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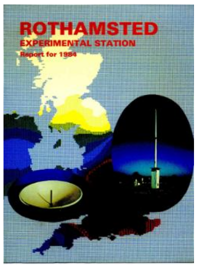

Long-term Effects of Fertilizers at Broom's Barn, 1965-82

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Long-term effects of fertilizers at Broom's Barn, 1965–82

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M. J. DURRANT and K. W. JAGGARD

Abstract

The long-term experiment testing various dressings of fertilizer in a three-course rotation has measured yields and nutrient uptakes in beet, winter wheat and spring barley grown with recommended dressings in comparison with those obtained by applying much larger inputs. Modifications to the experiment in 1977 included varietal changes and doubling the FYM application to 61 t ha^{-1}.

Sugar yields have been greatly increased by using nitrogen, sodium and potassium but there has been little yield response to phosphorus dressings in the beet crop. Sugar yields were not significantly increased by using the large NPK inputs, mainly because of the deleterious effect of the nitrogen component on dry matter apportioning between tops and roots, and between sugar and non-sugar within the root. Barley grain yields have been increased by applying double the recommended NPK inputs since the inception of the trial in 1965, but only since 1977 have the large inputs improved wheat grain yield.

At the recommended NPK levels FYM increased sugar yield on average by 0·71 t ha^{-1}, wheat grain yield by 0·55 t ha^{-1} and barley grain yield by only 0·23 t ha^{-1}. No effect of FYM on grain yields occurred when large inorganic inputs were used. The beneficial effect of FYM on beet seedling establishment has diminished since the application rate was doubled in 1977.

The effects of the main treatments on the offtakes of N, P, K, Na and Mg in the harvested crops averaged over 1977–82 and the changes in the availability of nutrients in both top and subsoils since 1965 are discussed.

The efficiency of sugar extraction from beet is closely related to the amount of water soluble impurities present in the roots at final harvest, and the influence of the main fertilizer treatments and of individual nutrients on the concentrations of the major impurities is outlined.

Introduction

The long-term experiment at Broom's Barn which was started in 1965 has investigated the effect of a range of NPK fertilizer inputs on sugar beet and grain yields and nutrient balance in a three-course rotation of sugar beet, wheat and barley. In addition the experiment has also measured the long-term effects of farmyard manure and sodium chloride, both of which are extensively used for the beet crop. Reports by Draycott, Durrant and Webb, (1971, 1977) gave details of the site and soil characteristics, treatments and results up to 1976. The main features of the first 12 years of the experiment were:

(i) Large inputs of N, P, or K inorganic fertilizer gave no improvement in sugar yield compared with yields obtained by standard applications, although FYM was beneficial irrespective of fertilizer input.

(ii) On average doubling the fertilizer inputs increased barley grain yields, but had no effect on the yield of wheat grain.

(iii) At the higher input levels, grain yields of both cereals were unaffected by the FYM applications.

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(iv) Sodium chloride applied for the beet crop had no effect on subsequent cereal yields.
(v) Phosphorus fertilizers had little effect on beet yields but large responses in sugar yield occurred to both potassium and sodium fertilizer applications.

In this report results up to the spring of 1983 and a general appraisal of the experiment after six rotations are discussed.

Treatments and chemical analysis 1977–82

Since the results were last reported, the experiment and the procedures used for harvesting, sampling (plant material and soils) and chemical analysis have remained unchanged except that in 1977 the cultivars of spring barley and winter wheat were changed to 'Ark Royal' and 'Hobbit' respectively; also since 1977, the applications of FYM have been increased from 30 to 61 t ha^{-1}. The determination of clarified juice purity ceased in 1976 but this assessment of beet quality can be calculated from measurements of individual impurities (Last & Draycott, 1977).

Yields

Previously the influence of only four major treatments on crop and soil parameters were either tabulated or discussed in detail. These were:

F0 (N0 P0 K0 Na0)—which tested the effect of no fertilizer.
F1 (N1 P1 K1 Na1)—this tested the amounts of fertilizer recommended for each crop in 1965.
F2 (N2 P2 K2 Na1)—this treatment tested twice the amounts of NPK given in F1 and resulted in large residues of P and K.
F2+FYM (N2 P2 K2 Na1 plus farmyard manure).

In this report, another treatment F1+FYM (N1 P1 K1 Na1+FYM) is also included in some tables and frequently referred to in the text. Amounts of fertilizers tested are given in Appendix Table 1.

Mean yields 1965–82

Table 1 shows the main effects of the major treatments on crop yields for each six-year period since 1965. Mean sugar yield with the standard dressing (F1) during the most recent phase was 7·20 t ha^{-1}, compared with a national average of 6·22 t ha^{-1}. During the previous six-year phase, F1 yielded only 5·67 t sugar ha^{-1}, and the recent improved sugar yields are attributed to virus-free years and the lack of severe water stress which constrained yields between 1974 and 1976 (see Figure 1). The differences between F1 and F0 increased markedly between 1977–82 compared with previous years but there continued to be little benefit in sugar yield from increasing the fertilizer application from F1 to F2, although in each of the six years F2+FYM increased yield more than F2. A mean sugar yield of 6·78 t ha^{-1} produced by F1 for the entire 18 year period was not significantly increased when the fertilizer input was doubled, although the addition of FYM increased sugar yield to 7·24 t ha^{-1}. The greatest sugar yield of 7·49 t ha^{-1} was obtained by the F1+FYM treatment.

The mean difference in cereal yields between F1 and F0 has gradually increased during each successive six-year period. Doubling the fertilizer inputs (F2) increased barley grain yield by 0·41 t ha^{-1} to 4·51 t ha^{-1}, but FYM applications improved barley grain yields only at the F1 input level. In the wheat crop, which had shown inconsistent responses to the higher inputs during both previous phases, grain yields were improved by the F2 dressing in each year and the mean effect was to significantly increase grain yield from 4·53 to 5·58 t ha^{-1}. The F2+FYM treatment increased wheat grain yield to 5·80 t ha^{-1}.

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TABLE 1

Effect of five fertilizer treatments on crop yield, 1965–82

Sugar Beet

	Mean 1965–70	Mean 1971–76	Mean 1977–82	Mean 1965–82
	Sugar (t ha^{-1})			
F0	5·50	3·93	4·05	4·49
F1–F0	+1·90	+1·74	+3·15	+2·26
(F1+FYM)–F1	+0·71	+0·58	+0·83	+0·71
F2–F1	+0·23	−0·18	+0·20	+0·08
(F2+FYM)–F2	+0·34	+0·24	+0·64	+0·41
SED	±0·253	±0·255	±0·289	±0·154

Winter Wheat

	Grain 85% DM (t ha^{-1})				Straw 85% DM (t ha^{-1})			
	1965–70	1971–76	1977–82	1965–82	1965–70	1971–76	1977–82	1965–82
F0	2·91	2·59	2·22	2·57	4·12	3·24	2·04	3·12
F1–F0	+1·08	+1·80	+2·31	+1·73	+2·38	+2·77	+2·16	+2·45
(F1+FYM)–F1	+0·36	+0·16	+1·15	+0·55	+0·21	+0·46	+0·56	+0·41
F2–F1	−0·24	−0·24	+1·05	+0·19	−0·23	+0·27	+0·65	+0·23
(F2+FYM)–F2	−0·06	−0·13	+0·22	+0·01	+0·23	+0·16	+0·39	+0·26
SED	±0·200	±0·271	±0·338	±0·159	±0·300	±0·428	±0·230	±0·190

Barley

	Grain 85% DM (t ha^{-1})				Straw 85% DM (t ha^{-1})			
	1965–70	1971–76	1977–82	1965–82	1965–70	1971–76	1977–82	1965–82
F0	2·43	2·55	2·08	2·35	1·97	1·61	1·49	1·69
F1–F0	+1·31	+1·45	+2·02	+1·59	+1·52	+1·64	+1·76	+1·64
(F1+FYM)–F1	+0·18	+0·30	+0·22	+0·23	−0·08	+0·28	+0·41	+0·20
F2–F1	+0·35	+0·38	+0·41	+0·38	+0·86	+0·94	+0·91	+0·90
(F2+FYM)–F2	−0·01	−0·12	−0·11	−0·08	+0·08	−0·10	+0·25	+0·08
SED	±0·183	±0·168	±0·260	±0·120	±0·163	±0·159	±0·193	±0·100

Figure 1 shows the sugar yields from the four treatments each year. Sugar yields exceed 8 t ha^{-1} with some treatments only in 1965–67, 1980 and 1982; the relatively late sowing dates and early harvest dates combined with lack of irrigation has precluded the growing of 10 t ha^{-1} yields which are a desirable target in an investigation of this nature. For clarity the responses relative to F1 are shown in Figure 2. Insufficient replication generally combined with a consistently poor yield on one particular plot of F1 obscure any trends in the responses. However, the depression in yield associated with F0 gradually increased from about 20 to 45% between 1965 and 1979 and yields with F0 have been just under half those with F1 since then. No continuous trends in responses to F2 or F2+FYM were found.

