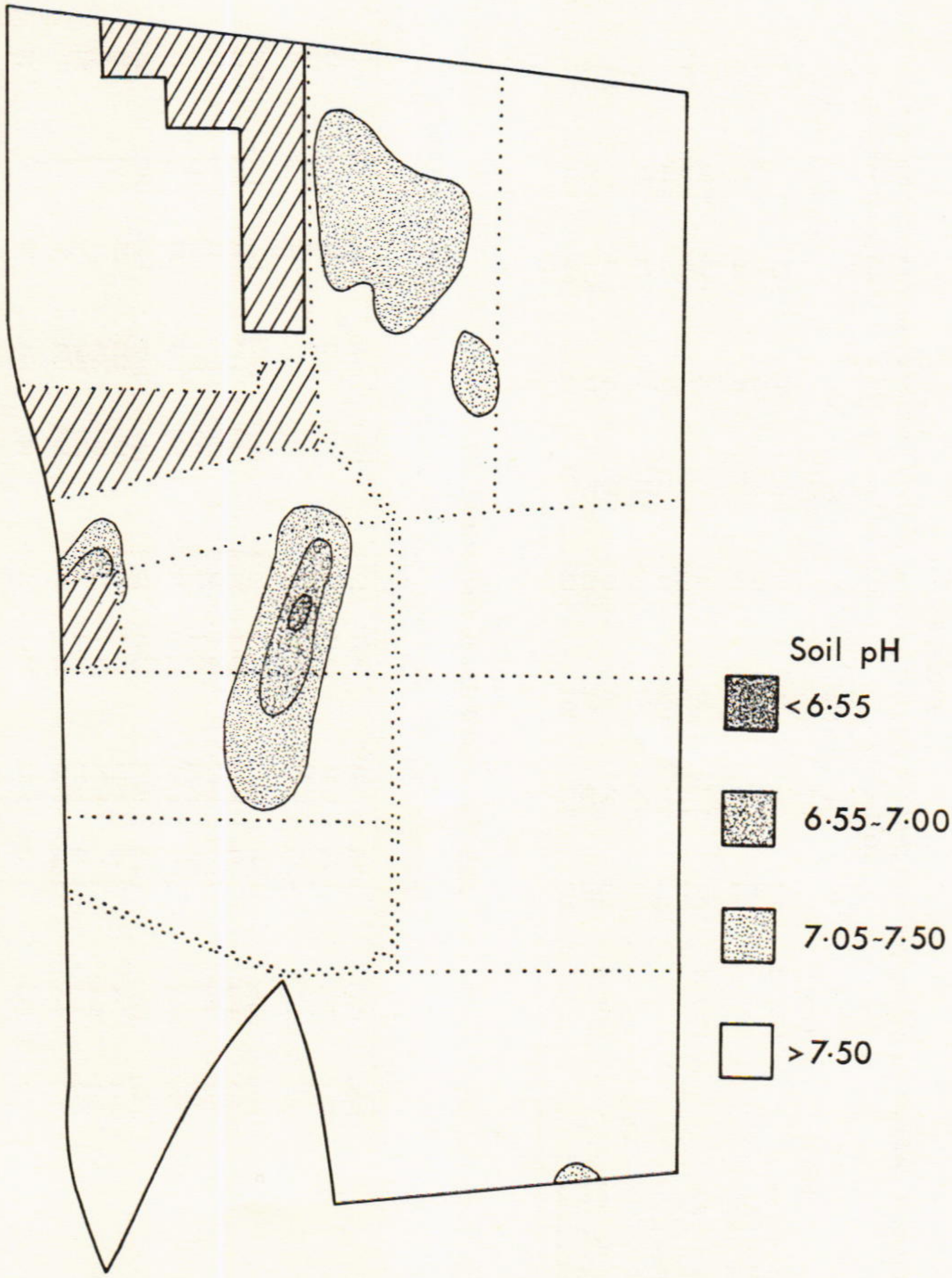

FIG. 2b. Topsoil pH, 1973–75.

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TABLE 5

Total offtake and nutrient balance for each field for the period 1960 to 1972–74 and the average nutrient balance each year

Field	Period	Total offtake P	Total offtake K	Total offtake Mg	Nutrient balance 1960–72–74 P	Nutrient balance 1960–72–74 K	Nutrient balance 1960–72–74 Mg	Average nutrient balance P	Average nutrient balance K	Average nutrient balance Mg
		kg ha⁻¹			kg ha⁻¹			kg ha⁻¹ year⁻¹		
Dunholme	1960–72	162	545	71	+155	+177	−46	+12	+14	−3·5
Marl Pit		158	442	73	+126	+464	+5	+10	+36	+0·4
The Holt		169	472	81	+156	+378	−31	+12	+29	−2·4
Brome Pin	1960–73	186	542	99	+82	+417	+8	+6	+30	+0·6
Bull Rush		187	571	70	+128	+515	+68	+9	+37	+4·9
Flint Ridge		213	723	104	+147	+271	−54	+10	+19	−3·9
Hackthorn		185	619	80	+140	+347	−5	+10	+25	−0·4
Little Lane	1960–74	203	706	89	+157	+130	+1	+10	+9	+0·1
White Patch		202	729	84	+169	+295	−34	+11	+20	−2·2
New Piece		233	773	104	+127	+320	−10	+8	+21	−0·7

