Chambers, W. E. 1953. Nutrient composition of the produce of the Broadbalk continuous wheat experiment II. Changes occurring during one season's growth. *The Journal of Agricultural Science.* 43 (4), pp. 479-484.

NUTRIENT COMPOSITION OF THE PRODUCE OF THE BROADBALK CONTINUOUS WHEAT EXPERIMENT

II. CHANGES OCCURRING DURING ONE SEASON'S GROWTH

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(With One Text-figure)

The changes in the nutrient composition of Broadbalk wheat at harvest were discussed in Part 1 of this paper. Knowles & Watkin (1931), Chambers & Gardner (1951), and other workers, have found that the composition of wheat changes during growth, and that as the crop matures nutrients, particularly potassium, are lost from the aerial parts of the plant. It has been suggested that these losses might be larger when wheat is grown with an adequate nutrient supply, and the nutrient composition might become less dependent on nutrient supply as the crop matured. In this paper analyses are given of samples taken from eight Broadbalk plots during the summer of 1945. These analyses were all obtained by the Lundegårdh flame method of spectrographic analysis as described in Part 1 of this paper.

METHOD OF SAMPLING

One-fifth of each Broadbalk plot has been fallowed each year since 1931. In 1945 samples were taken on eight plots from section 1 (4th crop after fallow) and section 2 (3rd crop after fallow). The samples from these two sections were bulked for analysis. An estimate of the plant population was obtained by counting the number of tillers in 1 m. of row at five places, chosen at random, along each side of each section. At every site a known number of tillers were uprooted, the roots cut off just above ground-level, and the tops and roots kept separately. After ear emergence the tops were subdivided into ears and stems. The stem fraction included all the aerial parts of the plant except the ears; for convenience this fraction will be referred to as stems.

The samples of the tops were dried and weighed, and the dry matter per acre was calculated. An analysis of variance gave a standard error for the mean yield of two sections of $\pm 3\cdot5$ cwt./acre or $12\cdot5\,\%$ of the general mean.

The samples of the roots from each section were washed free from soil, dried, and weighed. The total root weight was not estimated by this procedure since only part of the root system could be removed without damage to the rest of the crop. Analyses of this material may have given low values due to nutrients being leached when the soil was washed from the roots. Incomplete washing might have resulted in high calcium values as Broadbalk soil contains large amounts of calcium.

The first samples were taken on 3 May, and afterwards samples were taken at 3-weekly intervals until 25 July. The last samples were taken on 7 August just before the crop was harvested.

PRODUCTION OF DRY MATTER

The estimates of dry matter at each sampling time are shown in Fig. 1. The mean yields of dry straw and grain for the years 1901–21 are included. The estimated yields at harvest in 1945 were very similar to the mean yield. On every plot the estimated yield of ears at the last sampling was greater than the mean yield of grain because the ear fraction included chaff and offal corn. The difference was greatest on the NP plot where the proportion of offal corn had always been high.

Dry matter was produced on all plots from May until the beginning of July, but the rate of production varied from plot to plot. Later in the season very little dry matter was produced and on some plots the dry matter per acre decreased. During this later period there was considerable translocation of dry matter from the stems into the ears. The weight of the part of the root system which was collected increased to a maximum in June and then declined. This might have been due to the surface roots dying back as the crop matured, or to the drier soil reducing the amount of the roots which were collected.

At every sampling time the dry matter per acre reflected the yields at harvest. On 3 May (1st sampling) spring growth had started and the crop was about 7 in. high on the most advanced plot (dung). Even at this early date, dry matter per acre varied with fertilizer treatment in the same way as the yield at harvest. During growth the differences between plots were maintained; the higher yielding plots produced dry matter more rapidly than the lower yielding plots.