The effect on sugar concentration of four treatments each year is shown in Figure 3. The large year-to-year variation resulted mainly from differing rainfall patterns immediately prior to harvesting. A substantial accumulation of residual soil nitrogen caused by a series of dry winters plus the effects of virus yellows in some years depressed sugar concentrations between 1969 and 1976. Average amounts of winter rainfall and leaching occurred between 1977 and 1982, and Figure 3 indicates that the mean sugar concentrations during that period exceeded those obtained previously. In almost every year since 1965 F1 gave the highest sugar concentration, but doubling the fertilizer input consistently depressed it on average from 17·6 to 16·7%. Thus although F2 gave larger fresh root yields and total dry matter than F1, this was offset by lower sugar concentrations. FYM depressed sugar concentration in roots by about 0·2% and this effect has remained consistent even though FYM application rates have been doubled to 61 t ha^{-1} since 1977.

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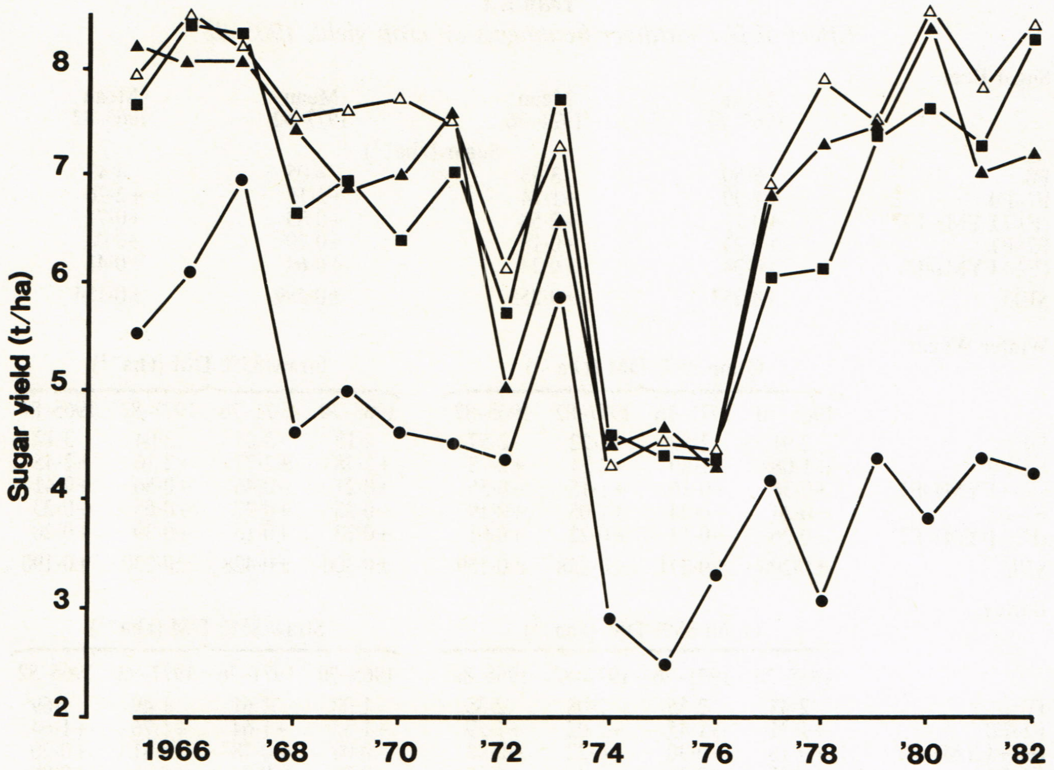

FIG. 1. Effect of four fertilizer treatments on sugar yield, 1965–82. ● F0, ■ F1, ▲ F2, △ F2+FYM.

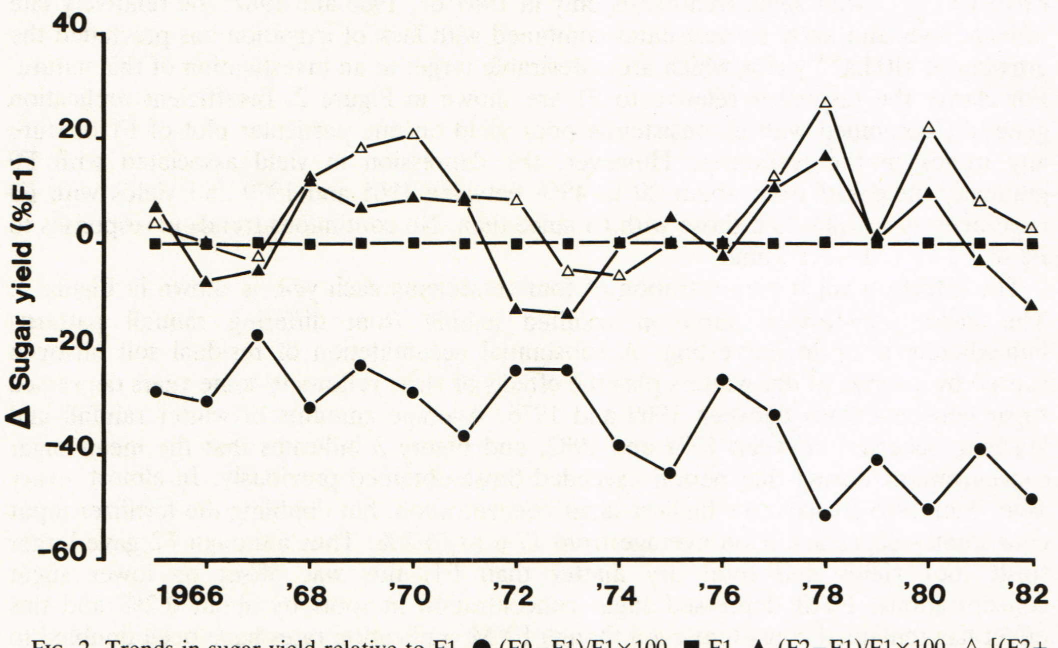

FIG. 2. Trends in sugar yield relative to F1. ● (F0−F1)/F1×100, ■ F1, ▲ (F2−F1)/F1×100, △ [(F2+FYM)−F2]/F1×100.

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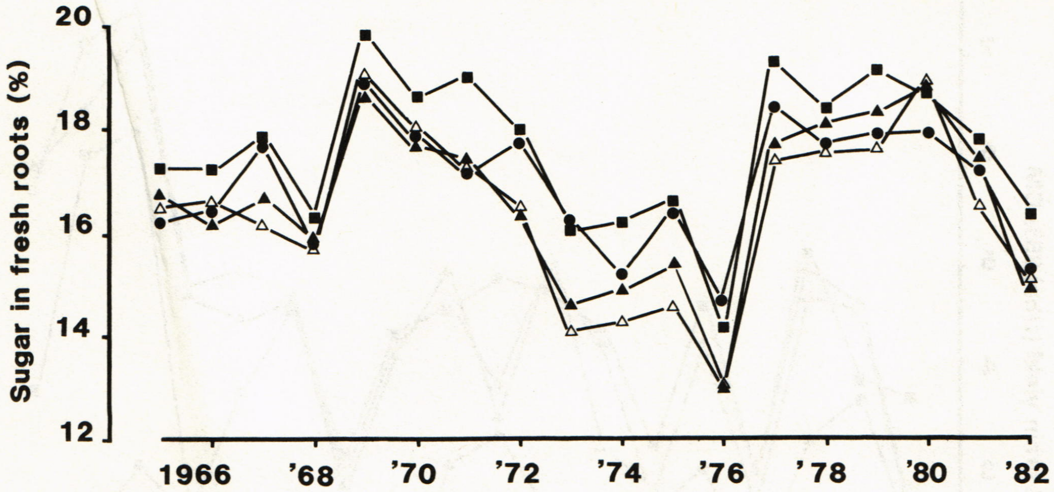

FIG. 3. Effect of four fertilizer treatments on the sugar percentage of fresh roots, 1965–82. ● F0, ■ F1, ▲ F2, △ F2+FYM.

The distribution of dry matter between tops and roots was adversely affected by the F2 treatment; on average the top/root ratio was 0·53 compared to 0·45 for F1. The increase in the proportion of tops was almost certainly caused by the extra nitrogen supplied by that treatment. Applying FYM at either the F1 or F2 input levels had no adverse effects on the distribution of dry matter between the tops and roots, but increased the total amount produced. The dry matter distribution between sugar and non sugar within the roots was also adversely affected by the nitrogen component of F2 in relation to F1, decreasing sugar percentage dry weight from 72·9 to 72·0%. FYM increased those proportions by about 0·5%. In contrast to sugar concentrations on a fresh weight basis, sodium and potassium fertilizers had little mean effect on the sugar to root dry matter ratio. This suggested that the water contents of the roots at final harvest were decreased by these two fertilizers although Cormack (1979) found no such effect in a study at Broom's Barn in 1975.