TABLE 6

Topsoil analysis 0–23 cm, 1960 and 1973–75

	pH in water		Organic matter %		$NaHCO_3$-soluble P mg litre⁻¹		NH_4^+-exchangeable mg litre⁻¹ K		Na		Mg	
	1960	1973	1960	1973	1960	1973	1960	1973	1960	1973	1960	1973
Dunholme	7·3	7·6	1·80	1·81	22·7	31·1	133	138	30	23	42	31
Marl Pit	7·8	7·9	2·06	1·90	22·0	27·2	161	162	25	11	37	35
The Holt	8·3	7·8	2·10	2·00	21·7	25·8	127	147	25	25	39	39
	1960	1974	1960	1974	1960	1974	1960	1974	1960	1974	1960	1974
Brome Pin	7·2	8·0	1·49	1·57	19·8	28·6	92	119	32	105	43	31
Bull Rush	7·3	8·0	1·71	1·67	16·1	23·9	126	156	22	66	47	50
Flint Ridge	7·7	7·9	1·61	1·58	36·3	54·0	142	137	26	16	30	28
Hackthorn	7·6	7·5	1·71	1·67	22·1	23·7	160	135	39	18	47	43
	1960	1975	1960	1975	1960	1975	1960	1975	1960	1975	1960	1975
Little Lane	8·2	7·8	2·38	2·19	35·0	45·7	156	222	25	63	55	67
White Patch	8·1	8·1	2·24	2·28	23·1	26·0	165	203	21	8	49	47
New Piece	7·8	7·3	1·89	1·79	19·8	25·9	127	164	28	11	50	54
Windbreak	7·6	7·5	2·06	1·98	42·2	46·3	164	150	33	24	71	58
Mean of all samples	7·7	7·8	1·92	1·88	25·7	33·7	140	161	27	37	45	43

White Patch and Dunholme) increased in organic matter and the remaining eight decreased. The organic matter concentration of the subsoils (Table 7) decreased more than the topsoil (1·39 down to 1·31%). Again the differences were very small but changes of nearly 0·3% were found on Little Lane, New Piece, White Patch and The Holt.

Farmyard manure is produced on the farm by about 80 bullocks fattened under cover on the silage and hay. This produces adequate FYM for a dressing of about 25 t ha^{-1} on the five large fields one year in five, 18 months before sugar beet. Any manure remaining is spread on the small field in the same stage of the rotation (Table 2). Manure application has been omitted on the south-west quarter of Flint Ridge field, to produce an area containing a small amount of organic matter for future experiments. The mean organic matter concentration for this area was 1·42% in 1974.

The combined effects of organic manuring and of the ley, which is grown on the five large fields, can be deduced from results in Table 6. All the small fields, generally not given FYM, show a decrease in topsoil organic matter. Flint Ridge also shows a slight decrease due to the no-manure area. The large fields show no effect or a small increase in organic matter content with the exception of Little Lane. This field contained most organic matter in 1960 and still had a larger than average value in 1975.

Phosphorus. Table 6 shows the change in available phosphorus between 1960 and 1973–75. The soil phosphorus in the plough layer of each field increased greatly, and the mean increase for the whole farm was 8 mg litre^{-1} (from 25·7 to 33·7 mg litre^{-1}). The largest increase (18 mg litre^{-1}) was on Flint Ridge. The distribution of phosphorus in topsoil over the farm is shown in Fig. 3; the majority of the soil in 1973–75 was ADAS Index 3 or above (ADAS indices are defined in figure legends).

As shown in Table 7, the subsoils also increased in available phosphorus, but to a much smaller and more variable extent. The average concentration for the whole farm increased from 18·5 to 20·8 mg litre^{-1} although Dunholme, Marl Pit and White Patch decreased slightly. The largest change, as with the topsoils, was on Flint Ridge where the concentration doubled.

Results of long-term experiments at Broom's Barn (Draycott *et al.*, 1972b) showed a negligible response by sugar beet to the application of phosphorus fertiliser in soil of ADAS Index 3 or above. This suggest that areas of the farm above Index 2 can be regarded as uniform in their ability to supply crops with phosphorus, which would include about 75% of the farm in 1973–75 compared with about 30% in 1960.

Table 5 shows that over the period 1960 to 1973–75 about 150 kg P ha^{-1} was applied to each field in excess of that removed by the crop. Comparing the values in Table 5 with those for changes in soil analysis in Table 8, leaving a residue of about 10 kg P ha^{-1} year^{-1} increased available soil P by 0·4 mg litre^{-1} year^{-1}. This is comparable with previous findings in a long-term experiment (Draycott *et al.*, 1972b) where a residue of 30 kg ha^{-1} year^{-1} increased soil P by 1·5 mg litre^{-1} year^{-1}.

In order to keep an area of the farm at a fairly small concentration of soil P and K, the policy of applying about half the normal dressing to the west side of Brome Pin was adopted in the early 1960s. The phosphorus concentration of Brome Pin, including the west side of the field, has however, increased. The west side increased generally from ADAS Index 1 to 2 but the remainder of the field, which has been given the normal fertiliser application, is now mainly in Index 3.

Potassium. The exchangeable potassium concentrations are given in Table 6 and 7. The former shows the mean soil potassium in the plough layer increased from 140 to 161 mg litre^{-1}. Only three fields decreased—Flint Ridge, Windbreak and Hackthorn; the last of these decreased most (by 25 mg litre^{-1}). The largest increase was on Little Lane