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Table 1. *Changes in nutrient concentrations during growth*

Plot no.	...	2	3	5	7	11	12	13	14
Treatment	...	14 tons dung	Nil	PK NaMg	NPK NaMg	NP	NPNa	NPK	NPMg
		Potassium percentage of dry matter							
Ears	13 June	1·34	1·58	1·61	1·49	1·42	1·32	1·40	1·39
	24 July	0·63	0·67	0·68	0·62	0·63	0·61	0·62	0·62
Stems	3 May	3·65	2·49	2·84	3·06	0·99	1·38	3·34	1·36
	13 June	2·02	1·77	2·03	1·88	0·97	1·15	1·86	1·33
	24 July	1·11	0·81	1·03	0·95	0·51	0·62	0·90	0·68
Roots	3 May	1·43	1·18	1·20	1·50	0·71	0·80	1·53	0·79
	13 June	0·84	0·70	0·66	0·75	0·26	0·36	0·80	0·57
	24 July	0·61	0·48	0·66	0·65	0·28	0·42	0·61	0·41
		Calcium percentage of dry matter							
Ears	13 June	0·08	0·06	0·07	0·05	0·06	0·06	0·06	0·06
	24 July	0·05	0·04	0·06	0·04	0·04	0·08	0·06	0·05
Stems	3 May	0·39	0·50	0·43	0·41	0·89	0·67	0·41	0·69
	13 June	0·28	0·29	0·32	0·31	0·53	0·49	0·27	0·37
	24 July	0·21	0·24	0·19	0·20	0·33	0·29	0·20	0·27
Roots	3 May	0·37	0·36	0·48	0·45	0·54	0·46	0·41	0·44
	13 June	0·56	0·59	0·56	0·44	0·44	0·49	0·46	0·43
	24 July	0·57	0·64	0·57	0·46	0·40	0·44	0·56	0·39
		Magnesium percentage of dry matter							
Ears	13 June	0·09	0·10	0·11	0·12	0·14	0·13	0·14	0·10
	24 July	0·10	0·10	0·09	0·12	0·10	0·10	0·10	0·10
Stems	3 May	0·12	0·11	0·13	0·10	0·22	0·20	0·10	0·23
	13 June	0·09	0·12	0·08	0·08	0·14	0·10	0·08	0·12
	24 July	0·08	0·05	0·07	0·07	0·11	0·10	0·06	0·10
Roots	3 May	0·06	0·07	0·07	0·08	0·10	0·09	0·07	0·11
	13 June	0·04	0·03	0·03	0·03	0·03	0·04	0·03	0·05
	24 July	0·03	0·02	0·02	0·02	0·03	0·02	0·02	0·03
		Sodium, parts per million of dry matter							
Ears	13 June	50	70	50	40	50	50	30	40
	24 July	40	40	60	60	40	50	50	50
Stems	3 May	130	100	100	95	1400	1300	80	370
	13 June	90	60	60	50	270	180	60	100
	24 July	80	100	100	90	185	210	80	140
Roots	3 May	320	270	210	270	2100	1900	190	1140
	13 June	210	200	150	120	950	710	130	490
	24 July	100	110	120	70	730	440	80	240

CONCENTRATION OF NUTRIENTS IN THE PLANT

Many of the changes in nutrient concentration during growth were similar on all plots. The highest concentrations of nutrients in stems and roots occurred at the first sampling and the highest concentration in the ears occurred at emergence. As the crop grew the concentration of nutrients in the plant decreased. The concentration of nutrients in the stems and roots varied with fertilizer treatment, but the concentrations in the ears were nearly independent of fertilizer treatment even when they were first formed.

Analytical results for three or the six sampling times are given in Table 1. The ears had formed on most tillers by 13 June.

Potassium concentrations

Fertilizer potassium increased the percentage of potassium in both stems and roots. In the early stages the stems and roots from the PKNaMg plot contained a lower percentage of potassium than the stems and roots from the plots which received nitrogen in addition to phosphorus and potassium. Later in the season this was reversed, due probably to a dilution effect which resulted from the extra growth when nitrogen was supplied.

The lowest concentrations of potassium in both stems and roots were obtained on the NP plot. The potassium concentrations were always higher on the NPNa and NPMg plots. At every sampling time, the crops on these two plots contained nearly the same potassium concentrations, and both sodium and magnesium sulphates had the same effect on the growing crop as they had on the crop at harvest (Part 1 of this paper).

