PH.D. THESIS

AVAILABILITY OF PHOSPHATE AND OTHER NUTRIENTS IN SOILS

1947 - 1950

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March, 1951.

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ADDITIONAL NOTES

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ERRATUM

On page 56, Part I, the statement that the phosphate in the top four inches of plot N* increased is due to an error in calculation in the fifth column of Table 23. The figure 488 should read 445, thus showing the same result as for the initial sampling (before the application of superphosphate). The results for plot N* therefore show that three years after the application of superphosphate only the top three inches of soil had increased in total phosphate.

ADDENDUM to Part IV

The determinations of extractable sulphate give no complete indication of the sulphur status of the plant. The purpose of determining sulphate ($-SO_4$) was to investigate the content of one of the major ions. There is reason to believe that much of the ash of land plants can be accounted for by potassium and sulphate, and that probably holds for seaweeds also, after allowance has been made for sodium and chlorine. Since extractable potassium had already been determined in this work, it was logical to determine extractable sulphate; and this proved to be a fortunate choice.

Attempts to determine total sulphur or to ascertain the partition of sulphur compounds lay outwith the scope of this work. To include

determinations of other forms of sulphur than extractable sulphate would have involved a very substantial amount of chemical work. (Two choices were open: to adopt the necessarily tedious method of Peterson (1914) or to discover a new method and establish the necessary protocols). Peterson's (1914) work yielded what seems to be the only proven technique yet devised for sulphur estimations in plants. It does not appear to have been adopted by any other investigator of plant sulphur. It may be mentioned that Peterson's analytical figures were merely indicative, having been obtained during tests of his chemical technique; though valuable as indications, they offer no body of data of systematic interest to the plant physiologist.

Published determinations of actual sulphate in plants are rare. When figures for total sulphur or sulphate in plants have been published, they have almost invariably been based on ash analyses; and therefore to have been subject to unknowable but probably serious analytical errors, and, where sulphate is nominally shown, to a re-calculation which assumes that the whole of the S is $-SO_3$ or $-SO_4$: such assumptions being untenable from a physiological or biochemical point of view.

These criticisms apply <u>inter alia</u> to the

voluminous and "classical" work of J.B.Lawes and J.H.Gilbert on ash of several crop plants; and also to most recent work, including, for example that of Walsh and Clarke (1945) (1) on sulphur in tomato plants.

Frazer (1935) (2) described a nitric-acid digestion method for determining total sulphur in plant tissue and gave results for total sulphur content of several species. No chemical protocols were, however, given by Frazer, and the accuracy of recovery of the plant sulphur does not seem to have been established.

In brief, the numerous published analyses which purport to refer to plant sulphur or sulphate mostly cannot be taken at their face value, and, except Peterson's, none is known to me which appears relevant to the present work.

"Extractable sulphate" was determined in the present work by a direct method which involved no assumptions.

ADDITIONAL REFERENCES

(Not given in bibliography to Part IV)

1. Walsh,T. and Clarke,E.J. 1945. Proc. Roy. Irish Acad., 50, Section B, No.11.

2. Frazer,J. 1935. Plant Physiology, 10, 529.

CONTENTS

PREFACE

This Thesis embodies the results of substantially more than three years' work. The whole of this scheme of work is original in the sense that none of it is a repetition of earlier work published or unpublished. Use has been made of a few established analytical chemical methods, but most of the methods have either been devised by me in the course of the work or have been modified by me alone or in conjunction with a former colleague to whom acknowledgment is made in the relevant place.

Much assistance has, however, been obtained from colleagues who have given help in sampling of soils, laying out field experiments and in recording yields of crops. Routine soil analyses have been performed by the Soil Laboratory of the Chemistry Dept. of the West of Scotland Agricultural College.

All other analyses of plant and soil material have been made by me personally or under my supervision by assistants in the Chemistry Dept. of the College.

The work falls into four parts:

1. Experiments on movement of phosphate in grassland soils, with special reference to soil conditions. A comparison/

comparison is made of penetration and availability of phosphate applied to soils differing in their degree of natural drainage.

2. Experiments on yield-response of swedes variously manured with phosphate. This, unpublished, work was actually done before my registration as Ph.D. candidate and was the origin of my interest in phosphate, and hence of the work done under (1) above, which was the nominal subject of the thesis.

3. Evolution of analytical methods

a) for total phosphate in soil (used in (1) above);

b) for extractable calcium in plant tissue.

These methods have been published; reprints of the papers are attached.

4. These and recognised methods for the study of soil conditions in relation to uptake and fate of phosphate, calcium, and other plant nutrients were applied to a three-years' study of tomato nutrition and yields, 1948 - 1950.

Several original conclusions are drawn and discussed under each heading.

It will be seen that the scope of the work has greatly widened since it was begun. The original interest in phosphate has been extended to other plant nutrients/

nutrients (or elements or ions present in plants).

No similarly extensive series of analyses of tomato tissue for (total or extractable) nitrogen, phosphorus, potassium, magnesium, calcium, manganese and sulphate is known. The observed relations of manganese to plant health are particularly interesting. A noteworthy finding, which also is virtually without precedent, is the large amount of sulphur (as sulphate) in tomato plants: the amount of sulphur was found to exceed the amount of phosphorus, which is generally regarded as a prime nutrient.

The applicability of the original technique for determination of total phosphate in soil has been extended to diverse other materials of agricultural interest.

PART I.

AVAILABILITY AND PENETRATION OF PHOSPHATE IN FIELD SOILS.

Introduction.

Many investigators have shown that the loss of phosphate by leaching from soil is usually almost negligible; and that phosphorus therefore tends to accumulate in the soil horizon in which it is incorporated. It is generally thought that penetration of phosphates is very slow and incomplete; but little definite information exists on the effect of soil type or general soil characteristics which might affect the rapidity of penetration into the soil.

From experience gained during field trips made to sample soils for advisory purposes, the question imposed itself why certain pasture fields should show low "available phosphate" contents, in spite of the fact that heavy applications of phosphates had been given in immediately preceding years.

At first sight it seemed possible that the reason for the apparent deficiency might be that an unusually rapid phosphate "fixation" had resulted in a low "available phosphate" content in these soils. However, closer examination of many of these soils, revealed that the surface layers (0 - 3") had much more "available phosphate" than the lower layers (see Table 1). The sampling to 9" was therefore diluting the top layer/

layer, which showed itself rich in "available phosphate" (and was presumably rich also in total phosphate), with much soil very poor in "available phosphate". This dilution led to a false measure of the phosphate accesible to the shallow roots of the pasture plants. Many fields were thereby reported as having a very low "available phosphate" content while in fact there was a sufficient supply of phosphate in the surface layers where the majority of the roots of pasture plants are found. After this experience, fields which were to remain under pasture were sampled for advisory purposes to a depth of 4". These samples represented the conditions much better and gave on the whole a more satisfactory estimate of the available phosphate content of the pastureland.

The need for knowledge of phosphate penetration is most urgent for crops, such as pasture, where surface top-dressing is the only practical method of manuring. For such crops an application of phosphate, to be fully effective, should reach roots below the most superficial layer of soil.

It seemed desirable to study in some detail the movement of phosphate in soil under grassland conditions and to determine the effect of soil characteristics/

characteristics on this penetration. Also information was desired as to what depth and after how long a period the actual available phosphate content was likely to be affected by surface applications of phosphate.

* These pasture soils were sampled by the usual method of auger sampling to a depth of 9". The "available phosphate" was estimated by the method of Williams and Stewart (1), which is essentially extraction of air-dry soil with 0.5N acetic acid and determination of the extracted phosphate by measuring the intensity of the blue colour developed with ammonium molybdate and stannous chloride.

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Table:- 1.

Field	Depth of sampling	mg. available P_2O_5 per 100 g. air-dry soil
I	0 - 3"	12.0
	0 - 9"	0.8
II	0 - 3"	10.0
	0 - 9"	0.6
III	0 - 3"	15.0
	0 - 9"	8.4
IV	0 - 3"	16.2
	0 - 9"	11.0
V	0 - 3"	39.0
	0 - 9"	5.0
VI	0 - 1½"	4.2
	1½" - 4½"	3.7
	4½" - 9"	0.5
VII	0 - 1½"	5.2
	1½" - 4½"	1.2
	4½" - 9"	0.1
VIII	0 - 1½"	4.0
	1½" - 4½"	1.7
	4½" - 9"	1.0

Review of Literature.

The strongest evidence against the leaching of phosphorus from most soils in any appreciable quantity is undoubtedly the results of lysimeter studies which with very few exceptions indicate that the loss of phosphorus in drainage water is almost negligible.

In the classical lysimeter studies at Rothamsted, Dyer (2) found that the annual loss of phosphorus did not amount to more than 2 lb. P_2O_5 per acre. The Broadbalk Field experiments led Dyer to conclude that added phosphate was generally retained in the top layer of soil except in the farmyard-manure plot where there was some evidence of some descent.

Hendrick's (3) lysimeter studies at Craibstone showed that there was an annual loss of only 1 lb. P_2O_5 per acre.

Higby (4), found that in the check tank of his lysimeter experiments the loss was 3 lb. P_2O_5 per acre per annum and this loss was reduced to less than half with lime and manure treatments, alone or in combination.

Schmitt's (5) lysimeter studies in Germany on various types of soil showed that the addition of complete fertilisers containing equivalent amounts of/

of P_2O_5 from either superphosphate or basic slag resulted in a loss of phosphate in the drainage water of 0.2 - 0.8Kg. P_2O_5 per hectare. The losses from the soils receiving superphosphate and basic slag paralleled each other in general, but slightly greater losses occurred where superphosphate was used.

In more recent lysimeter studies, Jacobson et al. (6) in Connecticut, reported that virtually no phosphate was leached from their soil except where heavy applications of phosphates had been given. They pointed out that the loss of phosphorus may be very important in light sandy soil where heavy dressings of phosphates are applied. The phosphorus outgo was influenced most by Na, then by K, Mg and Ca in decreasing order. Kardos (7), in Washington, reported a loss of 60 lb. superphosphate (about 12 lb. of P_2O_5) per acre per annum. In such studies something no doubt, depends on the depth, situation, and other conditions of the lysimeter - particularly whether the surface is cropped or bare.

Numerous other workers have studied the penetration and availability of phosphates in soils by soil sampling to various depths or by leaching experiments in the laboratory. As early as 1850 Way (8) demonstrated by percolation/

percolation experiments that phosphate of soda dissolved in water, and calcium phosphate dissolved in dilute sulphuric acid, when passed through soil, had all their detectable phosphate retained. Van Alstine (9) concluded that there was no movement of phosphorus except by erosion and crop uptake. Alway and Rost (10) showed that the phosphate content of prairie soils steadily decreases downwards, indicating that phosphates do not move down readily under conditions of minimal leaching.

Crawley (11), working on the amount of phosphate fixation in Hawaiian soils, demonstrated the tremendous fixing powers of these soils. In his experiment, over 7 tons of double superphosphate per acre was applied on the surface and given an immediate irrigation. The first inch of soil retained over one half, the 3" depth over nine-tenths and the 6" depth retained all the phosphate applied. When an interval of 15 hours existed before adding the water, the first inch retained over nine-tenths of the phosphate applied. These Hawaiian soils contain large amounts of iron and aluminium oxides.

Weidemann (12) pointed out that repeated applications of small amounts of phosphates failed to increase the amount of "available phosphorus" (as measured by the method of Truog (13) by which the soil is/

is extracted with 0.002N sulphuric acid buffered to pH 3.0 with ammonium sulphate) in the soils which he examined. He also found that about 400 lb. of 20% superphosphate per acre was required to produce a measureable increase in " available phosphorus ".

Fraps (14) and Schreiner and Failyer (15) showed, not only that phosphorus is fixed by soils almost at the point at which it comes in contact with the soil particles, but that clay soils fixed phosphorus more rapidly than did their sandy soils.

Scarseth and Chandler (16), working with a light-textured soil, found that the amount of phosphate which had travelled downward in the profile was too insignificant to measure accurately. They found, however, that although this soil contained only 6% of clay, this clay-fraction held over 50% of the total P_2O_5 in the soil; and they estimated that where superphosphate was used over a period of 26 years, 60% of the added phosphate was carried away in the clay fractions lost by erosion.

Hockensmith et al. (17) found in Colorado, that in calcareous soils, triple superphosphate did not penetrate below the depth at which it was placed. These workers also found that the depth of application made

a/

a marked difference in the yield of alfalfa. 4" - 6" was the optimum depth. More recent work by Das (18) on Indian calcareous soils has confirmed these results.

Beater (19) stated that, in the Natal soils he examined, the movement of total P_2O_5 could not be traced appreciably below the first inch from the surface, even in the lighter soils. When the superphosphate was buried at a given depth, even in the light soil no loss occurred. In a heavy soil the increase in water-soluble phosphate due to application of 800 lb. superphosphate per acre was negligible, whether the dressing was buried or applied on the surface.

Brown and Munsell (20) show that 20 months after surface application of phosphatic fertilisers on pasture in Iowa, neither rock phosphate nor superphosphate plots showed marked increase in the phosphorus content below the one inch layer. Superphosphate was almost entirely fixed in the surface inch.

Midgley (21) studied the response of Wisconsin permanent pasture to applications of phosphates. He applied superphosphate at the rate of 300 and 600 lb. per acre to old pastureland; and, after various intervals of time, soil samples were taken at different depths from/

from treated and untreated plots. "Available phosphate" was estimated on these samples by the method of Truog and Meyer (22). His results showed that most of the "available phosphate" was retained in the surface inch of soil even after six months. He pointed out that even allowing for uptake by plants the results did not fully account for all the "available phosphate" lost between the two and six month samplings; so he concluded that phosphate fixation must have taken place. No estimations of total phosphate, however, were attempted.

Midgley also experimented with response of pasture to various methods of phosphate application. He found that maximum results could not be obtained immediately unless the superphosphate was thoroughly mixed with the soil. Superphosphate worked into an old bluegrass (Poa pratensis) sod gave a total increase of 71.5% more than a similar amount of phosphate applied as top dressing.

Midgley's leaching experiments in the laboratory indicated that fertiliser salts mixed with superphosphate influenced the movement of the latter through soil. Sodium nitrate increased the movement of superphosphate, while potassium sulphate and ammonium sulphate slightly decreased it. Phosphate from NH_4, Na and K phosphates

was/

was more readily leached from their soils than phosphate from superphosphate.

Wrenshall and McKibbin (23) in Quebec, carried out phosphorus penetration experiments on pasture similar to those of Midgley (21). Their results showed that in untreated soil the dilute-acid-soluble phosphorus (as measured by the method of Wrenshall and McKibbin (24)) was higher in the topmost one-half inch layer than in succeeding layers. Analyses for total phosphorus showed a similar relationship for the distribution of total phosphorus. They suggested that this was due to the plants acting as pumps, bringing up some phosphorus from the lower soil layers, and, on being partly returned to the soil, adding phosphorus to the upper layers where it was closely retained, with only a small proportion in the readily-soluble form. A similar explanation may also hold for the findings of Alway and Rost (10).

Sigmond (25) states that it is not always the surface horizon of soil that is richest in P_2O_5; for, in acid soils, natural phosphates are more easily soluble in weak acids than in water. The fact that the surface horizon is nevertheless usually richest in P_2O_5 is due to the activity of plant roots, which transport P_2O_5 from the lower to the upper horizons. This/

This effect is exercised particularly by the natural vegetation of the steppe soils, which readily accumulates organic P_2O_5 in the upper horizons. This process is furthered by the calcium content of the steppe soils protecting the phosphoric acid set free from organic matter against leaching. In acid soils, on the contrary, the leaching may be extremely energetic, firstly, owing to the abundance of CO_2 and humic acids, which mobilise the P_2O_5, and secondly owing to the deficiency of calcium.

Wrenshall and McKibbin (23) suggested that the soluble phosphorus of untreated soil appears to be an equilibrium quantity (probably not varying significantly from year to year) approached in the treated soil after the effectiveness of the application has worn off. Even where heavy applications of superphosphate had been given there was little or no penetration below the surface one-half inch layer. This showed the very strong fixing powers of these Quebec "brown forest" soils.

Wrenshall and McKibbin's results for increase in the proportion of wild white clover, and of yield-increase over untreated pasture, showed close relationships to the amount of soluble phosphorus produced by fertilisation and remaining in the soil at/

at the time of measurement. In pot-culture work they found that phosphorus uptake by plants was not wholly attributable to the utilisation of readily-soluble phosphorus. The phosphorus obtained by the plants was in all cases considerably more than could be accounted for by decreases in the amount of readily-soluble phosphorus in the soil. They suggested that a considerable proportion of the phosphorus obtained by the plants came from the decomposition of nucleotides known to exist in this soil.

Metzger (26) found that phosphorus from superphosphate accumulated in considerable quantity at the surface of a Kansas soil which had grown alfalfa for 14 years; when only superphosphate was given, there was very little penetration into the soil. Marked downward movement of phosphorus was indicated where rock phosphate was applied.

In a later paper Metzger (27) stated that a large proportion of the easily soluble phosphorus (as measured by the method of Truog (13)) which accumulated in the same soil as a result of treatment with superphosphate was found in the surface 3" or 4". There appeared to be some accumulated phosphorus to depths of/

of 2' or 3', however, in plots treated with rock phosphate and farmyard-manure, and, with lime and farmyard-manure, and to a lesser extent in the superphosphate plot. Potash or potash and sodium nitrate applied with superphosphate resulted in more complete utilisation of the phosphorus by the alfalfa plants than did superphosphate alone.

Thor (28) in Illinois, found a marked penetration of phosphorus, from rock phosphate, to a depth of 7-14" in a compact soil and to depths of 16 - 24" in light-textured soils.

Brown (29), Pennsylvania, found that where superphosphate had been applied over a period of 16 years the available phosphate (as measured by the method of Truog (13)) was increased only to a depth of 2 - 3". Rock phosphate applied in the same manner penetrated more than 7". Field and laboratory tests all showed a greater proportion of soluble phosphorus in rock phosphate-treated soils than in superphosphate-treated. Brown pointed out, however, that in most field tests of superphosphate and rock phosphate, superphosphates proved better.

Heck (30) found a penetration of water-soluble phosphorus through 5" of a Wisconsin silt-loam under laboratory/

laboratory conditions. He added, however, that under field conditions the penetration would probably not be so great. He also reports that the penetration of added phosphate was greatest in slightly acid soils containing little active Fe and Al, and least in laterites containing large amounts of active Fe.

Stephenson and Chapman (31) working with soils of Californian citrus groves, date gardens, and fields, compared samples from fertilised and unfertilised areas. Samples were drawn from the horizons 0 - 6", 6 - 12", 12 - 24", and 24 - 36". Water-soluble and acid-soluble phosphate(as measured by the method of Truog (13)) were determined on the samples. Their results indicated appreciable penetration of phosphorus below the surface foot in light - to medium - textured soils. There was an indication that a more rapid penetration of phosphorus is effected through a few heavy applications of phosphates rather than more numerous lighter doses. Also, where farmyard manure was used, there were indications that the phosphorus in the manure moved through the soil or else that some effect of organic matter facilitates the more rapid penetration of phosphorus. This effect of organic matter is consistent with/

with results found by Dyer (2) and Metzger (27); and also with the findings of Blair and Prince (32) who reported greater penetration of phosphorus in manured plots than in those receiving superphosphate.

Robinson and Jones (33) stated that phosphates were rapidly leached from some soils in North Wales. They found that although great improvements were achieved on poor pasture by the application of basic slag, improvements were not maintained and there was a tendency for improved pastures to revert to their original state unless further applications of basic slag were made. The beneficial effect of basic slag on rough grazings in North Wales practically vanished after 6 - 8 years. These workers examined soils from six different locations where plots had received
a) 200 lb. P_2O_5 per acre as basic slag in 1914,
b) 200 lb. P_2O_5 in 1914 and again in 1922, and
c) control plots. They found that after 6 - 10 years the added phosphorus was removed from the surface layers which reverted to their original status. They did not discover whether phosphorus leached from the upper layers was lost in the drainage water or precipitated at depths below 18". These workers suggested a division of soil phosphorus (in soils of North/

North Wales) into a) the natural phosphorus compounds which are only subject to negligible wastage by leaching and b) the unstable phosphorus compounds of added dressings which are removed fairly rapidly from the surface layers by percolating waters.

Doak (34) found that the yields of dry matter from pasture plots in New Zealand were correlated with the amount of phosphate in the 0 - 2" layer of soil. His results also indicated that the penetration of added phosphorus was much more rapid when the applications of phosphate were heavy and infrequent than when smaller applications are made more frequently. He also states - "The fact that the phosphoric-acid content of the no-phosphate treatment has showed no appreciable change as compared with the downward tendency of the phosphoric acid added to the other treatments supports the contention of Robinson and Jones that the phosphorus in the soil can be divided into two groups a) natural stable phosphorus coppounds which are subject to negligible wastage by leaching and b) the unstable phosphorus compounds of added dressings which are removed fairly rapidly from the surface layers by percolating waters".

In a later study Doak (35) showed that during the/

the eight years of a trial on penetration of phosphate, the movement of phosphorus into the 6" and 10" layers of soil was quite appreciable. Use of carbonate of lime in conjunction with the phosphate fertilisers resulted in an increased retention in the 0 - 2" layer, of the phosphorus from superphosphate and Gafsa phosphate but not from basic slag.

Williams (36) compared the phosphate status of the 0 - 3", 3 - 6" and 6 - 9" layers of soil from meadow hay plots which had received annual dressings of 6 cwt. basic slag per acre with similar plots receiving no phosphate. His results suggested that about 65% of the total P_2O_5 of the added basic slag was retained by the top 3 inches of soil. About 40% of this remained in a form soluble in 1% citric acid. There was also some evidence of penetration of P_2O_5 to lower layers but the data was insufficient to permit an estimate of its extent being made.

Neller (37) in Florida, found considerable penetration of soluble phosphate (extracted by Morgan's (48) reagent) through a fine sand soil but only a trace through a sandy loam. After leaching an 8" depth of soil treated with superphosphate (20%) at the rates of 313, 625 and 1250 lb. per acre, he found that with the fine/

fine sand an average of 79.1% of the phosphorus was recovered but with the sandy loam soil recovery was only a trace - 1.6%. Rock phosphate used at the rates of 1,000, 2,000 and 4,000 lb. per acre yielded an average of 40.8% of the total phosphorus in leachates from unlimed and 8.9% from limed fine sand soil. Lime was also effective in reducing the leachate loss of superphosphate and calcined phosphate.

Sell and Olson (38) in Georgia, stated that the depth of phosphorus movement in the soil depends primarily on the rate of application of phosphorus. Heavy dressings (200 - 300 lb. P_2O_5 per acre) resulted in a penetration to 12". The use of nitrogen and potash reduced the penetration of phosphorus due to increased plant growth. Phosphorus in rock phosphate and basic slag appeared to penetrate further than phosphorus from superphosphate or mono-ammonium phosphate.

De Vries and Hetterschij (39) found that the drainage water from certain marsh soils of Holland contained 5 - 20 p.p.m. P_2O_5 indicating that important amounts of phosphate may be lost therein. The soil water in these soils was brown, pH 4.4 and the phosphate was probably associated with humus. Leaching of

fertiliser phosphate into lower horizons has been proved to occur with these soils and a similar effect has been observed with sandy heath soils.

Henderson and Jones (40) using mono-calcium phosphate containing radio-activated phosphorus found that soluble phosphatic fertilisers applied to the surface of various soils did not penetrate to an extent likely to reach the roots of plants feeding deeply in the soil. The addition of KCl caused the radio-active phosphorus to move down into the soil more than where no KCl was used, but $(NH_4)_2SO_4$ had no immediate effect. When mono-calcium phosphate was applied to the surface and washed down with water equivalent to a precipitation of 2.5", the penetration of phosphorus ranged from $1\frac{1}{4}$" for Cecil clay to about 4" for Crosby silt loam.

In addition to Dyer, Stephenson and Chapman, and Blair and Prince, (already mentioned) Spencer and Stewart (41) and Gaarder (42) have also reported on the effect of organic matter on the penetration of phosphorus in the soil. All are agreed that phosphorus associated with organic matter penetrates deeper than that in the inorganic form. Spencer and Stewart (41) demonstrated that certain organic phosphates escaped to a marked degree/

degree the fixation which occurs with phosphorus applied in some inorganic forms. In a study which has become almost classical, Gaarder (42) stated that in humid and semi-humid soils containing humus, such as some forest soils, the solubility of the phosphates depends mainly on the relative proportions of active sesquioxides and humus present, the former tending to decrease and the latter to increase their solubility. From such soils having only moderate sesquioxide contents and pH 4.5 - 6.5, organically combined phosphorus may be leached sufficiently rapidly to bring about a deficiency.

Das (43) in India, showed that organic phosphorus complexes were formed in the soil by the combined action of decaying organic matter and phosphatic fertilisers. These organic phosphates were soluble in water, neutral in reaction and possessed colloidal properties. They remained in a highly dispersed state in the soil and were shown, by water-culture experiments, to be more available to plants than the inorganic phosphates of phosphatic fertilisers used in ordinary farm practice, which are generally insoluble or eventually become so on reacting with soil bases.

This fixation of phosphate by the combination of phosphate from phosphatic fertilisers with organic matter/

matter has also been studied by Chaminade (44) in France. He found that the colloidal forms of humus, extracted from neutral soils by washing with a neutral ammonium salt solution, contained a significant quantity of P_2O_5, but very little P_2O_5 was obtained from similar extracts of acid soils. He showed that if the soil was treated with hydrogen peroxide before extraction, then very little P_2O_5 was obtained in the extract.

Chaminade stated that the P_2O_5 of these organic complexes was not in organic combination, but was in adsorption complexes linked to the humus through fixed ions of calcium. These complexes were not formed at pHs below 5.5. The P_2O_5 of the humus complexes was more available than that of $CaHPO_4$ and acted as a reservoir of available phosphate which could oppose the tendancy of available phosphate to enter unavailable combinations.

Williams and Stewart (45) studied phosphate fixation in a soil of the acid igneous group in Aberdeenshire. They stated that, in this soil, phosphate fixation took place very rapidly and was largely complete within 7 weeks with basic slag and probably in a few days with superphosphate and potassium phosphate. The general trend of their results and the field behaviour were compatible with an adsorption of phosphate by ferric and aluminium complexes or clay minerals./

minerals. They concluded that anion exchange reactions implicating - chiefly - the mineral constituents were of considerable importance in the phosphate relationships of this soil.

In 1947 Glentworth (46) gave a comparison of the phosphorus status of profiles of some Scottish (Aberdeenshire) soils differing in their degree of natural drainage - freely-drained and poorly-drained (gleyed) soils. He suggested that there may be a loss of phosphorus in the ground-water from the poorly-drained soils.

EXPERIMENTAL

The object of this work was to study the movement and availability of phosphates in grassland soils. It is an attempt to determine:-

1. the effect on the available phosphate content of the surface layers of soil, when pastureland is top-dressed with superphosphate:
2. to what depth the available phosphate content is affected:
3. for what period of time the dressing is likely to be effective:
4. the penetration of total P_2O_5 into the soil:
5. the effect of natural drainage conditions in the soil on this penetration and availability of phosphorus.

A light-textured sandy loam and a heavy clay loam, both in Stirlingshire, were used. Essentially the experiment consisted of plots receiving a heavy dressing of superphosphate and control plots receiving no phosphate. These plots were sampled at various times and at various depths. Available and total phosphate were determined on these samples. The investigation/

investigation was limited to the top 7" layer of soil, as the main rooting region of pasture plants is within this layer.

In this work, the soil-classification used, which refers soils to their degree of natural drainage is that adopted at the Macaulay Soil Research Institute, Aberdeen. The associates are:-

1. oromorphic, (O)
2. phytomorphic, (P)
3. phyto-phytohydromorphic, (P-PH)
4. phytohydromorphic, (PH)
5. hydromorphic, (HP)

in descending order from very well-drained soils to very poorly-drained.

SOIL TYPES.

The experimental plots were laid down on permanent pasture at Carbeth Home Farm, Killearn, Stirlingshire. Carbeth estate is situated on a north-facing slope at an altitude varying between 100 and 400 ft., and slopes down northwards in broadly rolling terraces to the Endrick Water, which runs westerly into Loch Lomond. The terraces have an east-west trend.

Geological

The following geological annotations and soil descriptions/

descriptions are taken from an unpublished local survey made for the West of Scotland Agricultural College by Dr. R. Glentworth of the Macaulay Institute.

The solid geology of the district is Old Red Sandstone formation. The overlying superficial deposits fall into three main groups :-

I. Boulder clay.

II. Littoral sands, gravel and water-worked drift.

III. Lacustrine laminated clay.

The experiments were carried out on groups I and II.

I. Boulder clay area. This area occurs above the 300 ft. contour. The boulder clay in the well-drained position is red-brown in colour, compact and of a clay-loam structure, and has a moderate stone content of flat pieces of fissile red sandstone. Some bright red sandstone and occasional brown ochreous staining occur.

II. Littoral sands, gravel and water-worked drift. This area lies between the 300 and 200 ft. contours, and is separated from the boulder clay area by a fairly well-marked escarpment of an old shore line. It can also be separated from area III by a distinct topographical change into a flattened condition, through a sloping, bank, resembling a beach formation.

Area II is variable topographically and texturally. The/

The main belt of this area slopes down to the north, but this is interspersed with ridges of higher land which run in an east-to-westerly direction. The relatively smooth slopes are underlain by sands, clay sands and sandy clays, sometimes of grey to yellow colour and sometimes red, similar in colour to the red sandstone of the region. The ridge formations tend to be gravelly, but in places appear to be of boulder clay, and water-worked boulder clay. Locally the depressions between the ridges and smooth slopes are filled with heavy lacustrine clay which was probably laid down with area III.

Soil Descriptions

Area I. Developed on Old Red Sandstone boulder clay. Island field: well drained slope.

a) O.R.S. boulder clay - phytomorphic.

The dominant soil of this area is a phytomorphic (naturally freely drained) associate with a description as follows:-

0 - 15/18 cm.	Bright brown fine loam to a very fine sandy loam, crumb structure, friable, roots throughout, stones few, worms common, damp.
15/18 - 32 cm.	Merging into red brown very fine sandy/

sand to silt loam, larger crumb structure than above, but friable, stones few, roots and worms plentiful, damp.

32 - 110 cm. Irregular change into red brown compact clay loam boulder clay; stones more frequent, some large flat pieces of fissile red sandstone and sub-angular pieces of the same. Structure is cloddy but laminated and is more pronounced with depth. The platelets tend to be dulled when drying out, but have a moist polished appearance when first removed. Throughout are occasional red specks and patches of decomposing sandstone, and brown ochreous staining from decomposing rock material.

Plots D, E, N and O were laid down on this type.

b) O.R.S. boulder clay - phytohydromorphic

The phytohydromorphic PH (poorly drained) associate has a profile description as follows:-

0 - 20 cm. Grey brown heavy loam, compact, tending to cloddy structure; few worms and stones; damp; roots plentiful.

20 - 120 cm./

20 - 120 cm. Sharp change at plough sole into mottled clay to clay loam, with grey, red brown, and limonite colours intermingled; cloddy and compact, the large clod aggregates have distinct grey-coated surfaces. Occasional red sandstone rocks present; the smaller pieces are very much weathered, and can be rubbed out into sand. Grass roots tend to penetrate the grey coating of the cloddy structural aggregates to about 60 cm., but large ($\frac{1}{2}$ - 1" diameter) old dead roots occur at 120 cm.. There is little change down the profile, and the texture and degree of compaction remain the same.

120 cm. The drift is brown to red brown, limonite-staining, and old dead roots are present in relatively large quantities.

This soil is only of local importance and occurs at the lower end of Island field where plots A and B were laid down.

Area II. Littoral sand, gravel and water-worked drift.

a)/

a) Littoral or fluvio-glacial sands-phyto-phytohydromorphic.

In this area the phyto-phytohydromorphic (P - PH) soil is the most extensive and plots H and I were laid down on this type. A typical profile description of this soil is as follows:-

0 - 20/25 cm. Red brown sandy loam to heavy sandy loam, loose and friable with very loosely cloddy structure; occasional erratic fragments of quartz, acid igneous rock, slate and pebbles; worms few.

25 cm. + Merging into yellow and grey smeared sandy loam becoming loamy sand and sand with depth. Some red sandy clay intermixed, structureless; ochreous staining in smears.

b) Littoral or fluvio-glacial sands - phytohydromorphic.

The phytohydromorphic (PH) is quite important: plots K and L were laid down on this type. The profile description is as follows:-

0 - 20 cm. Dark grey brown sandy loam, drying grey brown, weakly cloddy structure; roots plentiful; worms few.

20 - 45 cm./

20 - 45 cm. Merging into creamy sandy loam to clayey sand; more compact than above horizon; wet; locally coloured by soft decomposed rock and yellow sandstone; ochreous smears; roots penetrating.

45 - 100 cm. Sticky wet clayey sand, uniformly coloured grey.

EXPERIMENTAL PLOTS

The plots were in pairs.

The treatments consisted of:-

A plot receiving phosphates only, at the rate of 240 lb. P_2O_5 per acre as 20% superphosphate.

(This (treated) member of the pair of plots is indicated throughout by an asterisk.)

A control plot receiving no added fertilisers, of any kind, during the experiment.

The plots were grazed by cattle and sheep during the experiment.

Size of Plot:-

1/40th acre - 11 x 11 sq. yds.

Centres:-

Experimental plots were laid down at:

1./

1. Island Field.

Soil type - O.R.S. boulder clay

associate - phytohydromorphic (PH)

Plots - A* and B.

2. Island Field.

Soil type - O.R.S. boulder clay

associate - phytomorphic (P)

Plots - D* and E.

3. Spittal Field.

Soil type - O.R.S. boulder clay

associate - phytomorphic (P)

Plots - N* and O.

4. Mid Killearn Field.

Soil type - Littoral sands

associate - phyto-phytohydromorphic (P-PH)

Plots - H* and I.

5. Mid Killearn Field.

Soil type - Littoral sands

associate - phytohydromorphic (PH)

Plots - K* and L.

A comparison of centres 2 and 3 with 1, and of centre 4 with 5, gives a comparison of natural drainage conditions. Centres 2 and 3 are on similar soil-type, but centre 3 (Spittal Field) is in poorer condition - pasture/

pasture is poorer, reaction of soil more acid, total P_2O_5 content of soil lower. Centre 3 was included in the experiment to give an indication of the effect of pH on the availability and penetration of phosphates.

Application of Superphosphates.

The superphosphate was applied by dividing the plots into square yards and applying the appropriate amount per square yard. The applications were made on a calm day. Every care was taken to attain an even distribution of superphosphate.

Samples:-

Samples of soil were taken at depths of 0-1", 1"-2", 2"-3", 3"-4", 4"-5", 5"-6" and 6"-7". Such samples were drawn immediately before the application of fertilisers (June 1947) and at various times for 3 years afterwards.

Method of Sampling.

A special auger was designed to enable samples to be drawn at various depths. Essentially it consists of a cylindrical steel tube with an adjustable collar to give control of depth of sampling. A plunger is fitted to enable the sample core to be removed from the tube.

Initially/

Initially it was hoped that the auger could be pushed into the soil to the required depth (7"), the core removed and divided into sections representing definite layers of soil. It was found, however, that this was impracticable due to the following difficulties:-

a) in heavy soils, and under dry conditions in all soils, great difficulty was experienced in inserting the auger to a depth of 7":

b) the core of 7" was very difficult to remove from the tube:

c) the compaction of the core when removing it from the auger made it impossible to divide the core into sections representing definite layers of soil. The compaction was much greater in the surface layers (0-3") than in the lower layers.

It was found that the top 3" layer of soil could be easily cored and also that with this small core there was little or no compaction. This core could then be divided into 3 sections representing 0-1", 1"-2" and 2"-3". The depth control was then adjusted to 5", the auger reinserted in the hole and the 3"-5" layer removed. This core was divided into two sections representing 3"-4" and 4"-5". In a similar/

similar way the 5"-6" and 6"-7" layers were removed.

In the actual sampling of the experimental plots the adjustable collar of the auger was set at the 3" depth and 20 cores were taken at random over the plot. The collar was then adjusted to the 5" depth and the 20 cores of 3"-5" removed. Finally, adjusting the auger to 7" depth the 20 cores of 5"-7" were removed. Care was taken that the cores were kept in their correct order. The composite sample of each layer thus consisted of 20 sub-samples.

The method of sampling was tested by sampling a 1/40th. acre plot five times, each sample consisting of 20 cores. Available and total phosphate were estimated on these samples. The results are given in Tables 31 and 32. It will be seen that the mean deviation in each case is a reasonable figure and that a fair degree of accuracy may be expected. It is not claimed, however, that the layers are exactly 0-1", 1"-2", etc.; nevertheless the layers should be comparable at each sampling.

This method of sampling to various depths had the following advantages:-

1. in the sampling of the actual experimental plots, it was not practicable to dig holes and/

and draw samples from the profile:

2. random samples could be obtained which were representative of the whole plot. By ordinary profile-sampling methods such a random sample would necessitate the complete destruction of the plot.

Chemical Methods

Available phosphate was determined by the method of Williams and Stewart (1). 5 g. of air-dry soil were extracted with 200 ml. 0.5N acetic acid. Phosphate was determined on the extract, colorimetrically, using ammonium molybdate and stannous chloride.

Total phosphate was determined after digestion of finely-ground soil with concentrated nitric and sulphuric acids. Phosphate was determined in the extract, colorimetrically, using ammonium molybdate and metol.

This method was new. It has been published (47) after submitting its accuracy to exhaustive tests for which the Carbeth soils furnished most of the material. Details of the method and of the protocol whereby its suitability was established are given in attached Reprint 1. forming Part III of this Thesis.

AVAILABLE PHOSPHATE RESULTS

The available-phosphate status of the plots before treatment with superphosphate is given in Table 2. It is interesting to note that even before the application of phosphate, the percentage of available phosphate in the 0-1" layer of soil was everywhere greater than in the deeper layers. This may be due to treatment in the ordinary course of husbandry prior to the experiment.

I. Old Red Sandstone Boulder Clay.

On this type of soil, present in Island and Spittal Fields, comparisons are made of:-

a) an area which has good natural drainage conditions (plots D* and E) and one where there is impeded drainage (plots A* and B).

b) two areas of good natural drainage but differing in soil reaction. Plots D* and E where pH is near 7 and plots N* and O where acidity is stronger (pH under 6).

The original available-phosphate status of these plots shows that the percentage of readily soluble phosphorus was highest in the poorly drained associate and lowest in the acid, freely drained.

Results/

Results of available phosphate determinations are given in Tables 2,3,4,5,6,7 and 8.

It will be seen that the readily-soluble phosphate in the control plots has remained remarkably constant throughout the period of the experiment. There has been a slight fall in the % available P_2O_5 in these plots, but it would not appear to be sufficient to account for all the phosphate removed by the pasture in three years.

The effect of the superphosphate dressing on the available phosphate in the soil was most marked in the 1" and 2" layers. There is sometimes an indication of penetration of soluble phosphorus to greater depths, but this movement, where it exists, appears to be very slow. Diagrams 1, 2 and 3 illustrate the results of determinations of available phosphate on samples from the 1", 2", 3" and 4" layers of the treated plots.

A comparison of the % available P_2O_5 in the various layers of plots A*, D* and N* (see diag. 1,2 and 3, and tables 3, 5 and 7) shows that the effect of the superphosphate dressing in raising the % available P_2O_5 in the soil is much greater in plot A* than in plots D* and N*. The results also indicate that in plot A* (the poorly drained soil) treatment has [illegible] increased/

increase the available phosphate down to depths of 6" - 7". In plot D* (the freely drained soil) treatment produced no significant rise in the % available P_2O_5 below depths of 3 - 4". The freely drained more acid soil found in plot N* shows even less effect.

In plot A*, which showed the greatest penetration of the superphosphate into soil of this type, it was only after two years that there was any significant rise in the % available phosphate of the 4" layer.

II. Littoral Sands.

On this soil type a comparison is made between a moderately drained area (plots H* and I) and the poorly drained plots K* and L.

Results of available phosphate determinations on samples drawn from these plots are given in Tables 2,9,10,11 and 12. Diagrams 4 and 5 illustrate the change in available phosphate content of the 1", 2", 3" and 4" layers of the treated plots throughout the three years of the experiment.

The results on this soil are very similar to those on the boulder clay. Here again we find that the effect of superphosphate dressing in increasing the/

the available P_2O_5 mainly affects the 0 - 2" layer of soil. The available phosphate of control plots has, as in the control plots of O.R.S. boulder clay, remained remarkably constant throughout the period of the experiment.

The rise in available phosphate content was much more marked in the wetter soil, wherein, under these poor drainage conditions, there was a significant rise in the % available P_2O_5 at a depth of 7". Penetration, as judged by increase in available phosphate content, appears to be fairly slow, but comparatively more rapid in the wetter soil of plot K* than in plot H*.

The increase in available phosphate status of these soils, resulting from a dressing of soluble phosphates (superphosphate), is greater where poor drainage conditions prevail. Tables 13 and 14 show the increase in % available phosphate of the 1", 2", 3" and 4" layers above the % available phosphate before application of superphosphate. The increase and penetration of available phosphate is clearly shown to be greater in soils with impeded drainage.

Table:- 2.

Available phosphate content of plots, at various depths before the application of superphosphate. Date of sampling - 18/6/47.

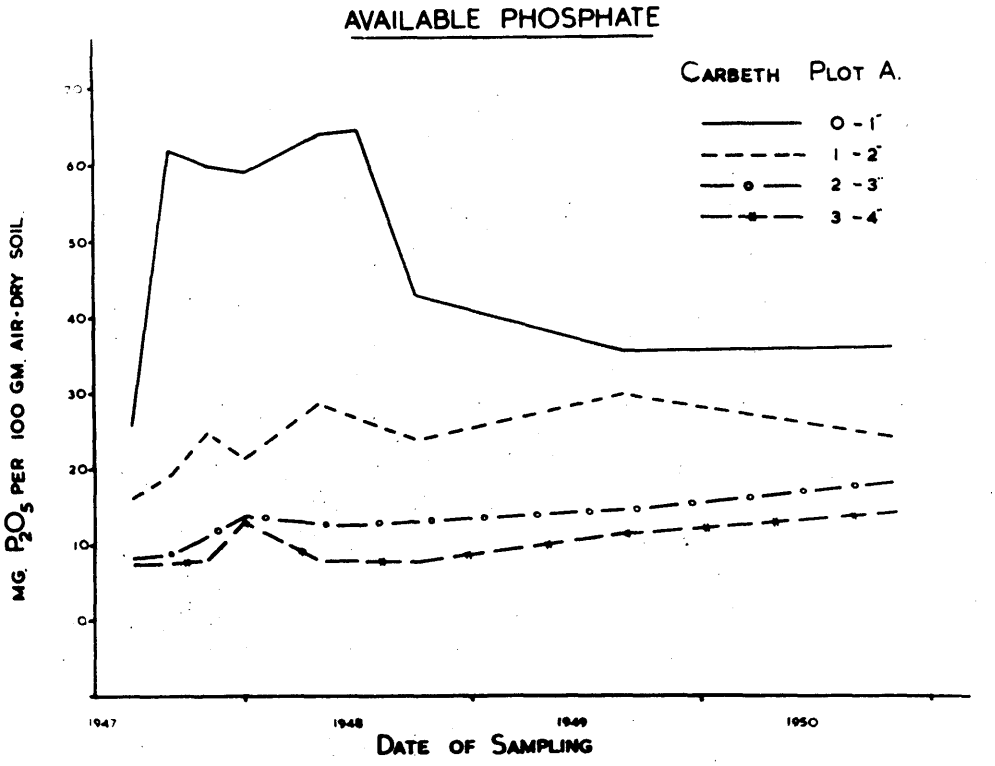
Depth of sampling	mg. available P_2O_5 per 100 g. air-dry soil.									
Drainage type - acidity	Plot PH A*	B	P D*	E	P-PH H*	I	PH K*	L	P N*	O
	pH 6.5		pH 6.5		pH 5.6		pH 5.8		pH 5.3.	
0 - 1"	25.6	32.5	24.2	22.5	7.8	5.4	8.3	8.5	1.2	3.0
1 - 2"	16.0	21.6	12.7	12.2	6.8	4.5	4.9	5.3	1.1	1.1
2 - 3"	8.1	11.0	7.3	6.2	5.0	2.6	4.1	5.2	1.1	1.4
3 - 4"	7.5	7.6	6.0	2.6	4.0	2.6	3.3	4.0	1.0	1.3
4 - 5"	7.5	7.6	6.3	2.3	4.0	2.3	2.2	4.4	0.8	1.9
5 - 6"	7.1	7.2	5.0	3.2	3.5	2.2	2.2	2.4	0.6	1.1
6 - 7"	6.5	6.8	4.4	2.6	3.6	1.9	2.4	3.4	0.8	1.1

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Plot:- A* Table:- 3. Treatment:- 240 lb. P_2O_5

Available phosphate content at various times after the application of superphosphate. Soil type:- O.R.S. boulder clay PH.

Depth of sampling	mg. available P_2O_5 per 100 g. air-dry soil							
	Date of sampling							
	Aug. 1947	Oct. 1947	Dec. 1947	Apr. 1948	Jun. 1948	Sep. 1948	Aug 1949	Aug. 1950
0 - 1"	62.0	60.0	59.0	64.2	64.6	43.0	35.5	36.0
1 - 2"	19.2	24.8	21.2	28.6	26.6	23.8	30.0	24.2
2 - 3"	8.7	11.0	13.7	12.6	12.6	13.2	14.4	17.8
3 - 4"	7.6	7.9	13.0	7.5	7.9	7.6	11.4	14.0
4 - 5"	7.5	6.0	9.0	6.0	6.4	5.6	7.6	9.2
5 - 6"	6.8	6.0	7.6	6.4	7.6	6.8	8.3	11.0
6 - 7"	6.5	6.8	6.0	5.2	6.0	5.6	7.6	7.8



Diag. 1 - Variation in % available phosphate of 0 - 1", 1"- 2", 2"- 3" and 3"- 4" layers of soil from Plot A*.

Soil type:- O.R.S. boulder clay - PH.

Plot:- B Table:- 4. Treatment:- Control.

Available phosphate content of control plot at various times.

Soil type:- O.R.S. boulder clay PH.