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TABLE 7

Subsoil analysis 24–46 cm, 1960 and 1973–75

	pH in water		Organic matter %		$NaHCO_3$-soluble P mg litre^{-1}		NH_4^+-exchangeable mg litre^{-1}: K		Na		Mg	
	1960	1973	1960	1973	1960	1973	1960	1973	1960	1973	1960	1973
Dunholme	7·2	7·5	1·38	1·33	22·3	20·5	96	79	36	28	37	29
Marl Pit	8·2	7·8	1·38	1·28	20·8	20·5	95	149	25	11	39	34
The Holt	7·9	8·0	1·21	1·41	11·9	12·5	68	79	19	28	33	35
	1960	1974	1960	1974	1960	1974	1960	1974	1960	1974	1960	1974
Brome Pin	6·8	7·6	1·12	1·02	10·2	15·7	65	56	35	17	45	28
Bull Rush	7·4	7·8	1·20	1·10	8·3	11·1	87	117	23	32	38	52
Flint Ridge	7·2	7·9	1·14	1·19	15·5	31·5	106	64	30	34	47	30
Hackthorn	8·0	7·9	1·16	1·36	13·0	28·4	63	123	30	22	55	39
	1960	1975	1960	1975	1960	1975	1960	1975	1960	1975	1960	1975
Little Lane	8·3	7·8	1·57	1·29	25·8	29·9	116	143	38	52	51	63
White Patch	8·3	7·8	1·45	1·71	21·6	18·6	91	142	27	10	39	47
New Piece	7·8	7·6	1·64	1·39	8·3	11·0	112	90	29	27	59	55
Windbreak	7·9	7·8	1·27	1·32	14·3	17·0	123	115	42	19	68	48
Mean of all samples	7·7	7·8	1·39	1·31	18·5	20·8	97	105	31	25	45	43

TABLE 8

Overall change and change per year in soil analysis, 1960 and 1973–75

	P: Topsoil	P: Subsoil mg litre^{-1}	P: Top and subsoil	K: Topsoil	K: Subsoil mg litre^{-1}	K: Top- and subsoil	Mg: Topsoil	Mg: Subsoil mg litre^{-1}	Mg: Top and subsoil	Top and subsoil: P mg litre^{-1} year^{-1}	K	Mg
Dunholme	+8·4	−1·8	+3·3	+5	−17	−6	−11	−8	−10	+0·3	−0·5	−0·8
Marl Pit	+5·2	−0·3	+2·5	+1	+54	+28	+1	−5	−2	+0·2	+2·2	−0·2
The Holt	+4·1	+0·6	+2·4	+20	+11	+16	0	+2	+1	+0·2	+1·2	+0·1
Brome Pin	+8·8	+5·5	+7·2	+27	−9	+9	−12	−17	−15	+0·5	+0·6	−1·1
Bull Rush	+7·8	+2·8	+5·3	+33	+30	+32	+3	+14	+9	+0·4	+2·3	+0·6
Flint Ridge	+17·7	+16·0	+16·9	−5	−42	−24	−2	−17	−10	+1·2	−1·7	−0·7
Hackthorn	+1·6	+15·4	+8·5	−25	+60	+18	−4	−16	−10	+0·6	+1·3	−0·7
Little Lane	+10·7	+4·1	+7·4	+66	+27	+47	+12	+12	+12	+0·5	+3·1	+0·8
White Patch	+2·9	−3·0	0	+38	+51	+45	−2	+8	+3	0	+3·0	+0·2
New Piece	+6·1	+2·7	+4·4	+37	−22	+8	+4	−4	0	+0·3	+0·5	0
Windbreak	+4·1	+2·7	+3·4	−14	−8	−11	−13	−20	−17	+0·2	−0·7	−1·1
Mean of all samples	+8·0	+2·3	+5·1	+21	+8	+15	−2	−2	−2	+0·4	+1·1	−0·1