The concentration of potassium in the ears was not related to potassium supply. On 13 July, when the ears had just formed, the potassium concentrations were on some plots higher and on other plots lower than the concentrations in the stems. As the ears matured the potassium concentration decreased on all the plots. This agreed with Lawes & Gilbert's (1884) conclusion that the composition of the grain at harvest varied more with degree of maturity than with fertilizer supply.

Calcium concentrations

The calcium concentrations in the roots did not vary with fertilizer treatment and tended to increase as the crop developed. This was probably due to the large amounts of calcium in Broadbalk soil. The calcium concentrations in the stem fractions were apparently controlled by the potassium supply at all stages of growth. The plots which received potassium produced stems with low concentrations of calcium; the calcium concentrations were higher on the plots which did not receive potassium. The highest calcium concentrations in the stems occurred on the NP plot; the NPNa and NPMg plots produced stems with lower but almost equal calcium concentrations.

The ears always contained very little calcium, and the concentrations were always smaller than in the stems. Fertilizer treatment did not affect the concentration of calcium in the ear.

Magnesium concentrations

The magnesium concentration in the stems and, to a lesser extent, in the roots, appeared to be controlled by the potassium supply and not the magnesium supply. During the early stages of growth the NP, NPNa, and NPMg plots produced plants containing nearly twice the concentration of magnesium found on the other plots. At all times the composition of the plants from the NPMg plot were very similar to the plants from the NPNa plot, although the soil on the NPMg plot contained considerably more exchangeable magnesium.

Sodium concentrations

On every plot the roots contained higher concentrations of sodium than the stems, but the concentrations in both roots and stems appeared to be controlled mainly by the potassium supply, although the sodium concentration only reached very high levels on the NP and NPNa plots. The sodium concentrations in the plants from these two plots were very similar at all times, and the sodium sulphate supplied on the NPNa plot did not appreciably increase sodium uptake.

THE TOTAL UPTAKE OF NUTRIENTS BY THE PLANT

The uptake of nutrients was never as rapid as the assimilation of carbon, and early in the season the nutrient concentrations declined although there was considerable nutrient uptake. As the crop matured nutrient uptake ceased and the amounts of nutrients in the stems decreased on all plots. These changes are illustrated in Fig. 1.

Potassium

The content of potassium in the aerial parts of the plant reached a maximum on all plots on 13 June. Afterwards, the total potassium in the crop decreased on all plots except the NP plot. This loss of potassium came almost entirely from the stem fraction; even on the NP plot the potassium content of the stems was reduced but on this plot the loss was due entirely to translocation into the ears. It can be seen from Fig. 1 and from Table 2 that the potassium content of the stems varied similarly on all plots and was always related to the mean value of the harvested crop. The relationship might have been closer than these figures indicate as, at any sampling date, there must have been differences in the state of development of the crops on the various plots.

These results indicated that the nutrient status of the crop did not affect the changes which occurred during growth. On the plots where potassium was lost from the aerial parts of the plant, the potassium must either have been leached from the plant or translocated to the deeper parts of the root system. Analysis of the portion of the root system which was sampled did not indicate translocation to the roots.

Calcium

The total calcium in the crop also increased to a maximum and then decreased. This maximum occurred rather later than with potassium (3 July) and was not so pronounced. The variations in stem composition were also much smaller than with potassium, partly because the total losses were smaller, but also because there was very little translocation of calcium to the ear.

Magnesium

The total amounts of magnesium in the parts of the root system sampled were always very small on all plots. The amount in the stems and ears increased until 3 July and then the total remained nearly constant until harvest. The total content of magnesium in the stems decreased after 3 July, but most of the decrease was due to transference of magnesium to the ears. At harvest the ears contained about the same amount of magnesium as the stems.