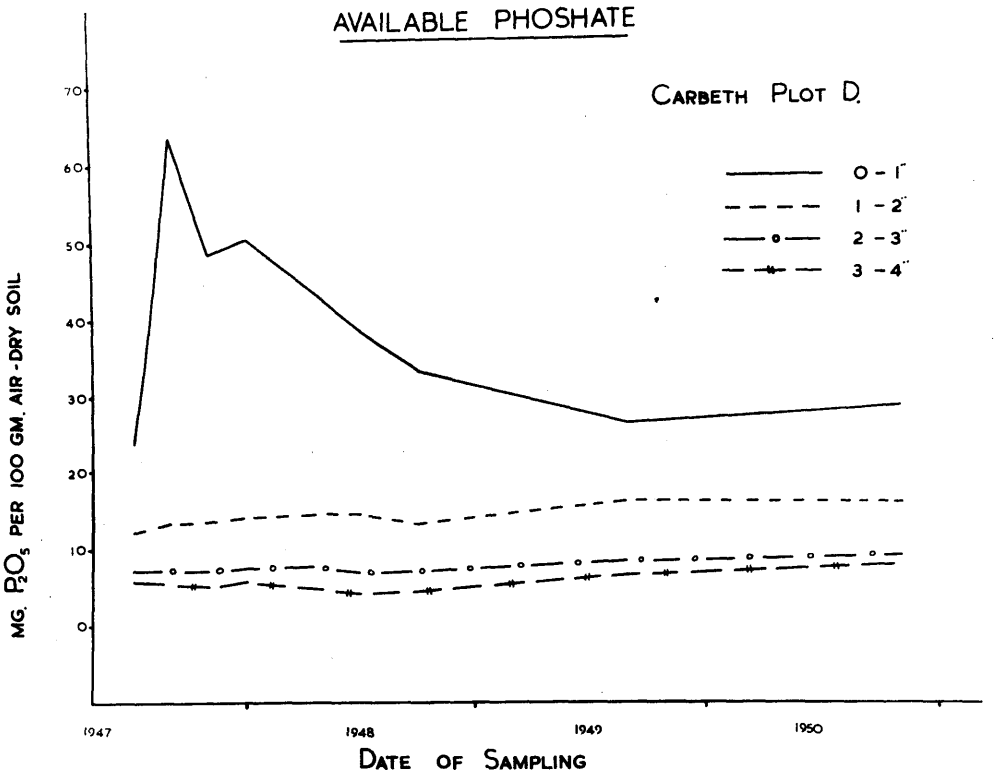
Depth of sampling	mg. available P_2O_5 per 100 g. air-dry soil							
	Date of sampling							
	Aug. 1947	Oct. 1947	Dec. 1947	Apr. 1948	Jun. 1948	Sep. 1948	Aug. 1949	Aug. 1950
0 - 1"	30.0	30.2	29.4	29.2	23.9	19.9	21.7	23.0
1 - 2"	18.0	20.1	24.8	22.7	21.4	13.7	20.5	14.1
2 - 3"	11.8	11.8	12.2	10.2	9.1	7.9	8.7	7.4
3 - 4"	8.7	8.7	7.9	7.2	6.4	6.8	6.3	7.2
4 - 5"	6.8	5.4	7.6	6.0	7.6	6.0	5.8	6.0
5 - 6"	7.5	5.6	7.6	6.8	7.6	6.0	6.8	6.2
6 - 7"	6.3	6.8	7.9	6.6	7.9	4.5	8.3	6.4

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Plot:- D* Table:- 5. Treatment:- 240 lb. P_2O_5

Available phosphate content at various times after the application of superphosphate. Soil type:- O.R.S. boulder clay P.

Depth of sampling	mg. available P_2O_5 per 100 g. air-dry soil							
	Date of sampling							
	Aug. 1947	Oct. 1947	Dec. 1947	Apr. 1948	Jun. 1948	Sep. 1948	Aug. 1949	Aug. 1950
0 - 1"	64.0	49.2	50.8	43.0	39.0	33.8	26.8	29.0
1 - 2"	13.5	13.7	14.2	14.9	14.9	13.3	16.5	16.0
2 - 3"	7.4	7.2	7.6	7.9	7.2	7.2	8.6	8.8
3 - 4"	5.5	5.0	6.0	4.9	4.3	4.5	6.8	8.0
4 - 5"	5.0	4.2	5.6	3.0	3.9	3.4	5.6	5.0
5 - 6"	3.5	4.2	3.9	3.4	4.2	3.4	5.1	5.0
6 - 7"	3.2	2.8	4.9	3.2	4.9	2.7	5.2	4.8



Diag. 2 - Variation in % available phosphate of 0 - 1", 1"- 2", 2"- 3" and 3"- 4" layers of soil from Plot D*.

Soil type:- O.R.S. boulder clay - P.

AVAILABILITY AND PENETRATION OF PHOSPHATES IN SOILS.

Plot:- E. Table:- 6. Treatment:- Control.

Available phosphate content of control plot at various times.

Soil type:- O.R.S. boulder clay. P.

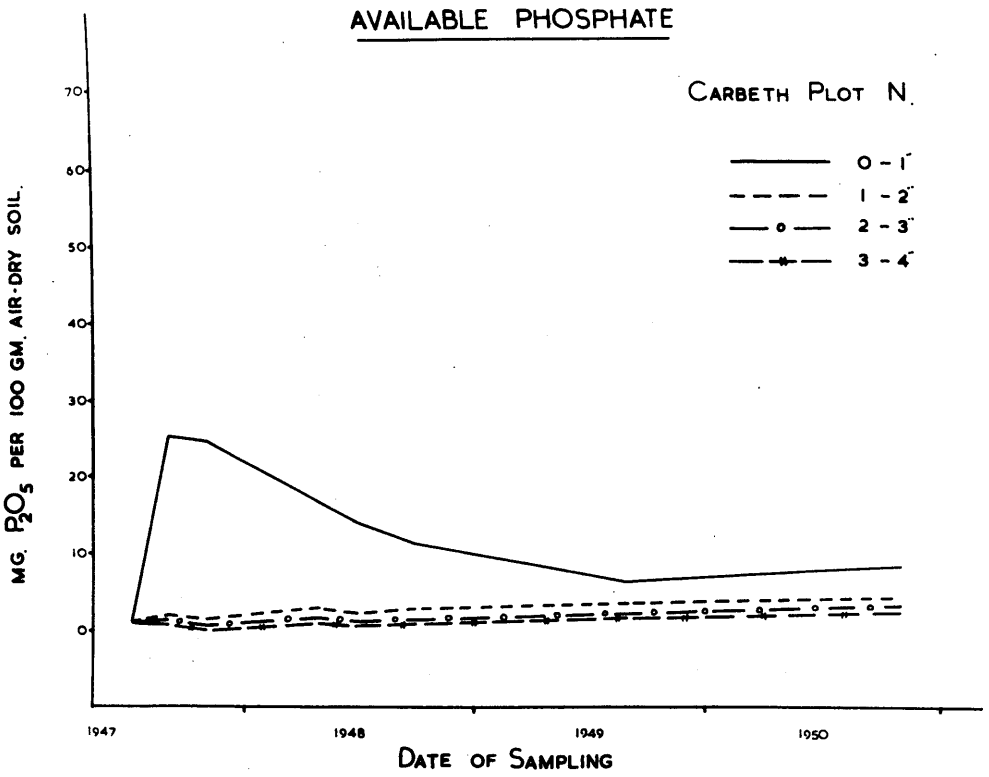
Depth of sampling	mg. available P_2O_5 per 100 g. air-dry soil Date of sampling							
	Aug. 1947	Oct. 1947	Dec. 1947	Apr. 1948	Jun. 1948	Sep. 1948	Aug. 1949	Aug. 1950
0 - 1"	19.0	16.5	15.5	16.4	16.6	13.7	13.0	14.2
1 - 2"	7.3	6.4	6.6	7.9	9.8	9.0	9.4	8.6
2 - 3"	3.4	4.2	3.4	6.4	4.9	4.4	6.0	6.5
3 - 4"	3.0	2.6	1.1	4.9	3.4	3.8	6.0	5.0
4 - 5"	3.7	2.6	2.5	3.4	3.4	2.6	4.9	3.2
5 - 6"	2.8	2.6	3.4	2.6	2.3	3.0	4.2	3.4
6 - 7"	2.8	1.9	3.0	2.6	2.6	3.0	3.9	3.8

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Plot:- N* Table:- 7. Treatment:- 240 lb. P_2O_5 per acre.

Available phosphate content at various times after the application of superphosphate. Soil type:- O.R.S. boulder clay P.

Depth of sampling	mg. available P_2O_5 per 100 g. air-dry soil. Date of sampling						
	Aug. 1947	Oct. 1947	Apr. 1948	Jun. 1948	Sep. 1948	Aug. 1949	Aug. 1950
0 - 1"	25.2	24.6	16.4	13.7	11.0	6.0	8.2
1 - 2"	1.9	1.3	2.6	1.9	2.6	3.4	4.0
2 - 3"	1.4	0.4	1.4	1.1	1.1	1.9	3.0
3 - 4"	1.6	0.2	0.9	0.8	0.8	2.3	2.2
4 - 5"	1.2	0.4	0.8	0.4	1.1	2.3	2.0
5 - 6"	1.2	0.4	0.4	0.4	0.4	1.9	2.0
6 - 7"	1.0	0.2	0.4	0.2	0.4	1.4	1.6



Diag. 3 - Variation in % available phosphate of 0 - 1", 1"- 2", 2"- 3" and 3"- 4" layers of soil from Plot N*.

Soil type:- O.R.S. boulder clay - P (acid).

Plot:- O. Table:- 8. Treatment:- Control.

Available phosphate content of control plot at various times.

Soil type :- O.R.S. boulder clay P.

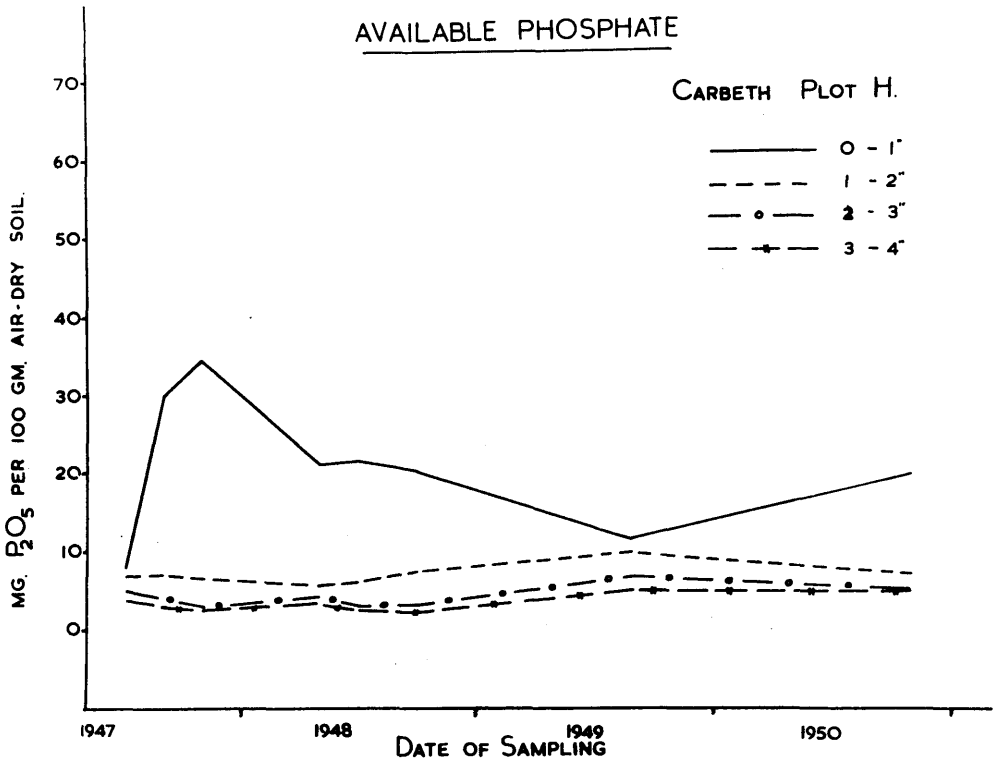
Depth of sampling	mg. available phosphate per 100 g. air-dry soil. Date of sampling						
	Aug. 1947	Oct. 1947	Apr. 1948	Jun. 1948	Sep. 1948	Aug. 1949	Aug. 1950
0 - 1"	3.0	1.1	1.4	1.9	1.1	3.0	3.2
1 - 2"	2.1	1.7	1.1	1.1	1.1	1.9	2.1
2 - 3"	2.1	0.8	0.8	1.1	1.1	1.9	1.8
3 - 4"	1.3	0.8	1.1	1.9	1.1	2.6	1.4
4 - 5"	2.0	1.1	1.1	1.4	1.4	2.3	1.2
5 - 6"	2.1	0.4	0.8	1.3	1.1	2.3	1.4
6 - 7"	2.1	1.0	0.4	0.4	1.1	2.0	1.1

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Plot:- H* Table:- 9. Treatment:- 240 lb. P_2O_5 per acre.

Available phosphate content at various times after the application of superphosphate. Soil type:- Littoral sands P-PH.

Depth of sampling	mg. available P_2O_5 per 100 g. air-dry soil						
	Date of sampling						
	Aug. 1947	Oct. 1947	Apr. 1948	Jun. 1948	Sept. 1948	Aug. 1949	Aug. 1950
0 - 1"	30.0	34.6	21.2	21.7	20.3	11.8	20.0
1 - 2"	7.0	6.4	5.6	6.0	7.4	10.0	7.0
2 - 3"	4.0	2.6	4.2	3.0	3.0	6.8	5.0
3 - 4"	3.0	2.8	3.4	2.6	2.3	5.2	5.0
4 - 5"	3.6	1.9	3.0	1.9	3.0	4.2	4.3
5 - 6"	2.8	2.6	3.0	1.9	2.4	3.9	4.8
6 - 7"	2.0	1.9	1.9	2.3	1.9	3.4	4.2



Diag. 4 - Variation in % available phosphate of 0 - 1", 1"- 2", 2"- 3" and 3"- 4" layers of soil from Plot H*.

Soil type:- Littoral sands - P-PH.

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Plot:- I. Table:- 10. Treatment:- Control.

Available phosphate content of control plot at various times.

Soil type:- Littoral sands P-PH.

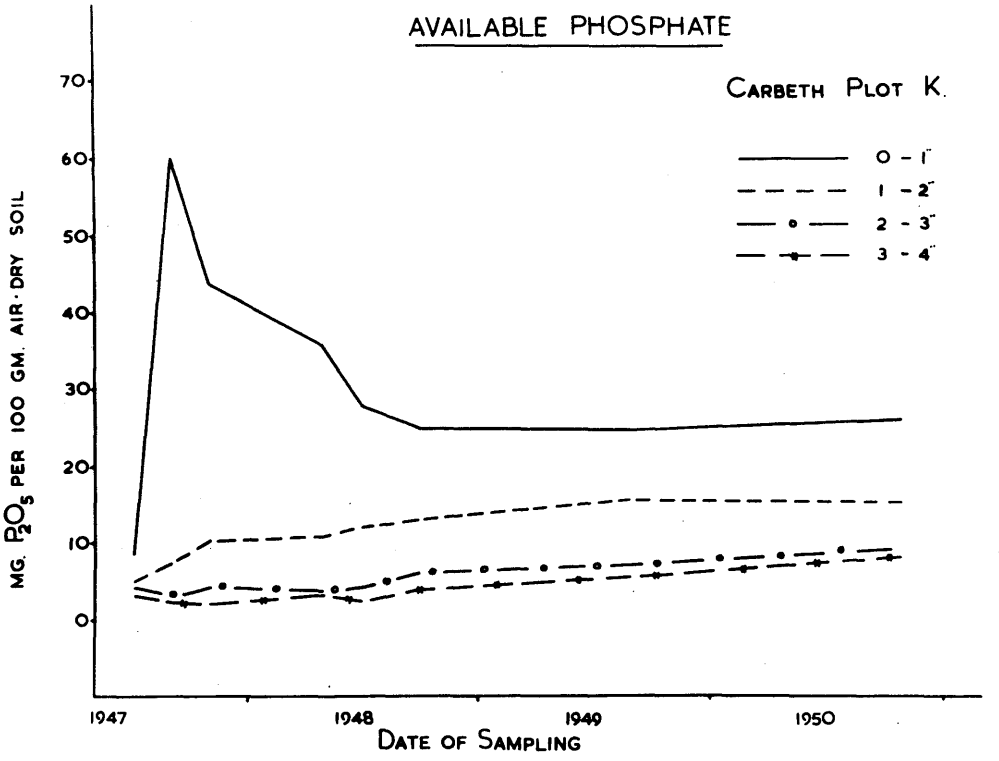
Depth of sampling	mg. available P_2O_5 per 100 g. air-dry soil						
	Date of sampling						
	Aug. 1947	Oct. 1947	Apr. 1948	Jun. 1948	Sep. 1948	Aug. 1949	Aug. 1950
0 - 1"	4.3	5.4	3.9	3.9	3.0	6.0	5.0
1 - 2"	2.3	2.6	3.4	3.9	2.3	3.9	2.0
2 - 3"	2.5	2.3	2.3	2.3	2.3	3.0	2.2
3 - 4"	2.5	1.7	1.9	1.9	2.3	2.6	2.6
4 - 5"	2.1	1.1	1.1	2.6	2.3	3.4	3.2
5 - 6"	2.2	2.5	2.3	2.3	2.3	3.4	3.0
6 - 7"	2.0	1.9	1.4	1.9	2.3	1.4	2.4

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Plot:- K* Table:- 11. Treatment:- 240 lb. P_2O_5 per acre.

Available phosphate content at various times after the application of superphosphate. Soil type:- Littoral sands PH.

Depth of sampling	mg. available P_2O_5 per 100 g. air-dry soil						
	Date of sampling						
	Aug. 1947	Oct. 1947	Apr. 1948	Jun. 1948	Sep. 1948	Aug. 1949	Aug. 1950
0 - 1"	60.0	43.8	35.6	27.0	25.0	24.4	26.0
1 - 2"	7.2	10.2	10.6	11.8	12.8	15.3	15.0
2 - 3"	2.7	4.2	3.4	4.2	6.0	6.8	9.2
3 - 4"	2.2	1.9	3.0	2.1	3.9	5.1	8.9
4 - 5"	1.3	1.1	2.4	1.1	3.0	3.0	5.2
5 - 6"	2.0	1.4	1.9	1.2	3.9	3.9	4.9
6 - 7"	1.2	1.4	1.4	1.1	2.6	3.0	4.2



Diag. 5 - Variation in % available phosphate of 0 - 1", 1"- 2", 2"- 3" and 3"- 4" layers of soil from Plot K*.

Soil type:- Littoral sands - PH.

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Plot:- L. Table:- 12. Treatment:- Control.

Available phosphate content of control at various times.

Soil type:- Littoral sands PH.

Depth of sampling	mg. available P_2O_5 per 100 g. air-dry soil						
	Date of sampling						
	Aug. 1947	Oct. 1947	Apr. 1948	Jun. 1948	Sept 1948	Aug. 1949	Aug. 1950
0 - 1"	8.3	11.0	6.8	4.9	7.6	8.3	8.4
1 - 2"	4.4	5.6	5.6	3.4	6.0	5.3	5.0
2 - 3"	6.3	3.4	3.4	3.0	3.4	3.9	3.0
3 - 4"	3.4	1.1	2.6	1.9	3.0	2.6	2.0
4 - 5"	1.3	0.4	1.4	1.1	2.3	2.6	2.0
5 - 6"	1.2	1.1	1.7	1.1	2.6	3.4	2.0
6 - 7"	1.4	0.4	1.1	0.4	2.3	2.8	2.2

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Table:- 13.

Increases in available phosphate content, above available phosphate content before application of superphosphate. Soil type:- O.R.S. boulder clay

Plot	Increase in available P_2O_5 (mg./100g.) after months						
Sample	2	4	10	12	15	26	38
0 – 1" layer							
A*	36.4	34.6	38.6	39.0	17.4	9.9	10.4
D*	39.8	25.0	18.8	14.8	9.6	2.6	4.8
N*	24.0	23.4	15.2	12.5	9.8	4.8	7.0
1 – 2" layer							
A*	3.2	8.8	12.6	10.6	7.8	14.0	8.2
D*	0.8	1.0	2.2	2.2	0.6	3.8	3.3
N*	0.8	0.2	1.5	0.8	1.5	2.3	2.9
2 – 3" layer							
A*	0.6	2.9	4.5	4.5	5.1	6.3	9.7
D*	0.1	-0.1	0.6	-0.1	-0.1	1.3	1.5
N*	0.3	-0.7	0.3	0.0	0.0	0.8	1.9
3 – 4" layer							
A*	0.1	0.4	0.0	0.4	0.1	4.1	6.7
D*	-0.5	-1.0	-1.1	-1.7	-1.5	0.8	2.0
N*	0.0	-0.8	-0.1	-0.0	0.0	1.3	1.2

Table:- 14.

Increase in available phosphate content, above available phosphate content before application of superphosphate. Soil type:- Littoral sands.

Plot	Increase in available P_2O_5 (mg./100 g.) after months						
Sample	2	4	10	12	15	26	38
0 – 1" layer							
H*	22.2	26.8	13.4	13.9	12.5	4.0	12.2
K*	51.7	35.5	27.3	18.7	16.7	16.1	17.7
1 – 2" layer							
H*	0.2	-0.4	-1.2	-0.8	0.6	3.2	0.2
K*	2.3	5.3	5.7	6.9	7.9	10.4	10.1
2 – 3" layer							
H*	-1.0	-2.4	-0.8	-2.0	-2.0	1.8	0.0
K*	-1.4	0.1	-0.7	0.1	1.9	2.7	5.1
3 – 4" layer							
H*	-1.0	-1.2	-0.6	-1.4	-1.7	1.2	1.0
K*	-1.1	-1.4	-0.3	-1.2	-0.6	1.8	4.7

TOTAL PHOSPHATE RESULTS

The results of total phosphate determinations are given in tables 16, 18, 19, 21, 22, 24, 25, 27, 28 and 30. An estimate of the weight of air-dry soil per acre was obtained by weighing the air-dry soil of a number of cores of each layer, calculating the area of the core and multiplying by a factor to give the weight per acre. It is realised that a considerable error is possible in this estimation and that the results are not likely to be accurate, but they serve to give some indication of the total weight of phosphorus in the various layers. The total weights of air-dry soil in the various layers are given in table 15 and the estimated total weights of P_2O_5 per acre in tables 17, 20, 23, 26 and 29.

The results of total phosphate determinations would indicate that there is a considerable downward movement of total phosphate; and some plots provide evidence of penetration to a depth of 7". In other words, the total - as distinct from the available - phosphate may be increased to that depth, after the application of superphosphate. The rate of penetration

to/

to increase "total" phosphate varies much with soil type.

It will be recalled that increases in "available" phosphate were seldom registered below about 4".

A. Old Red Sandstone boulder clay:-

Comparison of the three centres:-

Plot A* - poorly-drained soil;

Plot D* - freely-drained soil;

Plot N* - freely-drained soil but more acid reaction than A* and D*;

show the following results for total phosphate:-

1. Two months after the application of superphosphate there was an increase of total phosphate to a depth of 7" in the poorly drained soil of plot A*, to 5" in the freely drained soil of plot D*, but only to a depth of 3" in the acid freely-drained soil of plot N*.
2. In plot D* there is evidence of penetration of total phosphate to the 7" layer, six months after the application of superphosphate; but in the more acid soil of plot N* there was no indication of phosphate penetration below depth of 5" even at the end of three years.
3. In the freely-drained soils a high percentage of the/

the phosphate applied would appear to be retained in the top three inches. In the poorly drained soil the penetration to lower layers was much greater. A comparison of the three plots, three years after the application of superphosphate, shows that in the freely drained soils of plots D* and N*, the top four inches of soil has been raised in total phosphate content, but lower layers have similar total phosphate status to that found before the application of phosphate. In the poorly-drained soil of plot A* there has been a considerable increase in total phosphate content down to depths of 7" and probably deeper.

4. The total phosphate content of the various layers in the control plots remained fairly constant throughout the experiment.

B. Littoral Sands and Gravels:-

Comparison of the two centres:-

Plot H* - moderately-drained soil;

Plot K* - poorly-drained soil;

show the following results for total phosphate:-

A fairly rapid downward movement and possibly a considerable loss of phosphate, especially under poor drainage conditions, were indicated.

1./

1. The penetration of total phosphate in the moderately drained soil of plot H* appears to have been rapid in the early stages of the experiment. Samples taken two months after the application of superphosphate show a penetration to the 7" layer. A high percentage of the phosphate is retained in the upper layers. Further penetration of phosphate appears to be slower but after three years the total phosphate content of all layers down to a depth of 7" have been increased by a considerable amount.

2. In the poorly drained soil of plot K* the results are rather different from other centres. It will be noted (Table 28) that after three years the total phosphate of the various layers has almost reverted to the original values found before the application of phosphate. There must therefore have been a considerable loss of phosphate by leaching. As in other centres there is the tendency for phosphate to be retained in the upper layers.

3. The control plots at both centres on this soil type show that where no phosphate was applied, the total phosphate content of the various layers has remained fairly constant.

It/

It is reasonable to think that in a really badly-drained soil there would be movement of phosphate of a kind which could hardly occur extensively in a well-drained soil. The soil-solution conditions and the equilibrium between soil and soil solution would be different; and, in a soil continuously supplied with water, downward movement of phosphate might occur to an extent that would be nearly impossible in a soil frequently dried and re-wetted. The observed results suggest that some such mechanisms do indeed operate in poorly-drained soils.

The role to be assigned to the organic matter and its concomitants is obscure. The pairs K* L, and H* I, do not differ significantly in percentage of organic matter (as measured by Loss on Ignition) but the former are black and appear more humose than do the latter. It seems, that the more rapid leaching of phosphate in plot K* may be associated with some "mobilization" into which the organic matter enters.

Table:- 15.

Weight of air-dry soil per acre of various layers.

Layer	Weight of air-dry soil per acre (lb.):				
	O.R.S. boulder clay			Littoral sands	
	Plot A	Plot D	Plot N	Plot H	Plot K
0 - 1"	126,000	119,000	144,400	115,900	142,400
1 - 2"	201,200	191,600	229,400	217,800	198,500
2 - 3"	234,400	208,900	242,500	221,400	251,700
3 - 4"	272,000	200,700	262,300	290,000	229,400
4 - 5"	289,100	212,900	306,800	294,400	256,100
5 - 6"	219,500	215,700	241,900	271,800	264,000
6 - 7"	230,700	233,000	268,200	288,600	278,500
Total to 9"+	2,078,000	1,813,000	2,235,000	2,272,000	2,135,000

+ Assuming weight 7 - 9" = $\frac{1}{2}$ wt 3 - 7".

Plot:- A* Table:- 16. Treatment:- 240 lb.P_2O_5 per acre

Variation in total phosphate content of samples from various depths.

Soil type:- O.R.S. boulder clay PH.

Depth of sampling	mg. total P_2O_5 per 100 g. air-dry soil: Date of sampling								
	Jun+ 1947	Aug. 1947	Oct. 1947	Dec. 1947	Apr. 1948	Jun. 1948	Sep. 1948	Aug. 1949	Aug. 1950
0 – 1"	204	311	310	305	323	352	280	285	256
1 – 2"	187	194	233	200	213	236	238	261	232
2 – 3"	166	170	185	188	187	187	193	213	208
3 – 4"	165	162	184	183	181	172	172	174	179
4 – 5"	167	165	169	174	168	168	168	173	177
5 – 6"	166	189	163	177	168	169	169	170	174
6 – 7"	158	194	163	162	163	173	163	177	180

+ before application of superphosphate

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Table:- 17. Plot:- A*

Variation in total weight of phosphate per acre in soil at various depths.

Soil type:- O.R.S. boulder clay PH.

Depth of sampling	Weight of total P_2O_5 per acre (lb.) Interval between sampling and application of superphosphate:			
	+	1 year	2 year	3 year
0 - 1"	257	444	359	323
1 - 2"	376	475	525	467
2 - 3"	389	438	499	488
3 - 4"	449	468	473	487
4 - 5"	482	485	500	511
5 - 6"	364	371	373	382
6 - 7"	363	399	408	415

+ before application of superphosphate

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Table:- 18.

Plot:- B Treatment:- Control.

Variation in total phosphate content of samples from various depths.

Soil type:- O.R.S. boulder clay PH.

Depth of sampling	mg. total P_2O_5 per 100 g. air-dry soil Date of sampling		
	June 1947	June 1948	August 1949
0 - 1"	205	215	205
1 - 2"	187	174	185
2 - 3"	156	150	150
3 - 4"	149	147	155
4 - 5"	152	140	142
5 - 6"	146	136	146
6 - 7"	142	135	136

Plot:- D* Table:- 19. Treatment:- 240 lb.P_2O_5 per acre.

Variation in total phosphate content of samples from various depths.

Soil type:- O.R.S. boulder clay P.

Depth of sampling	mg. total P_2O_5 per 100 g. air-dry soil								
	Date of sampling								
	Jun.+ 1947	Aug. 1947	Oct. 1947	Dec. 1947	Apr. 1948	Jun. 1948	Sep. 1948	Aug. 1949	Aug. 1950
0 - 1"	331	465	460	450	440	444	430	413	387
1 - 2"	285	292	290	301	313	328	337	335	340
2 - 3"	247	269	250	269	280	275	258	277	274
3 - 4"	240	250	240	256	247	246	245	254	269
4 - 5"	236	250	238	240	244	240	238	246	239
5 - 6"	233	235	242	240	244	243	231	238	232
6 - 7"	223	225	223	236	246	246	232	233	210

+ before application of superphosphate

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Table:- 20. Plot:- D*

Variation in total weight of phosphate per acre in soil at various depths.

Soil type:- O.R.S. boulder clay P.

Depth of sampling	Weight of total P_2O_5 per acre (lb.) Interval between sampling and application of superphosphate:			
	+	1 year	2 year	3 year
0 - 1"	394	524	491	460
1 - 2"	546	628	642	651
2 - 3"	516	573	579	572
3 - 4"	481	493	510	540
4 - 5"	503	511	524	509
5 - 6"	503	524	513	500
6 - 7"	520	573	543	489

+ before application of superphosphate

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Table:- 21.

Plot:- E Treatment:- Control

Variation in total phosphate content of samples from various depths.

Soil type:- O.R.S. boulder clay P.

Depth of sampling	mg. total P_2O_5 per 100 g. air-dry soil Date of sampling		
	June 1947	June 1948	August 1949
0 - 1"	305	277	277
1 - 2"	255	245	262
2 - 3"	225	220	233
3 - 4"	215	218	200
4 - 5"	205	215	205
5 - 6"	205	218	210
6 - 7"	203	205	203

Plot:- N* Table:- 22. Treatment:- 240 lb.P_2O_5 per acre.

Variation in total phosphate content of samples from various depths.

Soil type:- O.R.S. boulder clay P.

Depth of sampling	mg. total P_2O_5 per 100 g. air-dry soil							
	Date of sampling							
	Jun.+ 1947	Aug. 1947	Oct. 1947	Apr. 1948	Jun. 1948	Sep. 1948	Aug. 1949	Aug. 1950
0 - 1"	178	298	264	240	243	252	215	196
1 - 2"	170	188	198	190	187	196	210	185
2 - 3"	171	183	179	185	172	178	173	186
3 - 4"	170	165	180	188	178	178	176	170
4 - 5"	168	166	174	182	178	175	171	165
5 - 6"	170	170	168	175	169	173	171	167
6 - 7"	169	165	164	177	166	168	166	164

+ before application of phosphate

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Table:- 23. Plot:- N*

Variation in total weight of phosphate per acre in soil at various depths.

Soil type:- O.R.S. boulder clay P.

Depth of sampling	Weight of total P_2O_5 per acre (lb.) Interval between sampling and application of superphosphate			
	+	1 year	2 year	3 year
0 - 1"	257	351	310	283
1 - 2"	390	429	482	424
2 - 3"	414	417	420	451
3 - 4"	445·9	467	454 461	488 445·9
4 - 5"	515	546	524	506
5 - 6"	412	409	413	403
6 - 7"	453	445	445	440

+ before application of superphosphate

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Table:- 24.

Plot:- 0 Treatment:- Control

Variation in total phosphate content of samples from various depths.

Soil type:- O.R.S. boulder clay P.

Depth of sampling	mg. total P_2O_5 per 100 g. air-dry soil Date of sampling		
	June 1947	June 1948	August 1949
0 - 1"	175	181	184
1 - 2"	173	179	175
2 - 3"	160	176	173
3 - 4"	173	176	170
4 - 5"	175	171	173
5 - 6"	157	172	170
6 - 7"	165	171	160

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Plot:- H* Table:- 25. Treatment:- 240 lb. P_2O_5 per acre.

Variation in total phosphate content of samples from various depths.

Soil type:- Littoral sands P-PH.

Depth of sampling	mg. total P_2O_5 per 100 g. air-dry soil							
	Date of sampling							
	Jun.+ 1947	Aug. 1947	Oct. 1947	Apr. 1948	Jun. 1948	Sep. 1948	Aug. 1949	Aug. 1950
0 - 1"	116	246	283	223	236	250	228	233
1 - 2"	105	141	144	138	151	149	181	159
2 - 3"	85	109	121	120	115	118	145	128
3 - 4"	87	101	118	122	113	105	124	127
4 - 5"	85	107	118	112	120	119	123	113
5 - 6"	84	105	117	116	125	109	110	106
6 - 7"	90	103	104	103	105	100	108	106

+ before application of superphosphate

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Table:- 26. Plot:- H*

Variation in total weight of phosphate per acre in soil at various depths.

Soil type:- Littoral sands P-PH.

Depth of sampling	Weight of total P_2O_5 per acre (lb.) Interval between sampling and application of superphosphate			
	+	1 year	2 years	3 years
0 - 1"	136	273	264	268
1 - 2"	229	329	394	346
2 - 3"	188	255	321	283
3 - 4"	252	327	359	368
4 - 5"	250	353	362	332
5 - 6"	228	339	299	288
6 - 7"	260	303	312	306

+ before application of superphosphate

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Plot:- I Treatment:- Control

Table:- 27.

Variation in total phosphate content of samples from various depths.

Soil Type:- Littoral sands P-PH.

Depth of sampling	mg. total P_2O_5 per 100 g. air-dry soil Date of sampling		
	June 1947	June 1948	August 1949
0 - 1"	111	130	119
1 - 2"	107	116	97
2 - 3"	93	96	86
3 - 4"	86	95	89
4 - 5"	89	90	85
5 - 6"	81	85	89
6 - 7"	77	86	86

Plot:- K* Table 28. Treatment:- 240 lb.P_2O_5 per acre.

Variation in total phosphate content of samples from various depths.

Soil type:- Littoral sands PH.

Depth of sampling	mg. total P_2O_5 per 100 g. air-dry soil							
	Date of sampling							
	Jun.+ 1947	Aug. 1947	Oct. 1947	Apr. 1948	Jun. 1948	Sep. 1948	Aug. 1949	Aug. 1950
0 - 1"	123	258	210	197	187	166	176	150
1 - 2"	105	110	121	130	142	116	128	120
2 - 3"	96	91	103	107	106	90	104	92
3 - 4"	90	95	92	96	99	95	99	90
4 - 5"	89	78	89	95	89	83	88	86
5 - 6"	91	77	96	89	95	83	86	86
6 - 7"	88	77	99	88	105	83	94	81

+ before application of superphosphate

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Table:- 29. Plot:- K*

Variation in total weight of phosphate per acre in soil at various depths.

Soil type:- Littoral sands PH.

Depth of sampling	Weight of total P_2O_5 per acre (lb.) Interval between sampling and application of superphosphate			
	+	1 year	2 years	3 years
0 - 1"	175	266	251	214
1 - 2"	208	282	254	238
2 - 3"	242	267	262	232
3 - 4"	207	227	227	207
4 - 5"	228	228	225	220
5 - 6"	240	251	227	227
6 - 7"	245	292	262	225

+ before application of superphosphate

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Table:- 30.

Plot:- L. Treatment:- Control

Variation in total phosphate content of samples from various depths.

Soil type:- Littoral sands PH.

Depth of sampling	mg. total P_2O_5 per 100 g. air-dry soil Date of sampling		
	June 1947	June 1948	August 1949
0 - 1"	120	102	112
1 - 2"	122	96	103
2 - 3"	103	90	91
3 - 4"	91	87	81
4 - 5"	95	80	73
5 - 6"	93	80	80
6 - 7"	92	73	81

DUSCUSSION OF THE VARIATIONS IN AVAILABLE AND TOTAL PHOSPHATE

The effect of applications of superphosphate, on grassland, on the available phosphate status of the soil has been found to be most marked in the surface two to three inches. This is in broad agreement with the results of other workers. Some of these earlier results have been already summarised and briefly discussed (pp. 5 - 23).

An investigation of the effects of natural drainage conditions, however, reveals that under wetter soil conditions the available phosphate is increased to a greater degree by the application of phosphate than where good natural drainage exists. Downward movement of available phosphate is also more marked in poorly drained soils. In the drier soils there is little if any increase in available phosphate below the 3 - 4" layer. In the wetter soils, however, increases were found down to a depth of 7"

As might be expected the application of phosphate to the acid soil of plot N* had much less effect on the/

the available phosphate content, than was found in other centres. Phosphate fixation in this soil must be very great. Increases in available phosphate in layers below 2" were almost negligible and even in the upper layers the increase in percentage available phosphate was not so great as in the less acid soil of plot D*.

In all centres the available phosphate status of the upper layers gradually decreases but after a period of three years the effect of the superphosphate dressing is still considerable and might still be expected to give increased yields of pasture. Measurement of pasture yields was not attempted but differences in growth between the phosphate treated plots and control plots were always apparent.

On the basis of available phosphate content, penetration of phosphate would not appear to be great. If, however, the total phosphate results are examined, it will be seen that under some conditions phosphate penetration must be considerable. The results also indicate that natural drainage conditions have a marked effect on the downward movement of phosphate.

In the Old Red Sandstone boulder clay soil, penetration to the 7" layer is quite marked in both

poor/

poor and freely drained associates, where the pH is over 6. The results suggest that penetration is more rapid and fixation less complete in the poorly drained soil. In the sandy loam there is also evidence of penetration of phosphate to depths of 7" and more, and under poor drainage conditions in this soil there would appear to be considerable loss by leaching.

The results are in agreement with what could be expected from influences of soil texture and structure. Comparing the freely-drained associates of the heavy boulder clay and the light sandy loam, the results reveal a more rapid penetration in the open loosely compacted soil.

Under acid freely-drained conditions (plot N*) the results show a greater phosphate fixation resulting in an accumulation of the applied phosphate in the top 2 or 3" of soil.

Although there is considerable fixation of phosphate in the upper layers the results suggest that soon after the application of superphosphate (this lapse of time depending, probably, on the rainfall and the evaporation balance) there is an initial rapid penetration of soluble phosphate into the lower layers. The amount of phosphate that was applied in these experiments is probably greater than that normally applied/

applied in grassland fertilisation. With large applications of phosphate, it is conceivable that considerable penetration might take place before absorption and fixation has removed most of the phosphate from solution. This effect is most strikingly shown in plots A* and H* (Tables 16 and 25). It is likely that large applications of phosphate will promote greater penetration in depth than an equivalent amount applied in small doses. This result has also been found by Doak (34) and Stephenson and Chapman (31).

The penetration of phosphate, in inorganic form, probably depends largely on the phosphate-fixing power of the soil and on the relative solubility of the fixed phosphate compounds. Under the prevailing reducing conditions of poorly drained soils, the phosphate may not be so firmly fixed as in the freely-drained, and losses of phosphate might be expected to be greater in these soils.

Gaarder (42) stated that in humid or semi-humid soils of high humus content, loss of phosphate may be very great. Some such conditions prevail in plot K*; and the results show that three years after the application of superphosphate, the phosphate status of this/

this soil had almost reverted to its original level.

With each soil type, the comparison of poorly and freely drained associates was carried out in the same field of which the management and fertiliser treatment has presumably been uniform over the whole area for many years. Examination of the data shows that the total phosphate content is much greater in freely drained soils. This would suggest a considerable removal of phosphate by leaching in poorly drained soils.

It was found that the total phosphate of the control plots in both soil types remained fairly constant throughout the period of the experiment. This result agrees with the suggestion of Robinson and Jones (33) and Doak (34) that the phosphorus in the soil can be divided into two groups (a) natural stable phosphorus compounds which are subject to negligible wastage by leaching and (b) the unstable phosphorus compounds of added dressings which are removed fairly rapidly from the surface layers by percolating waters.

The available-phosphate results lend support to the contention of Wrenshall and McKibbin (23) that the soluble phosphorus of untreated soil is an equilibrium quantity, probably not varying significantly from year to/

to year and approached in the treated soil after the effectiveness of the application has worn off. In some of the control plots there was an indication of phosphate penetration of residues of dressings applied prior to the experiment, but in general the available phosphate content of the various layers has remained constant.

Some important points, in phosphatic manuring of grassland, arise from the results. There is strong evidence to show, that drainage conditions (as suggested by Glentworth (46)) have considerable influence on the fate of applied phosphates. A comparison of the effects of superphosphate applied to freely- and poorly-drained soils shows:-

1. When superphosphate is applied to a poorly-drained soil, the increase in "available phosphate" content of this soil is likely to be greater and of longer duration than when a similar dressing is applied to a well-drained soil. Fixation appears to be less rapid and less complete under poor drainage conditions.

2. Application of superphosphate to poorly-drained soil may result in increases in "available phosphate" content down to depths of 7" or more, but, in freely-drained soil, increases are not likely to be registered below depths of/

of 3" to 4" and probably even less under acid freely-drained conditions.

3. Downward movement of "total phosphate" is likely to be considerable in poorly-drained soil and in some such soils may lead to considerable loss of added phosphate from the surface layers. In well-drained soil, however, nearly all the applied phosphate will be retained in the top 3" or 4" of soil.

4. It seems that most workers concerned with the problem of "phosphate fixation" have been preoccupied with the effects of soil acidity, and have therefore tended to relate their conclusions to acidity alone.

Soils of similar acidity can be naturally drained to varying degrees (and conversely).

Natural drainage, is equally with acidity, a soil phenomenon. Both these phenomena will require to be taken into account in considering the very considerable practical aspects of phosphate utilisation by crops.

Drainage conditions define more than just the water regime: they also determine the extent of aeration.

It is now suggested that the probable fate, of applied phosphate, will depend not only on the soil's acidity but also on the freedom and type of natural drainage.

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS

Table:- 31.

Results of method of sampling test

Depth of sampling	mg. available P_2O_5 per 100 g. air-dry soil						
	Sample					Mean	Standard Deviation
	1	2	3	4	5		
0 - 1"	20.2	19.4	20.5	18.4	20.0	19.7	0.8
1"- 2"	3.9	3.6	4.2	4.8	5.0	4.3	0.6
2"- 3"	2.3	2.3	2.0	2.3	4.1	2.6	0.8
3"- 4"	2.3	4.8	3.0	3.3	4.1	3.5	1.0
4"- 5"	2.3	4.5	2.3	2.3	3.6	3.0	1.0
5"- 6"	1.9	3.0	2.0	3.6	3.5	2.8	0.8
6"- 7"	2.0	1.1	2.7	3.0	3.7	2.5	1.0

Determinations of "available phosphate" were made by me by the method of Williams and Stewart (1).

AVAILABILITY AND PENETRATION OF PHOSPHATE IN SOILS.

Table:- 32.

Results of method of sampling tests

Depth of sampling	mg. total P_2O_5 per 100 g. air-dry soil						
	1	2	3	4	5	Mean	Standard Deviation
0 - 1"	243	233	243	240	233	238	5.1
1"- 2"	155	151	159	154	159	156	3.4
2"- 3"	133	131	132	121	128	129	4.9
3"- 4"	116	116	129	119	127	122	6.0
4"- 5"	113	120	113	111	113	114	3.4
5"- 6"	108	108	112	116	106	110	4.0
6"- 7"	107	105	105	112	106	107	2.9

Determinations of "total phosphate" were made by me by my then unpublished method (see reprint: Part III).

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PART II.

FIELD EXPERIMENTS WITH PHOSPHATES APPLIED TO SWEDES: WITH SPECIAL REFERENCE TO SOIL CONDITIONS.

It is pertinent to cite some original results of field trials on yields of swedes variously manured with phosphates. These experiments were made before the initiation of the work formally offered for Thesis requirements.

"Falcon" purple top seeds.

SWEDE EXPERIMENTS, 1945

Phosphate experiments were laid down on a total of seven associates of five soil types in Stirlingshire. The experiments were designed to study the response of the swede crop to dressings of phosphates on some typical soil types and to compare the effects of superphosphate and ground mineral phosphate and soils varying in hydromorphic type as well as in e.g., acidity and available phosphate.

Treatments:-

A. Control - no phosphate.

B. 0.5 cwt. P_2O_5 per acre as superphosphate.

C. 1.0 cwt. P_2O_5 per acre as superphosphate.

D. 1.0 cwt. P_2O_5 per acre as ground mineral phosphate.

Basal Manuring:-

2 cwt. sulphate of ammonia per acre.

1½ cwt. muriate of potash per acre.

10 lb. borax per acre.

Variety:-

"Falcon" purple top swede.

Layout:-

The experiments consisted of 4 x 4 latin squares. The plots were 1/80 acre.

Results:-

1. Soil Type*:- Sandy till boulder clay - PH.

Centre:- Burnhouse, High Bonnybridge.

Soil Analyses:-

Loss on Ignition	- 8.4%
pH	- 6.5
Available P_2O_5	- 4.2 mg. per 100 g.
Available K_2O	- 2.8 mg. per 100 g.

Yields per acre:-

Treatment	A.	- 4 ton 9½ cwt.
	B.	- 10 ton 1 cwt.
	C.	- 10 ton 10½ cwt.
	D.	- 8 ton 5½ cwt.
Mean		- 8 ton 7 cwt.
Standard Error		- ± 9½ cwts.

---

* These soils were classified by Dr. H. Hart, Macaulay Institute, Aberdeen.

2. Soil Type*:- Sandy till boulder clay - P.

Centre:- Woodend, High Bonnybridge.

Soil Analyses:-

Loss on Ignition	-	10.5%
pH	-	6.05
Available P_2O_5	-	2.6 mg. per 100 g.
Available K_2O	-	1.9 mg. per 100 g.

Yields per acre:-

Treatment	A.	-	1 ton 7½ cwt.
	B.	-	7 ton 6½ cwt.
	C.	-	7 ton 4 cwt.
	D.	-	5 ton 11½ cwt.
Mean		-	5 ton 8 cwt.
Standard Error		-	± 15 cwt.

3. Soil Type:- Littoral sands - P-PH.

Centre:- Carbeth Home Farm, Killearn.

Soil Analyses:-

Loss on Ignition	-	6.2%
pH	-	5.35
Available P_2O_5	-	1.5 mg. per 100 g.
Available K_2O	-	2.1 mg. per 100 g.

Yields per acre:-

Treatment A.	-	9 ton 5 cwt.
B.	-	17 ton.
C.	-	17 ton 16 cwt.
D.	-	15 ton 13 cwt.
Mean	-	14 ton 19 cwt.
Standard Error	-	± 3.2 cwt.

4. Soil Type:- Littoral sands - PH.

Centre:- Carbeth Home Farm, Killearn.

Soil Analyses:-

Loss on Ignition	-	8.5%
pH	-	5.45
Available P_2O_5	-	3.5 mg. per 100 g.
Available K_2O	-	2.8 mg. per 100 g.