Figures 4 and 5 show the yields of cereal grains for four treatments since 1965. The mean grain yields from unfertilized plots have declined during the study despite changes to newer cultivars. During the last six years the mean effect of F1 was to double the grain yields—from 2·22 to 4·53 t ha^{-1} of wheat and from 2·08 to 4·10 t ha^{-1} of spring barley. In contrast with previous reports, doubling the fertilizer inputs increased wheat grain yield in every year since 1977 and increased the mean annual yield from 4·53 to 5·58 t ha^{-1}. With sufficient fertilizer, yields of wheat grain have improved considerably since 1977 (particularly in 1980 and 1981) and the average of 5·58 t ha^{-1} compares favourably with the national crop average of 5·12 t ha^{-1} for the 1977–82 period.

Yields of spring barley grain were also increased by F2 in four of the last six years, although yields showed little improvement on those previously reported. Even so, the mean yield of 4·51 t ha^{-1} obtained with F2 was better than the national average of 4·17 t ha^{-1}1 which also includes yields of the more productive winter barley. The effect of FYM on cereal yields was larger with the winter wheat which followed sugar beet than with the barley. Responses also decreased as inorganic inputs were increased (Table 1). However, overall results for 1965–82 indicate that the yield of wheat grain was greatest, 4·85 t ha^{-1}, with the F1+FYM dressing. In the barley crop, applying F2 or alternatively doubling only the nitrogen input in conjunction with standard phosphate and potassium

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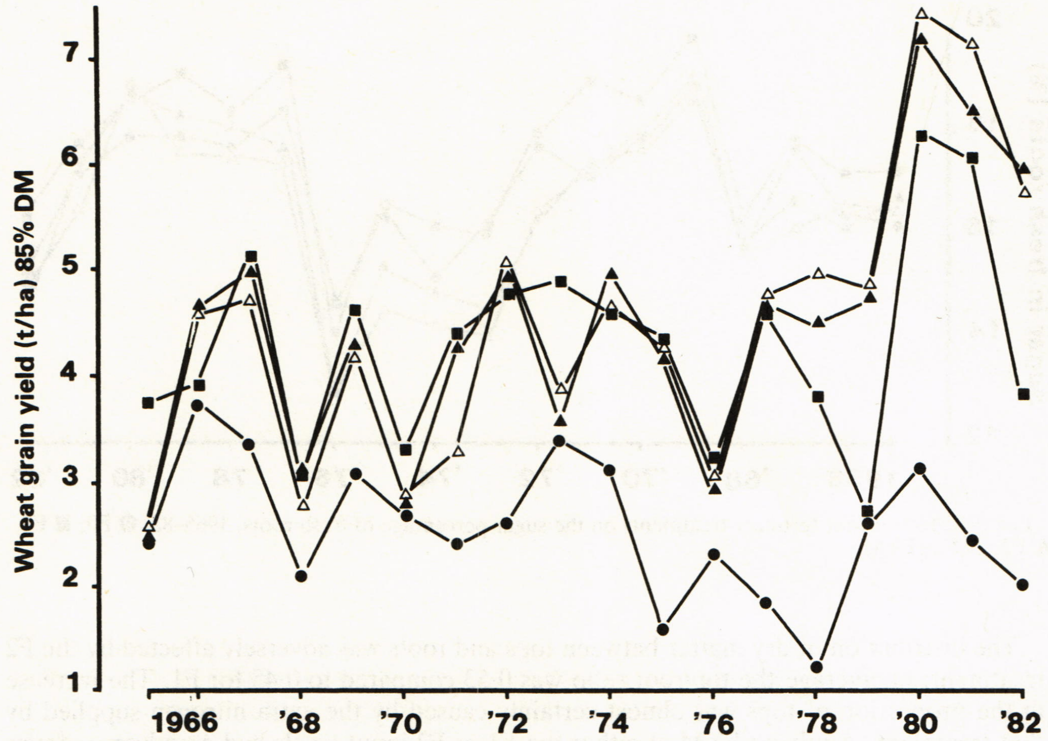

FIG. 4. Effect of four fertilizer treatments on yield of wheat grain, 1965–82. ● F0, ■ F1, ▲ F2, △ F2+FYM.

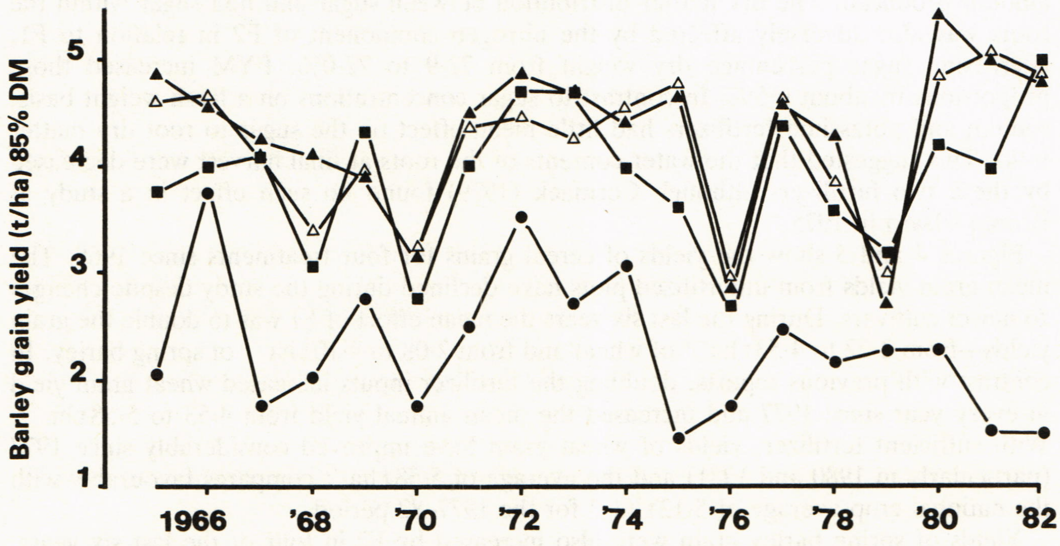

FIG. 5. Effect of four fertilizer treatments on yield of barley grain, 1965–82. ● F0, ■ F1, ▲ F2, △ F2+FYM.

dressings, N2P1K1, produced maximum grain yields of 4·4 t ha^{-1}. The influence of individual elements in these effects is discussed later.

Response to individual elements and FYM

Tables 2a, b, and c show the effects of each element and of FYM on yields in each year for the 1977–82 period, and also on the overall means since 1965.

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Nitrogen. In the beet crop during the most recent phase the mean response to N1 was large at 0·79 t sugar ha^{-1}, but Table 2a also shows that doubling the application of nitrogen depressed sugar yield in each of the six years. Since 1965 the mean effect of the N2 dressing has been to reduce sugar yield from 6·04 t ha^{-1} with N1 to 5·78 t ha^{-1}; a reduction occurred in 15 of the 18 years of study.

During the last six years applying N1 (at P1K1) significantly increased wheat grain yield from 2·57 to 4·74 t ha^{-1}. Over the same period N2 increased grain yield occasionally but its mean effect was small. In this experiment applying N2 (at P1K1) decreased wheat grain yield on average by 0·19 t ha^{-1} between 1965–82 which superficially conflicts with many other studies which justify the national practice whereby the average nitrogen application for wheat has almost doubled from 88 kg N ha^{-1} in 1965 to 166 kg N ha^{-1} in 1982. Unlike wheat, barley grain yields showed large and consistent responses to both nitrogen rates, continuing the pattern set in earlier years.