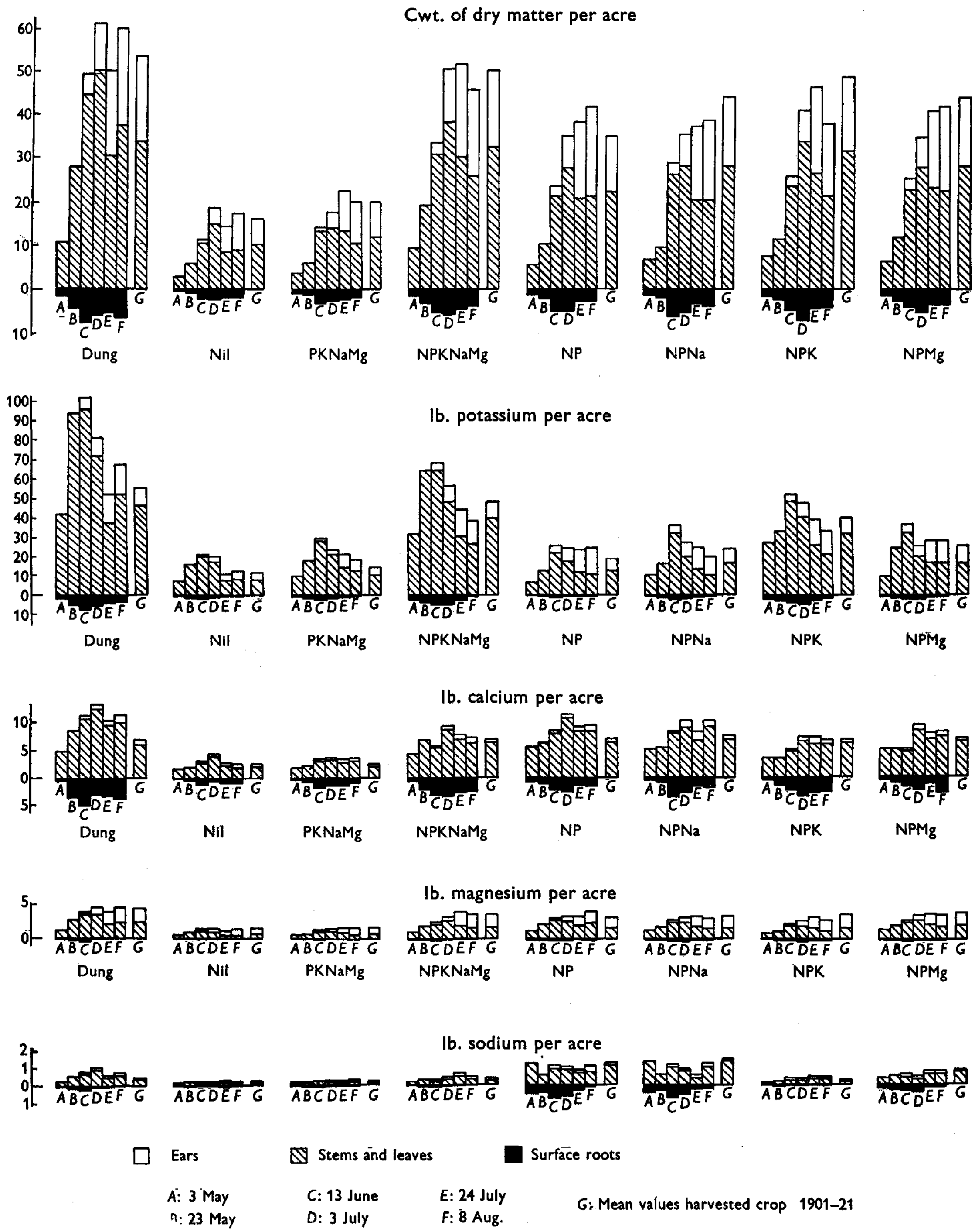

Fig. 1. Yield and total nutrient content of broadbalk wheat at various sampling times.

Sodium

Appreciable uptake of sodium occurred on the NP, NPNa, NPMg, and dung plots. On the dung plot this was due to the high yield, but on the other three plots it was due to high concentrations of sodium in the stems and roots. On both the NP and the NPNa plots the total sodium content of the stems was highest at the first sampling. On these plots sodium was lost from both stems and roots between 3 and 23 May but by 13 June the total sodium content had increased again.