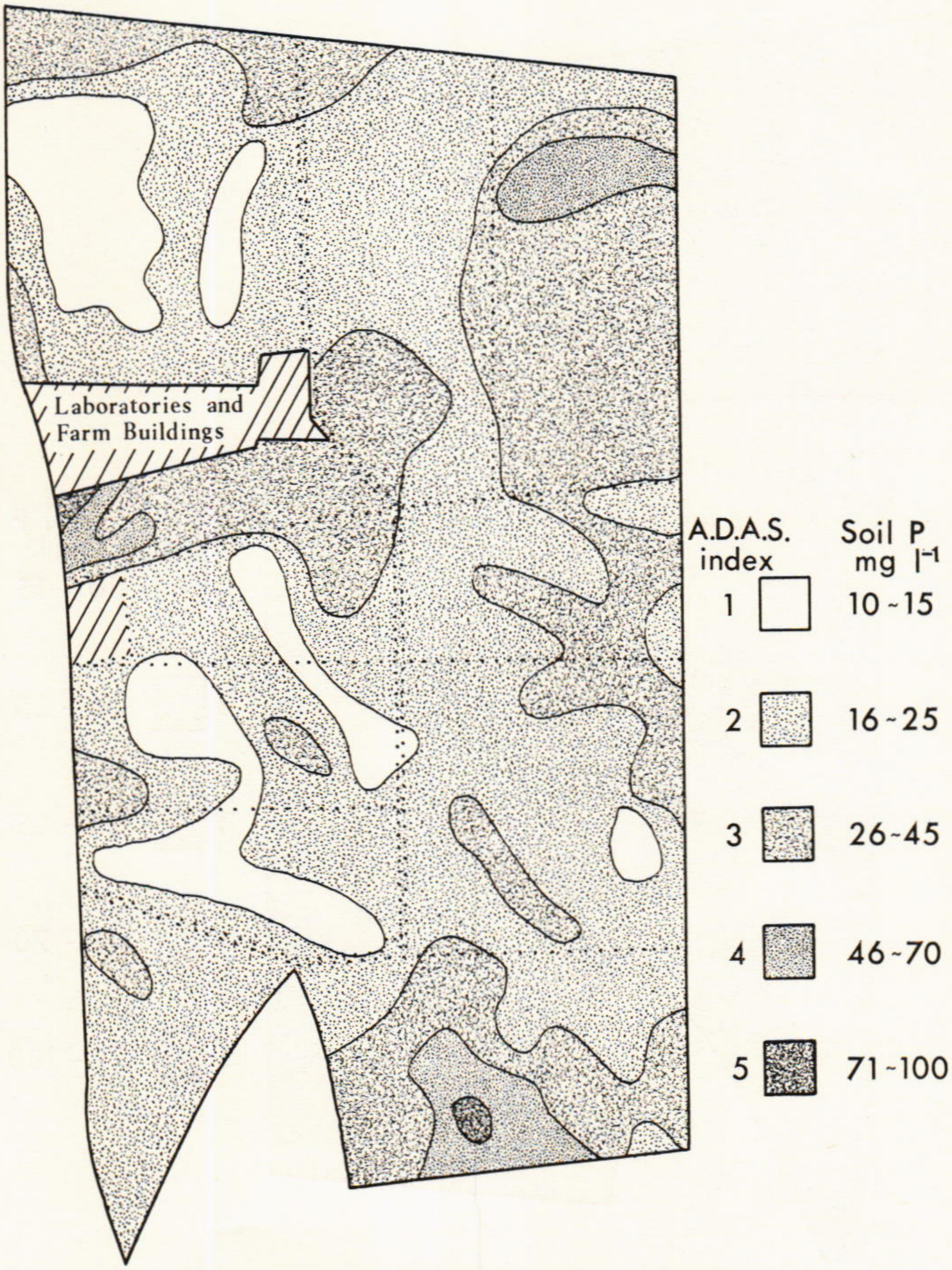

FIG. 3a. Sodium bicarbonate soluble phosphorus in the topsoil in 1960.

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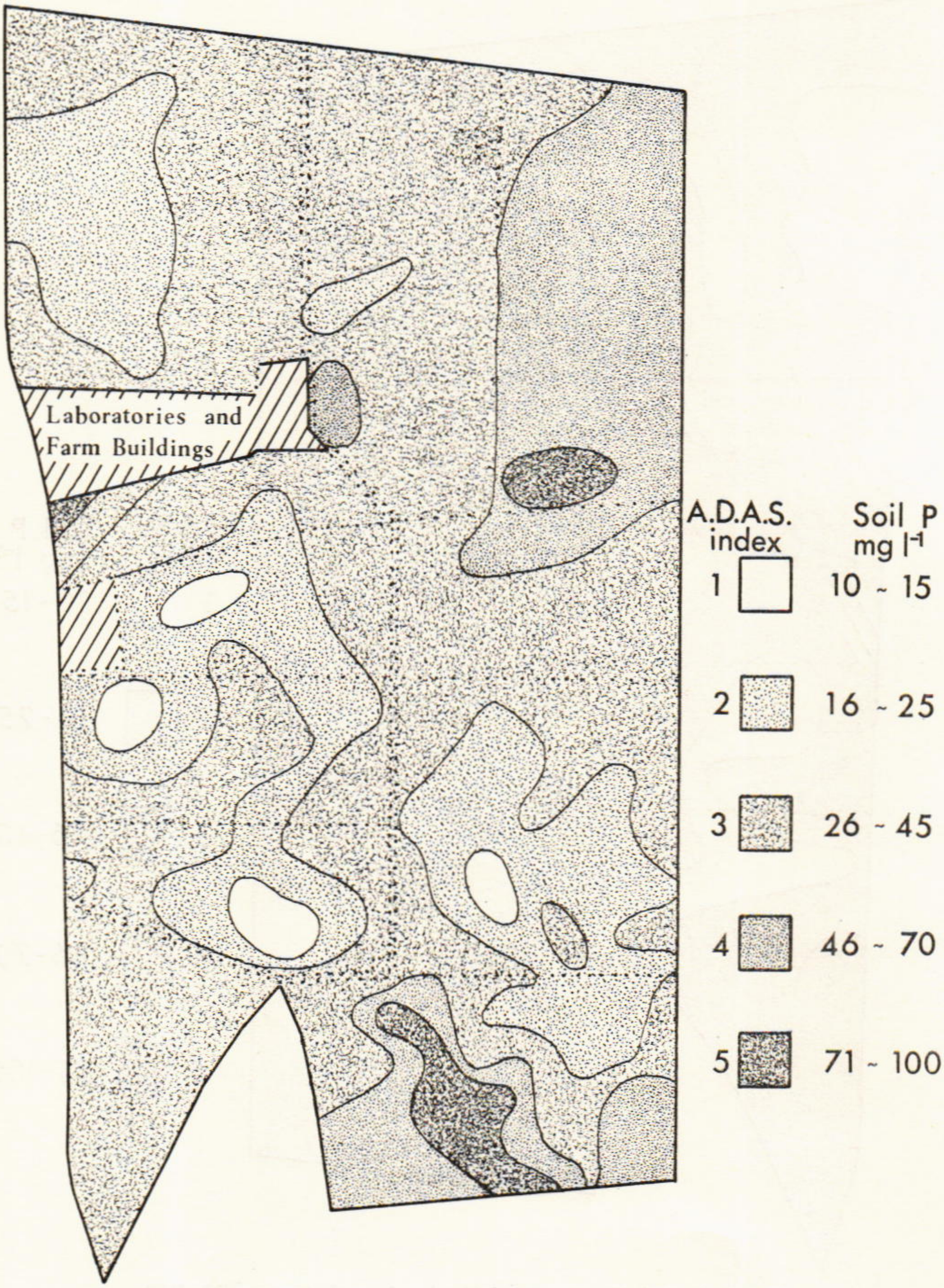

FIG. 3b. Sodium bicarbonate soluble phosphorus in the topsoil, 1973–75.