Phosphorus. The responses to phosphorus in the beet crops have remained variable, and Table 2a shows that for the period 1977–82 the mean effect of applying P1 was to

TABLE 2a

Effect of nitrogen and phosphorus on yields, 1965–82

	1977	1978	1979	1980	1981	1982	Means 1977–82	Means 1965–82
Nitrogen (P1K1 given)								
				Sugar (t ha^{-1})				
N0	4·97	3·94	5·54	4·79	5·47	5·49	5·03	5·25
N1–N0	+0·39	+1·94	+0·78	+1·95	+0·81	+2·17	+1·34	+0·79
N2–N1	−0·39	−0·23	−0·22	−0·48	−0·70	−0·43	−0·43	−0·26
SED	±0·346	±0·430	±0·359	±0·475	±0·510	±0·429	±0·289	±0·141
				Wheat grain at 85% DM (t ha^{-1})				
N0	2·87	1·62	2·30	3·23	2·81	2·60	2·57	2·77
N1–N0	+1·50	+1·15	+2·20	+2·41	+3·69	+2·04	+2·17	+1·71
N2–N1	−0·06	+0·07	+0·18	+1·14	−1·17	+0·39	+0·09	−0·19
SED	±0·463	±0·549	±0·565	±0·431	±0·570	±0·530	±0·338	±0·151
				Barley grain at 85% DM (t ha^{-1})				
N0	2·70	2·02	2·44	2·62	2·20	2·70	2·45	2·66
N1–N0	+1·34	+1·67	+1·02	+1·60	+1·88	+2·33	+1·64	+1·27
N2–N1	+0·83	+0·98	−0·62	+0·60	+1·22	+0·28	+0·55	+0·47
SED	±0·190	±0·244	±0·214	±0·257	±0·443	±0·389	±0·260	±0·112
Phosphorus (N1K1 given)								
				Sugar (t ha^{-1})				
P0	5·60	5·59	6·35	7·12	5·55	7·09	6·22	6·03
P1–P0	−0·24	+0·29	−0·03	−0·38	+0·73	+0·57	+0·15	+0·01
P2–P1	+0·94	−0·52	+0·06	+0·62	−0·63	−0·89	−0·07	+0·07
SED	±0·346	±0·430	±0·359	±0·475	±0·510	±0·429	±0·289	±0·141
				Wheat grain at 85% DM (t ha^{-1})				
P0	4·14	2·73	4·62	5·44	6·27	4·15	4·56	4·26
P1–P0	+0·23	+0·04	−0·12	+0·20	+0·23	+0·49	+0·18	+0·21
P2–P1	+0·18	+0·49	+0·74	+0·55	−0·22	+0·81	+0·43	+0·17
SED	±0·463	±0·549	±0·656	±0·431	±0·570	±0·530	±0·338	±0·151
				Barley grain at 85% DM (t ha^{-1})				
P0	4·17	3·49	3·53	4·06	3·79	4·80	3·97	3·84
P1–P0	−0·13	+0·20	−0·07	+0·16	+0·29	+0·23	+0·11	+0.09
P2–P1	+0·32	+0·19	+0·18	+0·37	+0·05	+0·26	+0·23	+0·20
SED	±0·190	±0·244	±0·214	±0·257	±0·443	±0·389	±0·260	±0·112

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TABLE 2b

Effect of potassium and sodium on yields, 1965–82

	1977	1978	1979	1980	1981	1982	Means 1977–82	Means 1965–82
Potassium (N1 P1 NaO given)								
				Sugar (t ha^{-1})				
K0	4·88	4·03	4·92	5·79	3·76	4·77	4·69	4·83
K1–K0	+0·48	+1·85	+1·40	+0·95	+2·52	+2·89	+1·68	+1·22
K2–K1	+0·99	+0·55	+0·54	+0·57	+0·72	−0·11	+0·45	+0·51
Potassium (N1 P1 Nal given)								
K0	5·79	6·19	6·28	7·35	6·53	8·09	6·70	6·53
K1–K0	+0·40	+0·07	+1·19	+0·30	+0·78	+0·21	+0·50	+0·29
SED	±0·346	±0·430	±0·359	±0·475	±0·510	±0·429	±0·289	±0·141
Potassium (N1 P1 given)								
				Wheat grain at 85% DM (t ha^{-1})				
K0	4·08	2·95	4·54	5·76	4·57	4·40	4·38	4·27
K1–K0	+0·29	−0·18	−0·04	−0·12	+1·93	+0·24	+0·35	+0·20
K2–K1	+0·13	+1·21	−1·07	+0·12	−0·11	−0·80	−0·09	−0·25
SED	±0·463	±0·549	±0·656	±0·431	±0·570	±0·530	±0·338	±0·151
				Barley grain at 85% DM (t ha^{-1})				
K0	4·23	3·64	3·29	4·64	3·13	4·42	3·89	3·84
K1–K0	−0·19	+0·05	+0·17	−0·42	+0·95	+0·61	+0·20	+0·05
K2–K1	−0·06	−0·19	+0·06	+0·07	−0·83	−0·11	−0·18	−0·11
SED	±0·190	±0·244	±0·214	±0·257	±0·443	±0·389	±0·260	±0·112

TABLE 2c

Effect of FYM on yields 1965–82

	1977	1978	1979	1980	1981	1982	Means 1977–82	Means 1965–82
				Sugar (t ha^{-1})				
(F0+FYM)–F0	+2·22	+2·80	+2·04	+3·82	+1·95	+3·50	+2·73	+1·85
(F1+FYM)–F1	+1·06	+1·21	+0·46	+1·23	+1·00	+0·02	+0·83	+0·74
(F2+FYM)–F2	+0·13	+0·60	+0·07	+0·95	+0·83	+1·25	+0·64	+0·41
SED	±0·346	±0·430	±0·359	±0·475	±0·510	±0·429	±0·289	±0·141
				Wheat grain at 85% DM (t ha^{-1})				
(F0+FYM)–F0	+0·83	+0·33	+1·14	+1·66	+2·62	+0·92	+1·25	+0·64
(F1+FYM)–F1	+0·30	+0·65	+2·20	+1·06	+1·30	+1·36	+1·15	+0·55
(F2+FYM)–F2	+0·11	+0·48	+0·01	+0·22	+0·63	−0·18	+0·21	+0·01
SED	±0·463	±0·549	±0·656	±0·431	±0·570	±0·530	±0·338	±0·151
				Barley grain at 85% DM (t ha^{-1})				
(F0+FYM)–F0	+0·44	−0·11	+0·65	+0·47	+0·91	+1·95	+0·72	+0·35
(F1+FYM)–F1	−0·12	−0·14	+0·30	+0·11	+0·35	+0·39	+0·15	+0·23
(F2+FYM)–F2	−0·01	−0·40	+0·33	−0·56	−0·01	−0·02	−0·11	−0·13
SED	±0·190	±0·244	±0·214	±0·257	±0·443	±0·389	±0·260	±0·112

increase sugar yield by only 0·15 t ha^{-1}. The positive responses to phosphorus have become more frequent during the latter half of the experiment and P1 has increased sugar yields in six of the last nine years. There were some indications that the positive responses in sugar yields to the double dressing of phosphorus (P2) were cyclic, but these could not be directly related to the amounts of soluble-P measured in the topsoils.

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Since 1977 the mean yields of wheat grain were increased from 4·74 with P1 to 5·17 t ha^{-1} by giving P2 whereas the mean effect of that treatment on wheat grain yield had been insignificant during the previous 12 years. Smaller but consistent responses in barley grain yields to the P2 dressings were obtained and in both crops it seems likely that the yield responses to phosphorus contribute toward the increased grain yields obtained with the F2 treatment previously discussed.

Potassium and sodium. The most recent results (Table 2b) confirmed that in the absence of sodium large responses in sugar yield to potassium dressings continued to occur almost every year. The standard input (K1) increased mean sugar yield from 4·82 to 6·04 t ha^{-1} and doubling the potassium input further increased yield to 6·55 t ha^{-1}. In the beet crop a very high proportion of potassium can be replaced by sodium (Durrant, Draycott & Boyd, 1974), but even at optimum potassium supply, sodium exerts a beneficial effect on both growth rate and sugar yield. Applying sodium chloride at 377 kg ha^{-1} increased sugar concentrations in fresh roots and mean sugar yields from 6·04 with N1P1K1NaO to 6·78 t ha^{-1}. However, the mean response of 1·22 t sugar ha^{-1} obtained with K1 in the absence of sodium was reduced to only 0·29 t ha^{-1} when sodium was also applied. When the potassium fertilizer inputs were doubled (F2) the sodium application nevertheless increased mean sugar yield from 6·33 t ha^{-1} with N2P2K2NaO to 6·84 t ha^{-1}. Although both available and residual K in the soil have been increased by this treatment, there was no evidence that the beneficial effect of sodium on sugar yield was greatly diminished.

The effects of K1 (at N1P1) on sugar and grain yields in the years 1977–82 were larger than had been reported earlier (Table 2b). This may have resulted from the gradual reduction of exchangeable-K values in plots which have not received any potassium fertilizer dressings since 1964—when measured in 1983 the exchangeable-K values in top soils from such plots were less than 50 mg l^{-1}. Alternatively, the ability of the soil to retain potassium originating from previous fertilizer dressings in a non-exchangeable form and its subsequent release when stressed to supply potassium (Johnson & Poulton, 1977) may have influenced the response of the crops to potassium dressings more during the earlier years of the experiment. Giving K2 (at N1P1) did not increase grain yields of either cereal and one interpretation is this data supports the current fertilizer recommendation of about 40 kg ha^{-1} for average yielding crops.