Yields per acre:-

Treatment	A.	-	12 ton 2 cwt.
	B.	-	16 ton 3 cwt.
	C.	-	16 ton 12 cwt.
	D.	-	15 ton 5 cwt.
Mean		-	15 ton ½ cwt.
Standard Error		-	± 15½ cwt.

5. Soil Type:- Old Red Sandstone boulder clay P.

Centre:- Carbeth Home Farm, Killearn.

Soil Analyses:-

Loss on Ignition	-	8.8%
pH	-	6.1
Available P_2O_5	-	3.8 mg. per 100 g.
Available K_2O	-	25.5 mg. per 100 g.

Yields per acre:-

Treatment	A.	-	20 ton 5 cwt.
	B.	-	20 ton 9 cwt.
	C.	-	22 ton 1 cwt.
	D.	-	20 ton 12 cwt.
Mean		-	20 ton 17 cwt.
Standard Error		-	$\pm$ 24½ cwt.

6. Soil Type*:- Falkirk sands - P.

Centre:- Myrehead, Polmont.

Soil Analyses:-

Loss on Ignition	-	13.3%
pH	-	5.0
Available P_2O_5	-	11.5 mg. per 100 g.
Available K_2O	-	5.0 mg. per 100 g.

Yields per acre:-

Treatment	A.	-	13 ton.
	B.	-	13 ton 11½ cwt.
	C.	-	14 ton 17½ cwt
	D.	-	12 ton 11 cwt.
Mean		-	13 ton 7 cwt.
Standard Error		-	± 13½ cwt.

7. Soil Type*:- Heavy Boulder Clay P.

Centre:- Glen Farm, Falkirk.

Soil Analyses:-

Loss on Ignition	-	9.8%
pH	-	5.8
Available P_2O_5	-	6.5 mg. per 100 g.
Available K_2O	-	1.0 mg. per 100 g.

Yields per acre:-

Treatment	A.	-	11 ton 10½ cwt.
	B.	-	14 ton 9 cwt.
	C.	-	14 ton 12 cwt.
	D.	-	13 ton 18 cwt.
Mean		-	13 ton 12½ cwt.
Standard Error		-	± 17 cwt.

DISCUSSION OF RESULTS

The results of the swede experiments showed the following points:-

1. There were no significant differences between yield-responses to the two rates of application of superphosphate. It would appear that 0.5 cwt. P_2O_5 (as superphosphate) per acre is a practically sufficient dressing for swedes of which the manurial treatment is otherwise adequate.
2. The results indicate that 1.0 cwt. P_2O_5 as ground mineral phosphate is hardly as effective as 0.5 cwt. P_2O_5 as superphosphate.
3. The control plots on poorly drained (centres 1 and 4) soils gave higher yields than the corresponding plots on the more freely drained soils (centres 2 and 3).
4. The percentage increase in yield resulting from the addition of phosphates was greater in the freely drained soils (compare centres 1 & 2 and 3 & 4).
5. The results at centre 5 are rather surprising. This soil which showed a low available phosphate centent gave a 20-ton per acre crop without the addition of phosphates and failed to respond significantly to dressings of phosphates.
6. The yield of swedes was little affected (where superphosphate was applied) by natural drainage conditions.

The foregoing discussion may once more serve to show the inadequacy of present-day determinations of "available" phosphate in soil as guides to manurial treatment and expectations of yield. Such soil tests are based on "snap" sampling. They may therefore be called static; at least they provide only one point on a curve of availability, and thus give no indication of the kinetics of nutrient equilibria; and it is upon rate of release, rather than upon a single equilibrium attained after an indeterminate time, that plant nutrition in the field must usually depend.

The higher yields of swedes from the control plots (no phosphate applied) on poorly-drained soil, as compared with freely-drained, provides further evidence of more complete fixation of phosphate under good drainage conditions.

Where phosphate fixation is great, there is reason to believe that the effect on the available phosphate status of arable soils, of phosphate dressings applied in the spring, will be very small by mid-season; and it is unlikely that the resultant effect at mid-season will be much greater with $\frac{1}{2}$ or 1 cwt. P_2O_5 per acre dressings.

Hunter (1) has shown that a very high percentage of the phosphate removed by a swede crop is absorbed

during July.

If the demands of a crop are high at one particular period, then the ultimate yield must be governed by the amount of available phosphate present in the soil and on the rate of release of available phosphate during this period (other nutrients being in adequate supply).

Such an explanation may account for the similar yields obtained by $\frac{1}{2}$ and 1 cwt. P_2O_5 per acre dressings of superphosphate in these experiments. It seems possible that top-dressings of soluble phosphates applied to swede crops in July might have beneficial results.

1. Unpublished work by Dr. J. G. Hunter (Glasgow Ph.D. Thesis, 1948).

PART III.

DETERMINATION OF TOTAL PHOSPHORUS IN SOIL.

DETERMINATION OF TOTAL PHOSPHATE IN SOILS.

In order to carry out the fairly large number of estimations of total phosphate in the Carbeth soils, a method had to be found which would give accurate results, be easily adapted for rapid routine analysis and would give a measure of total or at least a definite category of soil phosphorus. Several methods were tried but they were either long and tedious, or, if more rapid, the accuracy they permitted was not sufficient for investigational work. The published method (reprint I, attached) was therefore evolved.

The method has been further tested by applying it to diverse materials other than soils, e.g. organic manures, plant tissue, fertilisers.

Unpublished results of these analyses are given herewith.

It can be seen that satisfactory agreement between duplicates was uniformly obtained.

The method is therefore much more widely applicable for estimation of total phosphorus than was at first believed. It appears, in fact, to be generally applicable to all kinds of agricultural materials.

REPRINT I.

Reprinted from the Journal of The Science of Food and Agriculture, 1950, No. 4, pp. 105–107.

A COLORIMETRIC MODIFICATION OF McLEAN'S METHOD FOR THE DETERMINATION OF PHOSPHORUS IN SOILS

By A. J. McGREGOR

McLean's technique of extraction of soil phosphate by digestion of soil with concentrated sulphuric and nitric acids has been adapted to a colorimetric method of determining soil phosphate by use of metol. The complete technique is performed with use of glassware alone and is simple and accurate.

In order to carry out an investigation on soil phosphorus a method had to be found which would give accurate results, be easily adapted for rapid routine analyses, and would give a measure of total—or at least a definite category of—soil phosphorus. Various methods were tried but it was found that they were either long and tedious, or, if more rapid, the accuracy they permitted was not sufficient for investigational work.

Hydrochloric and hydrofluoric acid extraction methods were found to be laborious and not suited for rapid routine analyses. Colorimetric methods, in which extracts were prepared after sodium carbonate fusion, and the phosphorus determined on the extracts by reduction of the phosphomolybdate, were found to be more rapid but had several serious disadvantages, e.g. (*a*) platinum crucibles were necessary for the sodium carbonate fusion, (*b*) the small weight of soil (0·5 g., usually) extracted led to errors in sampling, (*c*) difficulties with sodium carbonate fusion gave incomplete extraction and (*d*) soluble silicates interfered with the estimation of phosphorus in the extracts.

McLean's method[1] for the extraction of phosphorus is relatively simple and is suitable for routine work. It was decided to adopt this technique and to determine the amount of phosphorus in the extract by one of the colorimetric procedures. Reduction of the phosphomolybdate by metol (*p*-methylaminophenol sulphate) was found to be the method most suitable for the range of phosphorus concentration in the soil extracts and also that most tolerant of soluble silicates.

McLean[1] showed that by boiling soil with hydrochloric acid (b.p. 110° c.) for 48 hr. under reflux an end-point of extraction was reached. He found that a brief digestion with sulphuric and nitric acids gave results in agreement with results by 48 hours' hydrochloric acid extraction. He suggested that the phosphorus extracted by concentrated mineral acid represents a definite category of soil phosphorus which may be taken as the total phosphorus present in the soil. Any soil phosphorus surviving such a digestion is probably either included within the soil mineral or is so insoluble as to play no part in the secular phosphorus cycle of the soil.

Method

The method consists in digesting a sample of finely ground air-dry soil with sulphuric and nitric acids, diluting the extract to a known volume and determining colorimetrically the concentration of phosphorus in an aliquot by reduction of the phosphomolybdate to the blue compound.

Reagents

Ammonium molybdate reagent.—10 g. ammonium molybdate (A.R.) are dissolved in distilled water and made up to 100 ml. If heat is required to dissolve the ammonium molybdate, the temperature should not be allowed to rise above 60° c. The molybdate solution is filtered into a mixture of 150 ml. conc. sulphuric acid (A.R.) and 100 ml. distilled water. Very slow addition of the molybdate solution and frequent shaking is required to prevent overheating.

Metol reagent.—40 g. sodium metabisulphite, 1 g. sodium sulphite and 0·2 g. *p*-methylaminophenol sulphate are dissolved in distilled water and made up to 100 ml.

Standard phosphate solution.—Solution *A*: 0·1917 g. potassium dihydrogen phosphate is dissolved in distilled water; the solution is made slightly acid with sulphuric acid and diluted to 1 l.

Solution *B*: 100 ml. of solution *A* are diluted to 1 l. with distilled water.

1 ml. solution *A* = 0·0001 g. P_2O_5
1 ml. solution *B* = 0·00001 g. P_2O_5

Procedure

Digestion.—4 g. finely ground soil are weighed into a 300-ml. Kjeldahl flask. 12 ml. conc. H_2SO_4 and 15 ml. conc. HNO_3 are added. The flask is heated gently at first and then with a slightly larger flame until the flask is filled with white fumes. Fuming is continued for about 5 min. and the flask is then allowed to cool. A further 5 ml. conc. HNO_3 are added and the contents are again heated until white fumes appear. Fuming is continued for 20 min.; the contents of the flask should then be opaque white. Soils with high organic matter content may require a further 5 ml. conc. HNO_3, the digestion being repeated as before.

The flask is allowed to cool somewhat and about 10–15 ml. distilled water are carefully added. This drives off any nitric acid which may still be present. The contents of the flask are transferred to a 500-ml. volumetric flask by washing with water and decanting. When cool the extract is made up to volume. About 50 ml. of the extract are filtered through a No. 42 Whatman filter paper.

Development of colour.—5 ml. of the extract are measured into a boiling tube. The extract is neutralized with 1 : 4 ammonium hydroxide and made up to approximately 25 ml. with water. One drop of a 1% aqueous solution of *p*-nitrophenol is used as indicator. 5 ml. ammonium molybdate reagent are then added and the tube is placed in a boiling water bath for 20 min. 5 ml., metol reagent are added and the tube is heated for a further 25 min. in the water bath. The tube is then cooled rapidly under the cold water tap. The contents of the tube are transferred to a 50-ml. or 100-ml. volumetric flask, depending on the intensity of the colour developed, and made up to volume.

Measurement of colour intensity.—The intensity of the colour is measured using a Spekker absorptiometer with drum set at 1·00 for distilled water. Heat filters H503 and red filters are used. The colour is measured in a 2-cm. or 4-cm. cell depending on the intensity.

Calibration.—Calibration curves are prepared using the standard phosphate solution *B* and developing the colours as described above. It is advisable to prepare 3 curves: (i) using 1, 2, 3, 4, 5, 6, 7, and 8 ml. soln. *B*. Colours are developed, diluted to 50 ml. and read in a 4-cm. cell; (ii) using 8, 9, 10, 11, 12, 13, 14, 15, and 16 ml. soln. *B*. Colours diluted to 100 ml. and read in a 4-cm. cell; (iii) using 16, 18, 20, 22, 24, 26, 28, 30, and 32 soln. *B*. Colours diluted to 100 ml. and read in a 2-cm. cell.

When 4 g. soil and 5 ml. extract are used, these graphs give the following ranges: (i) 25–200 mg. P_2O_5 per 100 g. soil; (ii) 200–400 mg. P_2O_5 per 100 g. soil; (iii) 400–800 mg. P_2O_5 per 100 g. soil.

Higher concentrations (up to 1200 mg. per 100 g.) if necessary can be measured using a 1-cm. cell or by reducing the volume of extract used in developing the colour.

Remarks on the procedure

Range of method.—One of the advantages of the method is the large range of concentrations of phosphate that can be measured. For routine work it is convenient to use 4 g. soil, dilute the extract to 500 ml., and use a 5-ml. aliquot for the development of colour. The intensity of the colour developed indicates which graph will be used. Thus a range of 25 to 800 mg. P_2O_5 per 100 g. soil can be measured without having to repeat with smaller aliquots. In each curve the standard error is likely to be greater with the lighter colours.

Development of colour.—The reduction of the phosphomolybdate by *p*-methylaminophenol sulphate to give a blue solution was first proposed by Leiboff,[2] but the method adopted is a slight modification of a method proposed by Allport.[3] A fairly strict time-table should be adhered to when developing the colours; the time of heating has an effect on the intensity of the colour developed.

Interference of silicates.—Silicates do not interfere with the method, although practically no soluble silicates are left after the digestion. In addition the metol method is fairly tolerant of soluble silicates.

Digestion.—The digestion, which is essentially that described by McLean,[1] is very simple and needs little attention; it was found, however, that the time of the final fuming is important, as Table I shows. 20 min. was found to give an end-point of extraction.

Table I

Determination of total phosphorus in soils: effect of times of fuming

Duration of final fuming, min.	Colour intensity developed* (Spekker readings × 100) Soil 1	Soil 2	Soil 3
5	65·5	73·0	41·3
10	63·0	70·0	39·0
15	61·1	68·3	38·5
20	61·0	68·0	37·8
25	61·3	68·0	37·5

* Averages of 4 determinations

Filtering of extract.—It will be noted that the extract is made up to volume before filtering. This technique is not conventional, but if care is taken in decanting and washing the volume of precipitate and soil residue in the volumetric flask is negligible. Several determinations were carried out by both methods (i.e. diluting to volume before and after filtering) with no significant difference in results. The technique adopted greatly reduces the time required for filtration, since 50 ml. are filtered instead of 300 ml.

Results

Ten digestions of each of six soils were carried out and the phosphorus content of the extracts determined in duplicate; agreement was good, as Table II shows.

Table II

Determination of total phosphorus in soils: results from metol method

Soil No.	P_2O_5 per 100 g. air-dry soil, mg.: mean of 10 determinations	Standard deviation
1	120·0	± 1·9
2	147·2	± 2·1
3	288·9	± 2·7
4	321·3	± 2·5
5	436·5	± 5·8
6	693·0	± 5·9

Results from a series of comparisons of the metol technique with McLean's original technique are given in Table III. In these (and in preliminary results not detailed here) the average by the McLean technique was slightly but not significantly lower than that given by the metol technique. Thus no preference can be accorded to McLean's or the present metol technique from the point of view of attainable accuracy, although the metol technique is appreciably neater and more rapid than McLean's. It avoids (i) overnight standing of the precipitate (ii) the subsequent filtration and (iii) the operative difficulties associated with gravimetric estimations of small amounts of phosphomolybdate precipitate: these are a common source of error in inexperienced hands.

The metol technique allows 24 complete estimations to be made in an 8-hour day; about three days would be needed for the same number of determinations by McLean's technique.

Table III

Determination of total phosphorus in soils

Soil	P_2O_5 per 100 g. air-dry soil, mg.* Metol method	McLean's method
A12	165	161
A8	309	295
N11	165	160
K10	91	89
H12	107	105
K12	78	84
A30	213	212
H13	105	95
Mean	154	150

* All results are from concordant triplicate determinations

Table IV

Determination of total phosphorus in soils: recovery of phosphorus

Soil*	P_2O_5 per 100 g. air-dry soil, mg. Metol method: Originally present	Amount added	Re-determined†	Recovered	McLean's method: Originally present	Amount added	Re-determined	Recovered
H47	‡118·8 ± 1·5	45·7	164·4 ± 2·0	45·6				
		76·2	194·7 ± 2·0	75·9				
		121·9	237·0 ± 2·3	118·2				
		152·3	269·8 ± 2·4	151·0				
		198·0	320·9 ± 3·5	202·1				
K12	78	24	101	23	84	16	98	14
		144	218	140		96	181	97
A30	213	24	238	25	212	24	240	28
		144	354	141		144	354	142
H13	105	24	130	25	95	16	111	16
		144	251	146		96	189	94

* The soils are surface soils from the region of Killearn, Stirlingshire, and are of Old Red Sandstone derivation. A30 is a boulder clay; H13, H47, and K12 are littoral or fluvio-glacial sandy loams; K12 is a more peaty associate of the H soils.

† Mean of 10 determinations for each addition of phosphate to soil H47. All results for other soils are the means of concordant triplicate determinations.

‡ Mean of 20 determinations.

For tests of recovery of P_2O_5 phosphate was added as KH_2PO_4 (Table IV).

To the three soils K12, A30 and H13 the same weight of phosphate was added for determinations by both methods recorded in Table IV, but the metol method could be satisfactorily completed on 4 g. of the phosphate–poor soils of which 6 g. of soil needed to be used for McLean's method to bring the determination within its limits of sensitivity. The added P_2O_5 was thus reduced from 24 to 16 mg./100 g. This limitation did not apply to the richer soil A30 of which 4 g. were used for each method.

Using 4 g. soil per determination, the metol method is satisfactory without dilution for soils containing from 25 to 200 mg., and by simple adaptations up to at least 800 mg. P_2O_5 per 100 g. of soil.

Used as a routine procedure over about 18 months, the metol method has given good agreement between duplicates.

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Received June 24, 1949

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Printed in Great Britain by Butler & Tanner Ltd., Frome and London

DETERMINATION OF TOTAL PHOSPHORUS IN PLANT TISSUE, ORGANIC MANURES, FERTILISERS, ETC.

The Metol method for the estimation of total phosphorus in soils has also been used for plant tissue, organic manures, etc.. The procedure is similar to that for soils. The weight of sample and the final dilution of extract depends on the material being analysed. Some examples are:-

1. Turnip bulbs:- 1 g. sample of turnip dry matter is digested and the extract diluted to 500 ml. 5 ml. of extract is used for the development of colour.
2. Dried grass:- 1 g. sample of dried grass dry matter is digested and the extract diluted to 500 ml. 2 ml. of the extract is used for the development of colour.
3. Organic manures:- ½ g. sample of dry matter is digested and the extract diluted to 500 ml.. 2 - 5 ml. of extract is used for the development of colour.
4. Phosphatic fertilisers:- ½ g. sample is digested and the extract diluted to 1 litre. 2 ml. of the extract is used for the development of colour.

Agreement between duplicates has been found to be satisfactory/

satisfactory; some typical results are given below.

Sample.		Spekker readings.		$\%P_2O_5$	Mean.
1. Turnip bulbs		(dry-matter)			
1.	a.	70.0	69.5	0.282	0.281
	b.	69.5	69.5	0.280	
2.	a.	54.5	53.5	0.450	0.451
	b.	53.5	54.0	0.452	
3.	a.	57.5	58.5	0.405	0.408
	b.	58.0	57.0	0.410	
4.	a.	58.5	58.0	0.400	0.398
	b.	58.5	59.0	0.395	
5.	a.	56.5	56.5	0.410	0.413
	b.	55.5	56.5	0.415	
6.	a.	51.5	50.5	0.478	0.477
	b.	51.5	51,0	0.475	
7.	a.	55.5	54.5	0.438	0.439
	b.	55.0	54.0	0.440	
8.	a.	41.0	41.0	0.585	0.585
	b.	41.5	40.5	0.585	
9.	a.	40.5	41.0	0.588	0.592
	b.	40.0	40.0	0.595	
10.	a.	41.5	40.5	0.585	0.583
	b.	41.0	41.5	0.580	

11./

Sample		Spekker readings		% P_2O_5 in D.M.	Mean
11.	a.	39.0	39.0	0.605	0.600
	b.	40.5	39.5	0.595	
12.	a.	43.0	44.0	0.559	0.560
	b.	43.5	43.0	0.560	
Dried Grass					
1.	a.	59.5	59.5	0.970	0.967
	b.	60.0	60.0	0.963	
2.	a.	56.0	56.5	1.033	1.036
	b.	56.0	56.0	1.038	
Tomato Leaves (lamina)					
1.	a.	52.5	53.5	1.138	1.138
	b.	53.0	53.0	1.138	
2.	a.	56.5	56.0	1.108	1.102
	b.	56.0	56.0	1.095	
3.	a.	72.5	73.0	0.620	0.617
	b.	72.5	72.0	0.613	
4.	a.	27.5	27.5	1.813	1.811
	b.	28.0	27.5	1.808	
Farmyard Manure					
1. Horse manure					
	a.	81.5	81.5	0.310	0.310
	b.	81.5	81.5	0.310	

2./

Sample	Spekker readings		$\%P_2O_5$ in D.M.	Mean
2. Poultry manure				
a.	45.0	45.5	2.69	2.685
b.	46.0	45.5	2.68	
3. Liquid manure			$\%P_2O_5$ in original	
a. 9.90 g.	76.5	76.5	0.021	
b. 10.09 g.	76.0	76.0	0.021	0.021
c. 9.92 g.	77.0	77.0	0.020	
d. 9.88 g.	77.5	76.5	0.021	

PART IV.

THREE SEASONS' EXPERIMENTS AND ANALYTICAL DATA ON TOMATOES GROWN UNDER LARGE SCALE CONDITIONS.

Because of the fundamental uncertainties of prediction based on any mode of soil analysis, there is an increasing belief that leaf or tissue analysis not only is more logical but does give a better guide to crop performance.

Tissue analysis has limitations; one of them is that it cannot be done in advance of sowing or planting (unless a special "crop" is sown for diagnostic purposes). Nevertheless, for some purposes tissue analysis is unrivalled. One of these is the study of the nutritional status of a crop throughout its growth. Provided that reasonable precautions are taken to avoid much defoliation or other damage during sampling, tissue analysis can furnish considerable insight into crop nutrition and health; and - once sufficient data have been collected - tissue analysis can often afford a very satisfactory basis for diagnosis. Such diagnosis can sometimes be made so early in the growth of the crop that remedial nutrient treatment can be applied in time to have a gratifying effect on the yield of the crop.

It is unnecessary to enlarge here on the general virtues and limitations of tissue analysis - still less

to/

to contribute an essay to the much discussed suject of the place of "rapid" and other tests in advisory soil analysis; but it is germane to say here that much of the Thesis work relates to, and is based on, tissue analysis.

I. Part of the thesis work has consisted of the development of an original technique of calcium determination suitable for application to plant tissue.

II. Another part of the work, not specifically embodied in the thesis but largely preceding the actual thesis work, was done in conjunction with Dr.J.G.Hunter. It, also, related to the development of techniques for determination of several elements in small samples of plant tissue. Some of these methods - as used in the present work - are described in full in appendix B.

III. The major burden of Part IV of this thesis is concerned 1) with data obtained from plant-tissue analysis of tomatoes, and 2) with the interpretation of those data in conjunction with yield-data and other field observations. By means of tissue analysis a mass of data has been obtained which throws much light on the nutrient status of tomato plants under various conditions and during a season lasting several months in/

in each of three years.

Some of the data thus obtained are probably new: at least in the sense that few similar sets of observations have been published regarding tomato cultivation.

Most previous information about sulphate and some other constituents of plants appears to be based on analyses of ash - usually of whole plants. The usefulness of such information is veiled by unknown losses from volatilization, uptake of oxygen, and other analytical uncertainties from which a direct extraction or other determination performed in the wet way is immune.

However carefully analyses of whole plants are performed and provided with "controls", they can do no more than yield values which are merely averages taken on one occasion. Studies of plant nutrition are not likely to be further advanced by techniques depending upon the grosser forms of snap sampling. It seems that, for future investigations of plant nutrition, much more recourse must be had to analyses of single tissues and parts of living plants sampled continuously throughout a season.

A large part of the present work has been devoted

to/

to the study of chemical means whereby such an aim can be realised. A further large part of the work has been an application of new and modern methods of chemical "tissue analysis" to a study of some problems of tomato culture.

INTRODUCTION AND REVIEW OF LITERATURE

In commercial culture in Scottish tomato houses a considerable loss of crop results from a check in growth during mid season. This "check period" usually occurs on the 5th - 8th trusses and sometimes on the 11th and 12th trusses. It is characterised by poor growth and development and by poor setting of fruit on these trusses.

After the plants are established in the border a period of rapid growth and development follows. The 2nd, 3rd, 4th, and sometimes 5th trusses are formed in rapid succession. The result is a large number of fruits set in a comparatively short period. These numerous small fruits then grow actively and simultaneously. It would appear that the demand on nutrient supply becomes so great that further growth and development of the top almost ceases. As this fruit approaches maturity, a new phase of growth and development occurs. The result is a second period of relatively heavy fruit production, which in turn is followed by a second but less intense "check period".

During these check periods it is found that the flower/

flower trusses become smaller, flowers fail to set fruit and in severe cases there is a yellowing of the truss followed by a dropping-off of immature flower buds. The result is that from 3 to 6 trusses out of a total of some 15 trusses, normally produced under commercial conditions, fail to produce fruit. The loss is severe.

This work is part of an experimental inquiry whether, and by what means, this loss can be prevented.

Brief Survey Of Previous Work.

As a result of pot-culture work in Missouri, Murneek (1) concluded that in the tomato plant vegetative growth is controlled or regulated by the fruit. He states that this control seems to be determined by two major factors: a) the number of fruits present on the plant and their proximity to the growing point and b) the relative amount of the available nitrogenous food supply.

Murneek studied the effects of fruiting on vegetative growth. His plants were grown in sand and soil pot-cultures, under glass, with different levels of nitrogen manuring. He found that a maximum crop

of/

of fruits had a very marked retarding effect on growth. It is interesting to note that after the maximum number of fruits that could be formed under a given set of conditions had been set, other flowers could not be fertilised, even with careful pollination. Murneek described the symptoms of this check, brought about by the developing fruit, as occurring in the following order: a) destruction of the fecundity of the blossoms, b) decrease in the size of the floral clusters, c)yellowing and abscission of flower buds, d) reduction and cessation of terminal growth and e) complete exhaustion and eventual death of all parts of the plant excepting the fruit. He pointed out that these signs are typical of a condition of nitrogen starvation of increasing severity.

Murneek's results strongly indicate a negative correlation between vegetative activity and fruiting. His chemical analyses of the plant pointed to nitrogen as a limiting factor effecting this correlation. He suggested that the fruit is able in some way to divert and monopolise almost all the available nitrogen in the plant. This is understandable, since it is usual for organisms under nutrient strain to mobilise their resources towards reproduction.

Murneek/

Murneek found that removal of fruits led in every instance to a complete recovery of the terminal end of the plant and to a marked increase in vegetativeness in all other parts. When this new growth set fruit, vegetative growth was once more retarded.

The observations of White (2) and Owen (3) in England are perhaps more nearly comparable with those made under Scottish conditions, since the material of both these workers was grown under glass at the Cheshunt (Lea Valley) Experimental Station.

White (2) compared the flowering, fruiting and rates of growth and development of plants grown in a) completely manured soil, and b) nitrogen deficient soil. These plants were grown (under glass) in soil beds which had been under observation for several years. White found that low nitrogen supply was associated with retardation of growth and development. His results showed that the check to growth and development associated with heavy fruit-bearing on the 2nd, 3rd and 4th trusses was related to the nitrogen supply. In nitrogen-starved plants cessation of growth was more severe, reduction in crop of the 5th and 6th trusses was accentuated and there was a high proportion of "retarded" apical fruits on the 2nd, 3rd and 4th trusses. Every characteristic/

characteristic of fruiting considered was retarded by low nitrogen supply, except the period of ripening of the fruit and this was accelerated only in the lowest trusses.

With plants grown in potassium-deficient soil, White found that the onset of and recovery from the check to vegetative growth associated with heavy fruit-bearing of the 2nd, 3rd and 4th trusses was accelerated by low potassium supply.

Owen's (3,4) results of composition of whole tomato plants grown under conditions similar to those of White, showed that the percentage of nitrogen in the fruit was at a minimum in fruits of the 5th truss. Owen (5) also pointed out that after heavy watering there was a heavy fall in nitrate-nitrogen concentration in the soil. He mentioned that in the traditional system of "dry" growing practised in England (and to some extent in Scotland), heavy watering is not done until April; and, as a result, low values for nitrate which follow are liable to persist unless nitrogen is applied. Consequently there is the serious risk that the 5th and 6th trusses are being laid down in the plant when the nitrate level is unduly low. Hence (Owen concluded) there is an imperative need to apply nitrogen sufficiently/

sufficiently early to eliminate this risk.

Considering these results of Murneek, White and Owen, it appears that nitrogen supply is closely associated with the "check period". Moreover, there is much reason to believe that it is the supply of available, or useful, rather than the total, nitrogen in soil and plant that is important in deciding the severity and duration of the "check" and hence of the losses of crop which ensue.

TOMATO EXPERIMENTS, 1948.

TOMATO EXPERIMENTS, 1948.

Centre:- Law Nurseries, Carluke.

For a preliminary investigation, a typical nursery in the Clyde area was chosen. Samples of leaves from the plants and samples of soil from the borders were taken from three glasshouses at various times during the season. It was hoped that analysis of these samples might give some pointer as to the cause of the "check" or at least show the effect on the composition of the plant.

The uppermost fully-developed leaf was used for analysis. At each sampling 12 leaves were taken at random over an area of the house. Samples were taken at approximately weekly intervals over a period of two months.

It was thought that the lamina (being the seat of metabolic activity) might reveal changes in composition; and that the changes occurring in the lamina of the uppermost fully-developed leaf might be closely related with changes in growth of the top of the plant.

The samples on arrival at the laboratory were separated/

separated into lamina and petiole. 5 g.-samples of the fresh lamina were extracted with Morgan's (6) reagent; and magnesium, potassium and phosphorus were determined on the extracts. The remainder of the lamina was dried; and manganese and nitrogen were determined on the dry-matter. Details of chemical methods are given later.

Cultural Details.

The general management of the crop was undertaken by the grower, in the ordinary way, and was not in any sense experimental.

a) Basal manuring. Base manures were applied by the grower two weeks before planting, raked in and watered. The dressing (of commercial type) was:

1 cwt. hydrated lime

1½ cwt. Mason's Base manure per "100 ft." (= 1500 sq.ft)

25 lb. sulphate of potash

b) Top-dressing (also applied by grower).

Houses 1 and 6.

April	3rd.	30 lb. Mason's Y compound per 100 ft.
"	23rd.	30 lb. Mason's Y compound per "
May	5th.	2½ tons Moss litter manure " "
		56 lb. Bone meal " "
		30 lb. Mason's Y compound " "

June/

June 3rd.	16 lb. Bone meal	per 100 ft.
" 18th.	16 lb. Bone meal	" "
" 28th.	16 lb. Bone meal	" "
July 1st.	2½ tons Moss litter manure	" "
	¾ cwt. Bone meal	" "

House 9 received the same dressings as Houses 1 and 6 but an additional dressing of 30 lb. superphosphate and 15 lb. sulphate of potash per 100 ft. was given in June. The top-dressing of moss litter manure was not applied to House 9.

c) Varieties:

House No. 1	Money Maker
No. 6	Money Maker
No. 9	Radio

Investigations at other centres.

In addition to the investigation at Law nursery, the percentages of nitrogen and manganese were determined on similar samples*. The results of these determinations are given in Tables 5, 6, 7, 8 and 9.

* I have to thank Miss P. M. Browning of the Horticulture Dept. of this College, for these additional samples and for notes on the condition of the respective crops.

RESULTS OF 1948 INVESTIGATIONS.

TOMATO EXPERIMENTS, 1948.

Table:- 1. Centre:- Law nursery, House No. 1.

Analysis of lamina.

Date of sampling	p.p.m. in extract* of Mg	K	P	Total N % in D.M.	Total Mn p.p.m. in D.M.
15th May	9.8	248	33	5.62	280
7th June	11.8	365	33	4.65	486
14th June	13.0	253	28	4.55	486
21st June	10.4	180	27	4.34	472
29th June	18.4	208	21	4.16	620
5th July	10.8	218	22	3.77	626
10th July	11.8	253	19	4.56	486
17th July	8.8	223	35	5.26	554
27th July	8.4	205	47	4.84	460

* 5 g. fresh lamina per 100 ml. Morgan's reagent.

TOMATO EXPERIMENTS, 1948

Table:- 2. Centre:- Law nursery, House No. 6.

Analyses of lamina.

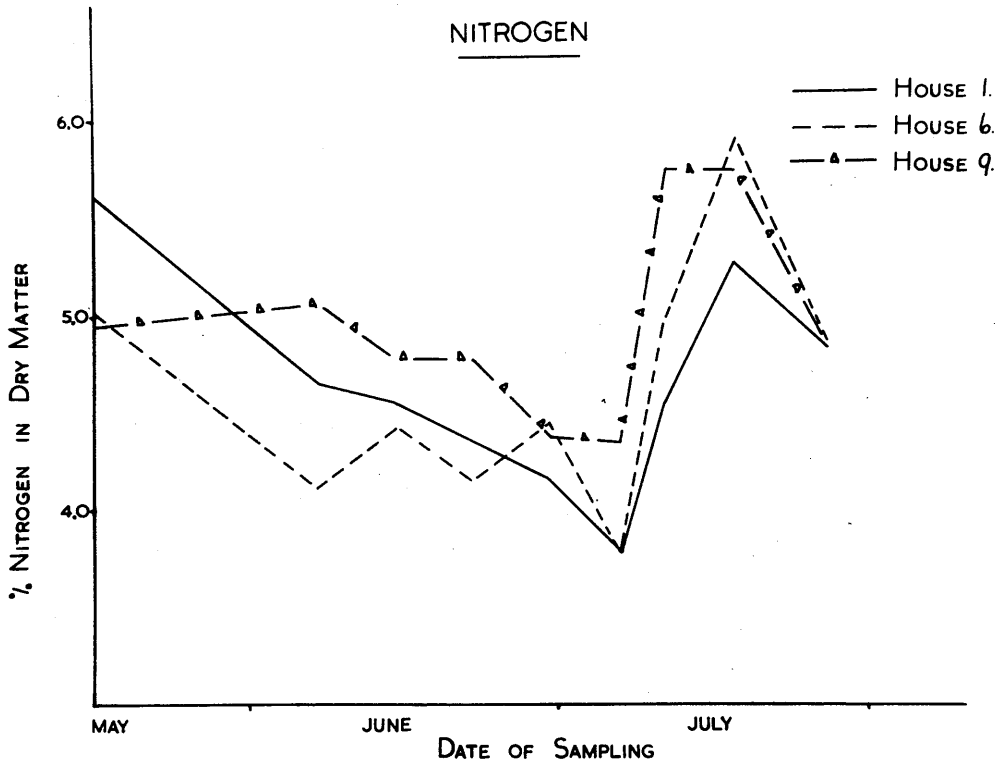
Date of sampling	p.p.m. in extract* of Mg	K	P	Total N % in D.M.	Total Mn p.p.m. in D.M.
15th May	10.0	225	34	5.02	300
7th June	4.8	365	28	4.11	346
14th June	6.0	215	31	4.41	466
21st June	13.0	175	20	4.15	580
29th June	13.8	203	22	4.44	426
5th July	17.2	170	25	3.77	374
10th July	13.4	233	29	4.97	334
17th July	8.0	238	38	5.92	260
27th July	3.0	183	48	4.83	360

TOMATO EXPERIMENTS, 1948

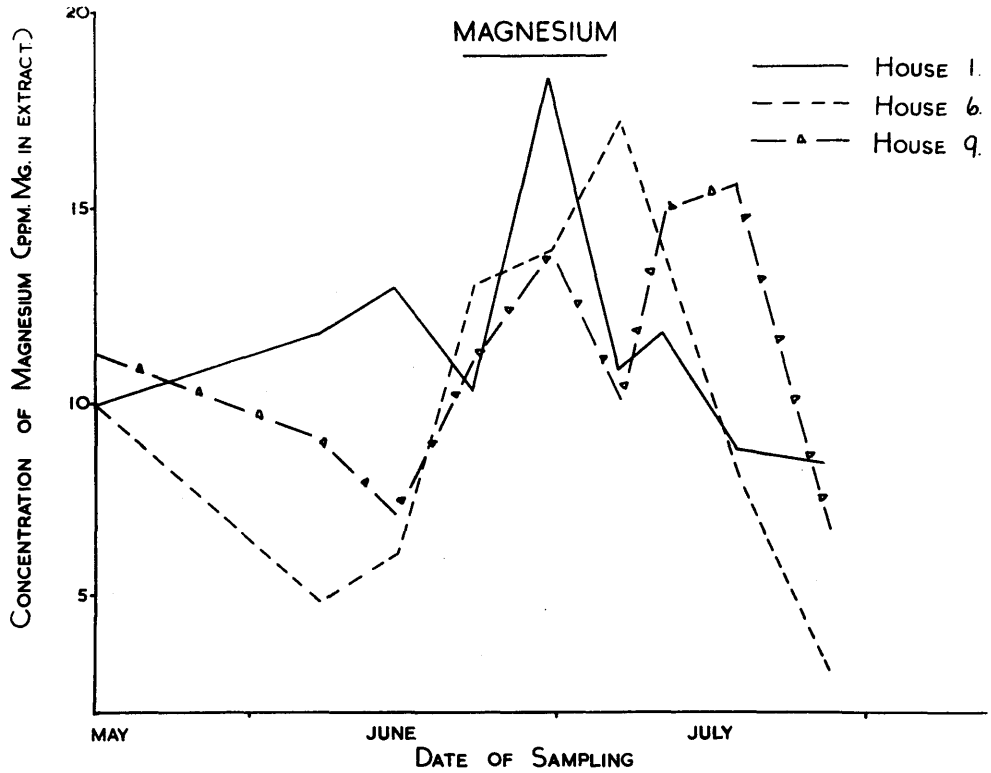
Table:- 3. Centre:- Law nursery, House No. 9.

Analyses of lamina.

Date of sampling	p.p.m. in extract* of Mg	K	P	Total N % in D.M.	Total Mn p.p.m. in D.M.
15th May	11.2	250	27	4.95	250
7th June	9.0	353	29	5.07	280
14th June	7.0	295	20	4.78	267
21st June	11.0	208	17	4.78	270
29th June	13.8	256	18	4.37	327
5th July	10.0	215	23	4.35	307
10th July	15.0	278	26	5.76	207
17th July	15.6	295	39	5.76	220
27th July	6.8	260	40	4.84	267

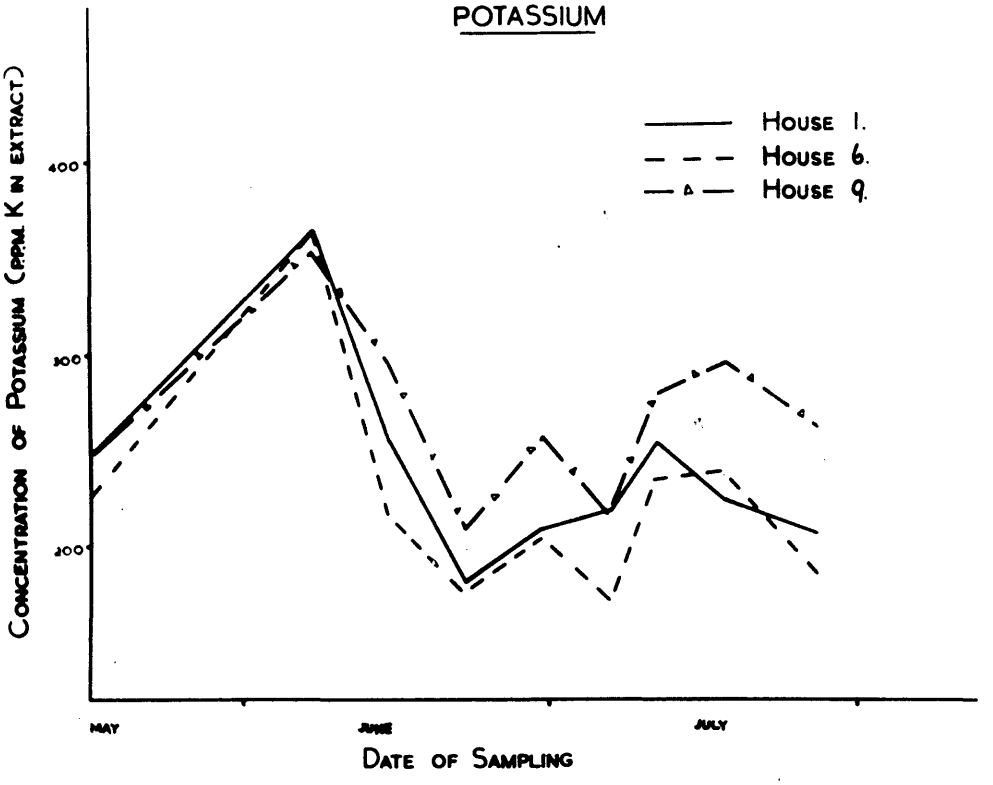


Diag. 1 - % total nitrogen in dry-matter of lamina of uppermost fully-developed leaves.

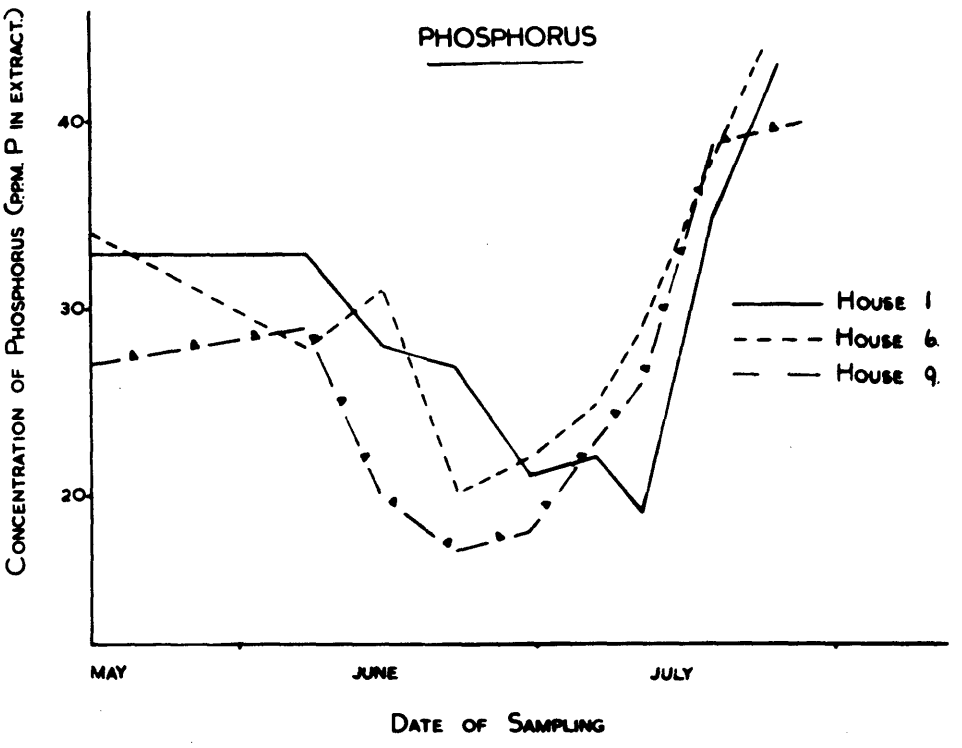


Diag. 2 - Concentration of magnesium in extracts* of lamina of uppermost fully-developed leaves.

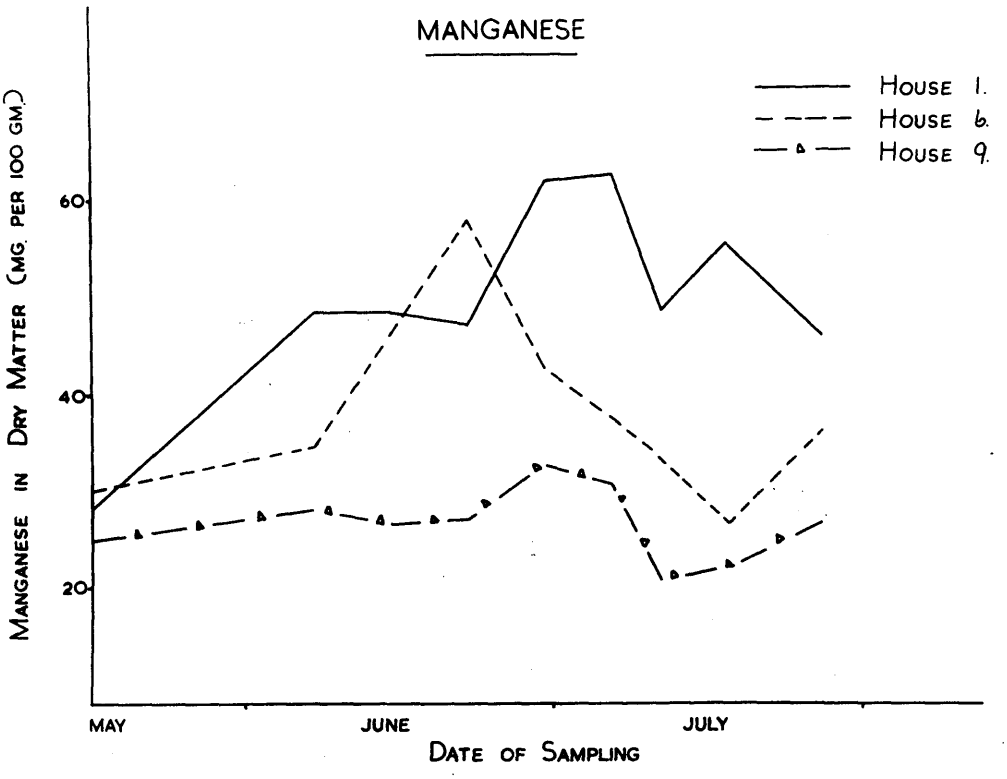
* 5 g. fresh material extracted with 100 ml. Morgan's reagent



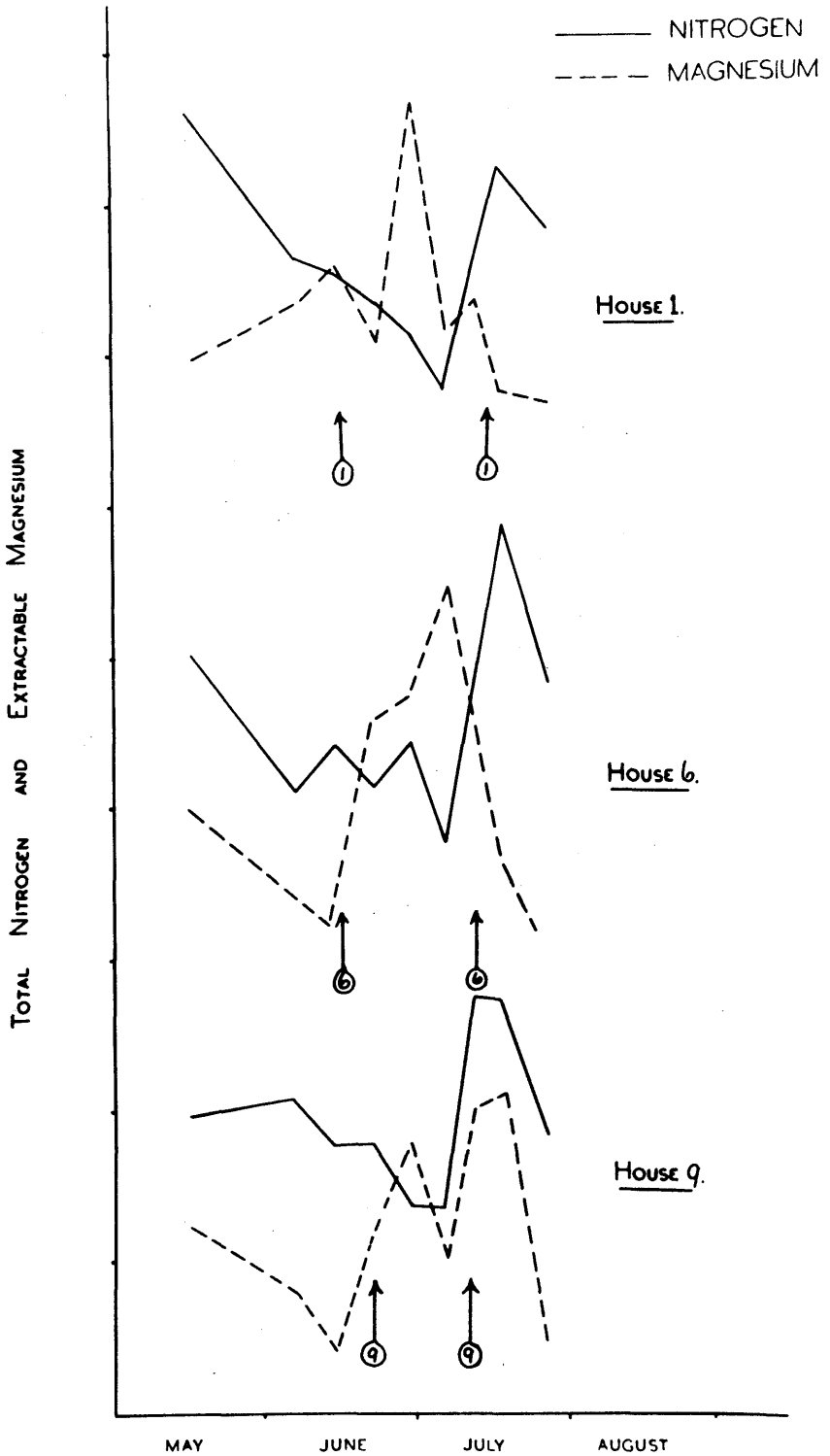
Diag. 3 - Concentration of potassium in extracts* of lamina of uppermost fully-developed leaves.