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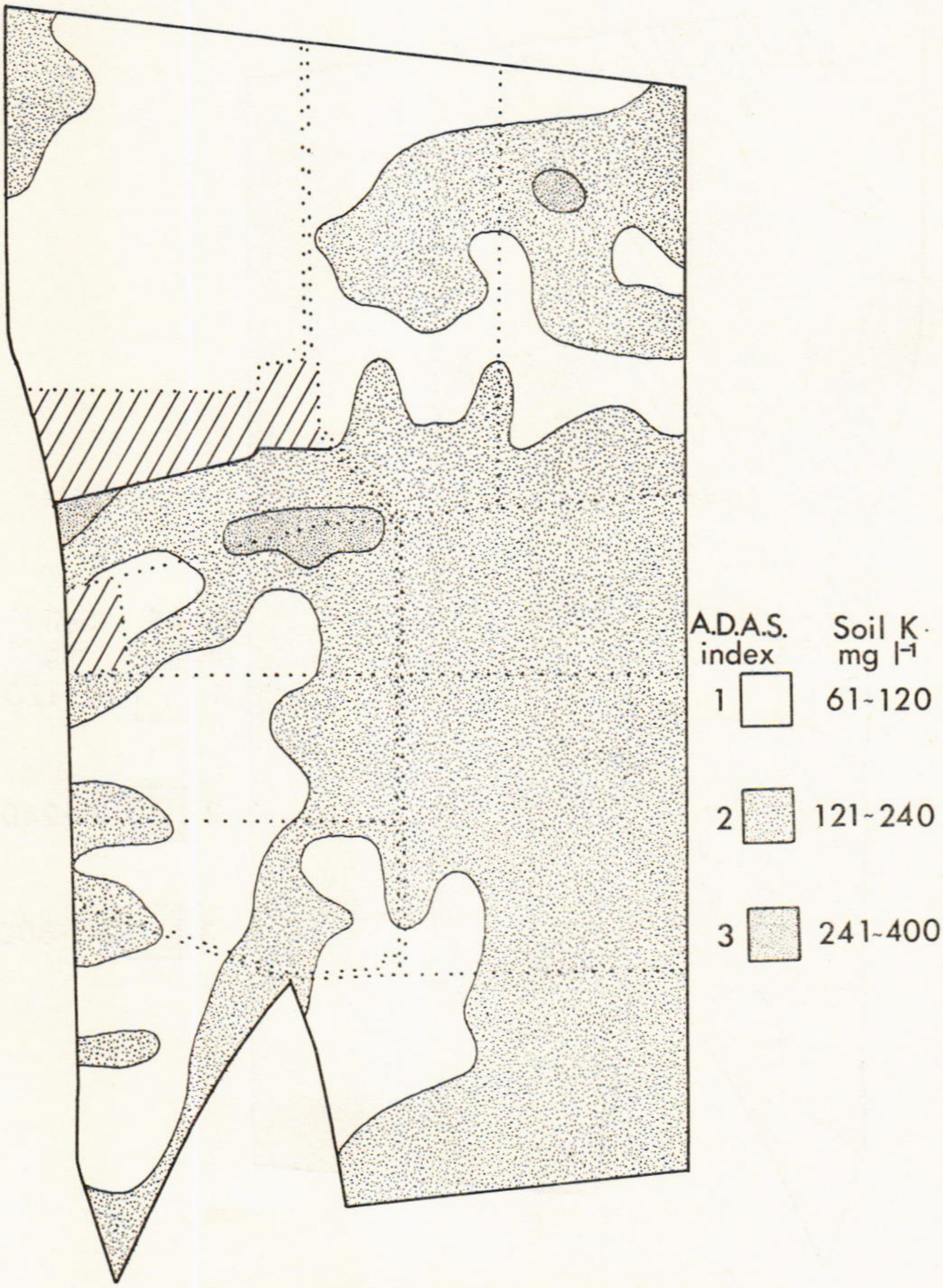

FIG. 4a. Exchangeable potassium in the topsoil in 1960.

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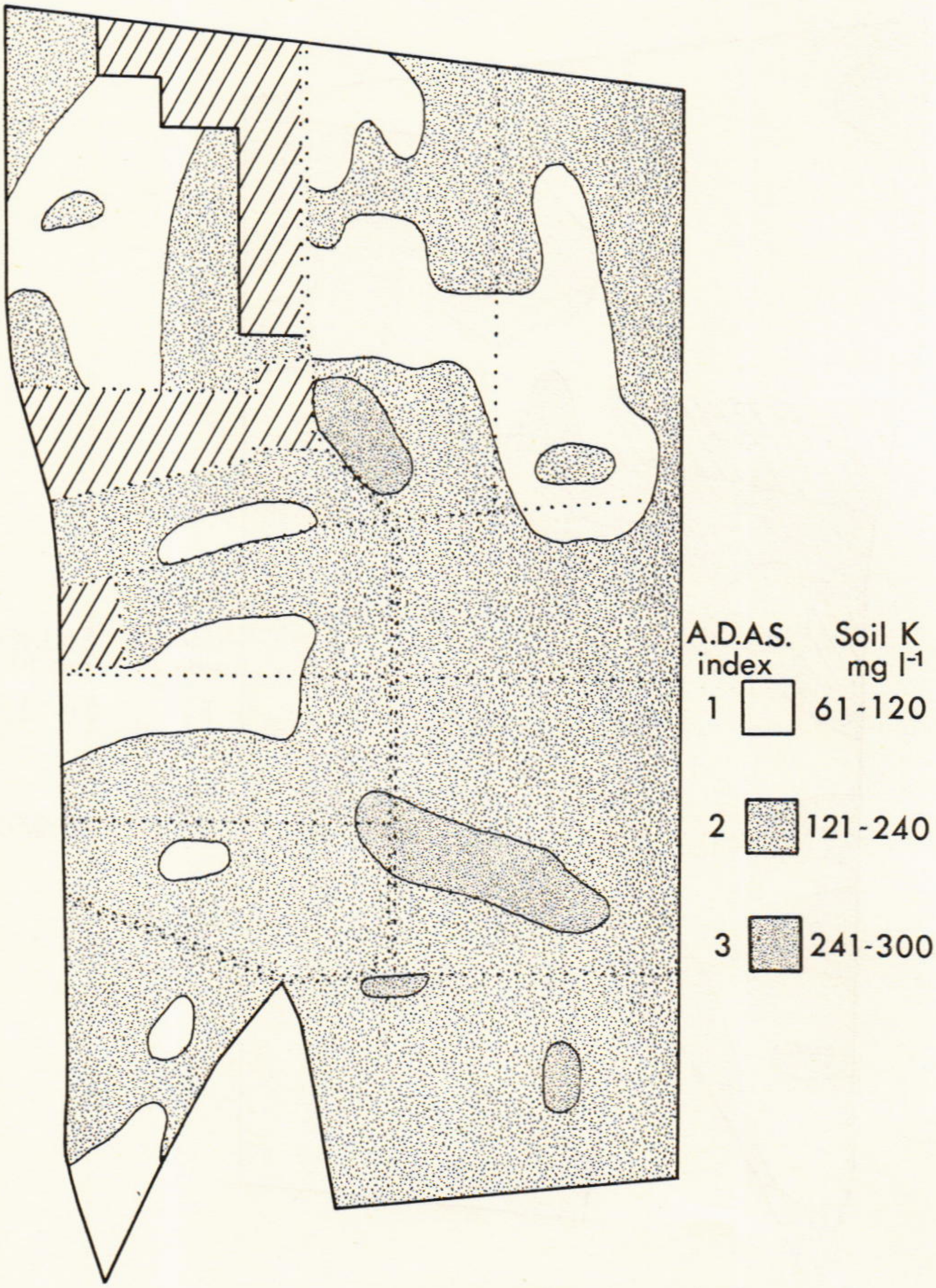