Although not given in detail, the results confirm that applying 377 kg sodium chloride ha^{-1} in the spring on this soil type, which is considered typical of many beet-growing areas, had no detrimental effects on either grain or straw yields in subsequent cereal crops, irrespective of the amounts of NPK tested. However, throughout the study, where sodium chloride was applied some slaking and weak crusting of the surface soil was frequently observed prior to the drilling of the beet and of the spring barley two years later but this caused no difficulty in seedbed preparations on the sandy loam soil. These observations suggest that on weakly structured soils, it may be more appropriate to plough down the sodium chloride during the previous autumn instead of applying it just before seedbed preparation.

FYM. Table 2c shows that the FYM continued to influence all crop yields, although its effect was more pronounced in the beet and wheat crops than in barley. In the absence of any inorganic fertilizers, FYM increased mean sugar yield by 2·73 t ha^{-1} to 6·77 t ha^{-1}, a response twice as great as that reported for the first 12 years of the experiment.

Beet seedling establishment and final plant populations. A model developed at Broom's Barn by Jaggard (1979) has indicated that in the majority of crops sugar yields are limited

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TABLE 3

Effect of fertilizers on beet seedling establishment. Seedlings m^{-1} of row

Treatment	1977–82	1965–82
F0	10·8	12·7
F1	11·2	12·5
F2	10·3	11·6
F1+FYM	10·6	12·9
F2+FYM	10·5	12·0

Phosphorus (N1 K1 applied) (kg ha^{-1})	1977–82	1965–82
0	10·4	12·5
22	10·5	12·3
44	10·4	12·2

Nitrogen (P1 K1 applied) (kg ha^{-1})	1977–82	1965–82
0	10·6	12·9
100	10·6	12·3
200	10·3	11·6
SED	±0·40	±0·49

Potassium and Sodium (N1 P1 applied) (kg ha^{-1})		1977–82	1965–82
0	0	10·0	11·2
83	0	10·2	12·2
167	0	10·4	12·1
0	148	10·7	12·4
83	148	11·0	12·5
SED		±0·40	±0·49

by a lack of plants and irregular spacing and results from this experiment identify one reason for this. Although applying F1 gave the largest number of seedlings in four of the most recent six year phase, its mean annual effect since 1965 (Table 3) has been to decrease establishment by 2% when compared with the values obtained with F0. Doubling the fertilizer input (F2) decreased establishment by a further 7% to 11·6 seedlings m^{-1}; this was largely caused by the extra nitrogen included in that dressing.

The beneficial effects of FYM on establishment occurred more frequently during the previous phases of the experiment and particularly when applied with the F1 dressing. Since the application rate of FYM was doubled to 61 t ha^{-1}, the FYM has had little influence on seedling establishment, presumably because any beneficial effects on soil structure were offset by detrimental effects arising from the extra nutrients applied.

Giving K1 (at N1P1) has consistently resulted in more seedlings than when no K was given but as shown in Table 3, the benefit did not increase as K reserves were depleted. In the absence of any potassium input, applying salt also increased establishment by about 10%, although when applied in conjunction with the K1 dressing the beneficial effect on seedling numbers was much reduced.

The seedlings have always been hand singled in order to achieve a target population of 80 000 regularly spaced plants ha^{-1}. During 1977–82 the annual mean population obtained was 84 000 and all annual values were similar and in excess of 80 000 ha^{-1} thus ensuring that any effects of fertilizers on establishment did not persist to contribute to differences in final yield.

Nutrient balance

Table 4 shows the cumulative balance over 18 years, and indicates that in the absence of any fertilizer applications the crops removed appreciable amounts of the major elements

TABLE 4

Cumulative nutrient balance over six rotations, 1965–82

	Amount applied—amount removed (kg ha^{-1})			
Treatment	N	P	K	Na
F0	−712	−172	−580	−58
F1	+120	+134	+40	+819
F2	+1030	+496	+832	+783
F2+FYM	+2368	+913	+1958	+922

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from the soil reserves. With the standard fertilizer dressing (F1) offtakes and inputs were approximately in balance, but during the 1977–82 period supplied a total of 22 kg K ha^{-1} less than the crops removed. The large residuals of 1030 kg N ha^{-1}, 496 kg P ha^{-1} and 832 kg K ha^{-1} which have occurred with the F2 dressing were increased greatly when FYM was also applied. In theory, large residual amounts of sodium could have been accumulated by both F1 and F2 dressings but no increased amounts of exchangeable sodium was measured in top soils three years after application. This was not unexpected because of the mobility of the sodium ion and the inability of this soil, which is low in organic matter and exchange capacity, to retain and subsequently release large amounts of sodium. Exchangeable sodium was decreased with F0 by only 4 mg l^{-1} during the 18 years, and the responses to sodium chloride remained similar in each year.

Similarly there is no evidence of accumulated residual effects of nitrogen with the F2 dressing. Depressions in sugar concentration were no greater than normally obtained from applying 200 kg N ha^{-1} in the beet year. These results suggest that a significant proportion of the residual nitrogen associated with the heavy inputs was lost from the system by processes such as fixation, denitrification and leaching.

During the years 1977–82 no inorganic fertilizers containing magnesium were applied and offtakes of this element have ranged from 24 kg ha^{-1} with F0 to 44 kg ha^{-1} with F2.

TABLE 5

Nutrient composition of sugar beet. Mean 1977–82

Concentration in dry matter (%)

	Nitrogen		Phosphorus		Potassium		Sodium		Magnesium	
	Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots
F0	1·97	0·54	0·29	0·14	2·07	0·73	1·27	0·07	0·171	0·101
F1	2·34	0·60	0·31	0·13	2·60	0·75	1·38	0·08	0·137	0·090
F2	2·68	0·74	0·34	0·15	2·96	0·82	1·47	0·09	0·139	0·096
F2+FYM	2·82	0·90	0·34	0·16	3·59	1·07	1·14	0·09	0·138	0·106
SED	±0·105	±0·034	±0·014	±0·005	±0·106	±0·038	±0·114	±0·008	±0·007	±0·004

Amount in the beet crop at harvest (kg ha^{-1})

	Nitrogen			Phosphorus			Potassium			Sodium			Magnesium		
	Tops	Roots	Total	Tops	Roots	Total	Tops	Roots	Total	Tops	Roots	Total	Tops	Roots	Total
F0	57	30	87	8	8	16	59	41	100	37	4	41	5	6	11
F1	100	59	159	13	13	26	111	74	185	60	8	68	6	9	15
F2	130	76	206	17	16	33	144	84	228	71	10	81	7	10	17
F2+FYM	158	100	258	19	17	36	203	118	321	65	10	75	8	12	20
SED	±9·8	±3·9	±10·6	±1·2	±0·8	±1·5	±11·7	±4·0	±11·1	±8·4	±0·8	±8·8	±0·7	±0·5	±0·9

Amounts of nutrients in cereals at harvest 1977–82 (kg ha^{-1})

	Nitrogen			Phosphorus			Potassium			Sodium			Magnesium		
Winter wheat	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
F0	28	8	36	7	2	9	13	14	27	0·2	1·0	1·2	2·1	1·0	3·1
F1	62	17	79	14	3	17	26	32	58	0·4	1·4	1·8	3·7	1·6	5·3
F2	89	27	116	17	4	21	32	44	76	0·5	1·0	1·5	4·7	1·6	6·3
F2+FYM	99	32	131	18	5	23	34	57	91	0·4	0·9	1·3	5·0	1·9	6·9
SED	±5·6	±2·0	±6·0	±1·2	±0·4	±1·3	±1·9	±4·7	±5·9	±0·07	±0·40	±0·41	±0·35	±0·19	±0·40
Barley															
F0	24	6	30	7	2	9	12	10	22	0·4	0·8	1·2	1·9	0·8	2·7
F1	50	13	63	14	2	16	24	21	45	0·6	1·8	2·4	3·6	1·3	4·9
F2	65	19	84	15	4	19	27	31	58	0·8	3·0	3·8	4·1	1·3	5·4
F2+FYM	66	22	88	15	5	20	27	46	73	0·7	2·5	3·2	4·0	1·4	5·4
SED	±4·9	±1·8	±6·1	±1·3	±0·6	±1·6	±2·3	±7·0	±8·4	±0·11	±0·39	±0·46	±0·32	±0·12	±0·35

Where FYM was also applied although the offtake of magnesium by the crops increased, a positive nutrient balance of 60 kg ha^{-1} was obtained.