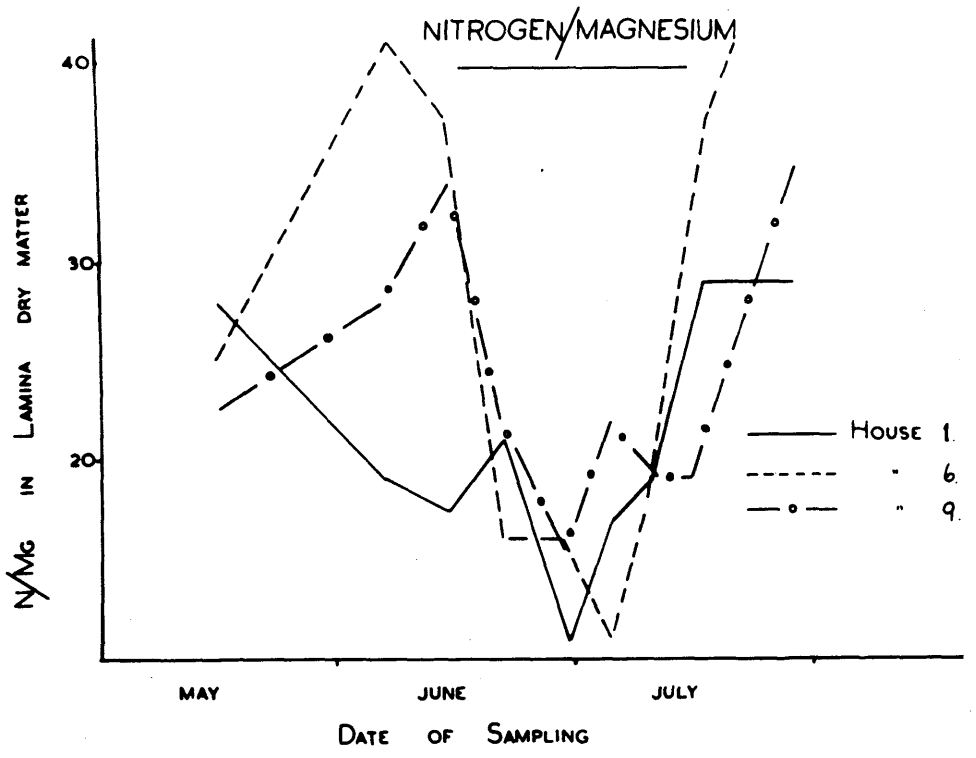
Diag. 4 - Concentration of phosphorus in extracts* of lamina of uppermost fully-developed leaves.



Diag. 5 - % total manganese in dry-matter of lamina of uppermost fully-developed leaves.



Diag. 6 - Total nitrogen and extractable magnesium in lamina of uppermost fully-developed leaves.



Diag. 7 - Ratio of total nitrogen to extractable magnesium in dry-matter of lamina of uppermost fully-developed leaves.

TOMATO EXPERIMENTS, 1948

Table:- 4. Centre:- Law nursery.

Soil analyses results*

Date	Moisture	Loss on Ignition %	Avail. P_2O_5 mg./100 g.	Avail. K_2O	pH
House No. 1.					
13/3	3.4	10.8	153	86	6.54
22/4	1.3	12.4	193	80	6.87
5/6	2.1	12.0	197	86	6.99
14/7	2.1	11.2	234	41	6.99
15/9	2.3	10.8	215	62	6.86
House No. 6.					
13/3	3.8	10.3	169	80	6.73
22/4	2.1	11.4	209	86	6.80
5/6	2.1	11.4	252	132	6.89
14/7	3.6	10.7	244	50	6.84
15/9	3.2	10.1	238	94	6.84
House No. 9.					
13/3	3.6	11.2	225	84	7.11
22/4	2.1	12.8	250	88	7.01
5/6	2.3	12.0	308	84	7.11
14/7	2.2	12.4	329	45	7.01
15/9	1.5	12.0	308	92	7.01

* For these and subsequent similar analyses of soil, I am indebted to Dr.C.L.Whittles and the staff of the Soils Laboratory of the Chemistry Dept. W.S.A.C. (Professor Hugh Nicol, Advisory Agricultural Chemist).

TOMATO EXPERIMENTS, 1948

Table:- 5. Centre:- 1.

Analyses of uppermost fully-developed leaf.

Date of sampling	% Nitrogen in lamina D.M.	p.p.m. Manganese in lamina D.M.
9th April	5.57	500
13th April	6.04	410
21st April	5.68	385
5th May*	4.62	335
24th May	5.24	120
8th June	5.32	325
17th June	4.26	370
23rd June	4.30	220
5th July	4.62	440
14th July*	3.86	565
21st July*	4.86	460
28th July*	3.86	510
13th August	4.41	355

* Trusses in flower at these dates gave poor setting of fruit.

TOMATO EXPERIMENTS, 1948

Table:- 6. Centre:- 2.

Analyses of uppermost fully-developed leaf.

Date of sampling	% Nitrogen in lamina D.M.	p.p.m. Manganese in lamina D.M.
19th April	4.85	540
27th April	4.79	380
10th May*	4.10	600
27thMay*	4.00	610
10th June	4.59	790
17th June	4.17	810
23rd June*	3.70	300
5th July*	3.78	790
15th July*	3.39	1070
21st July	3.86	770
29th July	3.40	950
13th August	4.48	900

* Trusses in flower at these dates gave poor setting of fruit. The plants had all the symptoms of a nitrogen deficiency during mid season.

TOMATO EXPERIMENTS, 1948

Table:- 7. Centre:- 3.

Analyses of uppermost fully-developed leaf.

Date of sampling	% Nitrogen in lamina D.M.	p.p.m. Manganese in lamina D.M.
4th April	6.07	120
11th April	5.62	140
19th April	5.70	160
27th April	5.70	150
18th May	4.75	730
27th May*	3.61	490
10th June	4.82	375
17th June	4.70	355
23rd June	4.83	300
5th July*	4.23	650
15th July*	4.40	320
21st July	4.23	355
29th July*	4.17	370
13th August*	4.07	260

* Poor growth and development at these periods. Setting of fruit was moderate.

TOMATO EXPERIMENTS, 1948

Table:- 8. Centre:- 4.

Analyses of uppermost fully-developed leaf.

Date of sampling	% Nitrogen in lamina D.M.	p.p.m. Manganese in lamina D,M.
4th April*	4.70	140
11th April	6.18	250
21st April	5.79	150
28th April	6.34	310
11th May	5.24	445
17th May	5.20	475
27th May	5.10	670
10th June*	4.44	680
17th June*	3.96	750
23rd June*	4.26	840
5th July*	5.12	500
15th July*	4.65	850
21st July	4.86	645
29th July	4.73	660
12th August	4.84	640

* Poor growth and development at these periods and trusses flowering during these periods gave poor yields of fruit. Plants were very pale and thin during the month of June.

TOMATO EXPERIMENTS, 1948

Table:- 9. Centre:- 5.

Analyses of uppermost fully-developed leaf

Date of sampling	% Nitrogen in lamina D.M.	p.p.m. Manganese in lamina D.M.
2nd April	4.33	460
11th April	6.15	360
19th April	6.11	270
27th April	4.25	240
11th May	5.21	270
18th May	5.21	250
27th May	5.26	230
10th June*	3.71	270
17th June *	4.58	290
23rd June*	4.23	330
5th July	5.15	240
15th July*	4.14	270
21st July	4.55	300
29th July	4.48	270
13th August	3.96	220

* Poor growth and development at these periods but fruit set was moderately good. Yield was well above average.

NOTES ON RESULTS OF 1948 EXPERIMENTS.

1. Law Nursery.

The yield of tomatoes (probably about 30 - 33 cwt. per 100 ft.) was definitely above average. The crop was considerably reduced by periods of poor fruiting. In houses 1 and 6 the "check period" was fairly severe; it resulted in a loss of fruit over three trusses. In house 9 the "check" was less severe, affecting only 1 or 2 trusses. After the plants were established in the borders there was a period of rapid growth with the production of 4 or 5 trusses in quick succession. This was followed by a period during which there was swelling of the fruit. Some symptoms of magnesium deficiency were noted at this stage. The top of the plant then became thin, trusses were less vigorous than before, and, in fact, the plant had all the appearances of a nitrogen deficiency. As the bottom fruit ripened a new period of growth took place at the top of the plant. Nitrogen-deficiency symptoms disappeared and good healthy trusses were formed. Magnesium-deficiency symptoms again appeared and gradually became more severe towards the end of the season.

It may be recalled that no attempt was made to control/

control the manuring or general culture of the tomato plants. The manurial programme shows the heavy applications of fertilisers normally applied to glass-houses in the Clydeside. The amount of phosphate given seems to be far in excess of the requirements of the plant.

Results of tissue analyses are given in Tables 1, 2 and 3 and are illustrated in Diagrams 1, 2, 3, 4 and 5. The results showed that during the "check period" (end of June to beginning of July) total nitrogen, extractable phosphorus and extractable potassium were very low, while total manganese and extractable magnesium reached a maximum. A simultaneous rise in total manganese and extractable magnesium is evident just before the "check period". The appearance of magnesium-deficiency symptoms tended to coincide with low magnesium content in the lamina of the uppermost fully-developed leaf.

In house 9, where the "check period" was less severe, the total nitrogen in the lamina during this period was higher than that in the lamina from houses 1 and 6 where the "check" was more severe. The maximum reached by manganese during the "check" was much higher in houses 1 and 6 than in house 9. It is not possible to/

to say whether these results are significant; such differences could possibly be varietal.

2. Centres 1 - 5:-

The results of total nitrogen and manganese found in the lamina of the uppermost fully-developed leaf are given in Tables 5, 6, 7, 8, and 9. There ~~was an~~ were indications that periods of poor growth and development and poor setting of fruit were correlated with low nitrogen and high manganese in the lamina of the leaf.

The results of the 1948 investigations indicated that the "check period" may result from a nitrogen deficiency, brought about by the heavy demands of the developing fruits. This implication of nitrogen supply and uptake is in agreement with the findings of Murneek (1), White (2) and Owen(5, 7) about nitrogen deficiency.

Owen's published comments (7, 8) about "physiological strain", seemed to suggest that it is correlated with magnesium deficiency. The results of 1948 investigations do not support this contention. The tendency at Law was towards low nitrogen and consistently high magnesium during the "check period". This is clearly borne out by Diagram 6 in which the levels of nitrogen and extractable magnesium in the leaves from the three houses are plotted. The approximate "check period", varying in length/

length in the different houses 1, 6 and 9 is roughly indicated by vertical arrows numbered to correspond. The individual nitrogen-magnesium ratios are plotted in Diagram 7.

An increase of total manganese in the lamina just before and especially during the "check period", may also have been an indication of abnormality. The magnitude of this increase in total manganese may be affected by variety. Whatever the explanation of the increase, Diagram 4 indicates that it was real. Moreover, since the soils were nearly neutral throughout,* the increase can hardly be associated with a manganese toxicity arising from soil acidity (see Hunter and McGregor (9); attached Reprint III). It may therefore be taken as having a physiological origin and meaning. It is probably connected with "physiological strain", though the available evidence is insufficient to establish the exact relationship between the plant's condition and the increase of total manganese in the leaf.

* It can be seen (Diag. 5 and Table 4) that the general level of manganese did vary with soil acidity (cf. p. 145).

TOMATO EXPERIMENTS, 1949.

TOMATO EXPERIMENTS, 1949

In commercial greenhouses where the soils are steam-sterilised there is always the fear among the growers that their plants will grow too strongly and, in fact, suffer from excessive "nitrogen vigour". There is a tendency to withold nitrogenous fertilisers until the plants are beginning to thin at the top. The results of the 1948 experiments showed that at the "check period" the total nitrogen in the lamina of upper leaves dropped to a minimum; also, the visual symptoms all pointed to a nitrogen deficiency at this period. There was therefore some reason to believe that nitrogenous manures were witheld too long. An investigation into nitrogenous manuring seemed to be the one most likely to yield results.

An experiment was designed to study the effects of three levels of nitrogen manuring with soluble salts and the importance of the time of application of nitrogen. In some treatments the ("soluble") nitrogen applications were started three or four weeks after the plants were planted and were continued at fortnightly intervals until the end of the season. In other treatments no nitrogen was applied until the first signs of the "check period".

Two/

Two centres in Lanarkshire were chosen, one at Springfield, Cleghorn, and the other at Kairn, Lanark. Greenhouses 200 ft. by 16 ft. were used at both centres. Strict control of management was maintained throughout the time of the experiment.

The experiments consisted of four randomised blocks of six treatments.

Size of plot:- 32 plants per plot (8 x 4). The plants were spaced 21" apart and 20" between the rows at Springfield and 18" apart and 20" between the rows at Kairn.

Size of plot harvested:- Fruit was weighed from 24 plants of each plot. The end rows of each plot were used as buffer rows and the fruit from these plants was not included in the yield of the plot.

Basal manuring:- ½ cwt. ground limestone per "100 ft.*

Top-dressings:- Two dressings of sulphate of potash (28 lb. per 100 ft.) were given. The first at the beginning of April and the second at the beginning of May. No phosphates were applied, because soil analyses indicated/

* "100 ft." = 1500 sq. ft. (100 ft. x 15 ft. planted area)

indicated that there was an abundant supply of available phosphate in these soils.

Variety:- Kairn - 'Ailsa Craig'
Springfield - 'Aldourie'

Treatments:-

A. No nitrogen applied - control.

B. Fortnightly applications of ½ lb. N. as sulphate of ammonia per 100 ft. from 1st. April.

C. Fortnightly applications of 1 lb. N. as sulphate of ammonia per 100 ft. from 1st. April.

D. Fortnightly applications of 1½ lb. N. as sulphate of ammonia per 100 ft. from 1st. April.

E. No nitrogen applied until first signs of "check period", then fortnightly applications of 1 lb. N. as sulphate of ammonia per 100 ft.

F. As for 'E' but fortnightly applications of 1½ lb. N. as sulphate of ammonia per 100 ft.

Nitrogen applications were started at 15th. May on plots E and F.

Total nitrogen applied:-

Plot A. - Nil
B. - 6 lb. N per 100 ft.
C. - 12 lb. N per 100 ft.
D. - 18 lb. N per 100 ft.
E/

E. - 8 lb. N per 100 ft.

F. - 12 lb. N per 100 ft.

Samples for analysis:- Samples of soil and tissue were taken from each plot at regular intervals during the season. The uppermost fully-expanded leaf was used for analysis, as in the 1948 experiments, 12 leaves per sample.

The leaves were separated into lamina and petiole. Extractable* magnesium, potassium and phosphorus, and, total manganese and nitrogen were estimated in the dry-matter of the lamina. Details of chemical methods are given in Appendix B.

* Extracts were prepared using 1 g. dry-matter and 100 ml. Morgan's reagent.

RESULTS OF 1949 EXPERIMENTS.

TOMATO EXPERIMENTS, 1949

Table:- 10. Centre:- Springfield.

Yields of fruit

Treatment	Plot Yield (lb.)	Mean Plot Yield (lb.)	Mean Yield per plant lb	Yield per 100ft.(cwt)
A.	224 212 214 217	217	9.04	36.94
B.	223 216 216 232	222	9.25	37.70
C.	214 221 213 217	216	9.00	36.77
D.	210 200 220 219	212	8.83	36.10
E.	193 217 234 236	219	9.12	37.33
F.	195 209 199 193	199	8.29	33.84

Mean – 36.44 cwt. per 100 ft.

Standard Error – ± 0.88 cwt. per 100 ft.

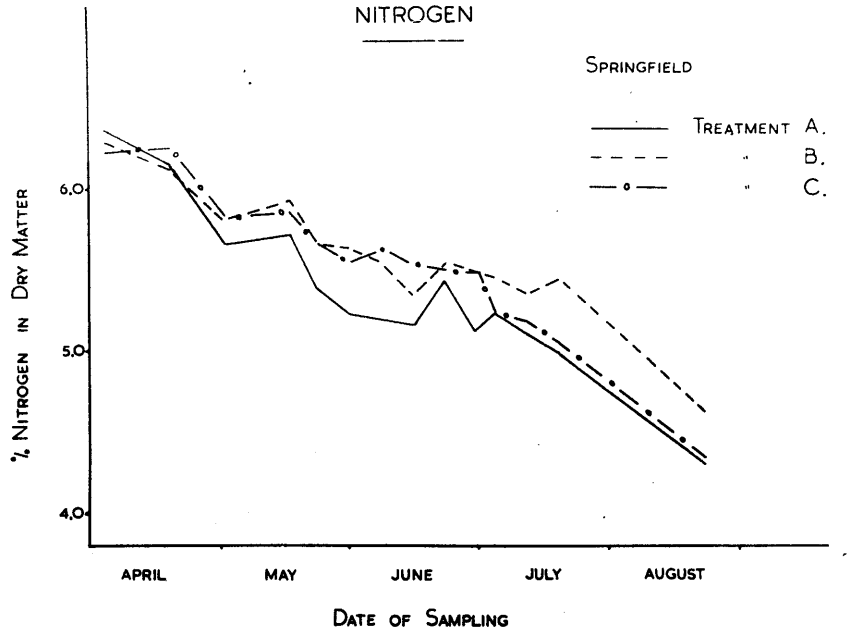
TOMATO EXPERIMENTS, 1949

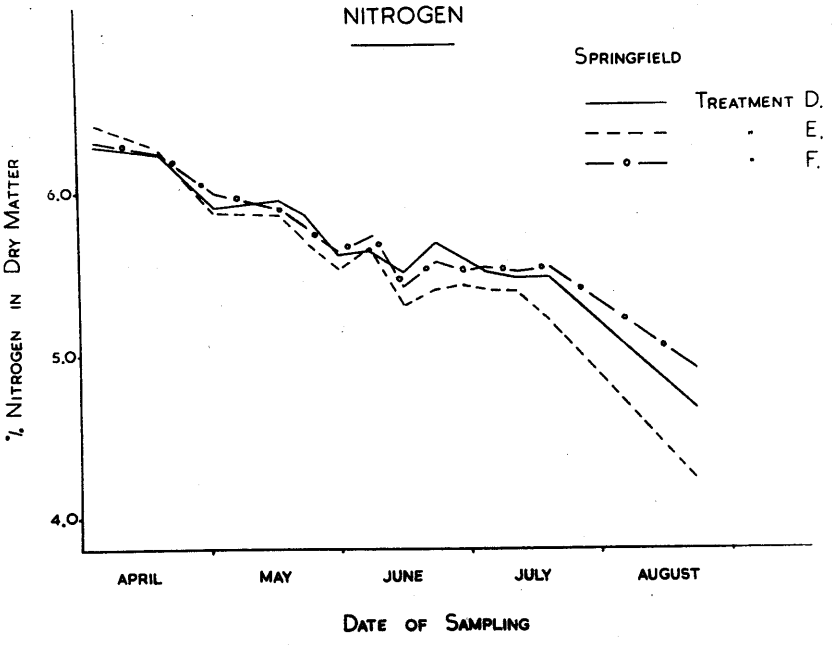
Table:- 11. Centre:- Springfield.

% Nitrogen* in Lamina dry matter

Plot	Treat-ment	Date of sampling													
		4/4	18/4	2/5	16/5	23/5	30/5	6/6	14/6	20/6	27/6	4/7	11/7	18/7	20/8
1.	E.	6.46	6.28	6.14	5.90	5.95	5.70	5.75	5.39	5.39	5.64	5.62	5.50	5.31	4.00
2.	F.	6.24	6.03	5.94	5.86	5.72	5.71	5.81	5.46	5.52	5.53	5.53	5.52	5.60	5.17
3.	B.	6.33	5.95	5.96	5.91	5.68	5.70	5.52	5.38	5.54	5.54	5.73	5.53	5.61	4.93
4.	D.	6.36	6.03	5.74	5.81	5.89	5.57	5.49	5.28	5.63	5.77	5.56	5.56	5.54	4.65
5.	A.	6.49	6.26	5.77	5.69	5.52	5.24	5.56	5.36	5.60	5.21	5.38	5.35	5.07	4.59
6.	C.	6.25	6.18	5.76	5.78	5.64	5.45	5.52	5.43	5.33	5.43	5.10	5.17	4.93	4.59
7.	E.	6.38	6.25	5.63	5.82	5.44	5.36	5.54	5.21	5.42	5.19	5.18	5.29	5.10	4.41
8.	A.	6.25	6.02	5.54	5.75	5.25	5.22	5.39	4.97	5.26	5.03	5.08	4.84	4.90	4.00
9.	B.	6.24	6.28	5.65	5.94	5.66	5.57	5.57	5.32	5.54	5.43	5.17	5.17	5.26	4.28
10.	F.	6.37	6.40	6.04	5.90	5.84	5.57	5.67	5.35	5.61	5.49	5.52	5.47	5.45	4.63
11.	C.	6.16	6.34	5.89	5.94	5.72	5.64	5.74	5.63	5.68	5.54	5.33	5.18	5.14	4.07
12.	D.	6.20	6.42	6.07	6.08	5.82	5.66	5.78	5.74	5.74	5.63	5.45	5.38	5.40	4.65

* Nitrogen was determined on two plots only of each treatment.





Diag. 8 - % Nitrogen in dry-matter of lamina of uppermost fully-developed leaves.

TOMATO EXPERIMENTS, 1949

Table:- 12. Centre:- Springfield

Concentration (p.p.m.) of Potassium in extracts of

Lamina dry matter

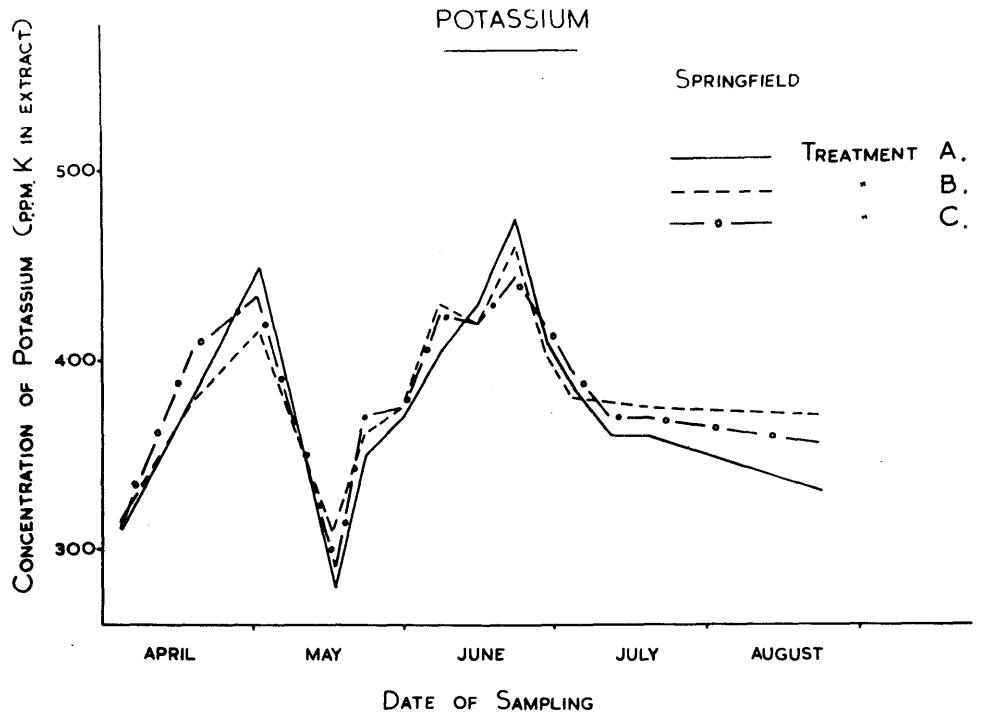
Plot	Treatment	Date of sampling													
		4/4	18/4	2/5	16/5	23/5	30/5	6/6	14/6	20/6	27/6	4/7	11/7	18/7	20/8
1.	E.	292	392	407	336	426	375	445	395	460	380	329	358	358	380
2.	F.	307	375	440	323	375	382	405	422	460	365	362	376	376	376
3.	B.	292	400	389	303	370	378	437	442	475	358	376	369	384	376
4.	D.	307	433	431	336	388	398	437	428	482	340	400	373	369	358
5.	A.	315	406	514	267	358	350	375	415	502	358	384	364	340	346
6.	C.	303	428	417	278	358	366	437	415	440	385	392	358	350	346
7.	E.	301	406	407	307	340	366	437	415	485	362	388	354	392	326
8.	A.	300	384	440	307	277	360	405	395	440	420	376	336	350	332
9.	B.	284	366	414	292	384	378	462	455	448	380	346	346	350	388
10.	F.	292	379	436	284	349	390	454	422	465	380	395	388	362	364
11.	C.	274	392	451	281	380	370	437	435	448	415	388	376	380	336
12.	D.	300	384	412	300	345	395	415	442	485	435	432	400	400	350

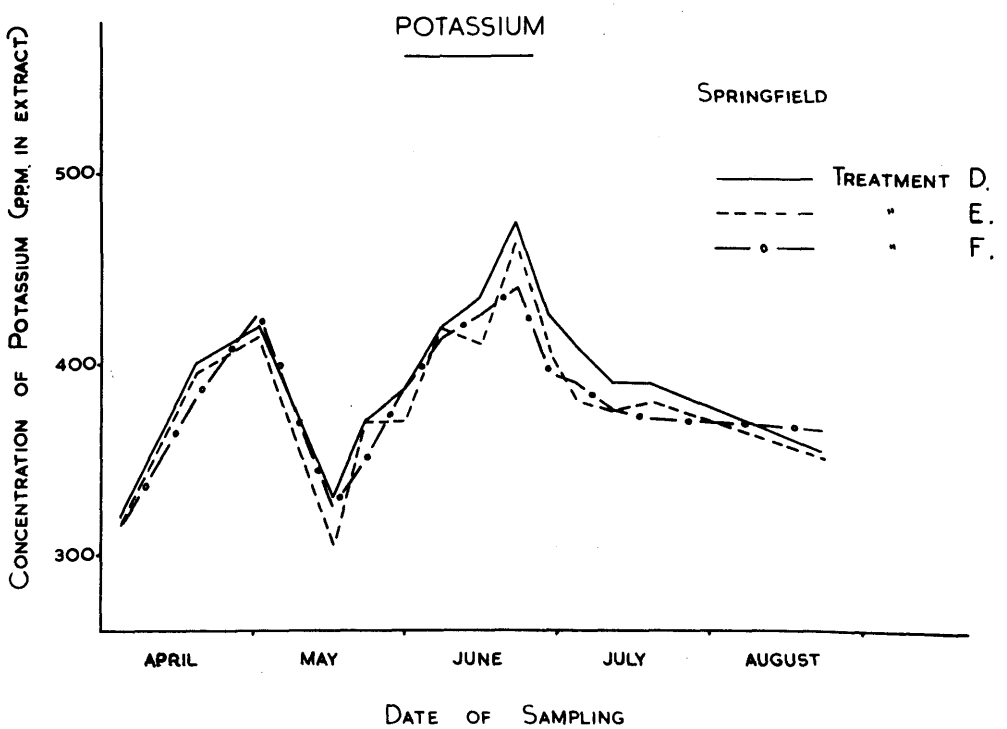
TOMATO EXPERIMENTS, 1949

Table:- 12 continued. Centre:- Springfield.

Concentration (p.p.m.) Of Potassium in extracts of Lamina dry matter

Plot	Treatment	Date of sampling													
		4/4	18/4	2/5	16/5	23/5	30/5	6/6	14/6	20/6	27/6	4/7	11/7	18/7	20/8
13.	E.	300	392	440	292	332	378	402	435	480	435	395	410	396	362
14.	A.	257	366	440	270	375	370	430	460	485	428	380	384	373	322
15.	B.	284	379	440	340	358	370	415	375	465	435	410	354	380	358
16.	F.	282	379	403	366	332	378	415	360	428	435	406	364	384	364
17.	C.	292	415	456	282	358	382	395	415	448	423	403	360	376	384
18.	D.	296	415	389	393	393	378	428	460	470	470	410	406	388	354
19.	B.	296	388	417	307	340	375	402	415	455	443	392	369	392	380
20.	E.	289	392	412	282	380	370	395	395	442	443	403	369	369	340
21.	C.	292	392	412	315	380	386	430	415	448	435	392	376	376	358
22.	A.	296	392	407	278	384	395	415	440	480	423	406	364	388	329
23.	D.	300	370	440	278	358	370	395	415	465	450	388	373	392	373
24.	F.	300	388	421	332	350	398	395	395	418	403	392	376	362	355





Diag. 9 - Concentration of potassium in extracts of dry-matter of lamina of uppermost fully-developed leaves.

TOMATO EXPERIMENTS, 1949

Table:- 13. Centre:- Springfield.

Concentration (p.p.m.) of Magnesium in extracts of Lamina dry matter

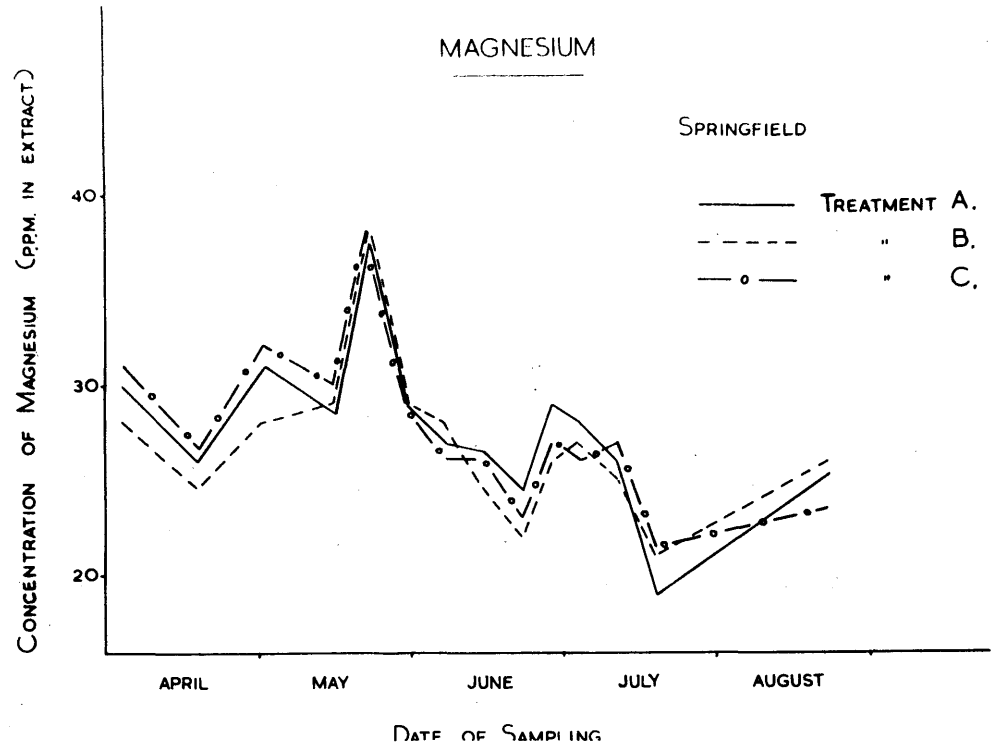
Plot	Treatment	Date of sampling													
		4/4	18/4	2/5	16/5	23/5	30/5	6/6	14/6	20/6	27/6	4/7	11/7	18/7	20/8
1.	E.	33	27	30	32	41	29	32	30	19	29	29	28	23	33
2.	F.	30	25	26	28	35	30	29	25	21	22	22	21	21	25
3.	B.	28	24	30	30	40	31	29	27	22	23	27	23	20	23
4.	D.	31	24	32	29	40	28	30	26	24	30	23	25	17	24
5.	A.	31	25	31	28	39	30	29	29	25	29	34	27	17	28
6.	C.	28	24	32	28	39	30	27	30	25	26	28	25	18	19
7.	E.	28	23	33	31	37	29	27	25	22	28	27	24	12	21
8.	A.	31	25	34	31	39	30	26	27	26	29	29	29	17	21
9.	B.	27	24	30	31	41	29	28	26	27	29	30	29	27	31
10.	F.	32	22	25	25	41	28	25	23	26	25	28	26	19	17
11.	C.	33	26	28	30	39	28	21	28	20	25	28	30	16	15
12.	D.	33	27	25	29	41	29	26	26	24	30	29	25	19	25

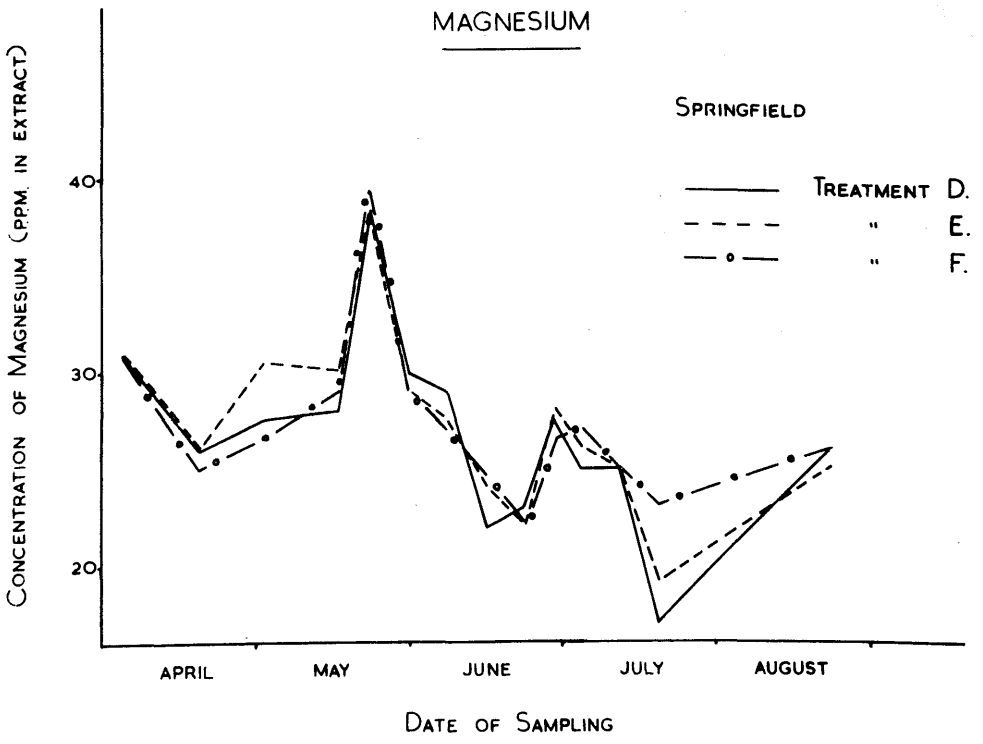
TOMATO EXPERIMENTS, 1949

Table:- 13 continued. Centre:- Springfield.

Concentration (p.p.m.) of Magnesium in extracts of Lamina dry matter

Plot	Treatment	Date of sampling													
		4/4	18/4	2/5	16/5	23/5	30/5	6/6	14/6	20/6	27/6	4/7	11/7	18/7	20/8
13.	E.	34	25	28	27	39	28	22	19	24	26	20	21	22	23
14.	A.	30	26	24	27	37	28	25	20	22	29	25	29	18	28
15.	B.	28	25	24	28	37	28	29	24	18	27	23	26	17	28
16.	F.	32	27	24	34	42	29	25	30	21	31	31	28	23	33
17.	C.	31	28	30	31	36	29	29	26	24	30	27	30	28	29
18.	D.	30	25	25	28	36	34	35	20	23	26	28	24	16	33
19.	B.	27	25	28	27	34	27	25	22	22	25	29	22	20	21
20.	E.	29	28	31	30	37	29	29	21	23	28	29	26	20	22
21.	C.	33	28	38	31	37	30	26	20	22	28	23	23	22	31
22.	A	29	28	31	28	35	27	29	30	24	30	24	20	23	25
23.	D.	29	27	28	25	35	28	26	17	22	24	20	17	16	23
24.	F.	33	27	31	30	40	29	30	14	21	28	28	26	28	30





Diag. 10 - Concentration of magnesium in extracts of dry-matter of lamina of uppermost fully-developed leaves.

TOMATO EXPERIMENTS, 1949

Table:- 14. Centre:- Springfield.

Concentration (p.p.m.) of Phosphorus in extracts of Lamina dry matter

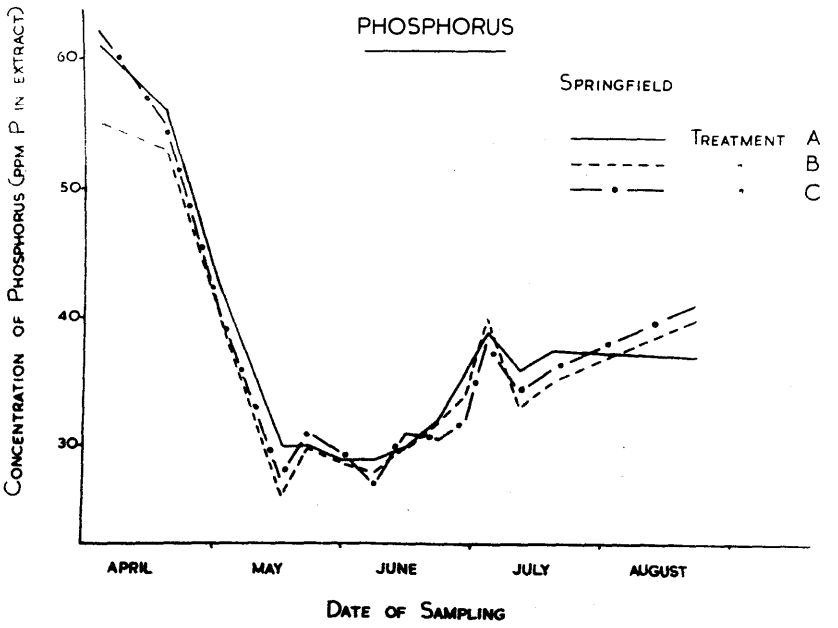
Plot	Treatment	Date of sampling													
		4/4	18/4	2/5	16/5	23/5	30/5	6/6	14/6	20/6	27/6	4/7	11/7	18/7	20/8
1.	E.	65	50	32	22	29	27	28	30	32	30	38	39	34	41
2.	F.	65	61	34	22	31	27	32	33	32	34	40	39	39	42
3.	B.	61	50	34	30	34	33	33	33	33	33	39	36	40	40
4.	D.	65	55	42	25	33	33	28	33	33	33	40	46	39	39
5.	A...	64	48	40	28	31	31	28	32	33	36	39	34	40	42
6.	C.	76	52	36	25	33	33	28	33	30	30	36	35	40	41
7.	E.	61	47	34	24	30	27	27	29	30	32	39	35	37	35
8.	A.	61	48	38	25	29	27	28	27	30	34	35	33	34	24
9.	B.	54	50	48	25	31	27	26	28	33	34	46	33	30	39
10.	F.	63	48	40	25	29	29	28	29	29	30	38	39	34	42
11.	C.	54	57	44	28	33	29	26	33	29	39	33	39	33	46
12.	D.	57	48	44	28	33	30	28	31	30	30	42	30	34	38

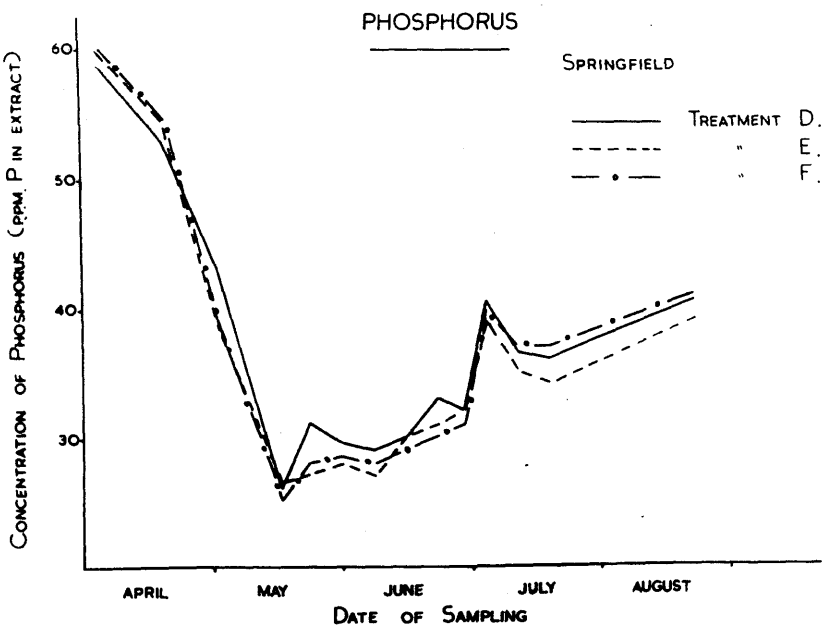
TOMATO EXPERIMENTS, 1949

Table:- 14 continued. Centre:- Springfield.

Concentration (p.p.m.) of Phosphorus in extracts of Lamina dry matter

Plot	Treatment	Date of sampling													
		4/4	18/4	2/5	16/5	23/5	30/5	6/6	14/6	20/6	27/6	4/7	11/7	18/7	20/8
13.	E.	50	57	40	32	33	29	26	30	30	33	36	32	34	40
14.	A.	65	61	44	34	32	27	28	30	30	38	42	30	34	35
15.	B.	52	50	44	25	27	29	25	26	29	34	36	28	32	41
16.	F.	54	48	36	24	25	29	25	26	29	30	46	34	34	38
17.	C.	52	52	38	28	28	28	25	26	27	29	44	28	33	33
18.	D.	61	48	44	22	28	27	28	27	33	30	38	34	32	34
19.	B.	54	61	44	25	29	29	28	32	33	34	39	35	40	42
20.	E.	63	65	48	28	31	29	28	31	33	34	42	35	32	42
21.	C.	67	61	42	28	29	28	29	33	36	32	39	33	40	46
22.	A.	54	65	48	32	29	31	32	30	34	36	40	48	42	48
23.	D.	54	63	42	30	31	29	33	30	36	34	42	36	39	47
24.	F.	57	61	44	30	27	30	26	29	30	30	40	37	42	42





Diag. 11 - Concentration of phosphorus in extracts of dry-matter of lamina of uppermost fully-developed leaves.

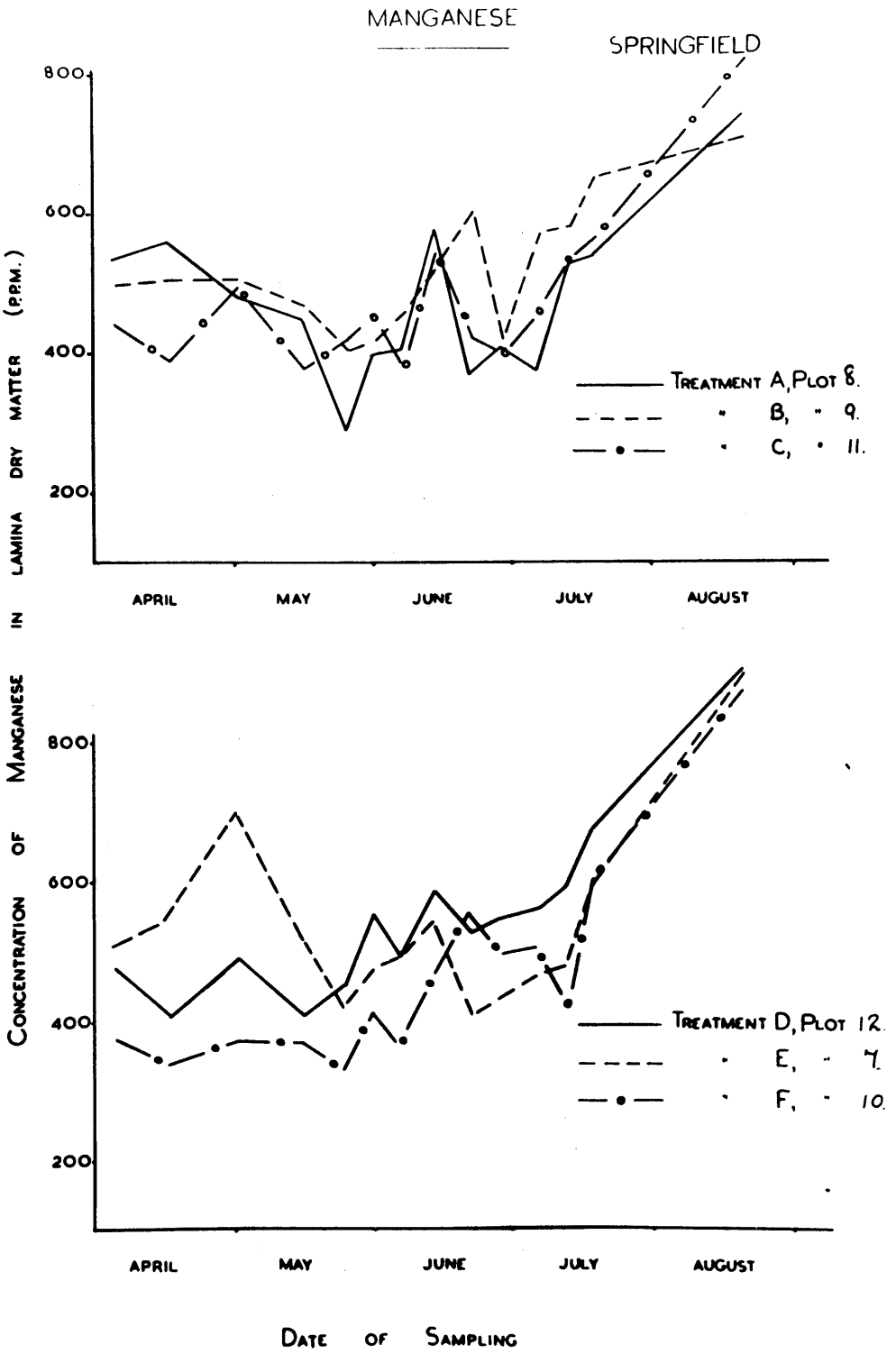
TOMATO EXPERIMENTS, 1949

Table:- 15. Centre:- Springfield.