Table 2

Plot no....	2	3	5	7	11	12	13	14
Treatment	14 tons dung	Nil	PK NaMg	NPK NaMg	NP	NPNa	NPK	NPMg
Total potassium content of the stem fraction, lb. per acre								
Sampling date:								
3 May	43·8	7·8	11·6	32·5	6·1	10·1	27·6	9·7
23 May	98·0	16·2	18·6	66·1	12·9	16·5	34·5	24·6
13 June	101·0	20·4	29·9	66·2	22·9	33·4	49·5	33·8
3 July	71·2	18·9	20·2	50·0	17·9	21·6	42·1	21·7
24 July	38·6	7·7	15·1	32·0	11·6	14·0	26·6	17·2
6 Aug.	54·4	8·4	12·3	27·8	11·2	15·1	22·9	17·2
Total potassium content of harvested straw, lb. per acre, mean value 1901–21								
	46·5	6·9	10·7	31·7	7·7	12·3	32·2	13·2
Potassium content of stem fraction as percentage of maxima								
3 May	44	38	39	49	27	30	56	29
23 May	98	79	62	99	54	49	70	73
13 June	100	100	100	100	100	100	100	100
3 July	71	88	68	75	78	65	85	64
24 July	39	38	50	48	51	42	54	51
6 Aug.	55	41	41	42	49	35	46	51

DISCUSSION

The relation between plant composition and nutrient supply is complicated by the changes in plant composition which occur during growth. Analysis of Broadbalk produce in 1945 showed that the concentration of nutrients in the plant, and particularly in the stems, varied with fertilizer treatment in the same way at every sampling time. In 1945 there was no indication that conclusions drawn from analyses of the harvested crop would differ from conclusions drawn from analyses of the crop at any other time during the growing season. Even the total nutrient contents of the stems and leaves were related at every sampling date to the contents of the crop at harvest.

At any particular date, the plants on the plots receiving potassium contained higher concentrations of potassium and lower concentrations of calcium, magnesium and sodium than the plants growing on the plots which did not receive potassium. Throughout the growing season the nil and the PKNaMg plots produced very similar plants. The NPNa and NPMg treatments also had very similar effects on plant composition. It has been suggested in Part 1 of this paper that the differences between these plots and the NP plot were due to increased availability of soil potassium. The present results show that throughout the growing season the plants on these two plots always contained higher concentrations of potassium than the plants on the NP plot.

Nutrients were lost from stems and leaves as the crop matured. Some of these nutrients were translocated into the ears, but this did not always account for the whole of the loss. It was unlikely that the other losses were due to leaf fall because the potassium losses started while dry matter was still increasing and before the losses of calcium. The potassium losses were also very much greater than the calcium losses and there were no net losses of magnesium from the aerial parts of the plants. There was no evidence of movement of nutrients into the roots; at the time when nutrients were being lost from the stems and leaves the concentrations of these nutrients in the roots were decreasing. Nutrients might have been excreted from the roots as rapidly as they were moved into the roots or they may have been concentrated in some part of the root system which was not collected.

It was also possible that the losses of nutrients were due to leaching by rain. Correlations between rainfall and the composition of Broadbalk straw at harvest (unpublished) have shown that rainfall above the average in June and July slightly reduced the amount of potassium in the crop at harvest. But the excretion of potassium by the

 https://doi.org/10.1017/S0021859600057956

roots would seem less improbable than that summer rain in 1945 leached 30 lb. of potassium per acre from the crop on the dung plot and none from the plot on the NP plot.

SUMMARY

1. In the summer of 1945 samples of the growing crop were taken from eight Broadbalk plots. On all the plots the concentrations of nutrients in all parts of the plants decreased during growth. The compositions of the roots and stems and leaves varied with fertilizer treatment at all times of the season. The nutrient composition of the ears was only slightly affected by fertilizer treatment.

2. The total uptake of nutrients by the crop increased to a maximum and then decreased. The losses of potassium and magnesium from the stems and leaves were particularly large, due to translocation into the ear but there were also net losses of potassium and calcium from the whole plant.

3. The changes which occurred were similar on all plots and the effect of fertilizer treatment on plant composition was always related to the effect at harvest. There was no evidence that the composition of the crop at harvest differed radically from the composition earlier in the season.

The author wishes to express his indebtedness to Dr E. M. Crowther for much help and many valuable discussions. Also to the late Dr J. B. Hale at whose suggestion this work was undertaken. This paper is based on a portion of a thesis approved for a Ph.D. degree of London University.

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(*Received* 18 *February* 1953)