Nutrient concentrations and uptakes 1977–82. All nutrient concentrations are given on a percentage dry matter basis. The concentrations and quantities of the major nutrients in the beet crop and the quantities in each cereal at harvest are given in Table 5. Magnesium was included in the analyses in an attempt to explain some of the benefits given by the FYM dressings. In the beet crop average annual uptakes of both nitrogen and phosphorus were similar to those measured during 1971–76, although all sodium uptakes were lower than recorded previously. Average annual uptakes of potassium were large and with the F2+FYM dressing averaged 321 kg ha^{-1}, whereas in the absence of FYM only 228 kg K ha^{-1} was contained in the crop at harvest. Magnesium uptakes in the beet crop with the standard dressing (F1) ranged between 10 kg ha^{-1} in 1977 to 17 kg ha^{-1} in 1981. However, with the exception of sodium, the uptakes of all the major elements were significantly increased as fertilizer inputs increased.

In both cereal crops, the annual mean uptakes of all analysed elements tested were almost doubled by applying F1 when compared with the amounts measured in crops which received no fertilizer dressing. F2 and F2+FYM significantly increased both N and K uptake in wheat but had little effect on the uptake of other elements in the crop. The total amounts of NPK in barley were on average lower than in the wheat crop whereas there was more sodium in the barley.

Magnesium uptake by cereals ranged between 3 and 7 kg ha^{-1}, but both the concentrations and uptake were not greatly influenced either by doubling the fertilizer dressing or by applying FYM. Sodium uptake by the cereals was small and ranged between 2 and 5 kg ha^{-1}.

Soil analysis

The analysis of soils sampled in 1964 and 1983 is presented in Table 6. In top soils, where no fertilizer (F0) has been applied, $NaHCO_3$-soluble P has remained virtually unchanged, even after 18 years. This is probably because at the outset much P was already present on high energy bonding sites from previous dressings. Both

TABLE 6

Soil analysis in 1964 and 1983

Treatment	Nitrogen (%)	$NaHCO_3$-Soluble phosphorus (mg l^{-1})	NH_4^+-Exchangeable Potassium	Sodium (mg l^{-1})	Magnesium	Organic carbon %
		Topsoil 0–25 cm in 1964				
None	0·102	22	65	30	36	0·91
		Topsoil 0–25 cm in 1983				
F0	0·094	21	53	26	24·8	0·92
F1	0·099	33	84	30	25·1	0·98
F2	0·104	42	106	32	27·7	1·04
F1+FYM	0·119	37	228	30	31·8	1·14
F2+FYM	0·127	54	255	31	33·2	1·20
		Subsoil 25–50 cm in 1983				
F	0·073	15	41	10	23·3	0·71
F1	0·072	19	60	18	24·9	0·70
F2	0·082	24	75	20	26·3	0·72
F1+FYM	0·094	25	219	29	31·0	0·92
F2+FYM	0·100	29	208	26	31·2	0·96

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TABLE 7

Changes in ammonium-N in soils sampled in 1983 when incubated anaerobically

	NH_4^+-N in air-dry soil (ppm)	
	Topsoil 0–25 cm	Subsoil 25–50 cm
F0	16	12
F1	20	14
F2	23	15
F2+FYM	27	21

exchangeable-K and Mg have declined with F0 and are now in category 0 on the current ADAS classification. Applying the standard dressings (F1) has increased $NaHCO_3$-soluble P and exchangeable-K, but the heavier fertilizer input (F2) almost doubled soluble-P from its original value of 22 to 42 mg l^{-1}. The F2 dressing has also increased exchangeable-K from 65 to 106 mg l^{-1} but the largest changes in nutrient status of both top and subsoils occurred where the organic manure was used, particularly in combination with F2.

Approximately 55% of the large positive balance for K which was obtained by applying F2+FYM was accounted for by the increase in amounts of exchangeable-K in both top and sub soils. By contrast the net K balance with F2 was +832 kg ha^{-1} but less than 25% of this was present as exchangeable-K values, indicating that much of this nutrient had been retained in a non-exchangeable form. Using the same treatments the corresponding calculations for phosphorus indicated that less than 15% of the net P balances remained in a $NaHCO_3$-soluble form, but this proportion was unaffected by FYM applications.

The soil analyses suggest that applying the F2 dressing annually would increase the soil index from 2 to 3 for P and from index 1 to 2 for K in periods of about 9 and 26 years respectively. If in addition FYM were used triennially the same enrichment of P and K could be achieved in two rotations while simultaneously enhancing the major nutrient concentrations in the subsoil.

The organic carbon content of the topsoil changed little with F0 (Table 6) but was increased progressively by the other major treatments. However, the concentrations in subsoils improved only when FYM was applied. One benefit to crops from increasing the

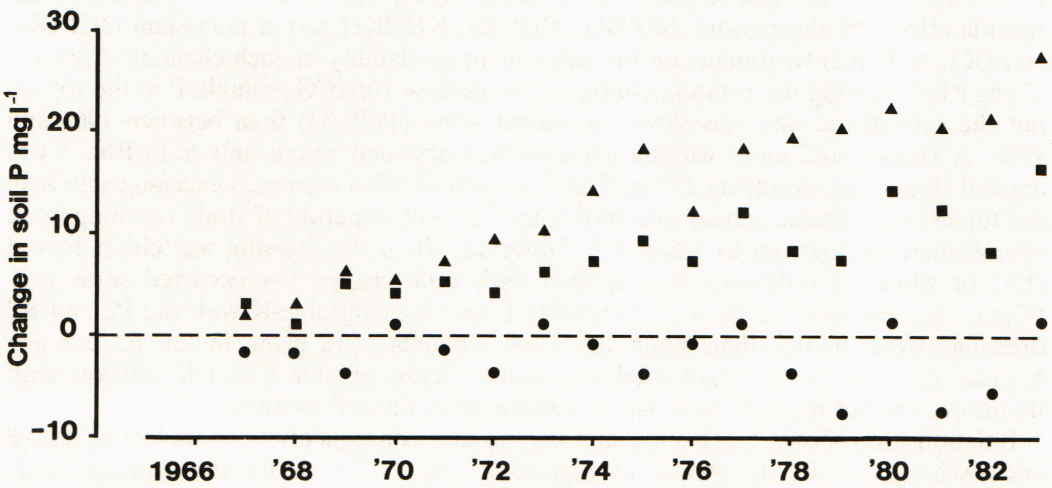

FIG. 6. Effect of phosphorus fertilizer on soluble soil phosphorus in the 0–25 cm horizon. Autumn 1964–Spring 1983. ● No P, ■ 22 kg ha^{-1} $year^{-1}$, ▲ 44 kg ha^{-1} $year^{-1}$.

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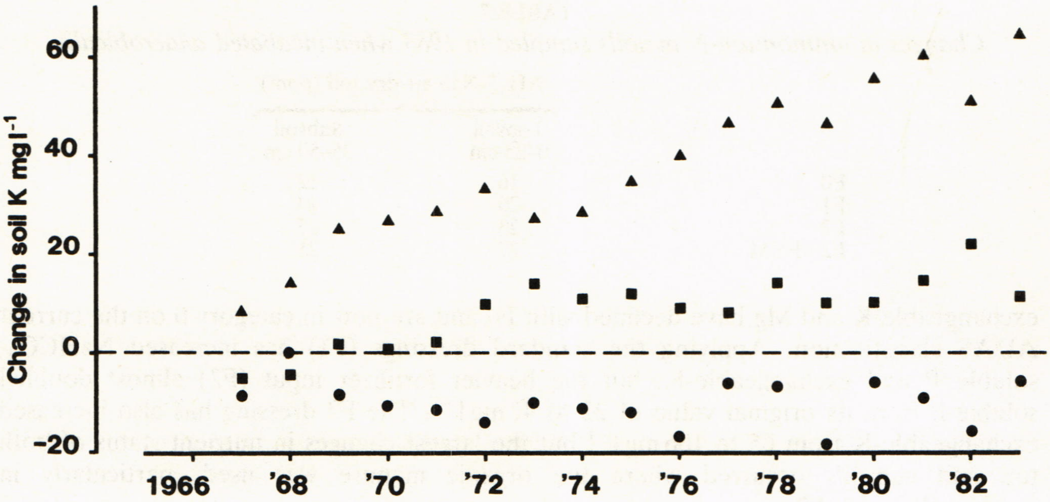

FIG. 7. Effect of potassium fertilizer on exchangeable soil potassium in the 0–25 cm horizon. Autumn 1964–Spring 1983. ● No K, ■ 42/83 kg ha^{-1} year^{-1}, ▲ 83/167 kg ha^{-1} year^{-1}.

organic matter content of soils is to increase the amounts of mineral-N which may be released and become available. A good indicator of potentially available nitrogen is the amount of NH_4-N produced when soils are incubated anaerobically (Waring & Bremner, 1964). Results in Table 7 show that where F2+FYM dressing was applied, 35% more potentially available-N was measured in topsoil and 50% more in the subsoil than in soils which had received the standard dressing F1. The enhanced mineralization of soil nitrogen was also indicated when the proportion of carbon and nitrogen retained in the humus fractions was considered. Applying F2+FYM since 1965 has increased %N and %C by 0·025% and 0·29% respectively and consistent with the findings of Mann and Barnes (1956), this indicated that about one half of the added nitrogen and less than one third of the added carbon from the FYM was retained as degradable humus.