Concentration (p.p.m.) of Manganese* in Lamina dry matter

Plot	Treatment	Date of sampling													
		4/4	18/4	2/5	16/5	23/5	30/5	6/6	14/6	20/6	27/6	4/7	11/7	18/7	20/8
1.	E.	465	400	420	300	265	315	305	335	360	355	395	355	340	500
2.	F.	295	385	385	275	235	275	250	375	345	350	355	335	360	425
3.	B	385	440	465	360	340	355	295	430	365	395	385	380	395	590
4.	D.	450	555	640	440	390	420	450	525	425	415	430	435	565	800
5.	A.	505	515	550	450	405	425	360	445	205	415	515	420	485	510
6.	C.	560	585	660	485	395	450	380	450	395	475	540	560	830	970
7.	E.	510	545	700	510	410	475	490	540	400	540	455	475	590	940
8.	A.	530	560	485	450	290	400	405	580	370	405	375	530	540	740
9.	B.	500	510	510	470	405	420	460	530	605	420	575	585	655	710
10.	F.	375	335	370	365	325	405	360	460	550	480	500	415	600	890
11.	C.	440	395	500	380	420	455	380	550	420	400	460	510	540	820
12.	D.	475	405	490	405	450	550	490	585	525	540	555	590	675	980

* Manganese was determined on samples from two plots only of each treatment.



Diag. 12 - Concentration of manganese in dry-matter of lamina of uppermost fully-developed leaves.

TOMATO EXPERIMENTS, 1949

Table:- 16. Centre:- Kairn.

Yields of Fruit

Treatment	Plot yield lb.	Mean plot yield lb.	Mean plant yield lb.	Yield per 100ft. cwt.
A.	115 96 128 110	112	4.67	22.27
B.	104 107 103 122	109	4.54	21.63
C.	118 96 103 103	105	4.38	20.84
D.	87 97 103 96	96	4.00	19.00
E.	116 85 119 93	103	4.30	20.49
F.	108 97 100 101	102	4.25	21.04
Mean		± 20.74 cwt. per 100 ft.		
Standard Error		± 0.89 cwt. per 100 ft.		

TOMATO EXPERIMENTS, 1949

Table:- 17. Centre:- Kairn.

Number of plants attacked by Stem Rot (Botrytis cinerea)

Treatment	% Diseased Plants
A.	17
B.	35
C.	29
D.	44
E.	29
F.	37
Standard Error	± 5

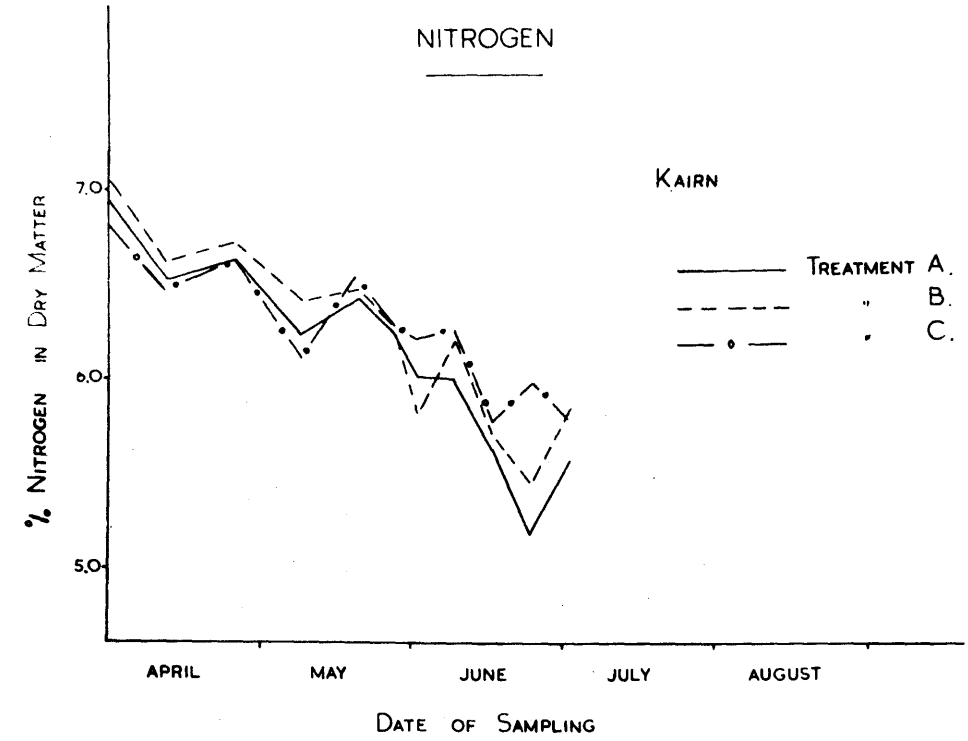
TOMATO EXPERIMENTS, 1949

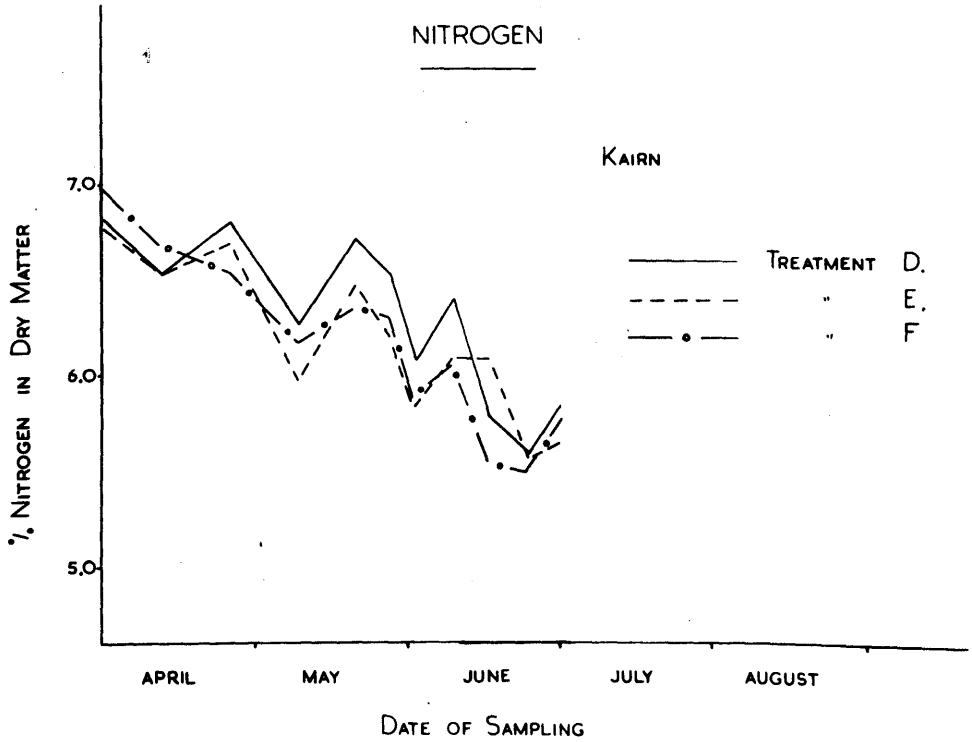
Table:- 18. Centre:- Kairn.

% Nitrogen* in Lamina dry matter

Plot	Treatment	Date of sampling										
		28/3	11/4	25/4	9/5	19/5	26/5	2/6	9/6	16/6	22/6	30/6
1.	D.	6.74	6.55	6.68	6.14	6.81	6.58	6.23	6.58	6.10	5.91	5.99
2.	C.	6.72	6.36	6.51	5.99	6.89	6.13	6.30	6.41	5.80	6.30	5.96
3.	E.	6.84	6.54	6.65	5.51	6.50	6.41	5.74	6.10	5.49	5.63	5.77
4.	F.	6.81	6.63	6.36	5.86	6.18	6.02	5.50	5.99	5.46	5.52	5.50
5.	B.	7.32	6.62	6.69	6.50	6.65	6.37	5.75	6.21	5.82	5.52	5.66
6.	A.	6.92	6.60	6.68	6.41	6.68	6.41	6.10	6.02	5.80	5.57	5.74
7.	F.	7.15	6.74	6.71	6.47	6.52	6.58	6.22	6.12	5.57	5.46	6.02
8.	C.	6.91	6.59	6.78	6.25	6.22	6.44	6.13	6.12	5.74	5.67	5.63
9.	A.	6.95	6.46	6.59	6.07	6.17	6.08	5.94	5.99	5.39	5.18	5.40
10.	D.	6.89	6.52	6.92	6.40	6.62	6.47	5.94	6.22	5.45	5.26	5.70
11.	B.	6.76	6.63	6.76	6.34	6.32	6.20	5.88	6.20	5.60	5.36	6.02
12.	E.	6.69	6.53	6.72	6.43	6.44	5.98	5.90	6.08	5.68	5.49	5.50

* Nitrogen was determined on samples from two plots only of each treatment.





Diag. 13 - % Nitrogen in dry-matter of lamina of uppermost fully-developed leaves.

TOMATO EXPERIMENTS, 1949

Table:- 19. Centre:- Kairn.

Concentration (p.p.m.) of Potassium in extracts of Lamina dry matter

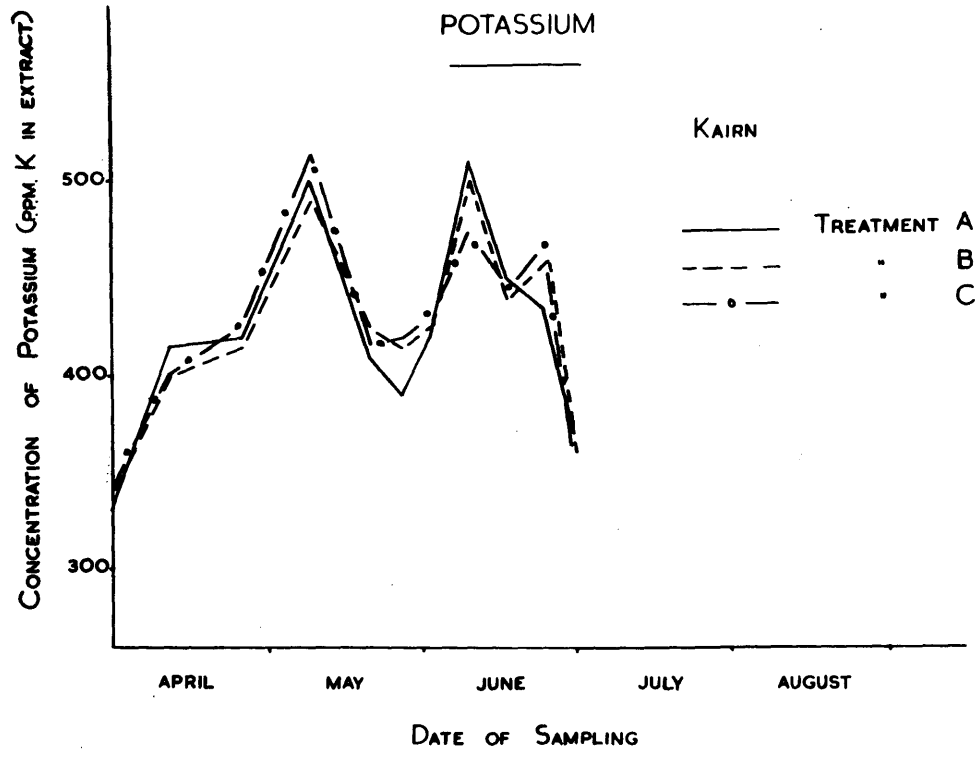
Plot	Treatment	Date of sampling										
		28/3	11/4	25/4	9/5	19/5	26/5	2/6	9/6	16/6	22/6	30/6
1.	D.	350	375	432	540	398	398	398	458	415	435	358
2.	C.	334	379	424	534	375	440	425	481	470	492	362
3.	E.	315	375	410	540	440	402	445	485	435	440	376
4.	F.	358	397	424	540	451	450	440	512	470	480	358
5.	B.	334	406	414	470	451	440	430	502	422	480	373
6.	A.	296	432	432	520	389	395	445	522	448	475	410
7.	F.	358	424	428	485	403	395	445	470	435	460	362
8.	C.	366	432	424	510	460	422	425	476	415	474	346
9.	A.	350	410	406	500	440	354	415	504	415	428	342
10.	D.	350	424	406	480	456	425	418	485	435	475	366
11.	B.	350	410	414	495	500	414	410	502	428	455	350
12.	E.	334	400	410	470	414	429	445	467	428	440	336

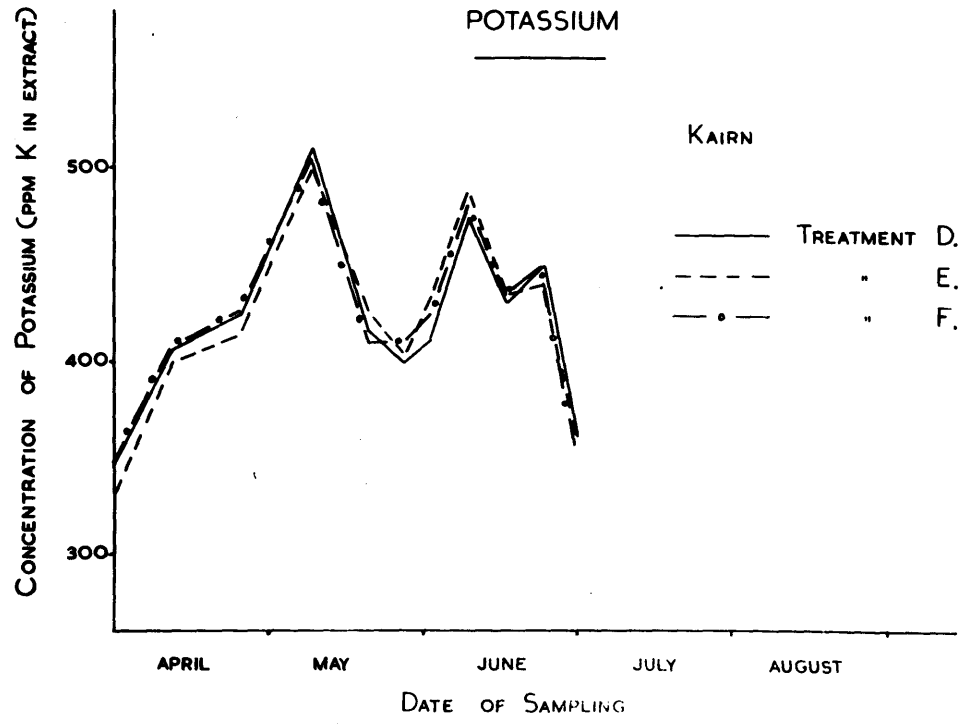
TOMATO EXPERIMENTS, 1949

Table:- 19 continued. Centre:- Kairn.

Concentration (p.p.m.) of Potassium in extracts of Lamina dry matter

Plot	Treatment	Date of sampling										
		28/3	11/4	25/4	9/5	19/5	26/5	2/6	9/6	16/6	22/6	30/6
13.	F.	350	410	410	524	407	414	425	485	415	415	350
14.	A.	334	406	424	495	407	433	398	476	455	400	350
15.	B.	342	410	442	466	380	386	425	476	450	475	369
16.	E.	326	432	428	510	414	390	425	505	455	460	376
17.	D.	350	406	442	505	398	395	405	476	435	460	362
18.	C.	342	397	410	514	414	375	430	458	440	460	369
19.	B.	374	361	400	534	370	414	430	512	455	428	342
20.	E.	334	388	406	476	440	398	415	502	418	428	350
21.	D.	342	424	428	505	407	386	415	485	422	435	346
22.	A.	354	424	410	480	407	375	425	535	485	442	366
23.	F.	330	388	432	480	380	375	385	482	422	448	340
24.	C.	318	392	438	505	417	437	437	480	460	448	369





Diag. 14 – Concentration of potassium in extracts of dry-matter of lamina of uppermost fully-developed leaves.

TOMATO EXPERIMENTS, 1949

Table:- 20. Centre:- Kairn.

Concentration (p.p.m.) of Magnesium in extracts of Lamina dry matter

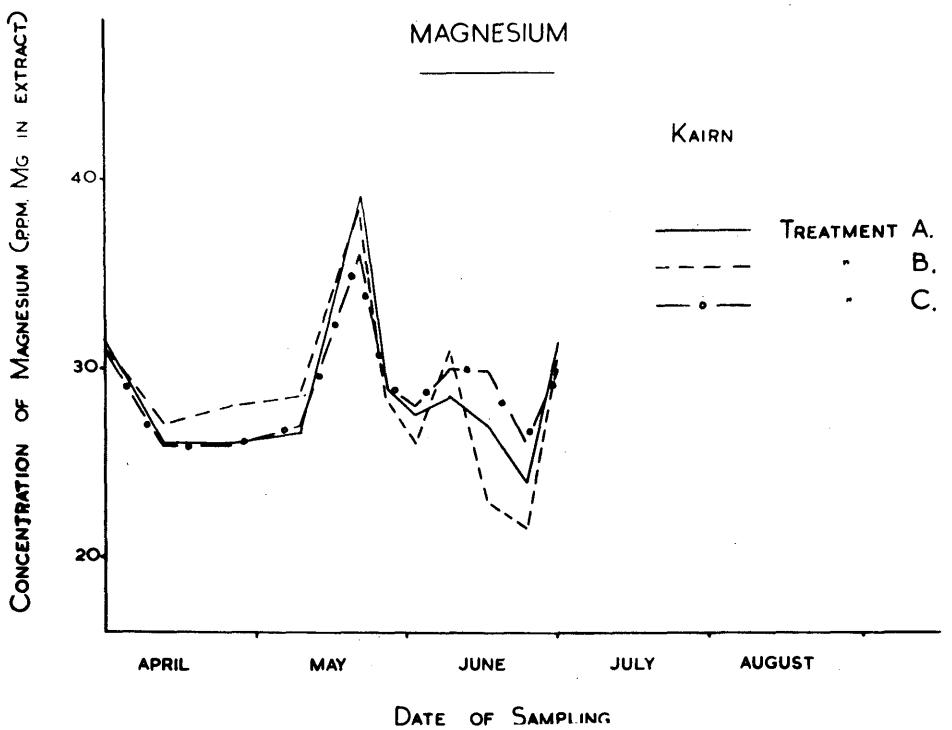
Plot	Treatment	Date of sampling										
		28/3	11/4	25/4	9/5	19/5	26/5	2/6	9/6	16/6	22/6	30/6
1.	D.	31	28	28	31	39	29	29	34	29	31	36
2.	C.	32	28	27	26	37	27	33	31	30	27	32
3.	E.	31	27	29	25	41	29	25	25	20	25	30
4.	F.	33	31	28	24	38	27	28	26	25	27	30
5.	B.	32	26	28	26	38	29	25	27	16	23	30
6.	A.	29	26	28	22	41	30	28	27	26	26	33
7.	F	35	31	28	26	39	27	27	31	20	31	32
8.	C.	30	28	23	28	33	30	26	23	25	26	29
9.	A.	28	28	24	25	36	27	25	24	24	19	29
10.	D.	32	26	25	23	34	27	28	27	18	28	33
11.	B.	34	31	28	27	38	29	27	29	25	19	31
12.	E.	31	31	28	27	40	29	29	29	29	27	29

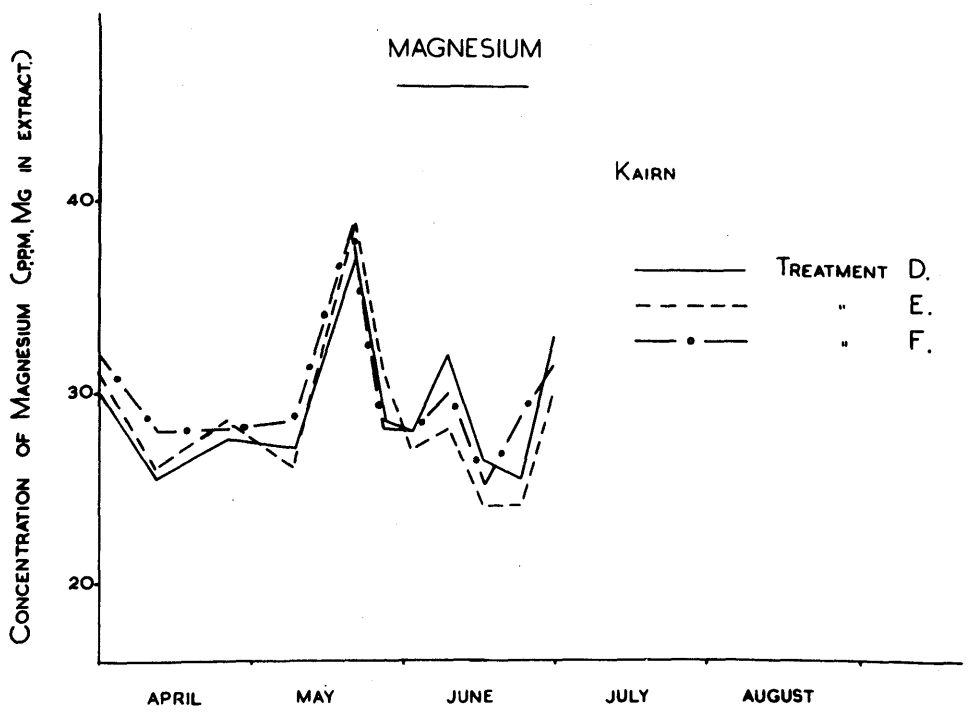
TOMATO EXPERIMENTS, 1949

Table:- 20 continued. Centre:- Kairn.

Concentration (p.p.m.) of Magnesium in extracts of Lamina dry matter

Plot	Treatment	Date of sampling										
		28/3	11/4	25/4	9/5	19/5	26/5	2/6	9/6	16/6	22/6	30/6
13.	F.	31	27	28	31	40	30	29	32	26	28	33
14.	A.	32	26	26	28	40	29	28	31	28	24	31
15.	B.	31	27	28	31	41	29	27	34	32	26	32
16.	E.	31	24	28	25	39	38	27	27	26	19	30
17.	D.	30	25	29	29	37	29	28	34	30	22	30
18.	C.	32	25	27	28	34	30	25	33	30	28	27
19.	B.	31	24	29	29	37	27	26	33	20	18	30
20.	E.	31	22	29	28	37	28	26	32	22	24	31
21.	D.	27	23	28	25	37	29	27	32	29	21	34
22.	A.	33	23	26	31	39	30	29	32	31	28	33
23.	F.	30	23	29	33	39	29	28	32	28	29	31
24.	C.	29	23	28	25	40	29	29	32	33	24	32





Diag. 15 - Concentration of magnesium in extracts of dry-matter of lamina of uppermost fully-developed leaves.

TOMATO EXPERIMENTS, 1949

Table:- 21. Centre:- Kairn.

Concentration (p.p.m.) of Phosphorus in extracts of Lamina dry matter

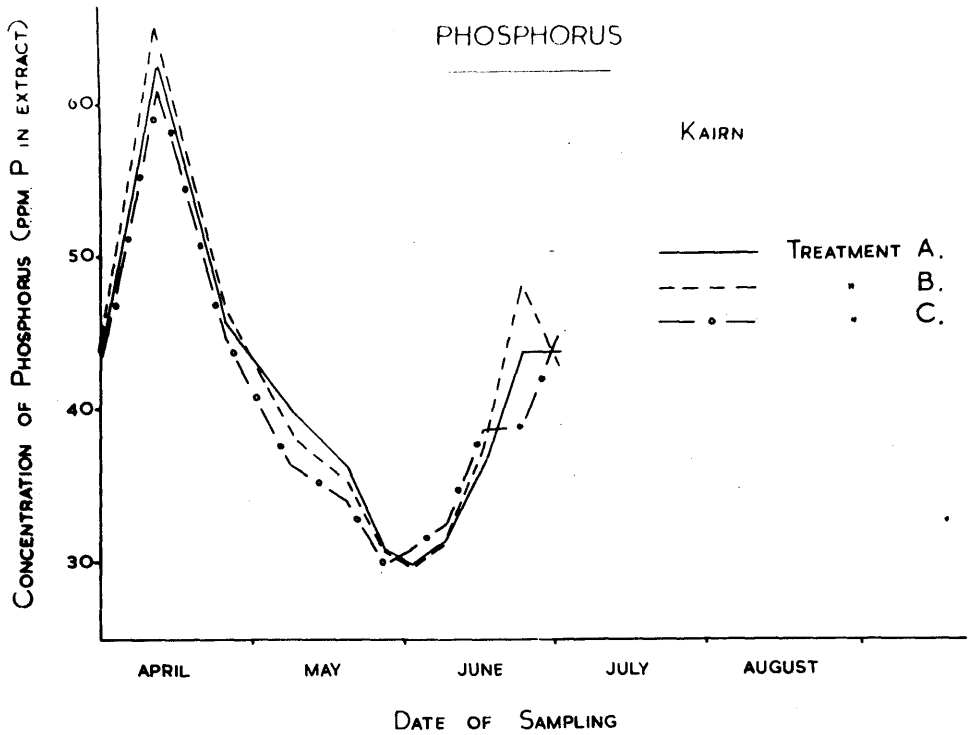
Plot	Treatment	Date of sampling										
		28/3	11/4	25/4	9/5	19/5	26/5	2/6	9/6	16/6	22/6	30/6
1.	D.	48	66	49	33	36	31	31	32	35	44	36
2.	C.	48	65	44	34	35	31	31	33	37	39	46
3.	E.	52	66	49	32	36	29	29	30	36	46	40
4.	F.	52	65	43	31	33	34	31	33	42	40	47
5.	B.	48	67	40	38	33	31	29	30	40	36	46
6.	A.	40	66	43	42	35	29	31	28	39	45	52
7.	F.	40	66	50	38	31	29	28	28	41	40	52
8.	C.	40	58	42	38	34	29	31	30	35	41	42
9.	A.	42	63	43	38	36	30	31	30	33	44	44
10.	D.	44	64	44	40	36	35	32	34	39	50	46
11.	B.	40	63	47	42	40	35	28	33	40	45	44
12.	E.	44	57	42	46	39	32	33	31	34	33	39

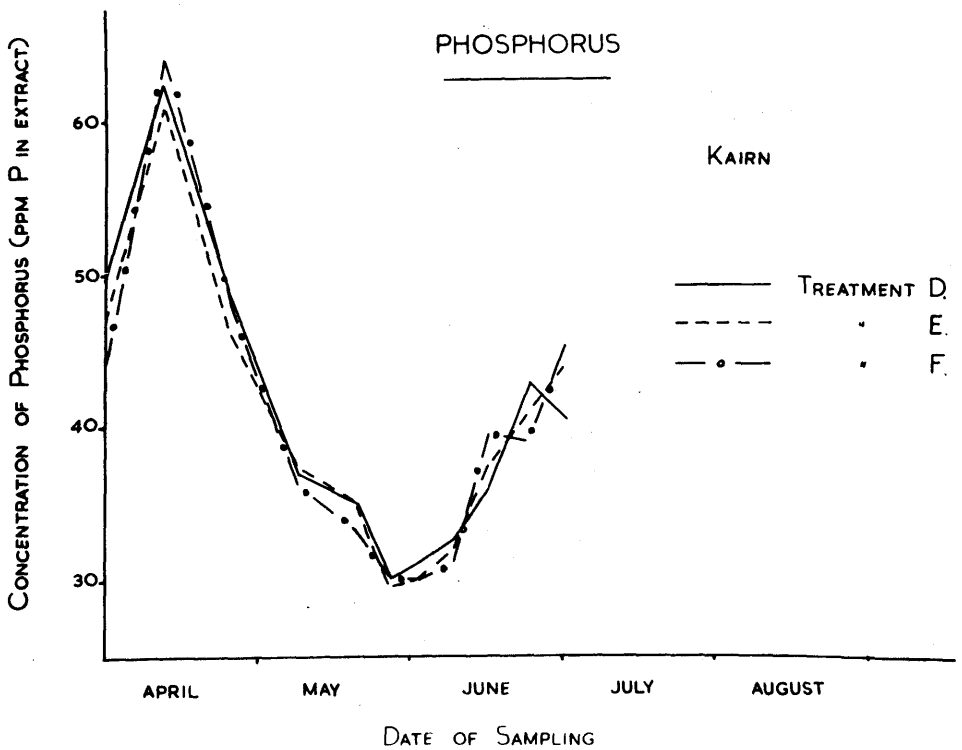
TOMATO EXPERIMENTS, 1949

Table:- 21 continued — Centre:- Kairn.

Concentration (p.p.m.) of Phosphorus in extracts of Lamina dry matter

Plot	Treatment	Date of sampling										
		28/3	11/4	25/4	9/5	19/5	26/5	2/6	9/6	16/6	22/6	30/6
13.	F.	46	63	48	34	35	29	31	31	36	33	39
14.	A.	48	58	46	36	36	32	26	34	34	37	40
15.	B.	44	66	50	37	37	28	30	31	35	46	40
16.	E.	48	61	46	36	33	28	29	33	41	44	46
17.	D.	50	59	50	37	33	27	30	30	34	34	38
18.	C.	44	61	44	37	32	28	28	31	39	36	42
19.	B.	44	63	50	37	32	31	33	32	35	47	42
20.	E.	44	60	49	36	33	29	28	33	39	40	40
21.	D.	46	61	52	37	36	27	30	33	35	45	42
22.	A.	44	63	52	44	39	32	33	34	42	51	41
23.	F.	38	61	52	42	33	28	30	33	40	42	44
24.	C.	52	59	50	37	36	31	33	33	44	42	50





Diag. 16 - Concentration of phosphorus in extracts in dry-matter of lamina of uppermost fully-developed leaves.

TOMATO EXPERIMENTS, 1949

Table:- 22. Centre:- Kairn.

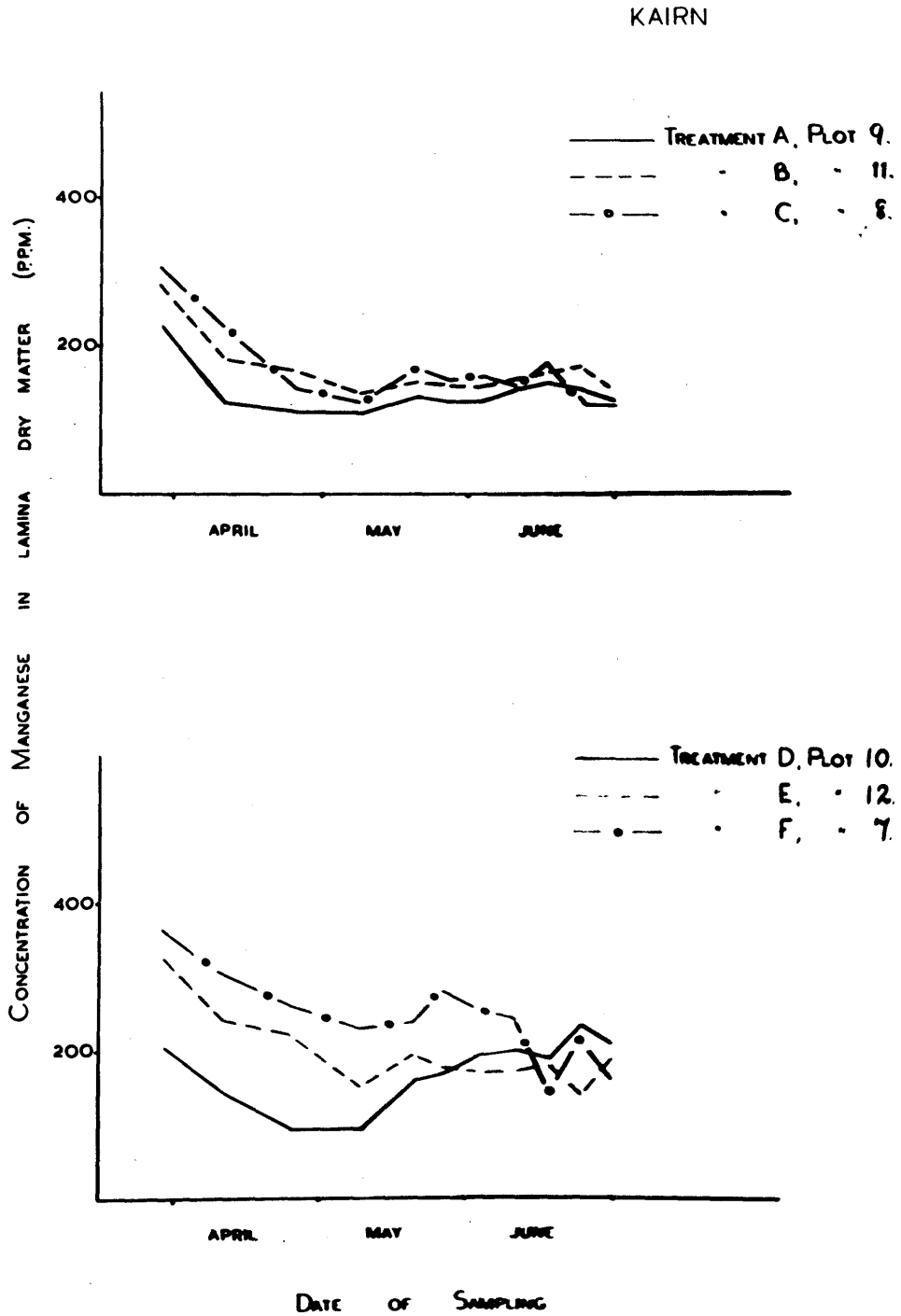
Concentration (p.p.m.) of Manganese*

in Lamina dry matter

Plot	Treatment	Date of sampling										
		28/3	11/4	25/4	9/5	19/5	26/5	2/6	9/6	16/6	22/6	30/6
1.	D.	210	235	145	150	140	125	130	110	130	210	90
2.	C.	335	265	160	210	170	150	160	140	140	140	120
3.	E.	180	100	130	235	160	195	170	185	200	120	160
4.	F.	310	195	150	190	120	135	150	175	200	185	140
5.	B.	280	175	130	165	150	110	135	170	190	185	130
6.	A.	350	420	380	315	375	370	215	255	255	420	245
7.	F.	370	310	265	230	240	285	260	245	140	215	160
8.	C.	310	225	140	120	170	150	155	145	175	120	120
9.	A.	230	120	110	110	130	125	125	140	150	140	125
10.	D.	205	145	95	95	160	170	190	200	190	235	210
11.	B.	285	185	165	135	150	145	145	150	160	170	135
12.	E.	330	245	220	150	190	175	170	170	180	135	190

* Manganese was determined on samples from two plots only of each treatment.

MANGANESE



Diag. 17 - Concentration of manganese in dry-matter of lamina of uppermost fully-developed leaves.

NOTES ON RESULTS OF 1949, EXPERIMENTS.

1. Springfield:-

After the first application of sulphate of ammonia to plots B, C and D there was a slightly stronger growth in these plots. This increased growth was not maintained, and later in the season no visual differences could be detected. The growth of the plants was never at any time heavy; in fact, the plants always appeared to be rather light. A steady growth was maintained throughout the season. The typical symptoms of the commencement of the "check period" were not apparent, but considering the thinness of the tops of the plants at the middle of May, it was decided to start the D and F treatments.

No very marked "check period" occurred, although there were some indications of a slight check about the 11th and 12th trusses. The crop was very good. Right from the first truss good yields of large-sized fruit were produced. This crop of 36 cwt. per 100 ft., approximately 9 lb. per plant, was probably as good as the best crops in the Clydeside that year.

The results show no significant difference between treatments except that treatment F differed significantly, from/

from the mean. The plot yields for treatment F were consistently low.

The lack of response to nitrogen is rather puzzling, considering the very thin plants which were produced. It must be pointed out, however, that although the plants were thin, the leaves were always a fairly dark green colour and never at any time were symptoms of nitrogen deficiency apparent. Magnesium-deficiency symptoms were noticed, but the chlorosis was not severe. These chlorotic symptoms were noted about the middle of July - later than the time at which checking usually shows itself. The leaves sampled in July sometimes showed a light green mottle but it was not definite enough to diagnose as magnesium deficiency. Tissue analyses results (Diagram 10) show that the concentration of extractable magnesium in the lamina was at a minimum during this period. Extractable magnesium was at a maximum about the end of May, when extractable potassium was at a minimum.

Diagram 8, illustrating changes in % nitrogen in the dry matter of the lamina, shows that at the beginning of the season the % nitrogen was rather higher than that at Law nursery and that it gradually dropped to a value of 4.5%. This lower level of nitrogen in the tissue may be correlated with the slight check at the 11th and 12th trusses/

trusses in August, but no definite results can be claimed. No significant differences are shown in the % nitrogen in the dry-matter from the different treatments. Even the heavy applications of nitrogen applied to the 'D' plots has made no difference to the concentration of nitrogen in the dry-matter. It was impossible, in a commercial greenhouse, to estimate the total amount of nitrogen removed by the crop. Considering, however, the uniformity in growth throughout all plots, it is unlikely that there were any great differences in total amounts of nitrogen removed under different treatments.

Tissue analyses results are given in Tables 11, 12, 13, 14 and 15, and are illustrated in Diagrams 8,9, 10, 11 and 12. Variations in concentration of magnesium, potassium, and phosphorus are fairly similar to those found at the Law nursery in 1948. The concentration of manganese does not rise rapidly during mid-season, but there is a rise in manganese content towards the end of the season, corresponding with low nitrogen and slight check at the 11th and 12th trusses. Differences in treatments do not, at Springfield, appear to have caused any significant differences in the composition of the plants.

2. Kairn:-

The/

The plants at this centre always appeared to be suffering from excessive "nitrogen vigour". Stems were very thick. Leaves and trusses were very large. The trusses had, in many cases, 40 - 50 flowers each but setting of fruit was very poor. Throughout the whole season only two or three fruits were set on each truss and it was impossible to detect any "check period" by a change in the setting of trusses. The strong rapid growth was maintained until the plants were topped (end of June).

Tissue analyses results (see Table 18) show that the concentration of nitrogen in the dry-matter was very high - about 7% in the young plants; and even when the plants had reached the top of the house the dry-matter had still about 5.5% nitrogen. These values were much higher than those found at Springfield and Law.

Changes in concentration of magnesium, potassium and phosphorus during the season show a similar trend to those found at Springfield and Law. Manganese was rather lower.

In this experiment applications of nitrogen have depressed the yield. This reduction in yield is probably accounted for by the increase in the number of plants affected by 'Stem Rot' where nitrogen has been/

been applied. The % of diseased plants is significantly higher (see Table 17) in plots treated experimentally with sulphate of ammonia than in the control plots receiving no nitrogen.

TOMATO EXPERIMENTS, 1950.

TOMATO EXPERIMENTS, 1950

It was decided to continue the investigation into nitrogenous manuring of tomatoes. Although there was no response to nitrogen as sulphate of ammonia in the 1949 experiments, it seemed possible that nitrogen applied as nitrate might show different results. Also it was considered that two sets of experiments did not yield sufficient evidence from which to claim conclusive results.

Three Lincolnshire centres - Garrion, Ravenswood and Springfield - were therefore chosen, each consisting of units of 200 ft. x 16 ft.. The manurial experiments varied in design at each centre and will be treated separately. A new experimental treatment - flower pruning of some trusses so as to regulate fruiting - was introduced at Garrion.

EXPERIMENT AT GARRION, 1950.

White (2) suggested that the cyclic cropping of the tomato, due to alternating periods of exhaustion and recovery, might be corrected by regulation of fruiting of the bottom trusses. If the mid-seasonal check is due to exhaustion brought about by the developing fruit, then it seemed possible that by reducing the numbers of fruits on the bottom trusses that the strain on the plant might be reduced. The question then arose how this pruning of the trusses should be done. Should the trusses be pruned when in flower or after the fruit was set?. It was thought that pruning when the truss was in flower might produce a greater saving in energy and nutrients than allowing all the fruit to set and then removing some. The next question was - what flowers should be removed?. It is frequently found that the first one or two buds, at the base of the truss, flower considerably earlier than the remainder, and the fruits set by these flowers develop at the expense of the rest of the truss. It was thought that removal of these basal flowers might give a more even truss. It was also noted, however, that, not infrequently, flower buds continue to develop/

develop at the apex of the truss for some considerable time after the main fruits are set and nearly fully developed. The apical buds seldom develop into good size fruits. Removal of the apex of the truss then might lead to a considerable saving in nutrients. Two alternative methods or schemes of pruning seemed possible.

i) Removal of the apex of the truss after a given number of flower buds had developed.

ii) Removal of apex and also the two basal flowers, leaving a similar number of flower buds.

An experiment was designed at Garrion nursery to test the effects of truss pruning in conjunction with nitrogen manuring. The treatments at Garrion introduced both the above schemes of pruning, and were as follows:-

Treatment A. No pruning - control.

Treatment B. Pruning of the apex of the truss, scheme (i): trusses reduced to 6 flower buds on the first truss and 8 buds on the second, third, fourth and fifth trusses.

Treatment C. Pruning of apical and basal buds, scheme (ii): trusses reduced to 6 flower buds on the first truss and 8 buds on the second, third, fourth and fifth trusses.

Some/

Some of the first trusses had only 6 or 7 buds and to keep the experiment uniform throughout it was decided to reduce the first truss to 6 buds.

All plots were treated with nitrogen at the rate of 12 lb. N per "100 ft." (58 lb. sulphate of ammonia per 1500 sq. ft.) and potash at the rate of 82 lb. sulphate of potash per 100 ft. 12 lb. of nitrogen was considered to be an adequate dressing of nitrogen; when applied with 82 lb. sulphate of potash, it gives an equivalent N/K_2O ratio to that found in nitrate of potash. Treatment A could therefore be used as a control for a comparison of nitrate of potash alone (Treatment D) and sulphate of ammonia. The fertilisers were applied over 12 fortnightly applications commencing on the 13th. April. Each application was bulked with sand to give even distribution.

The remaining plots received the following treatments:-

Treatment D. To give a comparison with sulphate of ammonia, 12 applications of nitrate of potash were given. The total dressing was 89 lbs. nitrate of potash or 12 lb. nitrogen per 100 ft.

Treatment E/

Treatment E. First 4 applications of sulphate of ammonia and sulphate of potash in similar amounts to treatment A. The second 4 applications consisted of a mixture of nitrate of potash and potassium phosphate. This dressing was an attempt to stimulate the plants at the "check period". The remaining 4 applications were as for treatment A. This made in total 8 lb. N per 100 ft. as sulphate of ammonia, 4 lb. N per 100 ft. as nitrate of potash, and 4 lb. P_2O_5 per 100 ft. as potassium phosphate. This treatment therefore received similar amounts of N and K_2O to treatments A and D. The potassium phosphate added a little extra K_2O but this was so small that it could be neglected.

Treatment F. Similar to treatment A but the middle 4 applications were doubled in quantity, thus making a total of 16 lb. N per 100 ft., the N/K_2O ratio remaining the same.

The experiment in total consisted of 6 treatments arranged in 4 randomised blocks of 6 plots.

Size/

Size of plot manured:- 32 plants per plot.

14 ft. x 6ft = 7/100 of 100ft. house.

Size of plot harvested:- 24 plants (end rows of each plot were discarded as buffer rows).

$10\frac{1}{2}$ ft. x 6 ft. = 65/1200 of 100 ft. house.

Variety:- "E. S. 1."

Samples for analysis:- The uppermost fully-developed leaf was again used, but an attempt was made to define more closely the position of the leaf used.

The second leaf below the uppermost flowering truss was sampled. Leaves associated with each truss, i.e. second leaf below the flowering truss, were sampled throughout the season from 1st truss to the 13th truss. The samples consisted of 12 leaves taken at random, 3 leaves from each plot of each treatment. These leaves were called "young" leaves.

A second set of leaves were sampled in a similar manner, but leaves associated with trusses which had fruit nearly fully developed, were used. These leaves were called "old" leaves. Old leaves were sampled from the second to eighth truss.

These two sets of samples of leaves ("young and old") associated with a given truss, enabled a comparison of composition/

composition of that leaf, at two different stages of development, to be made.

The samples were immediately weighed, separated into petiole and lamina, and duplicate samples of each lot were weighed out for dry-matter estimation. This preparation of samples in the field was found to be necessary as considerable loss in weight occurred during transit from field to laboratory.

Fruiting Records:- Three plants in each plot of each treatment, making a total of 12 plants in each treatment, were marked, and careful records kept of the number of fruits picked from each truss. The fruits were classified into Large A, A, B and C according to their size. An estimate of the weight of each class of tomato was obtained by weighing 100 tomatoes of each class. By this method an estimate of the yield of each truss was obtained. Results of estimated yield of all treatments by this method were fairly close to the actual mean yields obtained.

During the month of June when tomatoes were ripening on the bottom third and fourth trusses, several tomatoes varying in size were weighed and the number of seeds in each counted. This experiment was repeated later in the season with tomatoes from the 13th and 14th trusses.

RESULTS OF EXPERIMENTS AT GARRION.