FIG. 4b. Exchangeable potassium in the topsoil, 1973–75.

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field with 66 mg litre^{-1} more potassium. The distribution of soil potassium over the farm is shown in Figs. 4a and b where the most obvious change is the decrease in the area in ADAS Index 1 in 1960 and corresponding increase in 1973–75 in the area in Index 2. Potassium in the subsoil (Table 7) showed a smaller mean average increase than topsoil over the whole farm, increasing from 97 to 105 mg litre^{-1}.

The nutrient balance (Table 5) shows that all fields were given more potassium in the 14 years than was removed by the crops. On Hackthorn, Windbreak and Flint Ridge fields, however, the potassium concentration decreased. The loss of potassium on Flint Ridge may be due to the no-manure policy in the south-west quarter of the field which is now of ADAS Index 1, with a mean concentration of 104 mg litre^{-1}. The decrease of mean soil potassium concentration on Windbreak and Hackthorn fields reflects decline in the area of Index 3. Although the overall potassium concentration for Hackthorn decreased, the majority of the field by 1973–75 was of Index 2 and the uniformity of the field improved. The low PK area of Brome Pin west shows as a large area of Index 1, while normal fertiliser application to the eastern half increased the status to Index 2. The reduced fertiliser and manure applications are probably the reasons for the subsoils in the respective fields having the lowest potassium concentrations on the farm in 1973–75.

On average of all samples, soil K increased by about 1·1 mg litre^{-1} year^{-1} as a result of an average balance of + 24 kg ha^{-1} year^{-1}. In a previous experiment over a five-year period (Draycott *et al.*, 1972b), soil K increased by about 2 mg litre^{-1} year^{-1} with an average balance of + 20 kg K ha^{-1} year^{-1}.

Magnesium. The change in soil magnesium between 1960 and 1973–75 is given in Tables 6 and 7. Overall, soil magnesium slightly decreased from 45 to 43 mg litre^{-1}. Of the 11 fields, magnesium concentration on only three—Bull Rush, Little lane and New Piece—increased. The largest decreases were on Brome Pin and Dunholme, the concentration falling 12 and 11 mg litre^{-1} respectively, both of which fields had below-average magnesium concentrations in 1960. The distribution of soil magnesium concentrations is given in Fig. 5. This shows an undesirable and unexpected decrease in the area of soil in ADAS Index 2 at the northern end of the farm and a corresponding increase in the area of Index 1 and 0. The subsoils showed the same general trends and the average for the whole farm similarly fell from 45 to 43 mg litre^{-1}

The policy adopted in 1960 was application of about 25 kg Mg ha^{-1} as kainit for sugar beet. It was considered that this, together with the FYM and release of magnesium from weathering of clay, would balance losses through leaching and offtake. On the northern half of the farm, losses have clearly exceeded imputs, and soil magnesium has declined. The policy has now been changed and all the fields receive 63 kg Mg ha^{-1} in the autumn before sugar-beet.

Sodium. The mean sodium concentration of the topsoil (Table 6) increased from 27 to 37 mg Na litre^{-1} but in 1973–75 the variation from field to field was greater than in 1960. Much of the variability was explained by the interval between sampling and the previous sugar-beet crop (Table 9); sodium in samples taken immediately after sugar-beet increased by 39 mg litre^{-1} in top soil and 6 mg litre^{-1} in subsoil. Sodium in samples taken a year after sugar beet showed no increase in the topsoil but a small increase of 2 mg litre^{-1} in the subsoil. After two years there was no increase in either top or subsoil. These results confirm that sodium given for sugar beet leaches quickly even in the relatively dry climate of East Anglia. Tinker (1967) considered two years' rainfall usually sufficient to remove most of the sodium applied. Draycott *et al.* (1970) made measurements at Broom's Barn which showed all the sodium given for sugar beet had been leached after three years; nor has sodium accumulated to any extent on Barnfield at Rothamsted where