Figures 6 and 7 update similar diagrams in previous reports (*Rothamsted Report for 1971,* Part 2, 155–164 and *Rothamsted Report for 1977,* Part 2, 15–30) and illustrate the specific effects of phosphorus (N1P0K1, N1P1K1, N1P2K1) and of potassium (N1P1K0, N1P1K1, N1P1K2) treatments on the subsequent availability of each element. Applying 131 kg P ha^{-1} during the rotation continued to increase $NaHCO_3$-soluble P in the topsoil but the rate of increase was slower in recent years (1976–83) than between 1965 and 1976. A smaller and more variable increase was obtained where only 65 kg P ha^{-1} was applied (Figure 6). Applying 332 kg K ha^{-1} in each rotation increased exchangeable-K in the topsoil at a similar annual rate throughout the entire period of study resulting in an overall increase from 65 to 128 mg l^{-1}. However, when the dressing was either halved (K1) or when no potassium was applied (K0) little change has occurred since 1976 (Figure 7). The rates of increase of soluble-P and exchangeable-K with the P2 and K2 dressings were greater than when the same amounts were given in the F2 dressing because the latter gave larger total dry matter yields, greater P and K offtakes and, therefore, smaller residues were left to contribute to the soil analysis.

Relationships between net nutrient balances and consequential changes in soluble-P and exchangeable-K are shown in Figures 8 and 9. To clarify the diagrams only three-yearly mean values are shown. The results are in general agreement with observations and conclusions made by Draycott *et al.* (1977).

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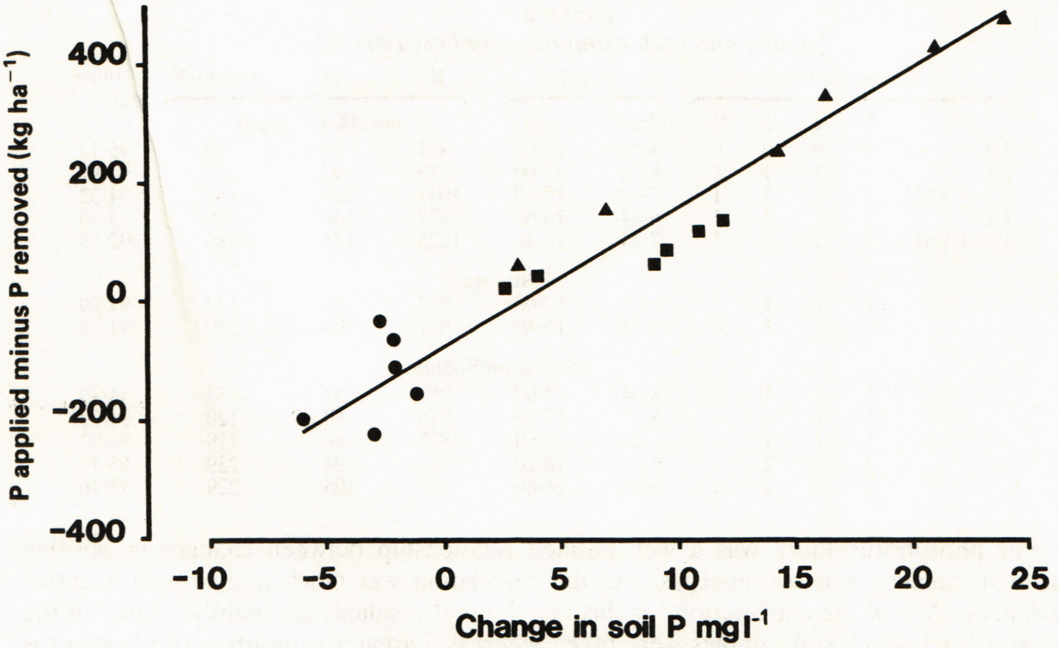

FIG. 8. Relationship between cumulative phosphate balance and changes in soil phosphate, 1964–83. ● No P, ■ 22 kg ha^{-1} year^{-1}, ▲ 44 kg ha^{-1} year^{-1}.

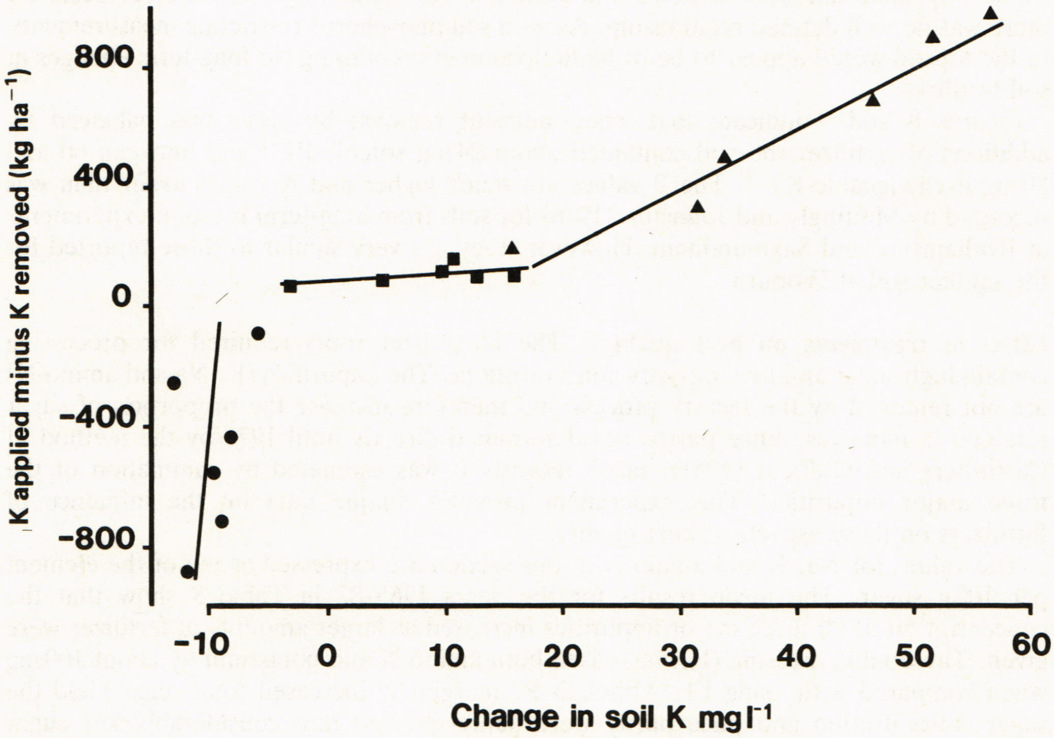

FIG. 9. Relationship between cumulative potassium balance and changes in soil potassium, 1964–83. ● No K, ■ 42/83 kg ha^{-1} year^{-1}, ▲ 83/167 kg ha^{-1} year^{-1}.

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TABLE 8

Quality and major impurities in beet 1965–82

	Treatment code				Sugar		K	Na	Amino-N	Juice purity %
	N	P	K	Na	t ha^{-1}	%	mg 100 g^{-1} sugar			
F0	0	0	0	0	4·49	17·00	821	83	86	95·14
F1	1	1	1	1	6·78	17·60	873	99	119	94·92
F1+FYM	1	1	1	1	7·49	17·50	1047	103	151	94·32
F2	2	2	2	1	6·84	16·60	977	148	229	93·76
F2+FYM	2	2	2	1	7·24	16·40	1225	135	285	92·68
						Nitrogen				
	1	1	1	–	6·04	17·00	853	81	132	94·89
	2	1	1	–	5·75	16·40	851	104	220	94·04
						Potassium/Sodium				
	1	1	1	–	6·04	17·00	853	81	132	94·89
	1	1	2	–	6·57	17·50	916	60	120	94·99
	1	1	1	1	6·78	17·60	873	99	119	94·92
	2	2	2	–	6·33	16·20	963	94	239	93·77
	2	2	2	1	6·84	16·60	977	105	229	93·76

For phosphorus there was a well defined relationship between changes in positive nutrient balance and soil analysis, but the correlation was much poorer with negative balances. Part of the explanation for this may be that residuals are mainly located in the topsoil from which soil samples were taken whereas a greater proportion of phosphorus removed in crops given no fertilizer may have originated from subsoil reserves for which no allowance was made in Figure 8. The relationship between potassium balance and changes in soil analysis (Figure 9) was in three distinct parts. There was a section with a positive linear relationship when large residuals were left, and an intermediate phase when only small amounts of potassium accumulated. When negative balances occurred there was no well defined relationship. As with soil phosphorus restricting measurements to the topsoil would appear to be of limited value in accounting for long-term changes in soil fertility.