TOMATO EXPERIMENTS, 1950

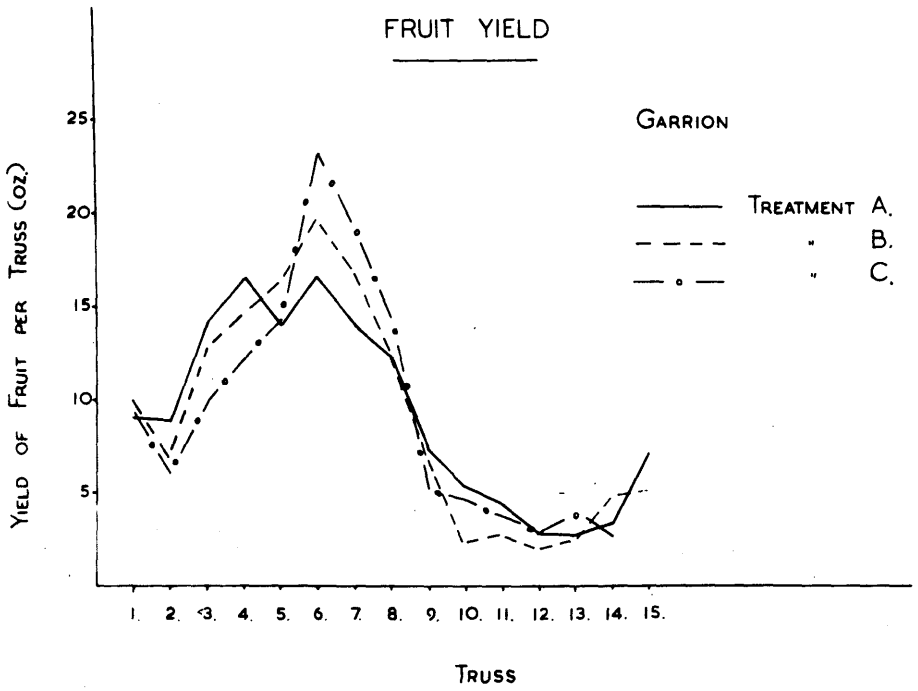
Table:- 23. Centre:- Garrion.

Yields of fruit

Treatment	Plot yield lb.	Mean plot yield lb.	Mean plant yield lb.	Yield per 100ft. cwt.
A.	219 213 210 208	212.5	8.85	33.15
B.	193 211 198 211	203.3	8.47	31.70
C.	188 201 187 201	194.3	8.10	30.30
D.	213 209 216 219	214.0	8.92	33.37
E.	216 218 200 220	213.5	8.90	33.31
F.	210 203 213 204	207.5	8.65	32.37

Mean – 32.37 cwt. per 100 ft.

Standard Error – ± 0.55 cwt per 100 ft.



Diag. 18 - Estimated yield of fruit per truss.

TOMATO EXPERIMENTS, 1950

Table:- 24. Centre:- Garrion.

Estimated fruit yields

Treatment	Number of fruits, graded* L.A.	A.	B.	C.	Total	Estimated plant yield oz.	Estimated yield of L.A & A. oz.
A. Mean+ yield of the first five trusses per plant							
Unpruned	4.7	16.5	12.1	3.7	37.0	62.8	46.4
Pruned, scheme (i)	6.6	16.2	7.0	1.4	31.2	60.3	51.2
Pruned, scheme (ii)	4.2	14.6	7.6	3.8	30.2	52.2	41.2
B. Mean+ yield of fifteen trusses per plant							
Unpruned	7.1	39.4	28.7	10.4	85.6	138.6	99.0
Pruned, scheme (i)	9.9	37.0	23.8	9.6	80.3	135.6	102.2
Pruned, scheme (ii)	6.8	36.8	29.8	15.1	88.5	136.4	93.0

* Average weight of L.A. - 2.85 oz.
A. - 2.00 oz.
B. - 1.2 oz.
C. - 0.5 oz.

+ Mean of 12 plants.

TOMATO EXPERIMENTS, 1950

Table:- 25. Centre:- Garrion.

Mean[+] number of buds per truss

Truss	Treatment A.	B[*]	C[*]	D.	E.	F.
1.	11.8	6.0	6.0	11.8	10.0	12.2
2.	15.6	8.0	8.0	15.0	19.2	17.9
3.	15.3	8.0	8.0	13.8	17.2	15.2
4.	14.7	8.0	8.0	16.2	15.4	16.6
5.	16.7	8.0	8.0	23.2	18.3	19.6
6.	30.8	24.4	33.3	32.5	31.8	28.9
7.	25.1	24.3	23.6	21.3	25.7	24.6
8.	17.3	15.8	16.5	15.4	15.4	19.2
9.	11.3	12.8	12.4	10.9	11.9	12.8
10.	11.3	10.5	11.9	10.8	12.6	10.3
11.	9.3	9.7	12.4	12.1	9.3	9.1
12.	9.1	6.8	9.6	8.7	7.5	7.7
13.	8.0	7.0	8.5	8.6	7.2	7.0
14.	8.3	8.3	7.8	9.3	9.0	8.3
15.	8.2	8.2	8.3	8.9	9.0	8.1

* First five trusses pruned to 6 and 8 buds as shown.

+ Mean of 12 plants.

TOMATO EXPERIMENTS, 1950

Table:- 26. Centre:- Garrion.

Mean[+] number of fruits per truss

Truss	Treatment A.	B[*]	C[*]	D.	E.	F.
1.	5.9	5.5	5.5	6.5	6.6	8.2
2.	6.6	4.0	4.5	5.0	6.8	6.3
3.	8.5	6.8	5.9	8.4	10.1	8.9
4.	8.7	6.8	6.3	9.4	9.1	10.0
5.	7.3	8.0	7.9	7.8	8.3	8.3
6.	11.0	10.8	15.8	11.2	10.1	10.1
7.	7.9	10.7	12.5	9.2	9.9	9.4
8.	7.2	7.8	9.1	6.3	7.3	7.8
9.	4.6	4.8	3.4	3.8	4.6	5.6
10.	3.5	1.8	3.1	1.8	3.3	2.5
11.	3.3	1.9	2.5	2.2	2.9	1.5
12.	1.9	1.6	2.4	2.2	3.0	2.3
13.	2.1	1.9	3.1	2.8	2.3	2.6
14.	2.2	3.7	2.5	3.8	3.6	3.2
15.	5.0	4.2	3.9	4.6	4.8	3.2

* First five trusses pruned to 6 and 8 buds.

+ Mean of 12 plants.

TOMATO EXPERIMENTS, 1950

Table:- 27. Centre:- Garrion.

Percentage of fruits set of buds formed

Truss	Treatment A.	B*	C*	D.	E.	F.
1.	50	92	91	55	66	67
2.	42	50	56	33	35	35
3.	56	85	74	61	60	59
4.	59	85	79	58	59	60
5.	44	100	99	34	45	42
6.	36	44	47	34	32	35
7.	31	44	53	43	39	38
8.	42	49	55	49	47	41
9.	40	39	28	35	39	44
10.	31	17	26	17	26	24
11.	35	20	20	18	31	16
12.	21	23	25	25	40	30
13.	26	27	36	33	32	37
14.	27	44	32	41	40	39
15.	60	51	47	52	53	40

* First five trusses pruned to 6 and 8 buds.

TOMATO EXPERIMENTS, 1950

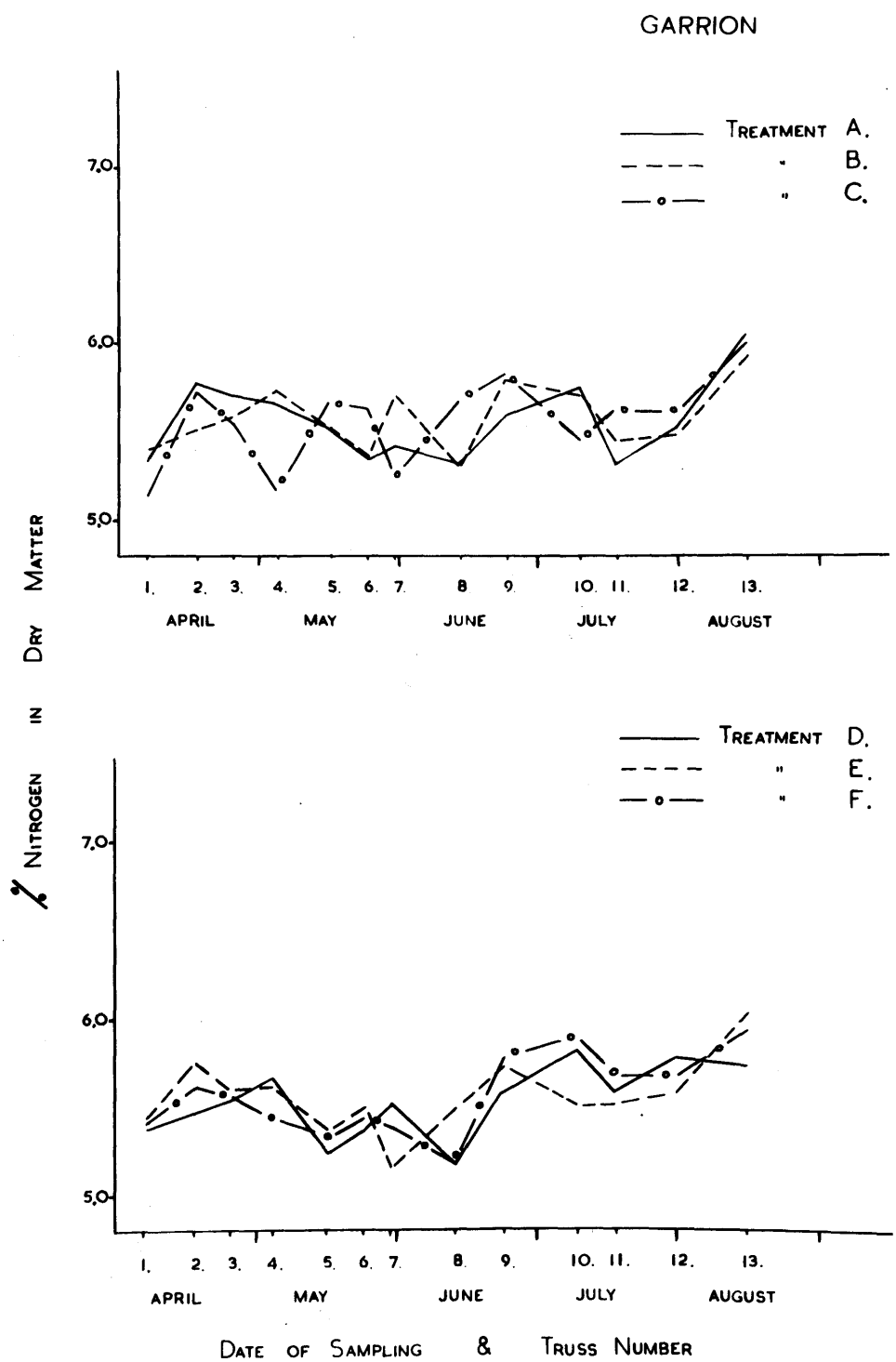
Table:- 28. Centre:- Garrion.

% Nitrogen in dry matter of lamina

"Young" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
6th April	1.	5.35	5.40	5.15	5.38	5.43	5.40
17th "	2.	5.78	5.52	5.73	5.47	5.75	5.62
24th "	3.	5.71	5.59	5.75	5.54	5.59	5.56
4th May	4.	5.67	5.75	5.56	5.67	5.61	5.43
18th "	5.	5.54	5.10	5.17	5.24	5.36	5.35
22nd "	6.	5.36	5.36	5.68	5.36	5.50	5.43
1st June	7.	5.43	5.71	5.64	5.52	5.15	5.39
12th "	8.	5.33	5.32	5.25	5.19	5.50	5.19
22nd "	9.	5.61	5.81	5.68	5.59	5.73	5.78
10th July	10.	5.77	5.73	5.84	5.81	5.50	5.90
17th "	11.	5.33	5.46	5.46	5.59	5.50	5.67
31st "	12.	5.54	5.50	5.63	5.78	5.56	5.66
14th August	13.	6.09	5.96	6.03	5.74	6.03	5.95

The diagrams in this section all refer to constituents in "young" leaves only.



Diag. 19 - % Nitrogen in lamina dry-matter of "young" leaves.

TOMATO EXPERIMENTS, 1950

Table:- 29. Centre:- Garrion.

% Nitrogen in dry matter of lamina

"Old" leaves.

Date of sampling	Truss *	Treatment A	B	C	D	E	F
11th May	2.	4.31	4.34	4.31	4.45	4.37	4.47
25th "	3.	4.54	4.45	4.45	4.45	4.66	4.21
5th June	4.	4.37	4.28	4.44	4.34	4.30	4.34
22nd "	5.	4.48	4.17	4.34	4.34	4.27	4.48
29th "	6.	4.06	4.16	4.17	4.20	4.14	4.17
13th July	7.	3.78	4.09	4.07	4.02	3.93	3.91
26th "	8.	4.02	4.00	4.11	3.98	4.00	4.05

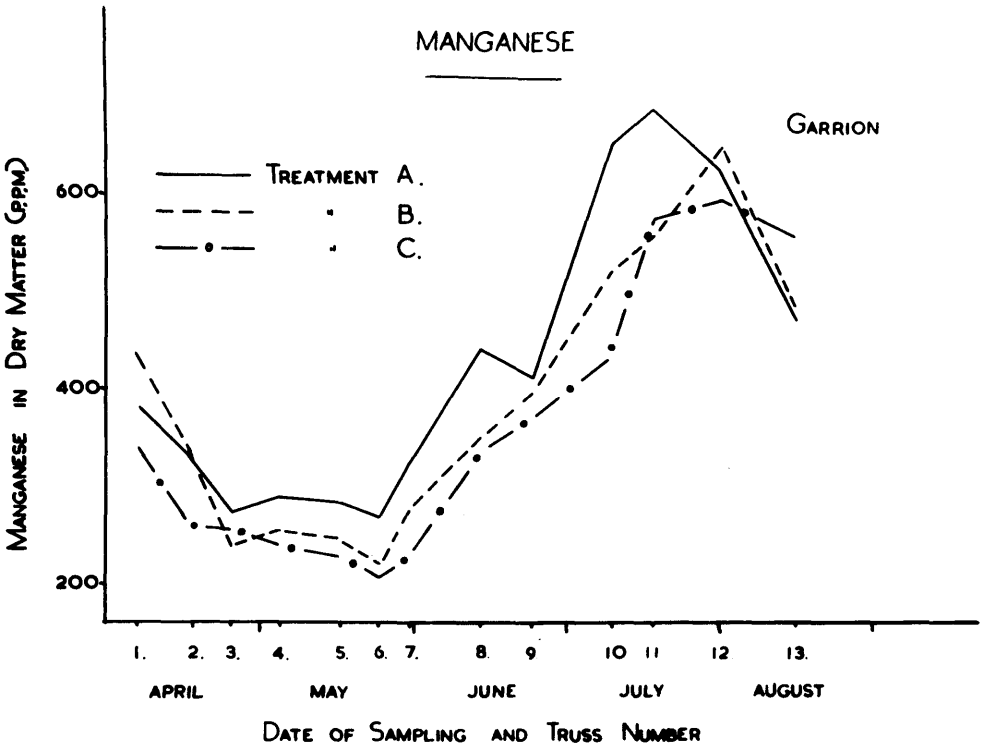
* Leaves associated with Truss 1 were contaminated with soil and were therefore discarded.

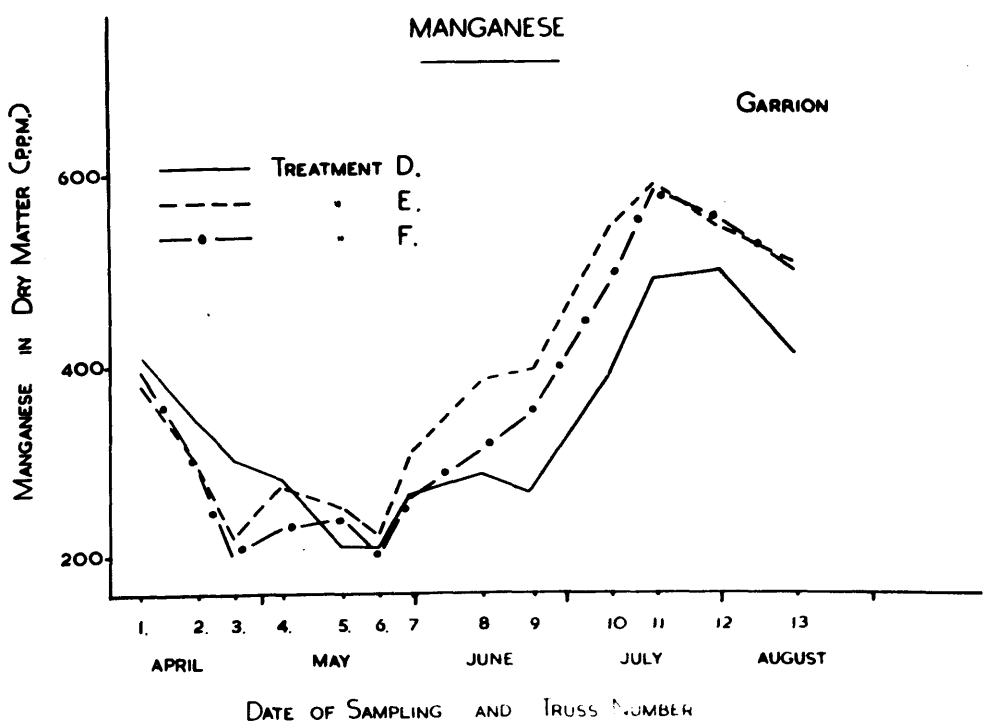
TOMATO EXPERIMENTS, 1950

Table:- 30. Centre:- Garrion.

Concentration (p.p.m.) of Manganese in lamina dry matter - "Young" leaves

Date of sampling	Truss	Treatment A	B	C	D	E	F
6th April	1.	385	440	340	410	380	395
17th "	2.	330	335	260	340	295	295
24th "	3.	275	240	255	300	220	200
4th May	4.	290	255	240	280	270	230
18th "	5.	285	250	230	210	250	240
22nd "	6.	270	220	210	210	220	200
1st June	7.	325	290	230	265	305	260
12th "	8.	445	355	340	285	385	310
22nd "	9.	415	405	375	265	395	350
10th July	10.	655	530	435	390	555	485
17th "	11.	690	565	580	490	590	585
31st "	12.	630	655	600	500	550	555
14th August	13.	475	490	560	410	510	500





Diag. 20 - Concentration of manganese in dry-matter of lamina of "young" leaves.

TOMATO EXPERIMENTS, 1950

Table:- 31. Centre:- Garrion.

Concentration (p.p.m.) of Manganese in lamina dry matter - "Old" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
11th May	2.	430	520	450	540	490	530
25th "	3.	485	370	475	450	435	425
5th June	4.	520	435	400	460	555	470
22nd "	5.	460	495	485	420	480	540
29th "	6.	690	500	500	500	630	485
13th July	7.	870	680	625	580	770	690
26th "	8.	705	610	530	445	680	625

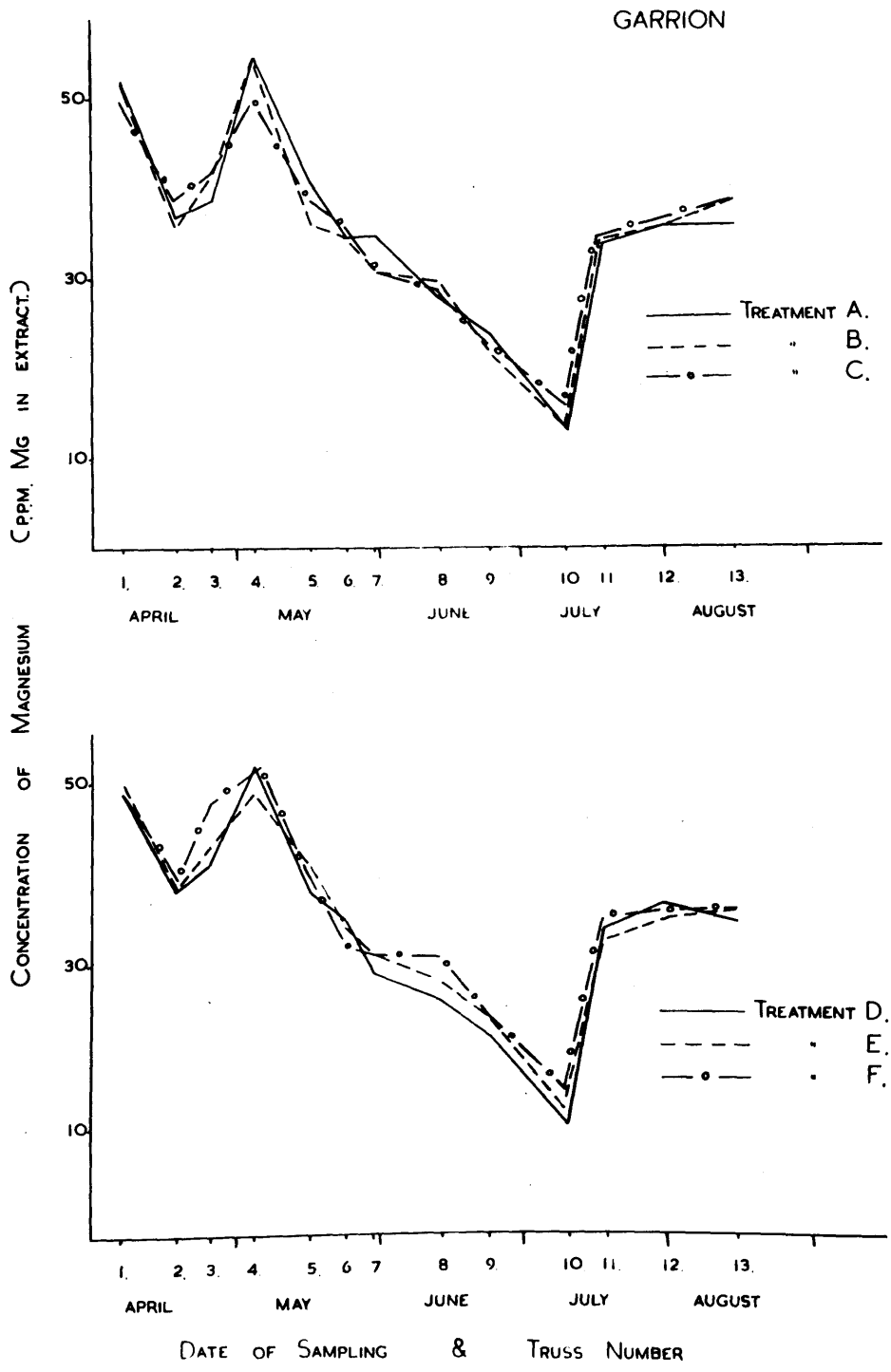
TOMATO EXPERIMENTS, 1950

Table:- 32. Centre:- Garrion.

Concentration (p.p.m.) of Magnesium in extracts of lamina dry matter - "Young" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
6th April	1.	52	52	50	49	50	49
17th "	2,	37	36	39	38	38	39
24th "	3.	39	42	42	41	43	48
4th May	4.	55	55	50	52	49	52
18th "	5.	41	36	39	38	41	40
22nd "	6.	35	35	36	35	34	32
1st June	7.	35	31	31	29	31	29
12th "	8.	28	30	29	26	28	29
22nd "	9.	24	22	23	22	24	24
10th July	10.	13	13	16	12	13	16
17th "	11.	34	34	34	34	33	35
31st "	12.	36	36	36	37	35	36
14th August	13.	36	39	39	35	36	36

MAGNESIUM



Diag. 21 - Concentration of magnesium in extracts of dry-matter of lamina of "young" leaves.

TOMATO EXPERIMENTS, 1950

Table:- 33. Centre:- Garrion.

Concentration (p.p.m.) of Magnesium in extracts of lamina dry matter - "Old" leaves.

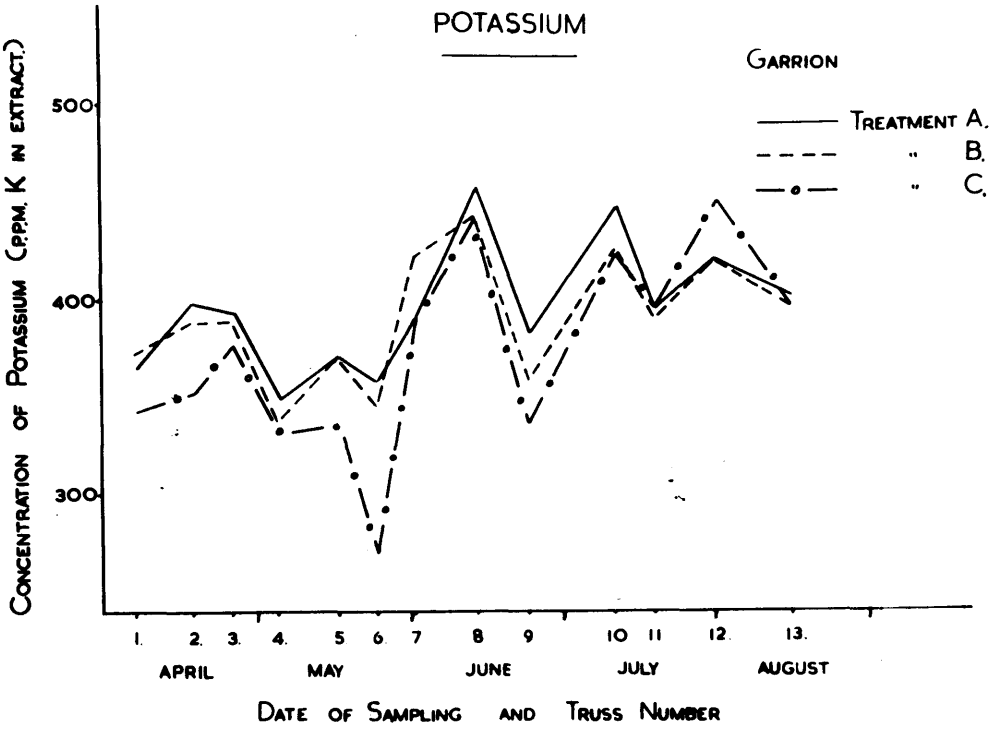
Date of sampling	Truss	Treatment A	B	C	D	E	F
11th May	2.	26	25	23	23	20	22
25th "	3.	38	40	39	39	38	40
5th June	4.	38	38	40	39	39	38
22nd "	5.	38	33	34	34	34	37
29th "	6.	28	25	28	28	28	29
13th July	7.	33	35	34	34	33	33
26th "	8.	28	33	32	33	34	33

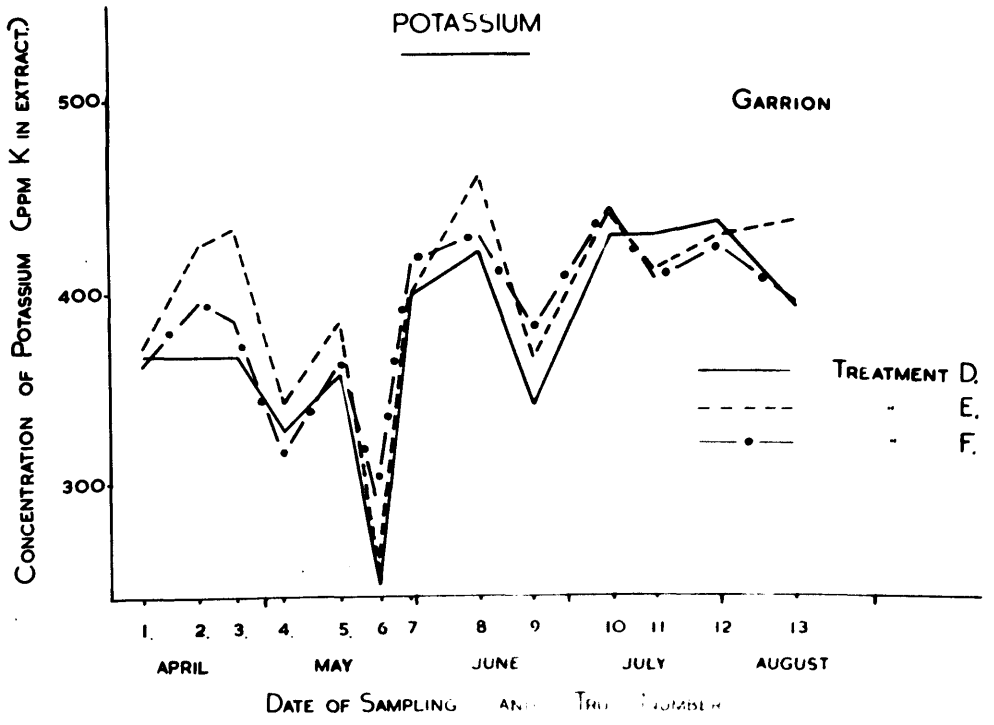
TOMATO EXPERIMENTS, 1950

Table:- 34. Centre:- Garrion.

Concentration (p.p.m.) of Potassium in extracts of lamina dry matter - "Young" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
6th April	1.	365	373	343	365	370	360
17th "	2.	400	390	353	365	425	395
24th "	3.	395	390	378	365	433	383
4th May	4.	350	338	333	325	341	315
18th "	5.	373	373	337	355	383	363
22nd "	6.	360	347	270	240	247	290
1st June	7.	393	424	393	398	397	415
12th "	8.	460	445	445	420	460	428
22nd "	9.	385	360	338	338	363	380
10th July	10.	450	428	425	428	440	442
17th "	11.	398	393	398	428	410	405
31st "	12.	424	424	453	437	428	424
14th August	13.	405	398	398	390	437	393





Diag. 22 - Concentration of potassium in extracts of dry-matter of lamina of "young" leaves.

TOMATO EXPERIMENTS, 1950

Table:- 35. Centre:- Garrion.

Concentration (p.p.m.) of Potassium in extracts of lamina dry matter - "Old" leaves.

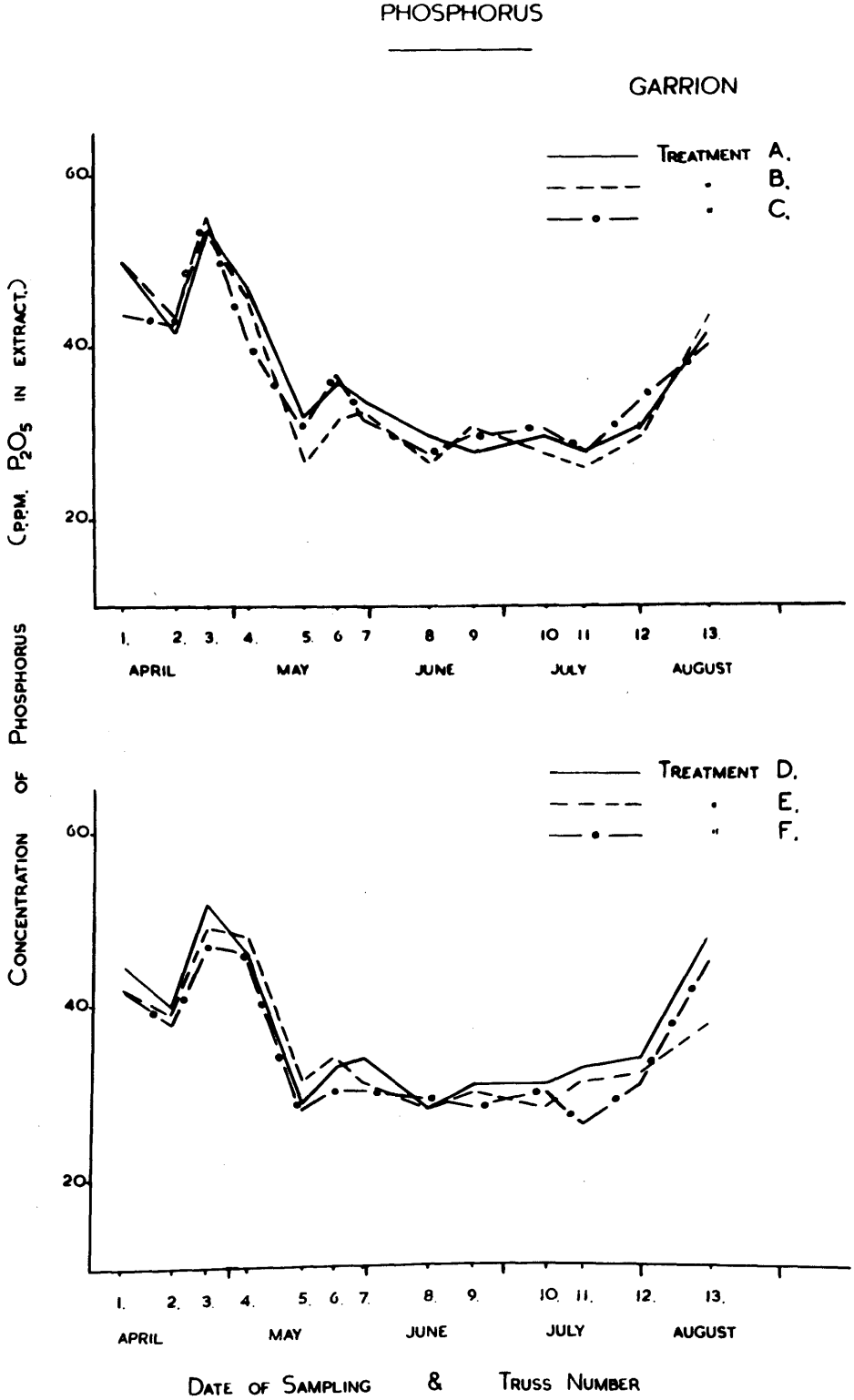
Date of sampling	Truss	Treatments A	B	C	D	E	F
11th May	2.	253	243	233	283	213	238
25th "	3.	428	420	428	428	415	405
5th June	4.	397	355	415	368	398	415
22nd "	5.	347	327	338	330	390	350
29th "	6.	323	327	347	290	305	318
13th July	7.	442	298	293	298	415	428
26th "	8.	483	470	424	390	470	437

TOMATO EXPERIMENTS, 1950

Table:- 36. Centre:- Garrion.

Concentration (p.p.m.) of Phosphorus in extracts of lamina dry matter - "Young" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
6th April	1.	50	50	44	45	42	42
17th "	2.	42	44	43	40	39	38
24th "	3.	54	54	55	52	49	47
4th May	4.	47	46	41	46	48	46
18th "	5.	32	27	31	29	31	28
22nd "	6.	36	32	37	33	34	30
1st June	7.	34	33	32	34	31	30
12th "	8.	30	27	28	28	28	29
22nd "	9.	28	31	30	31	30	28
10th July	10.	30	28	31	31	28	30
17th "	11.	28	26	28	33	31	26
31st "	12.	31	30	34	34	32	31
14th August	13.	42	44	41	48	38	45



Diag. 23 - Concentration of phosphorus in extracts of dry-matter of lamina of "young" leaves.

TOMATO EXPERIMENTS, 1950

Table:- 37. Centre:- Garrion.

Concentration (p.p.m.) of Phosphorus in extracts of lamina dry matter - "Old" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
11th May	2.	19	26	23	25	21	24
25th "	3.	42	34	39	41	43	36
5th June	4.	32	37	40	34	40	35
22nd "	5.	36	36	32	32	30	34
29th "	6.	30	28	25	30	28	28
13th July	7.	28	30	30	31	28	29
26th "	8.	30	29	30	37	32	30

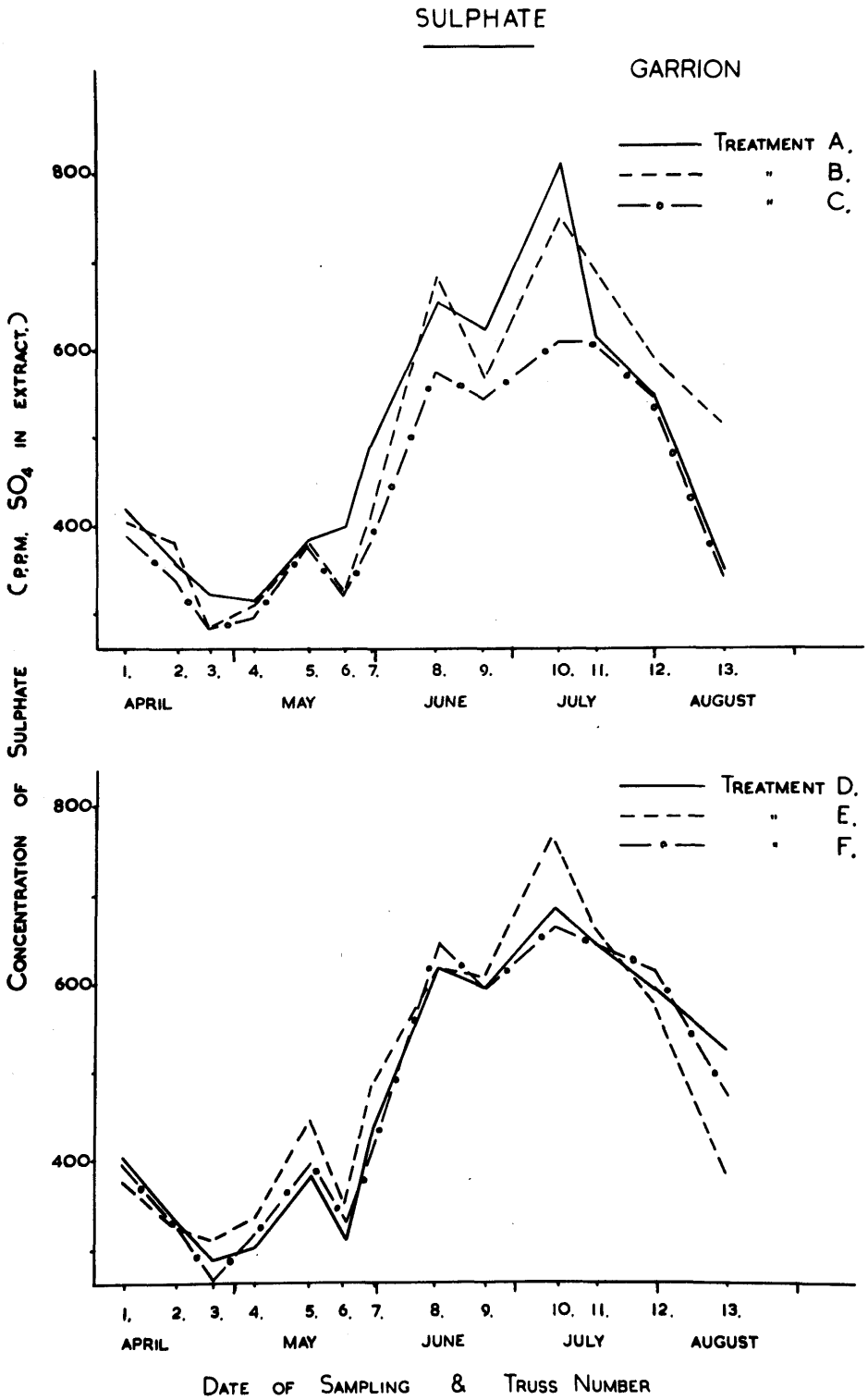
TOMATO EXPERIMENTS, 1950

Table:- 38. Centre:- Garrion.

Concentration (p.p.m.) of Sulphate in extracts of lamina dry matter - "Young" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
6th April	1.	420	405	385	405	375	395
17th "	2.	360	380	338	333	328	328
24th "	3.	323	283	283	287	310	238
4th May	4.	315	310	295	300	333	315
18th "	5.	385	385	385	380	445	395
22nd "	6.	400	323	323	310	350	330
1st June	7.	490	410	380	438	483	410
12th "	8.	655	685	575	618	618	645
22nd "	9.	625	568	545	593	610	593
10th July	10.	813	753	610	685	772	663
17th "	11.	620	620	610	643	662	643
31st "	12.	550	588	545	588	578	615
14th August	13.	350	513	350	525	383	475

Note:- These figures correspond to a figure of the order of 4% of sulphate (say 1.0 - 1.5% or more of sulphate sulphur) in the dry matter of the lamina of "young" leaves.



Diag. 24 - Concentration of sulphate in extracts of dry-matter of lamina of "young" leaves.

TOMATO EXPERIMENTS, 1950

Table:- 39. Centre:- Garrion.

Concentration (p.p.m.) of Sulphate in extracts of lamina dry matter - "Old" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
11th May	2.	263	305	238	225	185	185
25th "	3.	685	675	628	700	650	660
5th June	4.	745	752	753	753	788	738
22nd "	5.	943	1025	973	910	958	985
29th "	6.	973	853	843	938	938	973
13th July	7.	1170	1063	982	938	1073	1085
26th "	8.	920	888	828	888	928	980

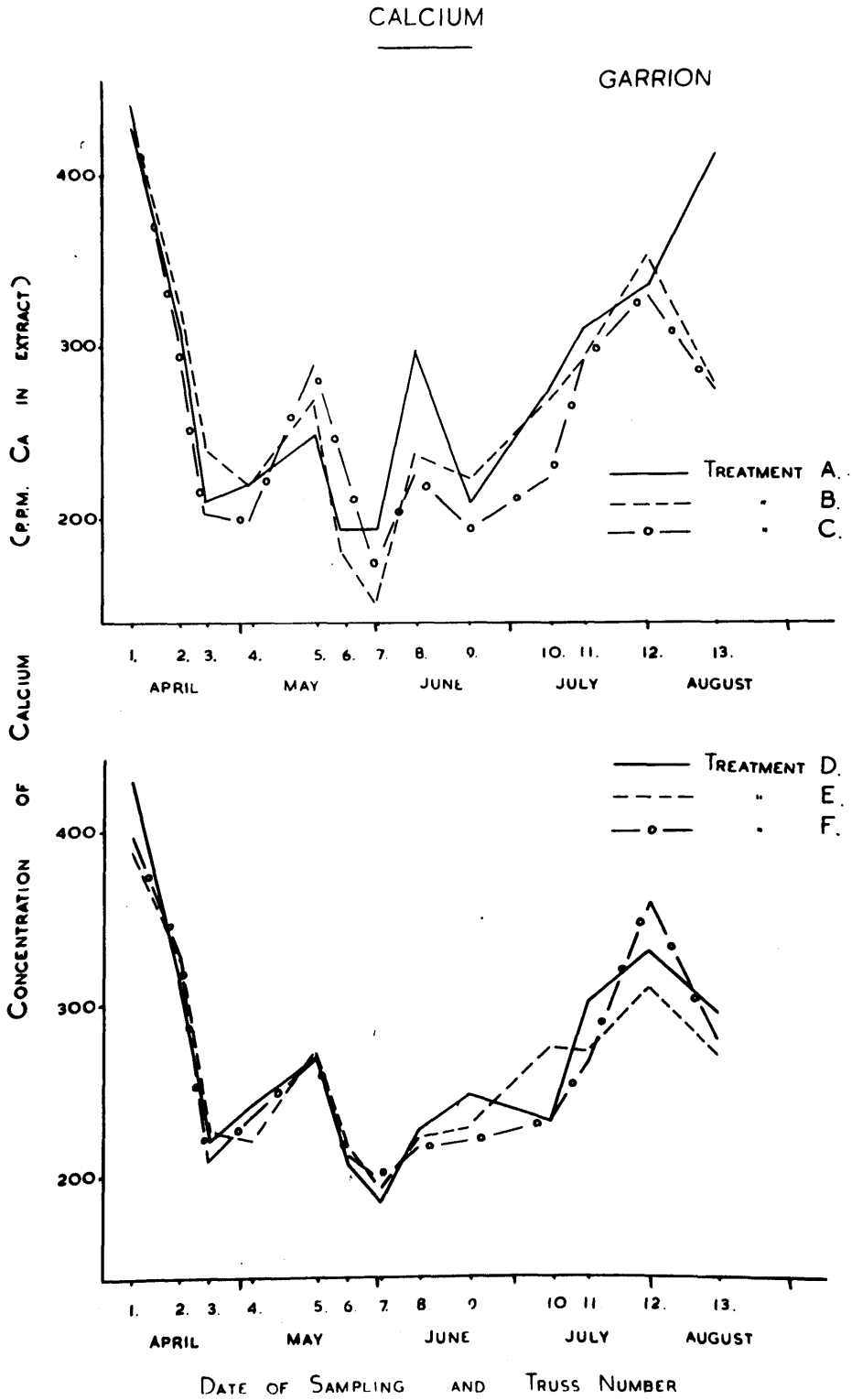
Note:- Corresponding to about 2.5 - 12% of sulphate (0.8 - 4% of sulphate sulphur) in the dry matter of lamina of "old" leaves.

TOMATO EXPERIMENTS, 1950

Table:- 40. Centre:- Garrion.

Concentration (p.p.m.) Of Calcium in extracts of lamina dry matter - "Young" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
6th April	1.	428	428	443	430	390	398
17th "	2.	313	325	305	313	325	325
24th "	3.	213	240	205	220	225	208
4th May	4.	223	220	200	240	220	233
18th "	5.	250	270	293	268	270	268
22nd "	6.	195	180	240	205	215	210
1st June	7.	195	150	175	183	190	195
12th "	8.	300	240	228	225	220	215
22nd "	9.	210	225	195	245	225	218
10th July	10.	278	270	223	230	273	230
17th "	11.	313	293	293	300	270	265
31st "	12.	338	355	333	330	308	358
14th August	13.	415	280	278	293	268	278



Diag. 25 - Concentration of calcium in extracts of dry-matter of lamina of "young" leaves.

TOMATO EXPERIMENTS, 1950

Table:- 41. Centre:- Garrion.

Concentration (p.p.m.) of Calcium in extracts of lamina dry matter - "Old" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
11th May	2.	203	258	210	188	163	163
25th "	3.	503	515	505	510	470	550
5th June	4.	510	543	520	503	515	538
22nd "	5.	515	505	515	510	500	530
29th "	6.	503	435	470	503	490	495
13th July	7.	475	455	483	478	470	463
26th "	8.	475	483	465	510	475	470

TOMATO EXPERIMENTS, 1950

Table:- 42. Centre:- Garrion.

Weight (g.) of dry matter in lamina

"Young" leaves

Date of sampling	Truss	Treatment A	B	C	D	E	F
6th April	1.	1.03	1.04	1.03	1.06	1.10	1.13
17th "	2.	2.05	2.03	1.83	1.97	1.93	1.92
24th "	3.	2.70	2.42	2.26	2.58	2.35	2.34
4th May	4.	2.37	1.93	2.00	2.13	2.15	2.23
18th "	5.	2.08	2.12	2.03	1.97	2.14	2.17
22nd "	6.	1.65	1.49	1.57	1.56	1.70	1.81
1st June	7.	1.48	1.52	1.53	1.86	1.62	1.62
12th "	8.	1.60	1.61	1.69	1.55	1.60	1.50
22nd "	9.	1.48	1.50	1.19	1.68	1.61	1.49
10th July	10.	1.06	1.14	0.82	1.05	1.27	1.02
17th "	11.	1.25	1.19	1.47	1.16	1.20	0.92
31st "	12.	1.14	1.06	1.13	1.13	1.14	1.18
14th August	13.	0.84	0.97	0.82	0.91	0.90	0.92

TOMATO EXPERIMENTS, 1950

Table:- 43. Centre:- Garrion.