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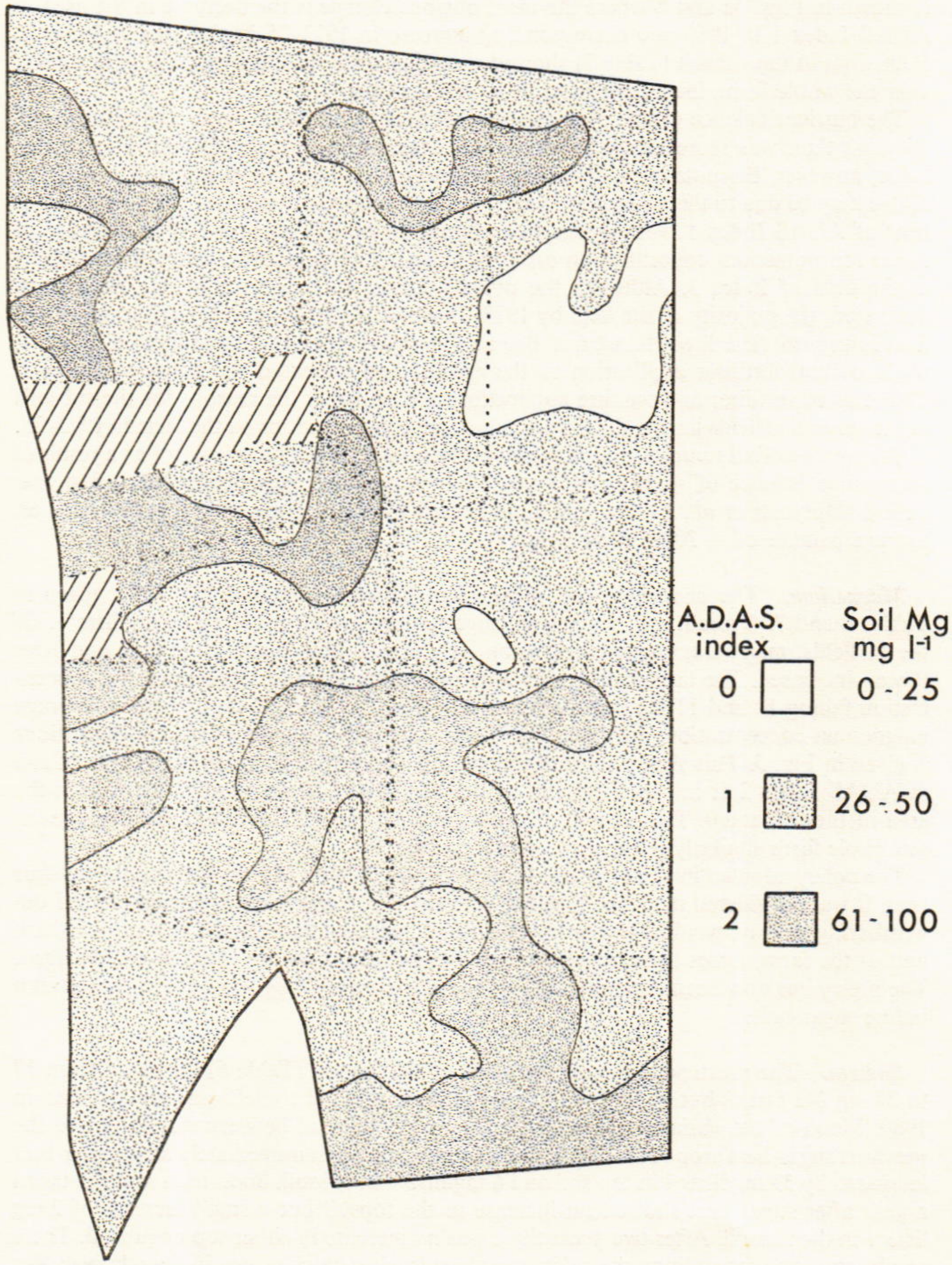

FIG. 5a. Exchangeable magesium in the topsoil in 1960.

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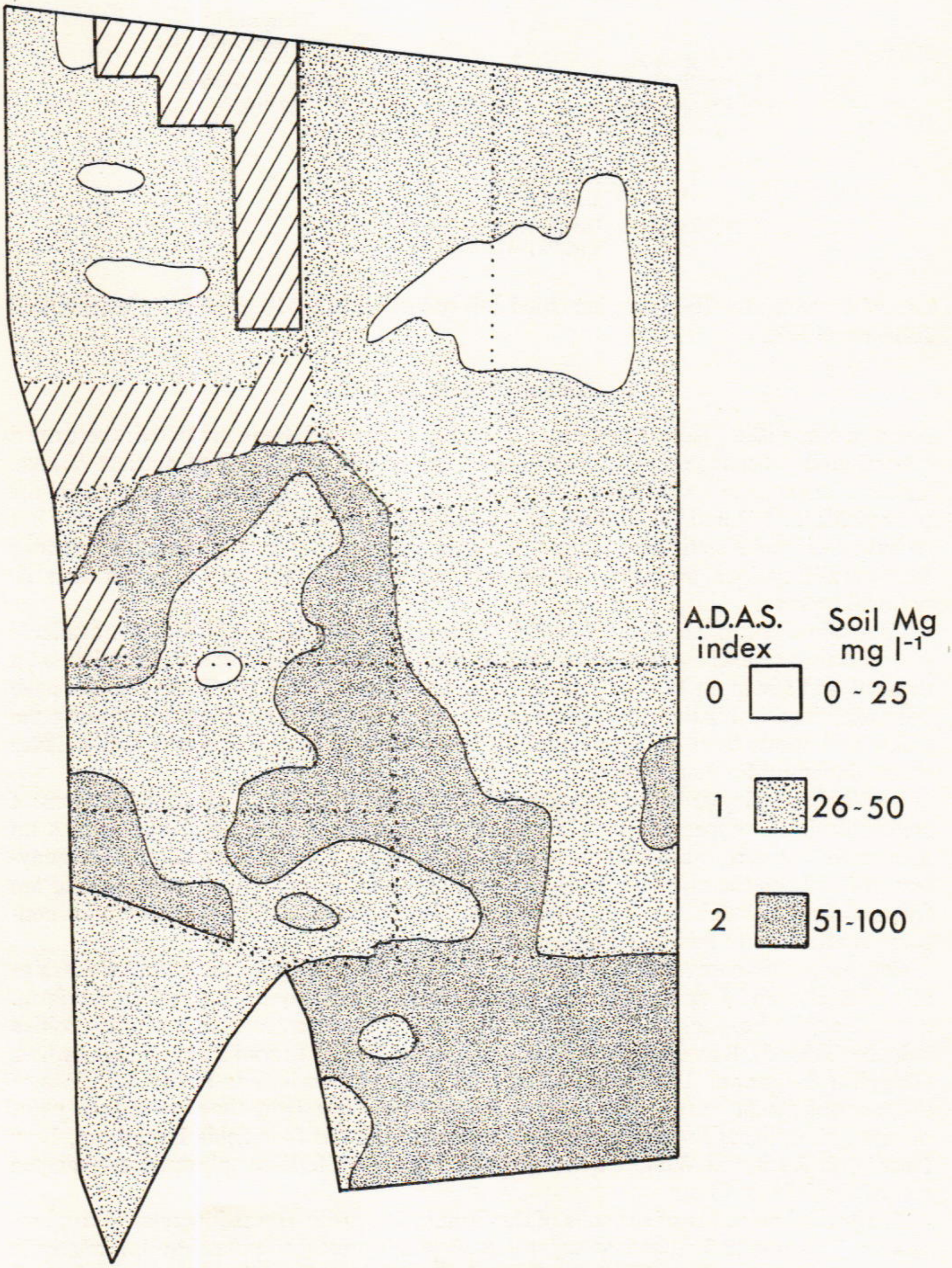