Figures 8 and 9 indicate that when nutrient removal by crops was balanced by additions of fertilizer the soil contained about 24 mg soluble-P l^{-1} and between 60 and 80 mg exchangeable-K l^{-1}. The P values are much higher and K values lower than was recorded by Mattingly and Johnston (1976) for soils from long-term rotation experiments at Rothamsted and Saxmundham. However, they are very similar to those reported for the sandier soil at Woburn.

Effect of treatments on beet quality. The ideal beet roots required for processing contain high sugar and low impurity concentrations. The impurities (K, Na and amino-N) are not removed by the factory process and therefore increase the proportion of sugar retained in molasses. Juice purity was determined directly until 1976 by the method of Carruthers and Oldfield (1961); more recently it was estimated by summation of the three major impurities. This experiment provides unique data on the influence of fertilizers on these aspects of beet quality.

The values for Na, K and amino-N in this section are expressed as mg of the element per 100 g sugar. The mean results for the years 1965–82 in Table 8 show that the concentration of all three major impurities increased as larger amounts of fertilizer were given. The double dressing (F2) increased both amino-N and potassium by about 100 mg when compared with using F1. Although F2 marginally increased total sugar yield the sugar concentration and juice purity were depressed and thus considerably less sugar could be extracted. Applying FYM in addition to F1 had little effect on Na concentration but increased K and amino-N in roots by 21% and 27% respectively. However, in

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comparison with the 0·71 t ha^{-1} extra yield of sugar the change in juice purity was relatively small and most of the additional sugar was extractable.

Table 8 also shows that in the comparison of N2P1K1 and N1P1K1, applying 200 kg N ha^{-1} to beet, which is almost double the current recommendation, increased amino-N concentrations in beet by 67% to 220 mg and the Na contents by 27% to 103 mg. The concomitant decrease in sugar yield and concentration clearly refutes the practice of many growers who use significantly more nitrogen fertilizer than is recommended. In agreement with other data (Draycott, Durrant & Last, 1974), both potassium and sodium fertilizers increased the concentrations of these two impurities in root juice but any adverse effect on the extractability of sugar was ameliorated because the amino-N concentration was simultaneously decreased. The various phosphorus treatments had no effect on quality in this experiment.

Invert sugars in beet decompose into organic acids during the factory process and may also impart unwanted colour to white sugar. Measures taken to correct these effects also lead to increased molasses production. During this study invert sugar concentrations in roots were measured in four years and the mean results show that, with the F1 dressing, beet contained 0·623 g of invert sugar per 100 g sucrose which was increased 19% to 0·764 g by doubling the fertilizer input. As with the amino-N concentrations, this was caused by the excessive amount of nitrogen applied by that treatment. The concentrations of invert sugars were not influenced by FYM, but were slightly diminished when either extra K or Na were applied.

Discussion

Fertilizer recommendations for sugar beet have resulted from many annual experiments but ideally the nutrition of any one crop in the rotation should not be considered in isolation. The main objective of this long-term experiment was to test if much greater fertilizer applications than recommended in 1965 would ultimately result in increased yield.

Nutrient balance calculations and soil analyses clearly show that, even in the absence of FYM, the double fertilizer input left large residuals of most elements and increased nutrient availability. However, although total dry matter production in the beet crop was increased, the double dressing had little effect on sugar yield. This is attributed to changes in the partitioning of dry matter between tops and roots and the large depression in sugar concentration of roots which resulted from applying the 200 kg N ha^{-1} component of F2. These effects nullified any potential benefits in sugar yield obtained by applying extra potassium to this soil which has low reserves of both exchangeable-K and Na.

The lack of response to phosphorus dressings in the beet crop has been a permanent feature of the experiment. This is attributed to the small decrease in topsoil soluble-P (22 to 21 mg P l^{-1}) measured where no phosphate fertilizer had been applied for 18 years. In addition, response to phosphorus must depend on the volume of soil explored by roots and substantial amounts of soluble-P were measured in subsoils on the nil plots as recently as the winter of 1983. The results gave no indication as to the total length of time during which the soil alone could continue to supply adequate amounts of phosphorus for crop growth.

The experiment has demonstrated that where recommended amounts of sodium fertilizer are correctly applied for the beet crop, they improve seedling establishment despite small visual effects on soil structure. It is also confirmed that sodium is essential to maximize sugar yield and quality in beet grown on mineral soils which have low cation exchangeable values. The mean offtake of sodium per rotation amounted to less than 20 kg Na ha^{-1}, but the large residual amounts of sodium had no deleterious effects on the

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grain yields of the following cereal crops. The results provide no justification for exceeding the amounts of inorganic fertilizer recommended for sugar beet; in fact, they indicate that some reduction in phosphorus application might improve profitability.

Throughout this study, increased yields of barley grain have been obtained with the heavier inputs, and this can be explained in terms of response to nitrogen and, to a lesser extent, phosphorus. Until 1976 there was no response in wheat yields to the heavier inputs. In 1977 the cultivar was changed from Capelle to Hobbit, and since then the larger inputs (F2) have been justified. However, the responses to the large levels of individual elements were small or not significant (Tables 2a and 2b). This implies a large positive interaction between N, P and K on this site, but unfortunately this cannot be confirmed because the experiment design does not include the appropriate treatments.

No measurements of soil physical properties have, as yet, been made in this experiment, so the influence of FYM on yields can only be interpreted from nutritional aspects. These include rapid build up of large amounts of available P, K and of potentially available nitrogen throughout the soil profile, and a slowing of the progressive decline in exchangeable-Mg. Giving some nitrogen and potassium in this way must be important factors in the enhanced sugar and grain yields obtained when FYM was applied with the recommended dressing (F1) and also at the heavier input level in the wheat crop since 1977. Based on earlier results from this experiment Draycott (1981) proposed that rotational applications of inorganic fertilizers totalling 98 kg P ha^{-1} and 311 kg K ha^{-1} were necessary in high yielding situations to maintain nutrient balance, with reductions to 65 kg P ha^{-1} and 187 kg K ha^{-1} when yields approximated to those more commonly achieved. The more recent results suggest that when the soils have reached index 3 for phosphorous and 2 for potassium, then an application of 60 t ha^{-1} of FYM every third year would lower these amounts by 40 kg P ha^{-1} and 125 kg K ha^{-1} respectively. FYM improved plant establishment particularly during the earlier years of the experiment and also produced an unexplained increase in the proportion of sugar in root dry matter.

The concentration of all melassagenic impurities in beet, especially amino-N, were increased by the major treatments. The F1+FYM treatment produced the largest sugar yields and these beets contained, on average, 151 mg amino-N per 100 g sugar. Such measurements are currently of much interest as a substantial proportion of the beet crop is being analysed for its amino-N concentration in an attempt to identify where excessive amounts of fertilizer-N are being applied to the crop. The results from this study will help advisers interpret amino-N values in relation to fertilizer practice with more precision.

The primary objective of this experiment was to test whether prolonged usage of large amounts of inorganic fertilizers would progressively increase both nutrient availability and yields. Soil analysis clearly showed that nutrient availability was improved, and in recent years this seems to have been exploited by the wheat crops. There is no evidence that this has occurred in beet, and yields in this study were frequently lower than was achieved in adjacent annual experiments. Beet yields have been restricted by diverse factors such as lack of irrigation, indifferent disease control and relatively short growing seasons which allowed winter wheat to follow beet in the rotation. In addition many of the heavier fertilizer inputs tested included 200 kg N which is too extreme; this amount has often slowed the establishment phase and, almost without exception, depressed sugar yields and quality in annual experiments.

The above limitations on yields must be remedied before the potential beneficial effect of enhanced nutrient availabilities on yield can be fully tested. It is therefore intended to modify the experiment during the autumn of 1985. Consideration will be given to recent changes in the recommendations, in the timing and amounts of fertilizer applied and to testing intermediate amounts of nitrogen fertilizer in order to minimize any deleterious

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effects. The treatments receiving FYM will be retained and some of the plots used to investigate the critical concentrations of sodium and potassium in soils and plants necessary for optimal seedling establishment and growth.

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APPENDIX TABLE 1

Amounts of fertilizer tested

	N1	N2	P1	P2	K1	K2	Na	FYM
	(kg N ha^{-1})		(kg P_2O_5 ha^{-1})		(kg K_2O ha^{-1})		(kg NaCl ha^{-1})	t ha^{-1}
Sugar beet	100	200	50	100	100	200	377	61*
Winter wheat	75	150	50	100	50	100		
Spring barley	50	100	50	100	50	100		

*Since 1977, previously 30 t ha^{-1}

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