Weight(g.) of dry matter in lamina

"Old" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
11th May	2.	2.40	2.66	2.39	2.76	2.71	3.02
25th "	3.	4.04	4.04	3.68	4.08	3.58	4.02
5th June	4.	3.12	3.29	3.10	3.02	3.24	3.33
22nd "	5.	2.90	2.76	2.80	2.97	3.05	3.42
29th "	6.	2.50	2.48	2.98	2.44	2.70	2.47
13th July	7.	2.25	2.41	2.75	2.48	2.67	2.50
26th "	8.	2.13	2.36	2.64	2.22	2.45	2.23

TOMATO EXPERIMENTS, 1950

Table:- 44. Centre:- Garrion. Treatment:- A.

Total weight (mg.) of nutrients present in lamina of "Young" leaves.

Leaf - associated with Truss	Extractable K	Mg	P	SO_4	Ca	Total N	Mn
1.	37.6	5.4	5.2	43.3	44.1	55.1	0.40
2.	82.0	7.6	8.6	73.8	64.2	118.2	0.68
3.	106.6	10.5	14.9	87.2	57.5	154.0	0.74
4.	82.9	13.0	11.1	74.6	52.8	134.4	0.69
5.	77.6	8.5	6.7	80.1	52.0	115.2	0.59
6.	99.4	5.8	5.9	66.0	32.2	88.4	0.45
7.	58.2	5.2	5.0	72.5	28.9	80.3	0.48
8.	73.6	4.5	4.8	104.7	48.0	85.3	0.71
9.	57.0	3.6	4.1	92.5	31.0	83.0	0.61
10.	47.7	1.4	3.2	86.2	29.5	61.2	0.69
11.	49.7	4.3	3.5	77.5	39.1	66.6	0.86
12.	48.3	4.1	3.5	62.7	38.5	63.2	0.72
13.	34.0	3.0	3.5	32.8	34.9	51.2	0.40

TOMATO EXPERIMENTS, 1950

Table:- 45. Centre:- Garrion. Treatment:- A.

Comparison of composition of dry matter[x] of lamina(L) and petiole (P) of "Young" leaves.

Date of sampling	Truss	Ext*P		Ext* K		Ext*Ca		Ext*Mg		Ext*SO_4		Total Mn+		Total°N	
		L	P	L	P	L	P	L	P	L	P	L	P	L	P
17/4	2.	42	51	400	850	313	180	37	58	360	72	330	145	5.78	3.54
24/4	3.	54	55	395	875	213	128	39	45	323	62	275	145	5.71	3.26
4/5	4.	47	52	350	825	223	107	55	45	315	76	290	145	5.67	3.15
18/5	5.	32	47	373	750	250	135	41	50	385	86	285	155	5.54	2.90
22/5	6.	36	46	360	750	195	117	35	47	400	89	270	170	5.36	3.11
1/6	7.	34	42	393	775	195	89	35	42	490	106	325	190	5.43	2.88
12/6	8.	30	32	460	850	300	67	28	33	655	140	445	200	5.33	2.63
22/6	9.	28	23	385	788	210	95	24	25	625	140	415	255	5.61	2.62
10/7	10.	30	17	450	825	278	107	13	19	813	250	655	345	5.77	2.76
17/7	11.	28	17	398	900	313	98	34	30	620	212	690	370	5.33	2.32
31/7	12.	31	22	424	850	338	110	36	30	550	196	630	395	5.54	2.66
14/8	13.	42	31	405	950	415	119	36	30	350	76	475	315	6.09	3.11

* p.p.m. in extract (1 g./100 ml. Morgan's reagent) + p.p.m. in D.M. ° % in D.M.

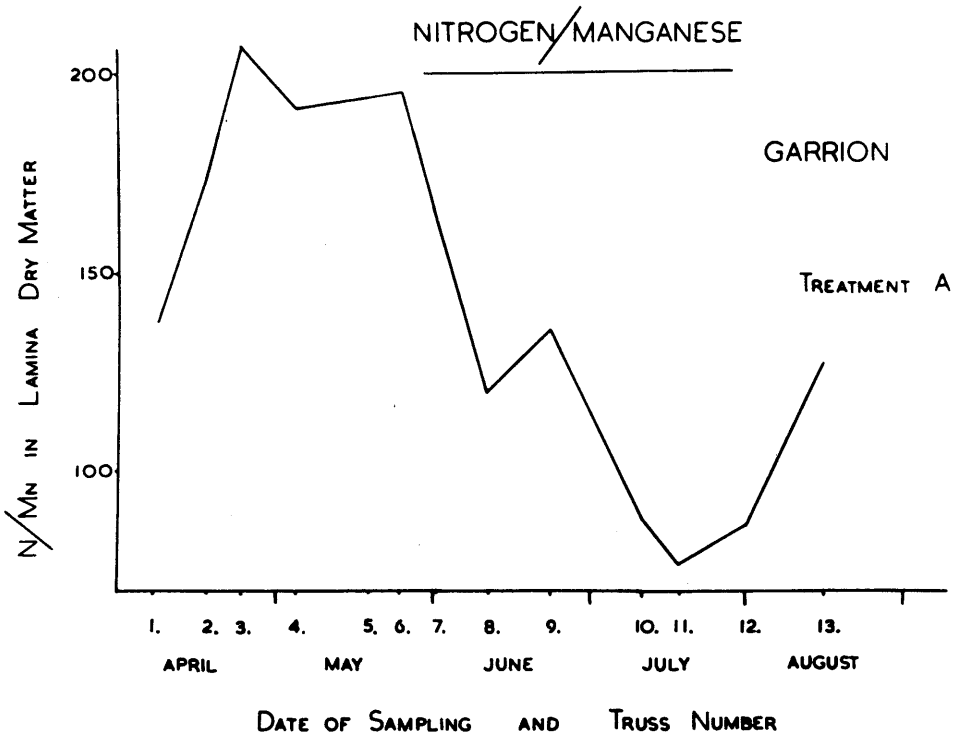
x Lamina contains about 11%, petiole about 7% of dry-matter.

TOMATO EXPERIMENTS, 1950

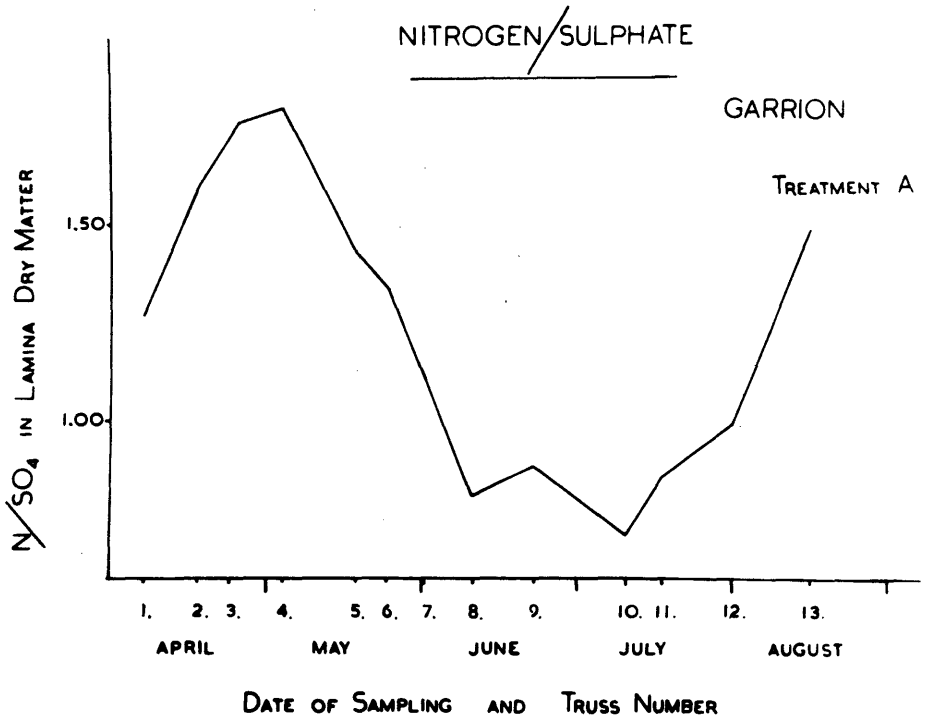
Table:- 46. Centre:- Garrion.

Ratios of nutrients in lamina of "Young" leaves from plants treated with sulphate of ammonia and sulphate of potash (Treatment A).

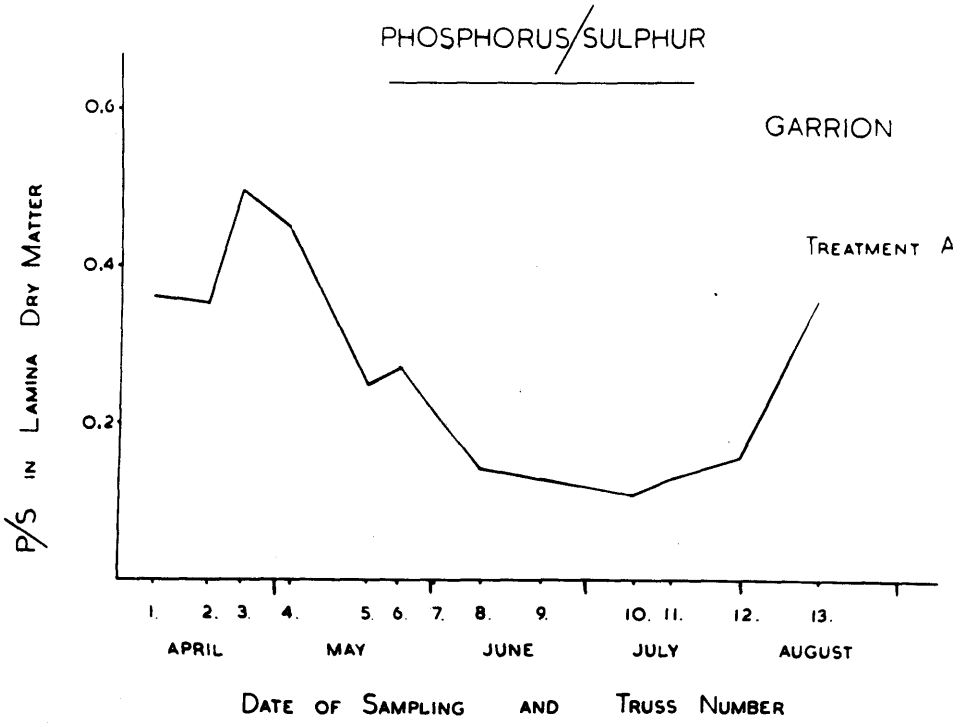
Leaf - associated with truss	Ratio N/Mn	Ratio N/SO_4	Ratio P/S
1.	138	1.27	0.36
2.	174	1.60	0.35
3.	208	1.77	0.50
4.	192	1.80	0.45
5.	195	1.43	0.25
6.	196	1.34	0.27
7.	167	1.11	0.21
8.	120	0.81	0.14
9.	136	0.89	0.13
10.	88	0.71	0.11
11.	77	0.86	0.13
12.	87	1.00	0.16
13.	128	1.50	0.36



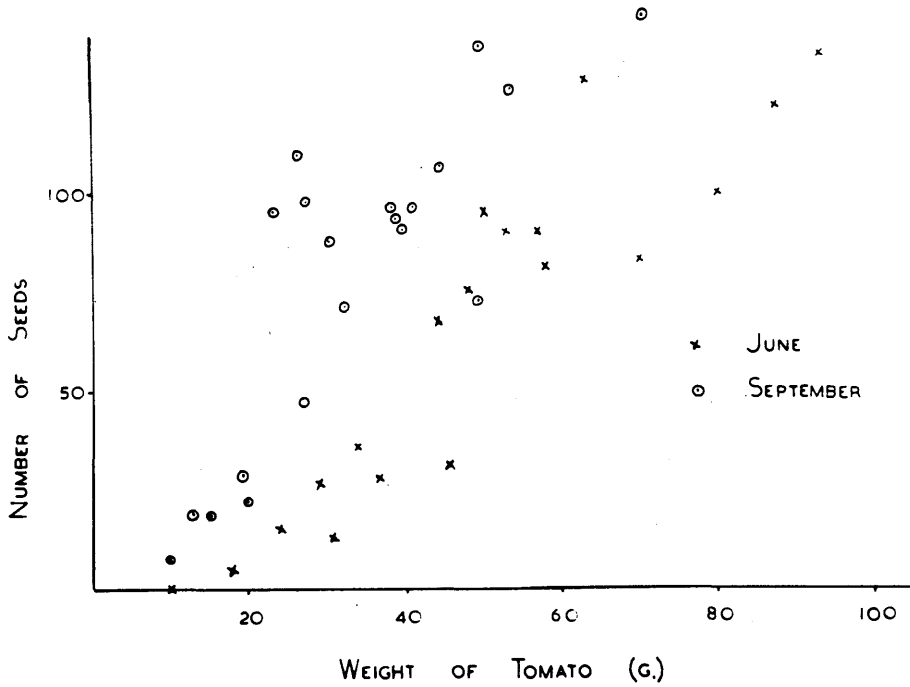
Diag. 26 - Ratio of total nitrogen to total manganese in dry-matter of lamina of "young" leaves.



Diag. 27 - Ratio of total nitrogen to extractable sulphate in dry-matter of lamina of "young" leaves.



Diag. 28 - Ratio of extractable phosphorus to extractable sulphate-sulphur in dry-matter of lamina of "young" leaves.



Diag. 29 - Graph of number of seeds per fruit against weight of fruit.

NOTES ON RESULTS OF EXPERIMENTS AT GARRION.

In the early stages the plants grew strongly and produced a heavy crop of fruit but by the 8th or 9th trusses a very obvious check took place. The plants became thin and trusses were small (see Table 25 and Diagram 18). There was some indication of a recovery in growth towards the end of the season after the bottom fruit had been removed. A severe attack of mildew greatly reduced the chances of a top crop. This crop is a good example of plants producing heavy yields on the bottom trusses resulting in exhaustion of the plants.

Pruning Experiment:- Results show that the total yields from the pruned plots (treatments B and C) were significantly lower than the control (Table 23). Bad setting conditions throughout the whole unit during the flowering of the 2nd truss resulted in a decrease in the percentage of flowers set. The result was that the 2nd trusses of the B and C plots with their reduced number of flowers gave a lower yield than the control. A reduction in strain brought about by the pruning of the first five trusses is shown by the increased yield of the 6th and 7th trusses (see Diagram 18). By the 8th truss/

truss, however, the beneficial effect of pruning had disappeared, and later trusses show similar yields to the control.

The estimated yields of first 5 trusses (Table 24) show that the apical and basal pruning (treatment C) has caused a greater reduction in yield of pruned trusses than pruning the apex of the truss alone (treatment B). The effect of pruning on reduction of strain on the plant is also shown in the higher yields of the 6th and 7th trusses of treatment C as compared with treatment B (see Diagram 18). The removal of the basal flowers is not a satisfactory method of pruning. It was noted during the season that the chances of the basal flowers setting are much higher than are those of the other flowers of the truss. Removing the basal flowers therefore tends to decrease the percentage of flowers set.

With treatment B (pruning of apex of truss: scheme (i)) there is an indication, however, that the reduction in yield consisted mainly of small-sized fruit and that the yield of large fruit (L.A. and A.) was not affected (Table 24).

Treatments A, D, E and F:- The yields of fruit from these treatments were almost identical. There were no differences/

differences between the sulphate of ammonia (treatment A) and nitrate of potash (treatment D), nor had there been any advantage from the stimulant of nitrate of potash and potassium phosphate (treatment E), nor from the increased dressings of treatment F. There is no control (no-nitrogen plots) for comparison; and therefore, it is not possible to say whether there has been a response to nitrogen; but the pertinent result is that an adequate dressing of nitrogen supplied at regular intervals throughout the season failed to prevent a serious check in growth.

Seed production :- Diagram 29 shows that there is a fairly close correlation between the number of seeds and weight of tomato produced, but it varies between the beginning and end of season. It seems likely that the size of the fruit depends on the number of seeds produced. This hypothesis is interesting in view of the findings of Luckwill (10). He suggested that a diffusible substance, such as phloridzin, present in the seeds of immature apples does actually control their growth.

The smaller weight/seed ratio found in tomatoes later in the season, may perhaps be attributed to a deficiency of nutrients then prevailing.

Tissue Analyses:- Tissue analyses results are given in/

in Tables 28 - 46 and are illustrated in Diagrams 19 - 28.

The "check period" at Garrion in 1950 was unusually long. It lasted through roughly the whole of July and August. The normal duration (when there is a "check period" at all) is about a month, and the onset is usually mid- or late June. The Garrion results are therefore exceptionally instructive about the relations between "checking" and the observed constituents of the laminae.

The most important results are:-

1. The percentage of nitrogen in the dry-matter of the lamina has remained at a fairly constant level (see Diagram 19). There is no distinct minimum value of nitrogen during the "check period" as was found at Law nursery in 1948. The percentage of nitrogen appears to have been at a satisfactory level throughout the whole season.

2. The manganese concentration during the early stages of growth when trusses were producing good yields, was fairly low; but it rose rapidly after the middle of June - at the beginning of the "check period" - to values of twice the initial concentration and more (see Diagram 20). This rapid rise to a sustained high concentration of manganese at the "check period" is in agreement with results found in 1948 at Law nursery (see p. 26).

3. The concentration of extractable sulphate shows a variation similar to that of manganese (see Diagram 24).

4. Extractable potassium in the lamina was inversely related to extractable magnesium (see Diagrams 21 and 22). In this respect the Garrion results confirm those of all other centres.

5. Slight magnesium-deficiency symptoms observed during July corresponded with a low level of extractable magnesium in the lamina of "young" leaves.

6. The magnesium deficiency just mentioned coincided with the "check period" but this magnesium deficiency was not the cause of "checking"; for the deficiency disappeared - as shown by visual signs and by analysing the lamina for extractable magnesium - during the second month (August) of the "check period".

This finding is alone sufficient to suggest strongly that there is no causal relation between "checking" and magnesium deficiency.

Taken in conjunction with the results from other centres in the same and preceding years, it affords apparently irrefragable ground for rejecting a belief that magnesium deficiency is a cause of "checking", or that the two are associated (unless accidentally).

Checking may be a "cause" of magnesium deficiency, since/

since the latter often follows a "check period". probably, however, appearance of magnesium deficiency late in the season is a seasonal effect not to be imputed directly to the preceding "check" (if any).

EXPERIMENT AT RAVENSWOOD, 1950.

The experiment at Ravenswood was designed to study the effects of two levels of nitrogen-supply, the nitrogen here being applied as nitro-chalk and nitrate of potash (at Garrion nitro-chalk was not used). In order to compare nitro-chalk and nitrate of potash, sulphate of potash was applied with the nitro-chalk so that the N/K_2O was the same in all treatments. The nitro-chalk introduced ammonia-nitrogen as well as nitrate-nitrogen. At Ravenswood no flower-pruning was done.

The treatments were as follows:-

Treatment A. No nitrogen applied - control.

Treatment B. 8 lb. N as nitro-chalk + 26.7 lb. K_2O as sulphate of potash (S/P) per "100 ft." (1500 sq. ft.).

Treatment C. 16 lb. N as nitro-chalk + 53.4 lb. K_2O as sulphate of potash per 100 ft.

Treatment D. 8 lb. N + 26.7 lb. K_2O as nitrate of potash per 100 ft.

Treatment E. 16 lb. N + 53.4 lb. K_2O as nitrate of potash per 100 ft.

Treatment F. As for treatment E + 10 lb. P_2O_5 per 100 ft. as potassium phosphate.

Size of plot/

Size of plot:- 20 plants per plot - 5 x 4. A buffer row of plants was left unmanured between each plot. The area of each plot was 10.8 x 6 sq. ft. = 11/200 of 100-ft.-house.

Variety:- "Aldourie".

Samples for analyses:- Samples for analysis were taken similarly to those at Garrion.

RESULTS OF EXPERIMENTS AT RAVENSWOOD.

TOMATO EXPERIMENTS, 1950

Table:- 47. Centre:- Ravenswood.

Yields of fruit

Treatment	Plot yield lb.	Mean plot yield lb.	Mean plant yield lb.	Yield per 100ft. cwt.
A.	117 95 110 97	104.8	5.24	19.69
B.	96 103 95 114	102.0	5.10	19.17
C.	92 98 126 128	111.3	5.57	20.92
D.	72 118 123 123	109.0	5.45	20.49
E.	73 113 116 128	107.5	5.38	20.21
F.	100 80 107 135	105.5	5.28	19.83

Mean - 19.93 cwt. per 100 ft.

Standard Error - ± 1.32 cwt. per 100 ft.

TOMATO EXPERIMENTS, 1950

Table:- 48. Centre:- Ravenswood.

% Nitrogen in dry matter of lamina

"Young" leaves

Date of sampling	Truss	Treatment A	B	C	D	E	F
6th April	1.	5.36	5.40	5.46	5.60	5.32	5.49
20th "	2.	5.54	5.57	5.60	5.66	5.66	5.88
1st May	3.	5.46	5.46	5.66	5.63	5.60	5.80
11th "	4.	4.75	5.26	5.33	5.35	5.47	5.53
22nd "	5.	4.98	5.54	5.56	5.53	5.35	5.73
1st June	6.	4.84	5.38	5.39	5.31	5.61	5.60
12th "	7.	4.72	5.19	5.39	5.08	5.35	5.30
26th "	8.	4.84	5.47	5.57	5.52	5.63	5.75
7th July	9.	5.25	5.68	5.66	5.42	5.57	5.54
21st "	10.	4.94	5.04	5.36	5.36	5.30	5.57
7th August	11.	4.91	5.14	5.36	5.32	5.63	5.24
18th "	12.	4.56	4.93	4.94	5.00	5.28	5.04

The diagrams in this section all refer to constituents in the lamina of "young" leaves only.

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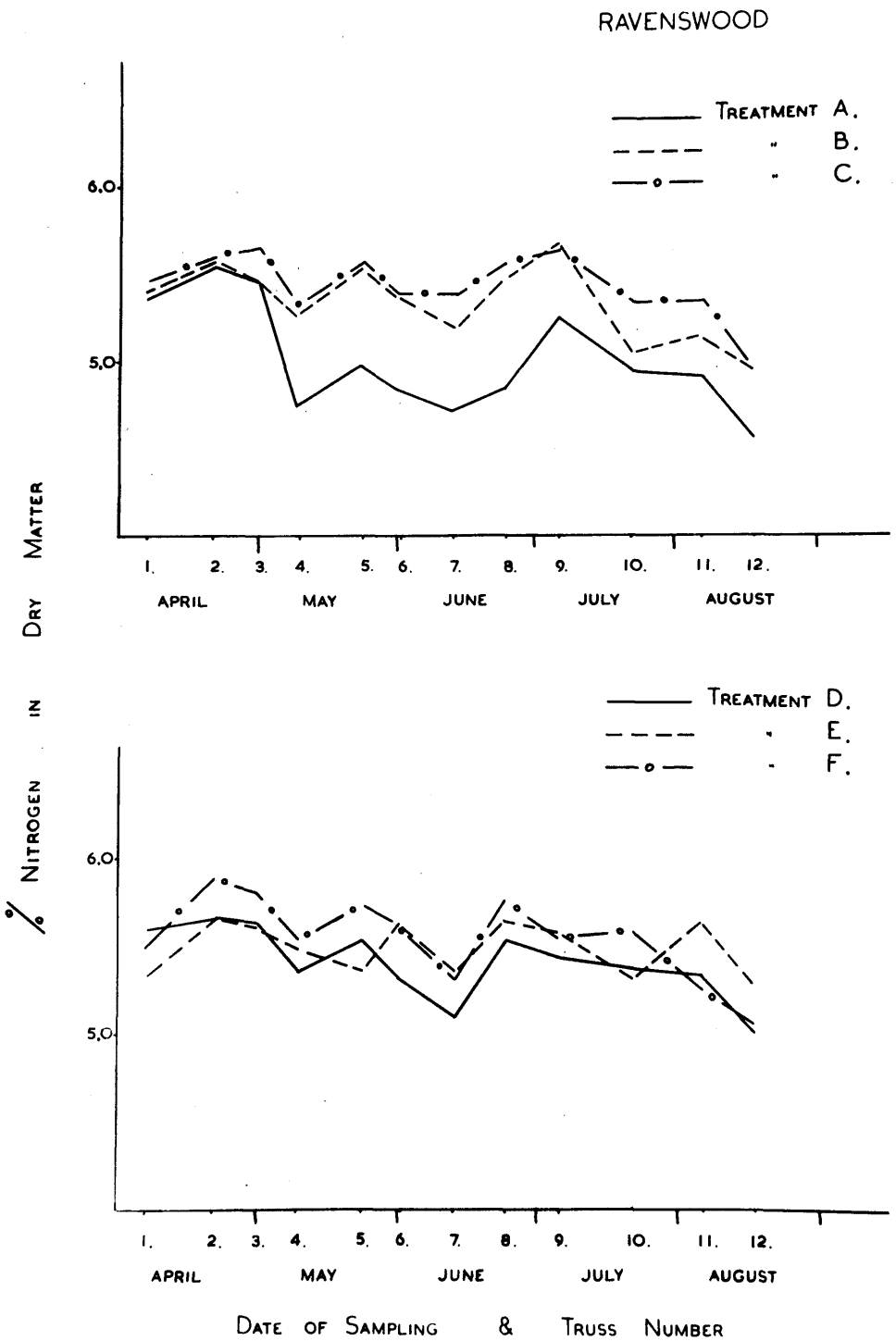


Diag. 30 - % Nitrogen in dry-matter of lamina of "young" leaves.

TOMATO EXPERIMENTS, 1950.

Table:- 49. Centre:- Ravenswood.

% Nitrogen in dry matter of lamina

"Old" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
25th May	2.	3.70	3.93	3.98	3.89	4.29	4.20
5th June	3.	3.44	3.49	4.09	3.91	4.42	4.66
26th "	4.	3.53	3.96	4.23	4.06	3.93	4.17
29th "	5.	3.72	4.24	4.47	4.30	4.24	4.51
13th July	6.	3.39	4.06	4.14	3.92	4.20	4.26
24th "	7.	3.29	3.91	4.00	3.84	4.24	4.16
31st "	8.	3.02	3.86	3.95	3.88	3.86	4.07

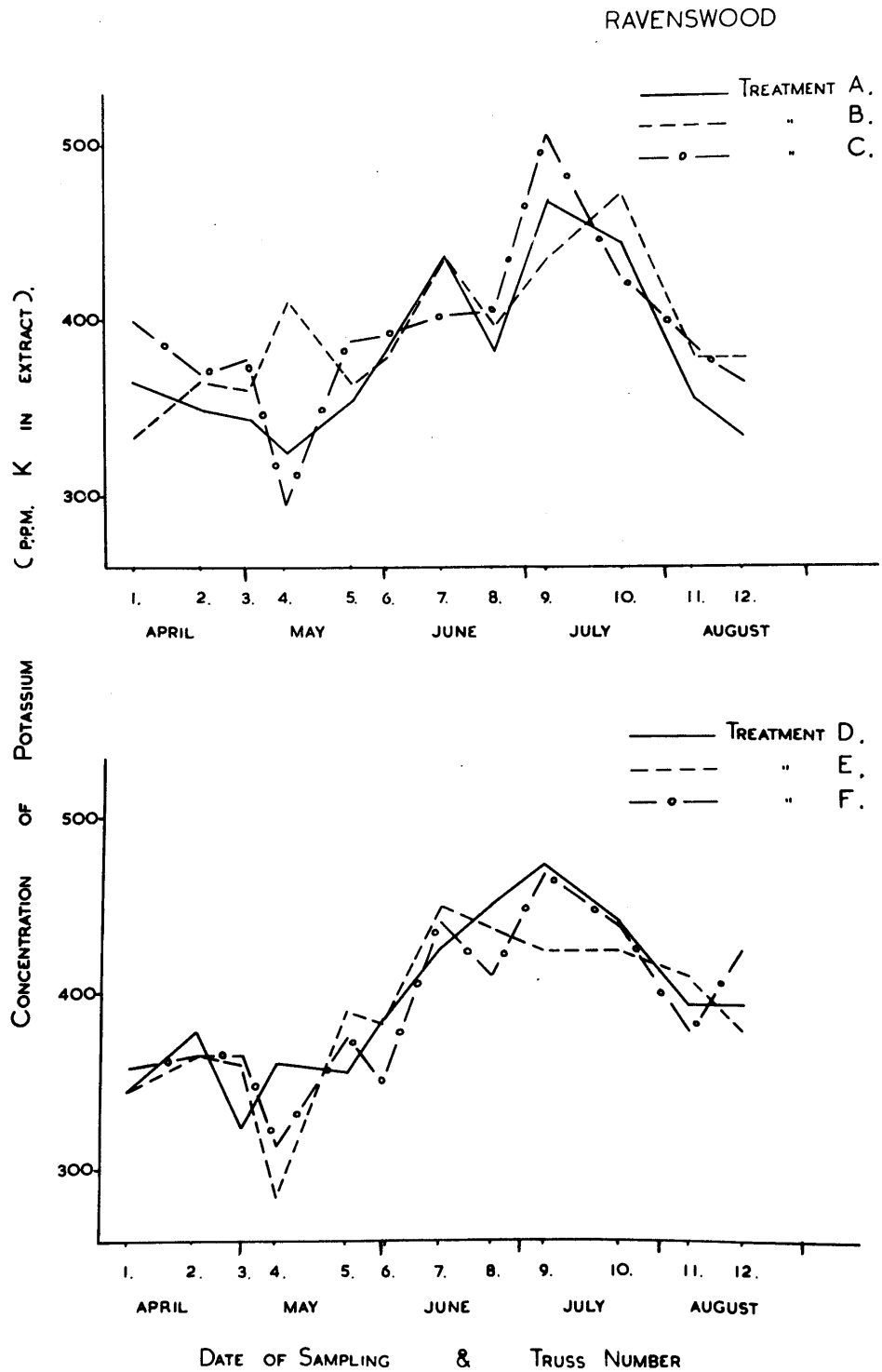
TOMATO EXPERIMENTS, 1950

Table:- 50. Centre:- Ravenswood.

Concentration (p.p.m.) of Potassium in extracts of lamina dry matter - "Young" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
6th April	1.	365	335	400	345	345	358
20th "	2.	350	365	370	378	365	365
1st May	3.	345	360	378	324	350	365
11th "	4.	325	410	295	360	283	315
22nd "	5.	355	363	390	355	390	375
1st June	6.	385	380	393	385	383	350
12th "	7.	437	437	403	424	450	440
26th "	8.	383	398	405	450	437	410
7th July	9.	470	437	507	473	424	468
21st "	10.	445	473	425	440	425	438
7th August	11.	355	378	385	393	410	378
18th "	12.	333	378	365	393	378	425

POTASSIUM



Diag. 31 - Concentration of potassium in extracts of dry-matter of lamina of "young" leaves.

TOMATO EXPERIMENTS, 1950

Table:- 51. Centre:- Ravenswood.

Concentration (p.p.m.) of Potassium in extracts of lamina dry matter - "Old" leaves.

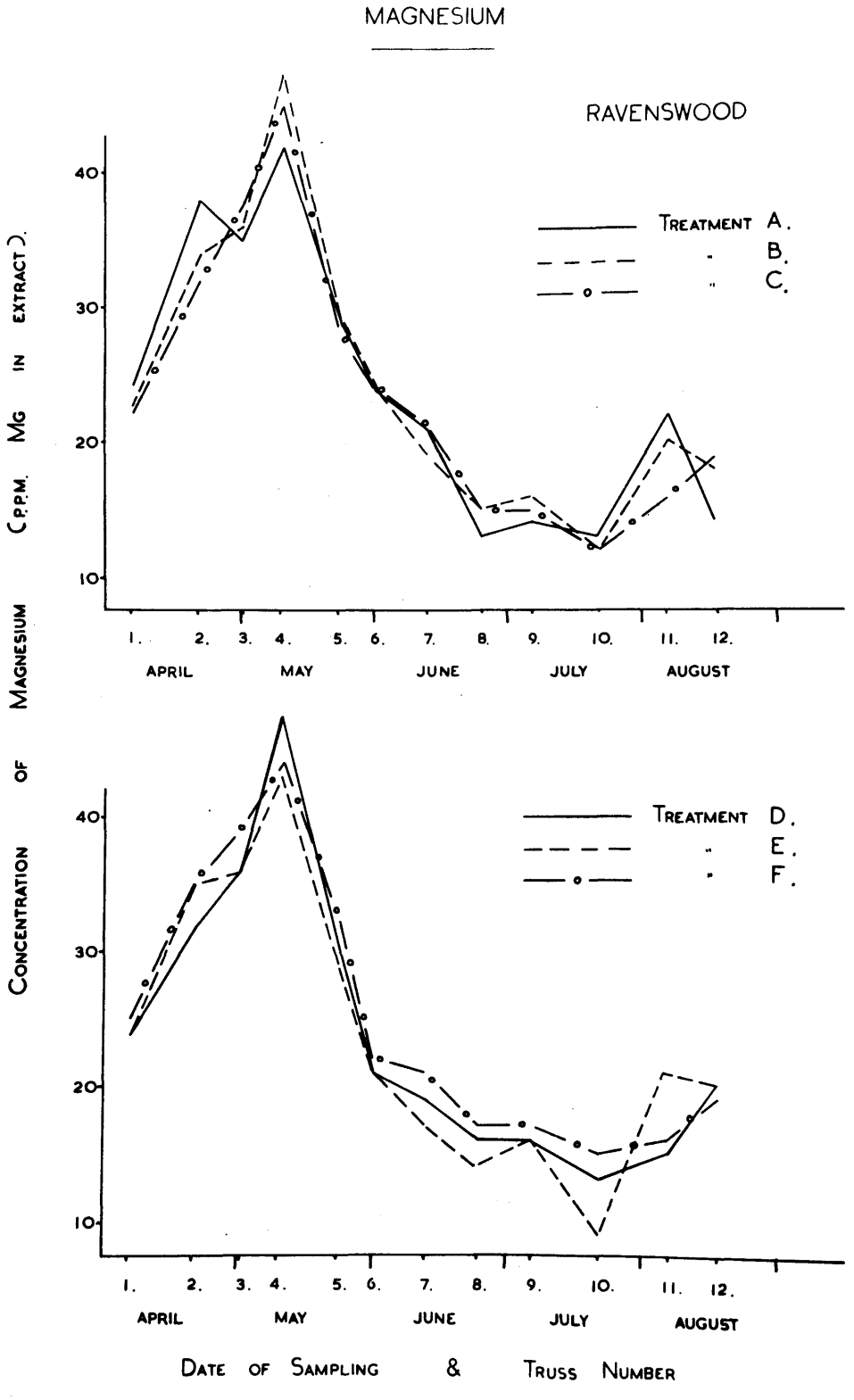
Date of sampling	Truss	Treatment A	B	C	D	E	F
25th May	2.	405	450	420	440	390	455
5th June	3.	437	442	470	437	442	505
26th "	4.	415	442	390	415	442	385
29th "	5.	398	415	393	363	420	398
13th July	6.	415	424	483	398	428	468
24th "	7.	370	378	425	415	410	440
31st "	8.	310	400	433	410	393	413

TOMATO EXPERIMENTS, 1950

Table:- 52. Centre:- Ravenswood.

Concentration (p.p.m.) of Magnesium in extracts of lamina dry matter - "Young" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
6th April	1.	24	23	22	24	24	25
20th "	2.	38	34	32	32	35	35
1st May	3.	35	36	38	36	36	39
11th "	4.	42	49	45	48	43	44
22nd "	5.	29	29	28	30	29	32
1st June	6.	24	24	24	21	21	22
12th "	7.	21	19	21	19	17	21
26th "	8.	13	15	15	16	14	17
7th July	9.	14	16	15	16	16	17
21st "	10.	13	12	12	13	9	15
7th August	11.	22	20	16	15	21	16
18th "	12.	14	18	19	20	20	19



Diag. 32. - Concentration of magnesium in extracts of dry-matter of lamina of "young" leaves.

TOMATO EXPERIMENTS, 1950

Table:- 53. Centre:- Ravenswood.

Concentration (p.p.m.) of Magnesium in extracts of lamina dry matter - "Old" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
25th May	2.	25	19	24	20	23	28
5th June	3.	20	15	28	26	25	29
26th "	4.	14	15	16	17	12	19
29th "	5.	4	13	11	10	7	16
13th July	6.	13	17	11	17	16	20
24th "	7.	15	14	9	9	12	16
31st "	8.	8	10	6	10	10	8

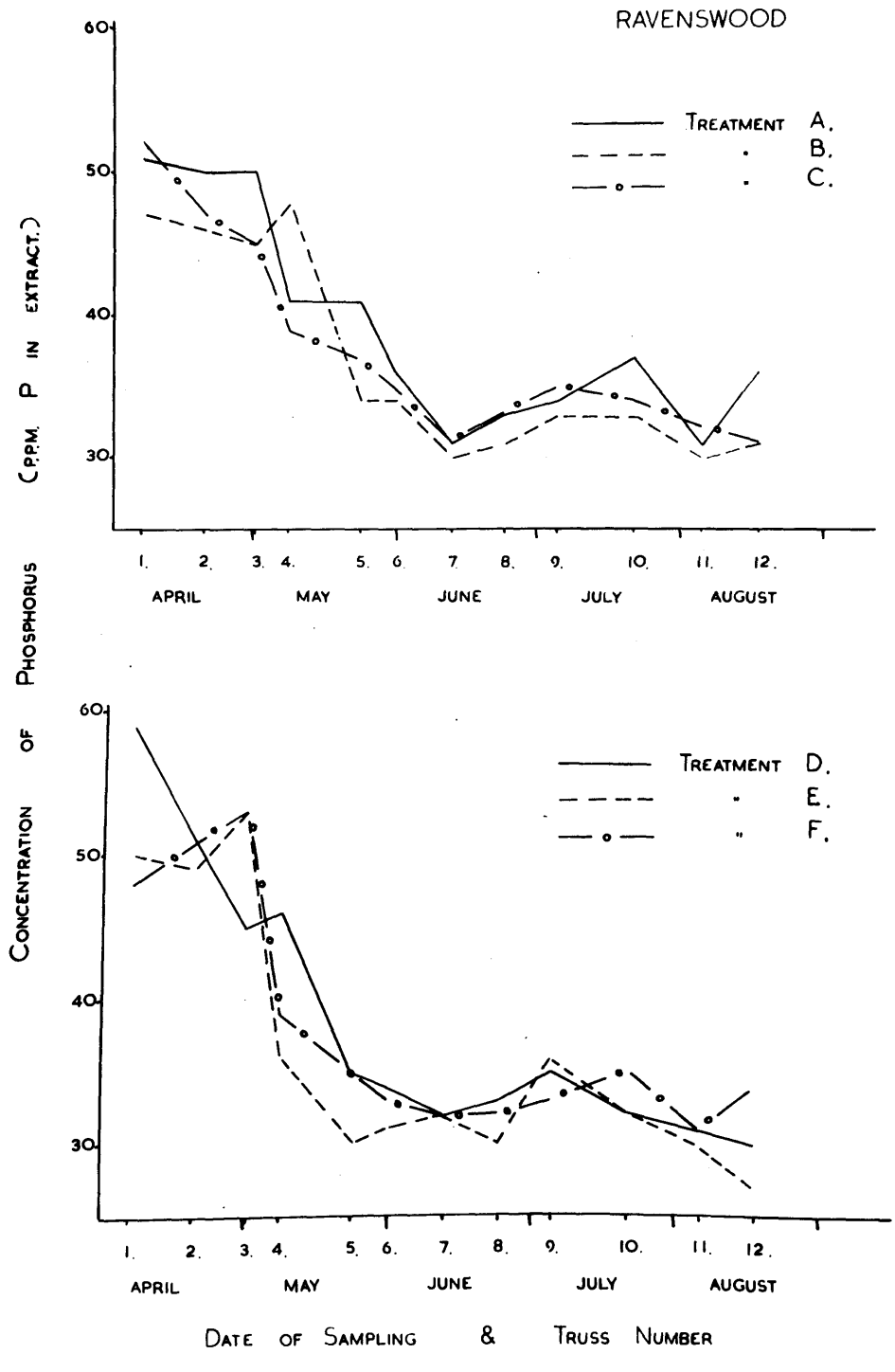
TOMATO EXPERIMENTS, 1950

Table:- 54. Centre:- Ravenswood.

Concentration (p.p.m.) of Phosphorus in extracts of lamina dry matter - "Young" leaves.

Date of sampling	Truss	Treatments A	B	C	D	E	F
6th April	1.	51	47	52	59	50	48
20th "	2.	50	46	47	51	49	51
1st May	3.	50	45	45	45	53	53
11th "	4.	41	48	39	46	36	39
22nd "	5.	41	34	37	35	30	35
1st June	6.	36	34	35	34	31	33
12th "	7.	31	30	31	32	32	32
26th "	8.	33	31	33	33	30	32
7th July	9.	34	33	35	35	36	33
21st "	10.	37	33	34	32	32	35
7th August	11.	31	30	32	31	30	31
18th "	12.	36	31	31	30	27	34

PHOSPHORUS



Diag. 33 - Concentration of phosphorus in extracts of dry-matter of lamina of "young" leaves.

TOMATO EXPERIMENTS, 1950

Table:- 55. Centre:- Ravenswood.

Concentration (p.p.m.) of Phosphorus in extracts of lamina dry matter - "Old" leaves.

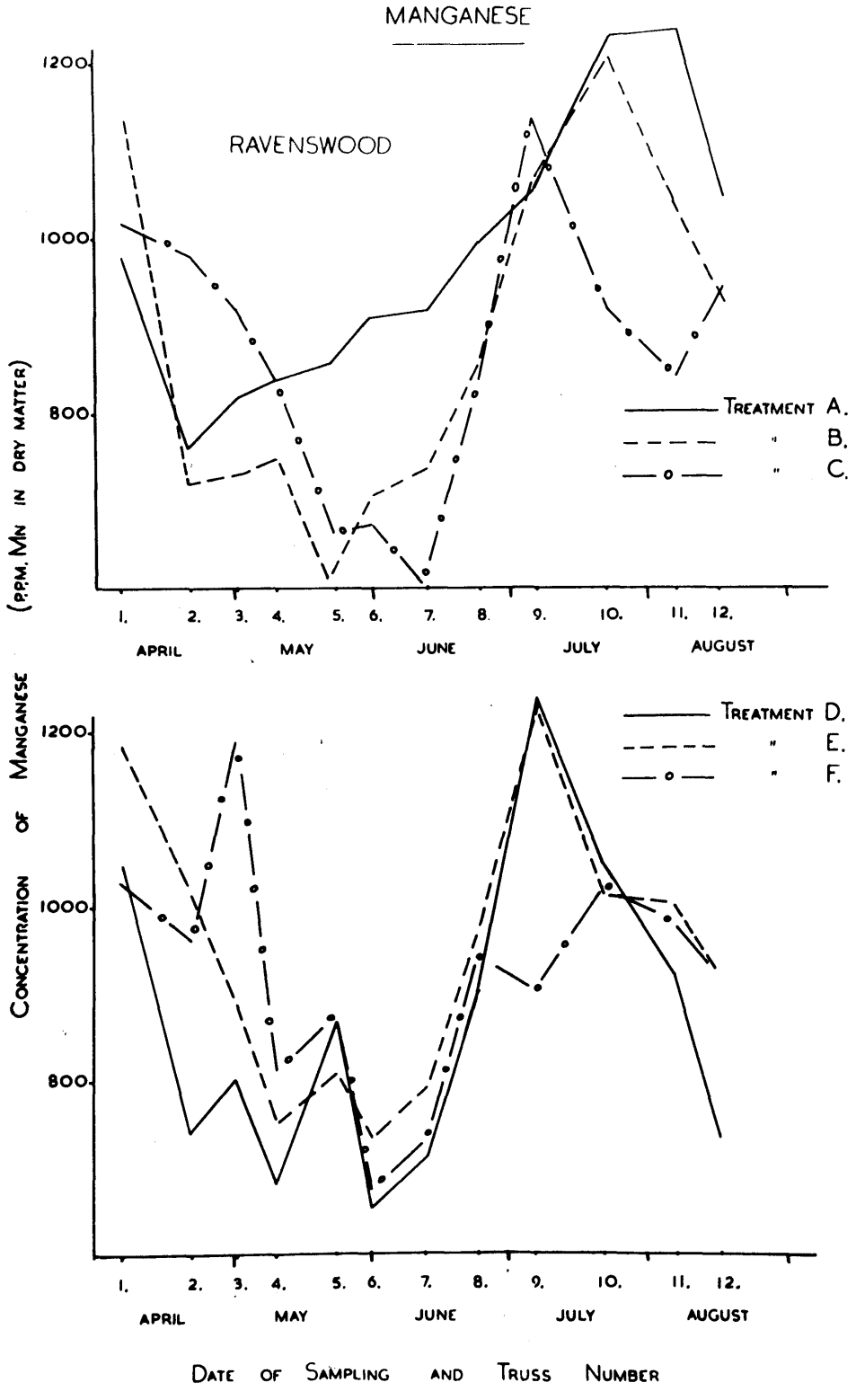
Date of sampling	Truss	Treatments A	B	C	D	E	F
25th May	2.	44	44	44	48	47	42
5th June	3.	46	37	41	44	42	44
26th "	4.	41	35	40	39	37	40
29th "	5.	37	34	37	34	33	34
13th July	6.	41	41	41	40	36	42
24th "	7.	40	35	36	36	33	40
31st "	8.	31	35	34	30	30	40

TOMATO EXPERIMENTS, 1950

Table:- 56. Centre:- Ravenswood.

Concentration (p.p.m.) of Manganese in lamina dry matter - "Young" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
6th April	1.	980	1140	1020	1050	1190	1030
20th "	2.	760	720	980	740	1020	960
1st May	3.	820	730	920	800	890	1300
11th "	4.	840	750	840	680	750	810
22nd "	5.	860	560	660	870	810	870
1st June	6.	910	710	670	650	730	670
12th "	7.	920	740	590	710	790	730
26th "	8.	1000	860	840	900	970	940
7th July	9.	1060	1080	1140	1290	1240	900
21st "	10.	1270	1220	920	1050	1010	1020
7th August	11.	1280	1050	840	920	1000	980
18th "	12.	1050	930	930	730	920	920



Diag. 34 - Concentration of manganese in dry-matter of lamina of "young" leaves.

TOMATO EXPERIMENTS, 1950

Table:- 57. Centre:- Ravenswood.