FIG. 5b. Exchangeable magnesium in the topsoil, 1973–75.

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TABLE 9

Effect of time of application of sodium fertiliser on soil sodium

Years between Na application and soil sampling	Fields	Increase in NH_4^+-exchangeable Na Topsoil (mg litre^{-1})	Subsoil (mg litre^{-1})
1	Brome Pin, Bull Rush Little Lane, The Holt	+39	+6
2	Dunholme Flint Ridge	0	+2
3, 4 and 5	Hackthorn, New Piece Marl Pit, White Patch	0	0

annual dressings for 100 years increased soil sodium by only 10 mg litre^{-1} (Warren and Johnston, 1962).

Summary and conclusions

Average crop yields (Table 1 and Fig. 1) for 15 years from 1960 are presented; these are a general guide to changes in fertility and form the basis of calculation of nutrient offtake. Yields of sugar were very variable; a general trend of improving yield was marred by the poor yields in 1974 and 1975. Barley and wheat yields also tended to increase slightly but so have their yields nationally. In general, yields of sugar, barley and wheat at Broom's Barn parallel national averages, with the Broom's Barn yield about 10% greater than the national average.

The main object of the present paper is to compare soil pH, organic carbon, available phosphorus, and exchangeable potassium, magnesium and sodium in samples taken on a detailed grid system in 1960 with similar samples taken in 1973–75. These changes have been examined in relation to applications of lime, fertilisers and manure. By using the yields and mean crop nutrient concentrations, offtakes were calculated and balance sheets drawn up for each nutrient.

The liming policy greatly decreased soil pH variability (Fig. 2), most of the areas of acidity having disappeared by 1975. Acidity still recurs, however, and there seems no alternative to rigorous checking once or twice during each five-year rotation. The sandy-textured soils on the northern fields and west of the farm contain no free chalk and are free-draining, so calcium is continually being leached; these areas therefore need continuous attention to maintain uniformity.

Organic matter concentration changed little in the 15-year period; it increased marginally after leys and farmyard manure and declined marginally on the rest of the farm. Available soil phosphorus increased greatly (Fig. 3), however, reflecting a large positive balance (Table 5). Results of experiments with sugar-beet at Broom's Barn and elsewhere (Draycott & Durrant, 1976) suggest the crop would respond little to further additions of this element except on the small areas of Index 1 soil. Thus, from the experimental point of view, phosphorus fertilising has been successful but the four fields Hackthorn, New Piece, Bull Rush and White Patch warrant a little more fertiliser phosphorus than the rest of the farm in future.

The potassium status of the soils of the farm in 1960 (Fig 4) was low relative to phosphorus. This was unfortunate as sugar beet responds greatly to potassium but relatively little to phosphorus. Experiments at Broom's Barn have substantiated this as sugar-beet yield increases steeply with potassium additions on these soils. The applied potassium in the period 1960 to 1973–75 greatly exceeded offtake on some fields (e.g. White Patch) and increased exchangeable soil potassium. On other fields (e.g. Dunholme) the positive

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nutrient balance was only sufficient to maintain amounts of exchangeable soil potassium. Differences in soil potassium shown in Fig. 4 suggest that, to improve uniformity, more attention needs to be given to potassium balance in future. On most fields an increase in the amount applied is warranted.

On several fields, soil magnesium status (Fig. 5) declined and the nutrient balance (Table 5) provides a reason, for offtake had exceeded application. The dressing of 25 kg Mg ha^{-1} before sugar beet was clearly insufficient on the sandy soils and this has now been increased to 63 kg Mg ha^{-1}. The magnesium status of Broom's Barn soils will need periodic checking; ideally, exchangeable magnesium should be increased to Index 2 as at that concentration sugar-beet will not respond to additions of the element (Draycott, 1972).

Analyses of subsoil samples showed they contained much smaller concentrations of most elements than top soils, nor had they changed much in the 15 years. In future, more attention will be given to the subsoil both in terms of chemical and physical properties. It seems likely that at Broom's Barn and elsewhere the fertility of the subsoil may be one of the main factors limiting yield, particularly of deep-rooted crops like sugar beet.

The authors thank their colleagues who have contributed to this work, especially Dr. S. N. Adams who organised the initial soil sampling by the agricultural staffs of the local sugar factories and Mr. J. A. P. Marsh who prepared and analysed these samples.

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BROOM'S BARN FARM