Concentration (p.p.m.) of Manganese in lamina dry matter - "Old" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
25th May	2.	1950	1250	1020	1320	1750	1700
5th June	3.	1660	1140	1540	1520	1480	1540
26th "	4.	1550	1400	1300	1350	1400	1200
29th "	5.	1240	1160	1140	1030	1100	1260
13th July	6.	2180	1450	1500	1630	1250	1580
24th "	7.	1650	1170	1230	1210	1320	1280
31st "	8.	1120	1330	1330	1480	1560	1600

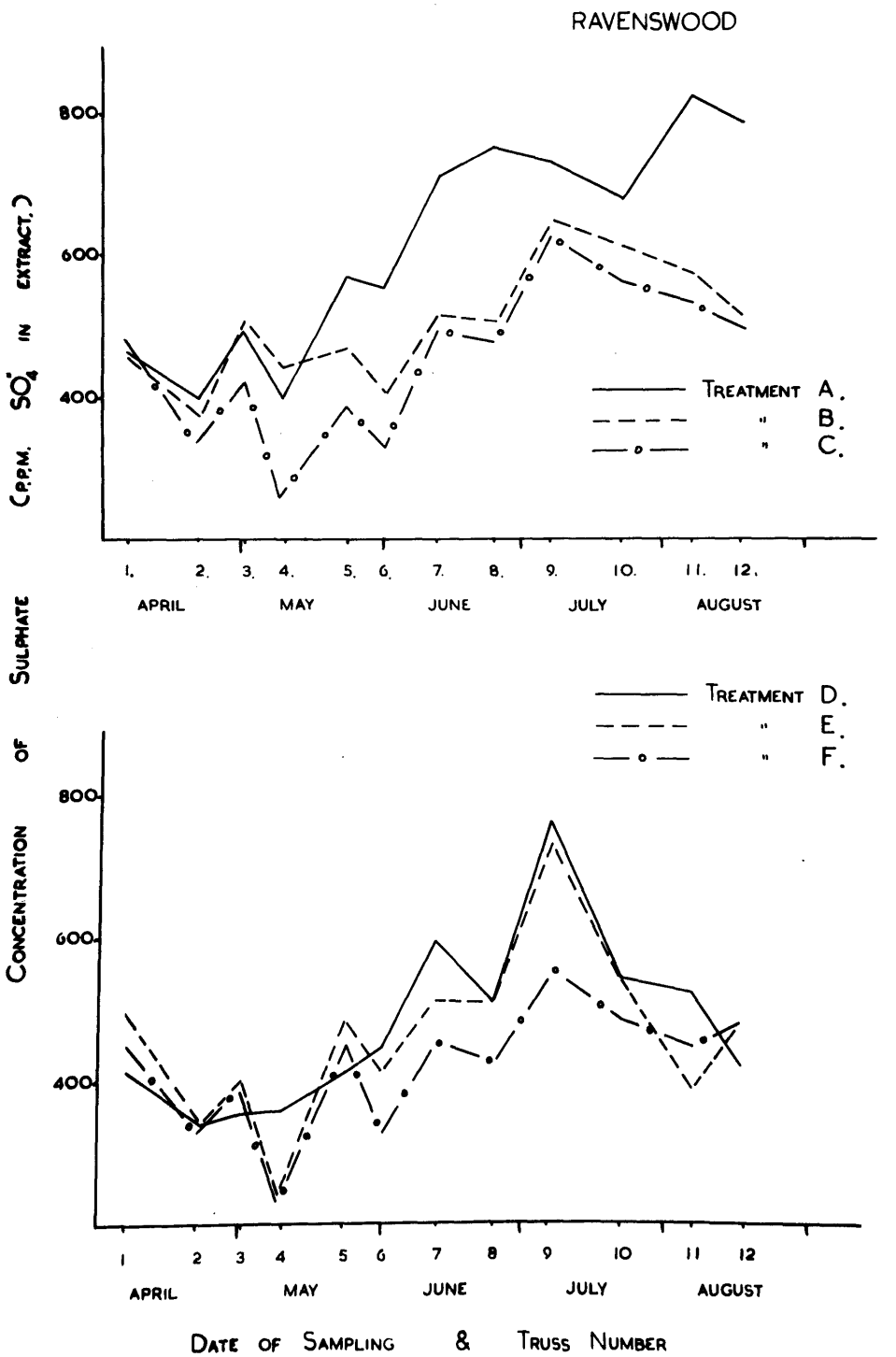
TOMATO EXPERIMENTS, 1950

Table:- 58. Centre:- Ravenswood.

Concentration (p.p.m.) of Sulphate in extracts of lamina dry matter - "Young" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
6th April	1.	465	460	483	413	500	450
20th "	2.	400	375	338	338	338	323
1st May	3.	495	510	423	355	400	395
11th "	4.	400	445	258	360	237	233
22nd "	5.	570	468	387	410	483	450
1st June	6.	555	405	330	445	410	325
12th "	7.	715	518	493	593	510	450
26th "	8.	753	507	478	510	510	423
7th July	9.	735	650	630	763	735	553
21st "	10.	685	615	563	545	545	483
7th August	11.	830	578	535	525	383	450
18th "	12.	790	513	500	415	475	480

SULPHATE



Diag. 35 - Concentration of sulphate in extracts of dry-matter of lamina of "young" leaves.

TOMATO EXPERIMENTS, 1950

Table:- 59. Centre:- Ravenswood.

Concentration (p.p.m.) of Sulphate in extracts of lamina dry matter - "Old" leaves

Date of sampling	Truss	Treatment A	B	C	D	E	F
25th May	2.	853	853	738	808	628	835
5th June	3.	1025	925	760	735	835	735
26th "	4.	1110	908	833	853	853	763
29th June	5.	983	853	773	853	843	803
13th July	6.	1233	1015	920	1005	833	895
24th "	7.	1163	908	908	930	855	780
31st "	8.	905	930	930	865	830	815

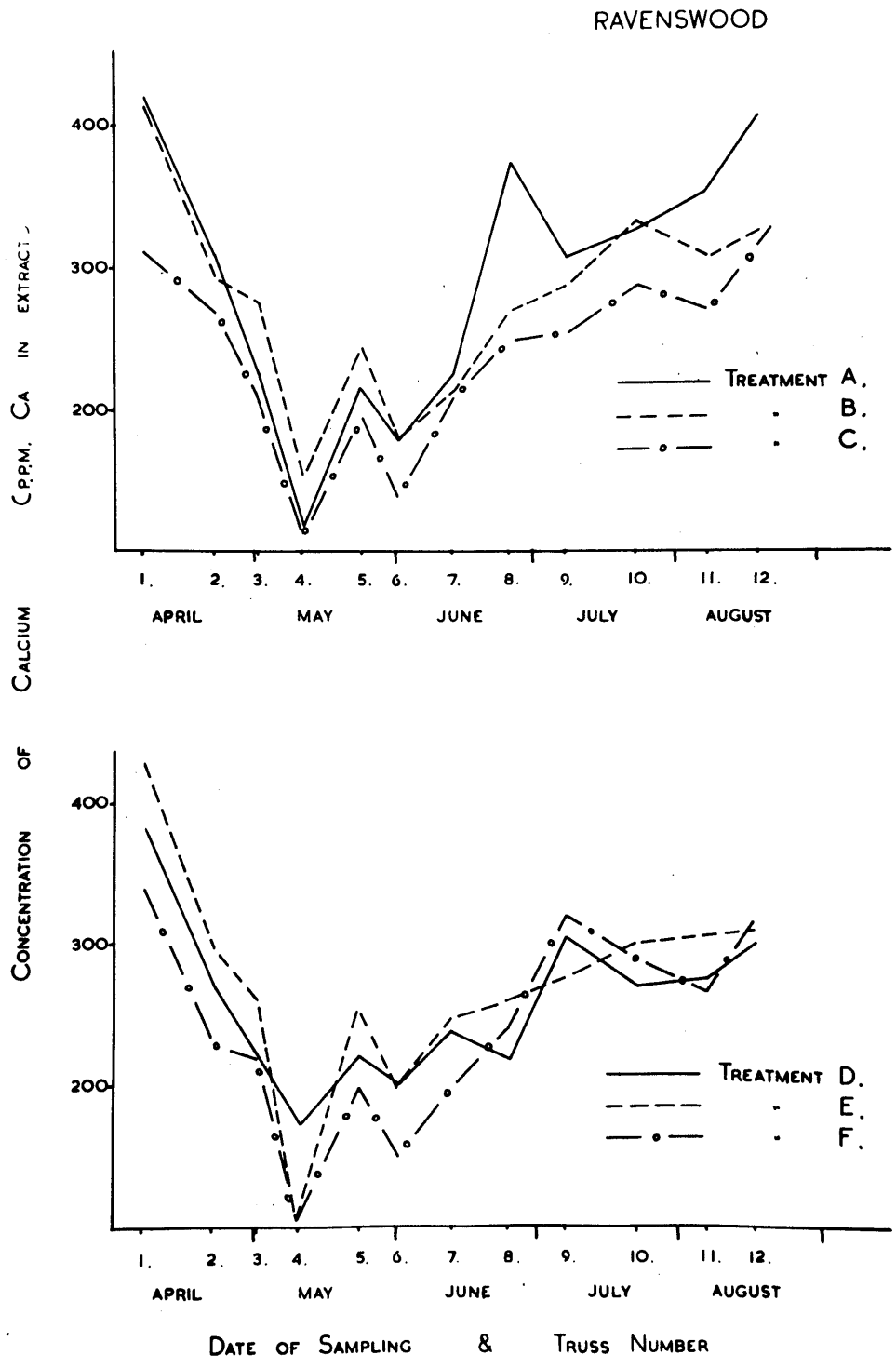
TOMATO EXPERIMENTS, 1950

Table:- 60. Centre:- Ravenswood.

Concentration (p.p.m.) of Calcium in extracts of lamina dry matter - "Young" leaves.

Date of sampling	Truss	Treatment A	B	C	D	E	F
6th April	1.	420	415	308	383	430	340
20th "	2.	310	295	268	270	300	228
1st May	3.	225	275	210	223	260	220
11th "	4.	118	155	113	173	90	93
22nd "	5.	215	245	193	220	254	198
1st June	6.	178	180	138	200	198	150
12th "	7.	225	213	208	238	245	198
26th "	8.	376	270	248	218	260	240
7th July	9.	308	288	253	305	273	320
21st "	10.	328	333	288	270	300	290
7th August	11.	355	310	270	273	220	265
18th "	12.	408	328	328	300	319	315

CALCIUM



Diag. 36 - Concentration of calcium in extracts of dry-matter of lamina of "young" leaves.

TOMATO EXPERIMENTS, 1950

Table:- 61. Centre:- Ravenswood.

Concentration (p.p.m.) of Calcium in extracts of lamina dry matter - "Old" leaves

Date of sampling	Truss	Treatment A	B	C	D	E	F
25th May	2.	570	538	528	525	515	458
5th June	3.	580	543	498	495	465	405
26th "	4.	538	483	490	465	483	455
29th "	5.	495	470	465	463	483	450
13th July	6.	548	498	443	503	445	468
24th "	7.	565	525	475	460	500	448
31st "	8.	465	465	495	448	500	483

TOMATO EXPERIMENTS, 1950

Table:- 62. Centre:- Ravenswood.

Weight of dry matter (g.) in lamina

"Young" leaves

Date of sampling	Truss	Treatment A	B	C	D	E	F
6th April	1.	0.85	0.92	0.88	0.87	0.84	0.91
20th "	2.	1.66	1.67	1.77	1.60	1.63	1.61
1st May	3.	1.62	1.78	1.80	1.62	1.79	1.77
11th "	4.	1.56	1.99	2.04	1.78	1.94	1.91
22nd "	5.	1.19	1.40	1.35	1.30	1.56	1.35
1st June	6.	1.09	1.39	1.27	1.57	1.41	1.18
12th "	7.	1.24	1.38	1.44	1.41	1.58	1.27
26th "	8.	1.06	1.21	1.32	1.08	1.27	1.13
7th July	9.	0.81	0.97	0.90	1.09	1.10	1.03
21st "	10.	0.74	1.06	0.96	0.93	0.88	0.96
7th August	11.	0.68	0.85	0.76	0.81	0.84	1.01
18th "	12.	0.67	0.87	0.74	0.82	0.70	0.85

TOMATO EXPERIMENTS, 1950

Table:- 63. Centre:- Ravenswood.

Weight of dry matter (g.) in lamina

"Old" leaves

Date of sampling	Truss	Treatment A	B	C	D	E	F
25th May	2.	3.38	4.04	3.31	2.96	3.51	3.98
5th June	3.	2.92	3.10	3.52	3.52	3.17	3.78
26th "	4.	2.44	2.46	3.06	2.60	2.92	2.62
29th "	5.	2.32	2.24	2.21	2.48	3.21	2.10
13th July	6.	1.81	1.97	1.82	1.81	2.05	1.90
24th "	7.	1.77	2.00	1.93	1.96	1.93	1.79
31st "	8.	1.56	1.72	1.79	1.57	1.82	1.64

TOMATO EXPERIMENTS, 1950

Table:- 64. Centre:- Ravenswood. Treatment:- A.

Total weight (mg.) of nutrients present in lamina of "Young" Leaves

Leaf - associated with truss	Extractable K	Mg	P	SO_4	Ca	Total N	Mn
1.	31.0	2.0	4.5	39.5	55.7	45.6	0.83
2.	58.1	6.3	8.3	66.4	51.4	92.0	1.26
3.	55.9	5.7	8.1	81.0	36.4	88.4	1.33
4.	50.7	6.6	6.4	62.4	18.4	74.1	1.31
5.	42.2	3.5	4.9	67.8	25.6	59.3	1.02
6.	42.0	2.6	3.9	60.5	19.4	52.7	0.99
7.	54.2	2.6	3.8	88.7	27.9	58.5	1.14
8.	40.6	1.4	3.5	79.8	39.8	51.3	1.06
9.	38.0	1.1	2.8	59.5	24.9	42.5	0.86
10.	32.9	1.0	2.7	50.7	24.3	36.5	0.94
11.	24.1	1.5	2.1	56.4	24.1	33.4	0.87
12.	22.3	0.9	2.4	52.9	27.3	30.5	0.70

TOMATO EXPERIMENTS, 1950

Table:- 65. Centre:- Ravenswood. Treatment:- C.

TOTAL weight of nutrients (mg.) in lamina of "Young" leaves

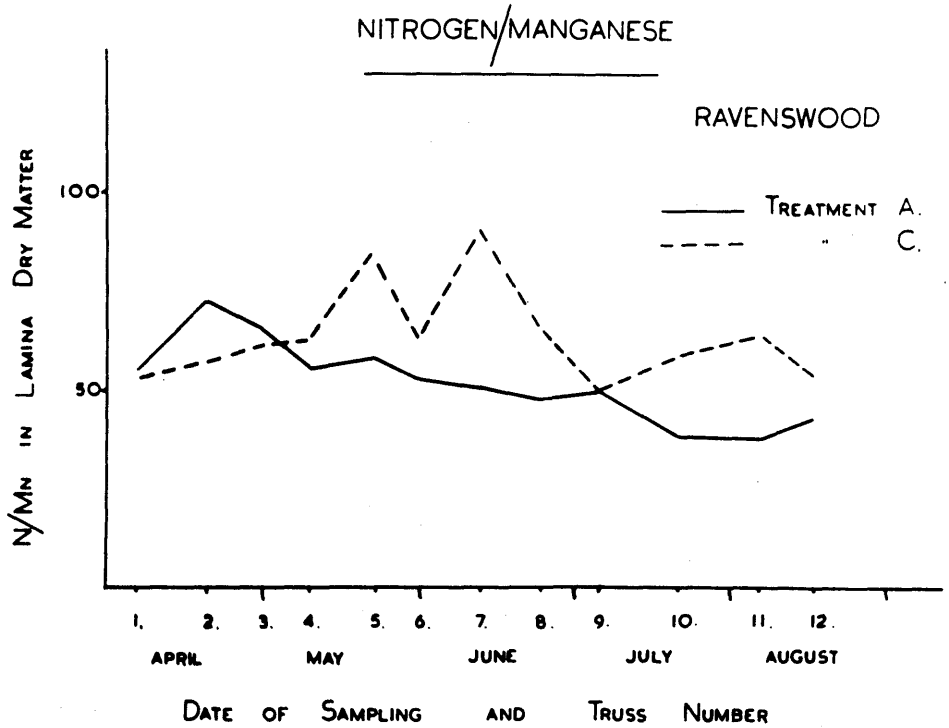
Leaf - associated	Extractable					Total	
with truss	K	Mg	P	SO_4	Ca	N	Mn
1.	35.2	1.9	4.6	42.5	27.1	48.0	0.90
2.	65.5	5.7	8.3	59.8	47.4	99.0	1.73
3.	67.2	6.8	8.1	75.3	37.3	101.8	1.64
4.	60.2	9.2	8.0	52.6	23.0	108.7	1.71
5.	52.6	3.8	5.0	52.2	26.1	75.0	0.89
6.	49.9	3.1	4.5	41.9	17.5	68.4	0.85
7.	58.0	3.0	4.5	71.0	29.9	77.6	0.85
8.	53.5	2.0	4.4	63.1	32.7	74.7	1.11
9.	45.6	1.4	3.2	56.7	22.8	50.9	1.03
10.	40.8	1.2	3.3	54.1	27.6	51.4	0.88
11.	29.3	1.2	2.4	40.7	20.5	40.7	0.64
12.	27.0	1.4	2.3	37.0	24.3	36.5	0.69

TOMATO EXPERIMENTS, 1950

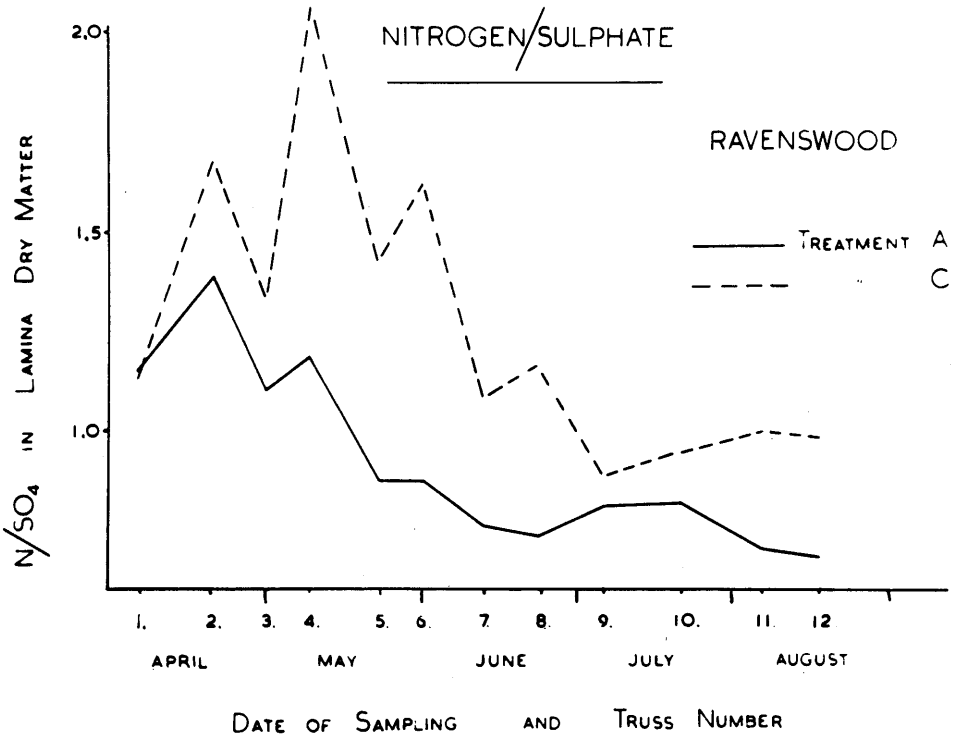
Table:- 66. Centre:- Ravenswood.

Comparison of nutrient ratios in lamina of "Young" leaves from treatments A and C.

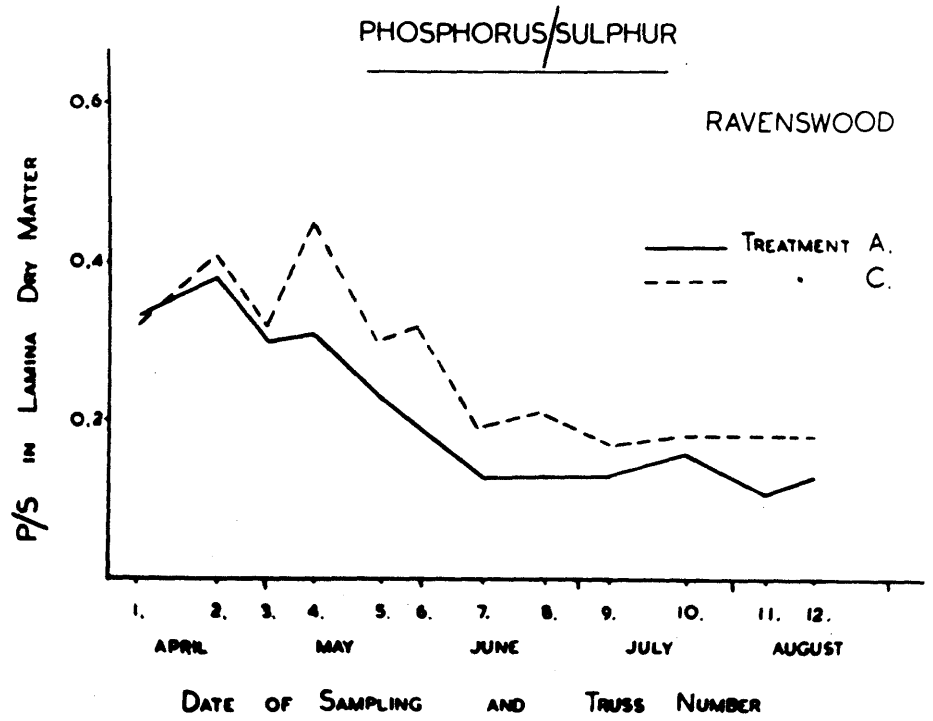
Leaf - associated with truss	Treatment A			Treatment C		
	N/Mn	N/SO_4	P/S	N/Mn	N/SO_4	P/S
1.	55	1.15	0.33	53	1.13	0.32
2.	73	1.39	0.38	57	1.69	0.41
3.	66	1.10	0.30	61	1.34	0.32
4.	56	1.19	0.31	63	2.07	0.45
5.	58	0.87	0.23	85	1.43	0.30
6.	53	0.87	0.19	63	1.63	0.32
7.	51	0.66	0.13	91	1.09	0.19
8.	48	0.64	0.13	66	1.17	0.21
9.	50	0.71	0.13	50	0.89	0.17
10.	39	0.72	0.16	58	0.95	0.18
11.	38	0.60	0.11	64	1.00	0.18
12.	43	0.58	0.13	53.	0.99	0.18



Diag. 37 - Ratio of total nitrogen to total manganese in dry-matter of lamina of "young" leaves.

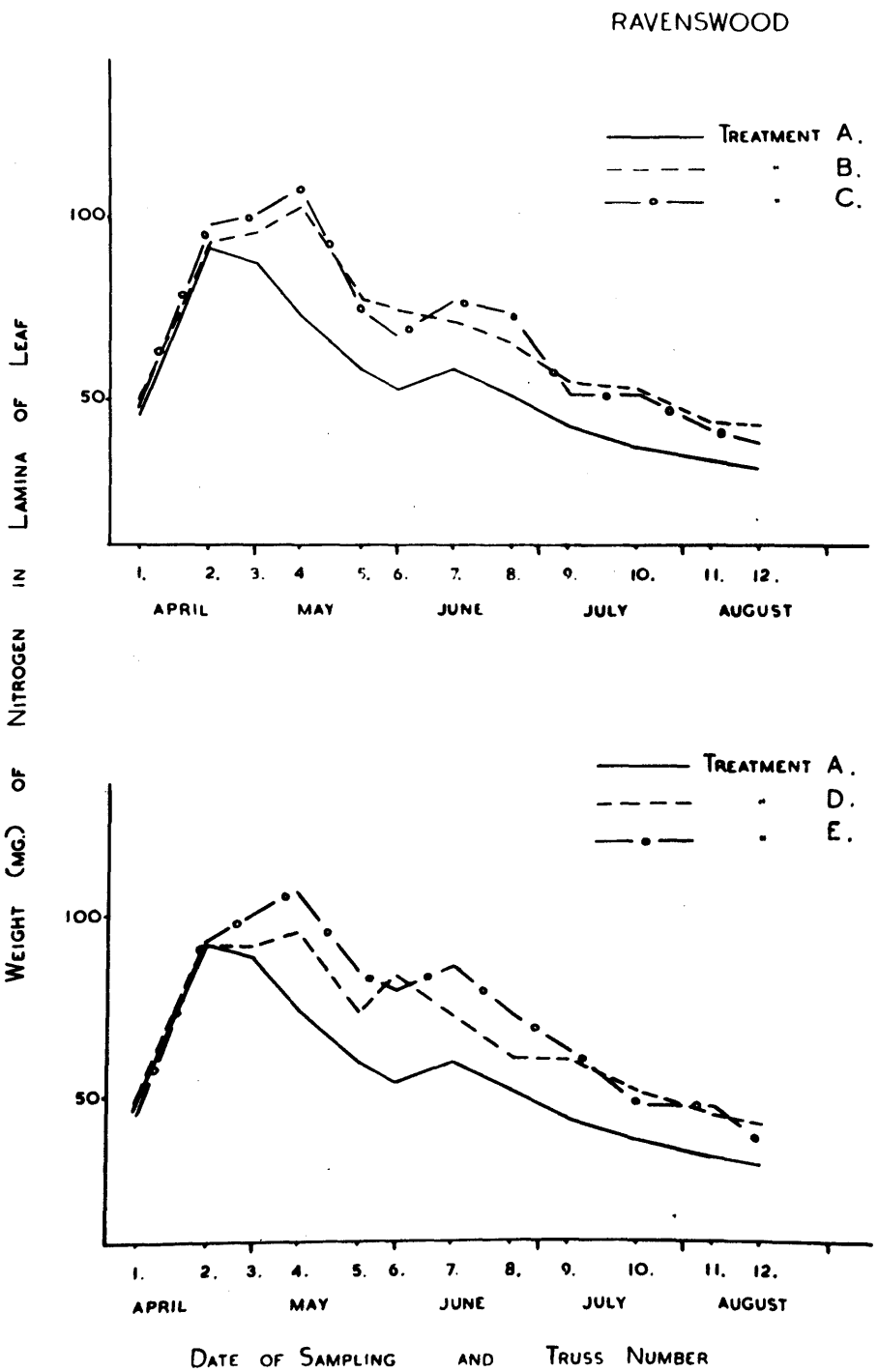


Diag. 38 - Ratio of total nitrogen to extractable sulphate in dry-matter of lamina of "young" leaves.



Diag. 39 - Ratio of extractable phosphorus to extractable sulphate-sulphur in dry-matter of lamina of "young" leaves.

NITROGEN



Diag. 40 – Weight of total nitrogen in lamina of "young" leaves.

NOTES ON RESULTS OF EXPERIMENTS AT RAVENSWOOD.

The crop was poor; setting of fruit was not satisfactory, and never at any time was a really strong growth produced. The first two trusses almost completely failed to set fruit. This was followed by a period of moderate setting to the sixth or seventh truss and from then till the end of the season setting was erratic - almost no fruit was set on the eighth and ninth trusses, and only odd fruits were set on the remaining trusses.

Soon after the first application of fertilisers an obvious difference in growth was apparent in the treated plots. The growth was stronger where either of the nitrogenous fertilisers had been given. The leaves of the nitro-chalk plots tended to be a lighter green colour than those in the nitrate of potash plots. Treatment F (nitrate of potash with potassium phosphate) showed a very good response: the leaves were dark green in colour and the plants appeared to flower more freely. The plants in the control plots soon showed signs of nitrogen deficiency and by the middle of the season the plants were very thin and very pale green in colour.

No response, in respect of fruit yield, was obtained from nitro-chalk, nitrate of potash, or nitrate of/

of potash with potassium phosphate (see Table 47). In spite of the fact that marked differences in growth were apparent, the average yields of fruit from all treatments were almost identical. It is interesting to note that the size of the fruit from the control plots did not appear to be affected by the evident nitrogen deficiency.

Tissue analysis results are given in Tables 48 - 66, and are illustrated in Diagrams 30 - 39. The most important results were:-

a) The percentage of nitrogen in the dry matter of the lamina from the treated plots remained fairly constant throughout the season. The lamina from the control plots had a lower concentration of nitrogen in the dry matter (see Table 48) but the difference between the concentrations of nitrogen in the lamina from treated and untreated plots was not so great as might have been expected considering the very obvious signs of nitrogen deficiency in the controls.

b) Magnesium deficiency symptoms were noted on the bottom leaves at the end of March. The symptoms then disappeared, but towards the end of June chlorosis of the leaves was again noted. From then till the end of the season most leaves showed a slight chlorosis

typical/

typical of magnesium deficiency. It will be seen from Diagram 32 that magnesium deficiency symptoms tended to coincide with low level of extractable magnesium in the lamina.

c) There was a well-marked maximum of extractable magnesium in the lamina of "young" leaves during May, and a minimum during July.

d) There appeared to be negative correlation between extractable magnesium and extractable potassium in the lamina of "young" leaves.

e) The nitrogen percentages in the lamina were appreciably raised by each of the nitrogenous treatments.

f) The concentration of manganese in the lamina was very high throughout the whole season and tended to be highest at periods of poor fruiting.

g) The concentration of sulphate in the lamina tended to be higher at periods of poor fruiting.

h) The concentration of total manganese and extractable sulphate tended to be higher in leaves ("young" and "old") from plants not top-dressed with nitrogenous fertilisers.

On examining the roots of the plants at the end of the season, it was found that there was a high incidence of root rot and considerable infestation by eelworms.

EXPERIMENT AT SPRINGFIELD, 1950.

Treatments A, B, C, and D, as at Springfield in 1949 were continued on the same plots. The plots were first carefully cultivated, then steam-sterilised *in situ*, and were replanted with tomato plants at the beginning of March. Two dressings of sulphate of potash (14 lb. per 100 ft.) were applied to all plots, one in April and the other in May. The yield of fruit from each plot was noted during the season. Time did not permit further tissue samples to be taken.

TOMATO EXPERIMENTS, 1950

Table:- 67. Centre:- Springfield.

Fruit Yields

Treatment	Yield per plot lb.	Mean plot yield lb.	Mean yield per plant lb.	Yield per 100ft. cwt.
A.	192 160 172 184	177.0	7.38	27.61
B.	183 158 186 183	177.3	7.39	27.65
C.	182 188 170 164	176.0	7.33	27.46
D.	172 162 176 155	166.3	6.93	25.94

Mean - 27.11 cwt. per 100 ft.

Standard Error - ± 0.90 cwt. per 100 ft.

NOTES ON RESULTS OF EXPERIMENT AT SPRINGFIELD, 1950.

The growth was very similar to that in the 1949 experiment. The mean yield of 27 cwt. of fruit per 100 ft. was nearly 10 cwt. less than in 1949. It was found, however, that this reduction in yield, probably caused by poor setting conditions in the late spring, was general throughout the whole nursery.

After mid-season the control plots were easily picked out from the rest by the very much lighter growth in these plots. The results, however, do not show any yield-response to nitrogen applications. As at Ravenswood, the average yields of fruit from all treatments were almost identical. In fact, treatment D, which had received 36 lb. of nitrogen per 1500 sq. ft. during the two years of the experiment, gave a yield which was almost significantly lower than the control which had received no nitrogen.

As in the Ravenswood experiment, it was noted that the fruit from the control plots was large-sized. The size of the truss (i.e., numbers of flower buds formed) may have been reduced by the low level of nitrogen in the soil, but a large percentage of the fruit set, developed into large-sized fruit.

TOMATO EXPERIMENTS, 1949 - 1950

Table:- 68.

Soil Analyses Results

Centre	Loss on Ignition	pH	Available* P_2O_5	Available* K_2O	% Nitrogen+ (total)
Springfield	10.6	6.4	140	90	0.33
Kairn	16.0	6.6	240	110	0.50
Ravenswood	10.6	5.8	140	50	0.22
Garrion	19.0	6.1	80	80	0.38

* mg. per 100 g. air-dry soil.

+ % nitrogen in air-dry soil.

DISCUSSION OF RESULTS OF THREE SEASON'S WORK WITH TOMATOES, 1948 - 1950.

The experiments of Murneek (1), and the observations of tomato plants, grown on low-nitrogen soil, by White (2), suggested that the inability of plants to produce fruit during mid-season was associated with a low level of effective nitrogen nutrition.

A few analyses made by Owen (3) of fruits taken during a season give some support to this idea; though since the reproductive parts of plants tend to have a constant composition, such evidence from fruits is possibly not as conclusive as evidence from analyses of laminae or other vegetative parts.

If fruit-development makes heavy and preferential demands upon nutrients, and if nutrients do not for any reason come forward to meet these requirements fully, non-fruiting parts of the plant must undergo metabolic disturbances - some of which may give rise to visible signs, and others may be detected only by analyses made at or about the relevant time.

It is realised that continuous tissue-analysis cannot by itself reveal the cause of a deficiency or

inbalance/

imbalance which it may detect.

There is little doubt that large quantities of nitrogenous nutrients are necessary for the development of practically all parts of the tomato and in particular the fruit. The symptoms of the mid-seasonal check, resulting from the heavy fruit-bearing of the bottom trusses, as reported by Murneek and White agree well with those found in tomato crops in the Clydeside. All signs point to a nitrogen deficiency in the plant at this period. The preliminary investigations carried out in 1948 appeared to confirm this. The percentage of nitrogen in the dry matter of the lamina of the uppermost fully developed leaf was found in nearly all plants examined to be at a minimum during mid season. After the fruit had been removed from the bottom trusses the percentage of nitrogen increased but again fell to low levels towards the end of the season.

It had, however, to be proved whether the low level of nitrogen in the tissue was caused by physiological strain or if it was in part due to a nitrogen deficiency in the soil. No records of any experimental work of this nature, in the Clydeside area, could be found. It therefore seemed desirable that some measure of the response of tomato plants to applications of nitrogenous fertilisers/

fertilisers should be made.

Experiments carried out at four centres, in two years, on soils ranging from 0.2 - 0.5% total nitrogen (Table 68), failed to show any response to nitrogen manuring, whether it be applied in the form of sulphate of ammonia, nitro-chalk or even nitrate of potash which is considered to be a good stimulant for tomato plants. At Ravenswood there was a response, measured by increase in weight of leaf produced, but the yield of fruit was not affected.

In some cases there was an indication that high levels of nitrogen manuring depressed the yield. This may, however, have been the result of plants being more susceptible to attack by disease organisms, after the soil had received heavy dressings of nitrogen. At Kairn it was shown that high rates of application of nitrogenous fertilisers resulted in a significantly higher percentage of plants attacked by 'stem rot' (due to Botrytis cinerea). At this nursery, however, even the control plots (receiving no nitrogen) appeared to be suffering from an unbalanced nutrient condition in the soil. The percentage of nitrogen in the soil at this nursery was very high - as was reflected in a high nitrogen content in the tissue. The excessive amounts of nitrogen may have caused too low a carbon/ nitrogen ratio resulting in a strong vegetative plant with/

with poor fruiting characteristics.

Results of pruning experiments provide further proof that the check period is to some extent caused by the high demands of the developing fruit on the available nutrient supply. Where regulation of fruiting (by apical pruning of trusses) was practised on the first five trusses there was an indication that larger fruits were produced on these trusses (Table 24). The relief of strain on the plant was shown by the increased yields of the sixth and seventh trusses of pruned plants (Diagram 18). The over-all effect of pruning of flower trusses was a reduction in total yield (Table 23), but this loss of crop probably consisted mainly of small-sized fruit. The lessened demand on nutrient supply resulting from the regulation of fruiting of the first five trusses was not sufficient to eliminate the period of poor growth and development.

The failure of the plants to respond to applications of nitrogen would indicate that in commercial greenhouses the poor fruit-bearing at mid-season is not the result of an actual deficiency of nitrogen in the soil. White's (2) results show that even plants growing in completely manured soil suffered a serious check to growth at mid-season. In the absence of

chemical/

chemical analyses, the inference was that deficiency of nitrogen or potassium in the soil tended to increase the strain. It is conceivable that a deficiency of available nitrogen (or any other essential element) in the soil might accentuate the check to growth and development which may occur just when the plants should be bearing their heaviest load of fruit.

Most commercial greenhouse soils have an abundance of total nutrients. Whether the plant can always utilise the nutrients is, however, another matter. It is possible that wrong balance of nutrients may cause such a condition, but the occurence of the "check period" is so widespread that it is unlikely that all soils are unbalanced. It would therefore appear that certain factors, other than total nutrient stock, determine this period of poor growth and development.

If we accept the tendency for cyclic growth as a natural phenomenon of the tomato plant, then the phases of the cycle must be determined by a large number of factors in the enviroment e.g. rate of supply of available nutrient, light, temperature, humidity and perhaps particularly physical conditions in the soil; also absence of toxic factors such as excessive ammonification, It would seem possible, however, that if favourable conditions were provided, the first period of heavy fruit-bearing might be extended sufficiently/

sufficiently long to allow the removal of ripe fruit from the bottom trusses before the commencement of the "check period". If this were achieved, then it is unlikely that there would be serious check to growth and development. That the first period of fruiting can be extended is shown by the variation in the trusses affected by the "check" under different conditions. White (2) reported the "check period" as occurring at the fifth to seventh trusses; and in the Clydeside these are the trusses commonly affected. At Garrion, good yields of fruit were obtained from the first to eighth trusses. At Springfield there was no indication of a check to growth and development until the eleventh or twelfth trusses and even then it was not severe.

Murneek (1) stated that the fruit is able in some way to monopolise the available nitrogen supplies in the plant. It seems likely that this is also the case for the many other nutrients contained in the fruit. The retardation of growth and development will be proportional to the number of fruits present. When a check to growth occurs then it would appear that the cause is either a deficiency of available nutrients in the soil or that the capacity of the plant for absorption has been reached. There must be a fairly delicate balance/

balance between absorption and assimilation. Any factor reducing the absorption of nutrients must therefore tend to increase the severity of the check.

The following observations are pertinent:

1. Excessive amounts of fertilisers are very often applied to greenhouse soils. The average dressings of fertilisers, including base and top-dressing, must be far in excess of the requirements of the tomato plant (see details of manuring at Law nursery p. 12). 93% of the soils (tomato) examined at the West of Scotland Agricultural College Soil Laboratory (*) contained at least 70 mg. of available P_2O_5 per 100 g. air-dry soil; 47% of the soils examined had at least 80 mg. of available K_2O per 100 g..

The fact that good crops can be grown on new soils containing much less phosphate and potash, supplies strong evidence that such high concentrations of fertilisers in the soil are not necessary. Some Clydeside growers with soils high in phosphate and potash have accepted advice to eliminate "base" fertilisers. No controlled experiments were carried out and therefore no results are available, but/

* Unpublished figures kindly supplied by Prof. Hugh Nicol.

but the indications were that increased crops were obtained. Pizer (11) had earlier made similar recommendations to English growers.

It is difficult to understand why the practice has grown up of applying large amounts of phosphate to greenhouse soils. At Law nursery over 2000 lb. P_2O_5 per acre were applied. Owen (5) stated that, except in the early stages of growth and perhaps at mid-season, the demands of the tomato crop for phosphate are comparatively small. He calculated the annual consumption of phosphate by a tomato crop to be 75 - 100 lb. P_2O_5 per acre. Experiments at Cheshunt (12) failed to show any response to phosphate dressings. Blenkinsop (13) went so far as to say that the failure of many old market-garden soils to produce good crops ~~is~~ were. the result of an unbalance caused by high water-soluble phosphate content in these soils. This may or may not be the case, but the fact remains that many greenhouse soils are over-manured and in these soils the salt concentration must be dangerously high. Such a condition must have a considerable influence on the absorption of nutrients from the soil and in serious cases it is possible that root hairs might be damaged.

2. Examination of tomato ~~soils~~ plants. at mid season showed very/

very few healthy roots. At the end of the season, roots were lifted at several nurseries, In nearly all cases, it was found that roots were attacked to a greater or lesser degree by the common root diseases. These root troubles are more serious and more widespread than many growers realise. Experience derived from the present work and other observations suggests that rooting troubles may be due to ammonification excessive to the point of toxicity; this leads, almost paradoxically, to interference with proper nitrogen nutrition in the plant.

3. Severe compaction of the soil by treading and watering occurred in medium and heavy soils. Even in light soils there was the tendency for a hard surface layer to be formed. This compaction must greatly reduce the aeration of the soil. It is believed to be the main cause of poor nitrification leading to excessive accumulation of soil ammonia.

4. In many nurseries, plants wilt more than they should during periods of bright sunshine. This may be an indication of too high a salt concentration in the soil or root disease: two factors which reduce the amount of water available to the plant.

5. Schofield-Palmer (14) has drawn attention to the dangers/

dangers of overmanuring in tomato soils. He mentioned that some of the beneficial effects of water come from its ability to reduce the concentration of the fertiliser salts in the soil, thus allowing more water (and also more nutrients) to enter the growing plant. Grainger (15) stated that the poor growth and tip-burn of the leaves of lettuce planted in tomato soils is frequently the result of high salt concentration in the soil.

6. After the fruit has set on the bottom trusses, very heavy watering is practised and from then till the end of the season regular heavy waterings are given. On heavy soil types, with poor natural drainage, excessive amounts of water would appear to be used, but as Schofield-Palmer (14) pointed out high salt concentration may necessitate the use of large amounts of water. Many of the soils examined were wet and sodden and had all the appearances of bad aeration. This reinforces the argument of (3) above; and indicates the importance of good drainage.

7. One of the most outstanding features of tomato culture is the reduction in yield by the continuous cultivation in the same soil. Tomato plants grown in new soil seldom fail to produce a heavy crop.

Investigations/

Investigations into this reduction in yield have been carried out at Cheshunt. Bewley (16) stated that in the first year of cultivation root-development was vigorous and the majority of the roots were clean at the end of the season. At the end of the second season, root action was still vigorous but a greater proportion of root rot occurred. From the fourth to the eighth year, root action became increasingly weaker and root decay started as early as July. Many of the organisms associated with root decay were not active parasites of healthy plants growing in new turfy soil. The extent of the injury they produce depends on the soil conditions, least damage occurring when the soil is spongy, well aerated and well drained.

Bewley suggested that the reduction in yield is connected with the continual use of horse-manure and the destruction of coarse organic matter which is so necessary to keep the soil in suitable physical condition (i.e. open to aeration) and also to supply conditions for good growth of beneficial soil organisms e.g. the nitrifiers. He found that the incorporation of heavy dressings of peat with the soil resulted in better physical conditions and gave increased yields. This is consistent with the view that aeration is especially

important/

important in good cropping.

8. The response to applications of fertilisers is most marked in the early stages of growth. When a response to the heavy top-dressing commonly applied at mid-season is seen, it is apt to be confused (by growers) with a natural recovery of the plants about the time when the bottom fruit is removed. The strong vegetative growth, said to result from the high nitrate content in the soil after steam-sterilisation, is very marked in the young plants, but applications of nitrates later in the season failed to show any response. This lack of response in later stages of growth may be the result of disease organisms attacking the roots, accumulation of fertilisers giving high salt concentration, degeneration of the root system under poor soil conditions; or a combination of two or more of these factors, all leading to a loss of power of the root system to supply the increasing demands of the plant. Some breakdown is therefore to be expected.

All these observations are in one way or another connected with absorption of nutrients. When a large number of fruits are developing the demand for nutrients by the plant must be very high. Any factor tending to reduce the efficiency of the roots must therefore accentuate the check to growth and development.

Owen (7) has claimed that the period of "physiological strain" can be very effectively reduced by applying a dressing of fertilisers rich in nitrogen, sufficiently early to meet the demand of the plant. This may be true providing other factors are not operating against the uptake of nutrients. Whether Owen's work can be taken to equate the "check period" with his "physiological strain", or whether under his conditions an association of magnesium and nitrogen deficiencies are to be held responsible for "checking", it seems that in Scotland the problem of the "check period" is not identical with what may (for lack of a better term) be called the corresponding condition in England.

TISSUE ANALYSES RESULTS.

Phosphorus: (1948 - 1950):

All centres showed a similar variation in extractable phosphate concentration in the lamina of the upper (young) leaves. High values were recorded during the early stages of growth; a rapid fall in concentration followed, and low values were maintained during mid-season. There was often a tendency for recovery in later stages of growth. Concentrations of extractable/

extractable phosphorus varied between 0.2 and 0.6% in the dry matter. Similar concentrations were found in the dry matter of the petioles. Older leaves had concentrations of extractable phosphorus similar to those found in the upper leaves (of the same truss) during mid-season.

It seems that appreciable diagnostic value cannot be attached to extractable phosphate.

Nitrogen: (1948 - 1950):

At the six centres at which leaves were sampled in 1948 only the upper (young) leaf was taken from each truss. All six centres experienced considerable "check". It appeared that the demands for nitrogen by the developing fruit caused a decrease in the percentages of nitrogen in the dry matter of the lamina. At the "check period" the percentage nitrogen reached a minimum. After the fruit of the lower trusses had been removed there was an increase in the percentage of nitrogen; this increase corresponds to a period of new growth and development. After this new growth had set fruit a second minimum sometimes resulted. These results agree with the findings of Murneek (1).

Leaf-analyses in 1948 consistently suggested that nitrogen percentages (calculated on dry matter) less than 4.5 were near/

near deficiency level. At Springfield in 1949 the nitrogen percentage did not fall below about 5.5 at mid-season and no check to growth was noted at this time. Lower values (4 - 5%) were found in leaves sampled later in the season. These lower values tended to coincide with a period of poor setting of the 11th and 12th trusses.

This attractive tentative conclusion was not supported by the results at Garrion in 1950. The nitrogen percentage calculated on the dry-matter of lamina of young (upper) leaves, although somewhat irregular, remained between 5 and 6% throughout the season i.e., from the first to the 13th truss in flower. It will be recalled that the "check" at Garrion was particularly severe, and produced.

At Ravenswood, plants growing in control plots showed symptoms of nitrogen deficiency from mid-season onwards. The percentage of nitrogen (about 5) in the dry matter of lamina of young leaves from these plants was not much lower than that found in leaves of plants treated with nitrogen. If the weight of leaf is considered, it will be seen that the total weight of nitrogen per leaf was considerably lower in the control plants (Tables 64 and 65)

The/

The young and old leaves were found, in 1950, to have similar trends but different absolute values of total nitrogen percentage; neither being diagnostic.

The percentages of nitrogen in the dry matter of petioles of young leaves was lower than that in their lamina. An average figure for lamina is about 5%. for petiole about 3%

Potassium: (1948 - 1950):

The concentration of extractable potassium in the dry matter of the lamina of upper (young) leaves varied between 3 and 5%. During the early stages of growth (2nd - 4th trusses in flower) the potassium was fairly high, but it fell rapidly as the fruit developed and was usually at a minimum when the 4th - 7th. trusses were in flower. The potassium percentage then rose rapidly and remained at fairly high levels until the end of the season, when there was a tendency for lower values.

The extractable potassium in the dry matter of petioles of young leaves was much higher than that of their lamina (Table 45). The dry matter of upper and lower leaves had similar concentrations of potassium.

Magnesium: (1948 - 1950):/

Magnesium: (1948 - 1950):

The percentage of extractable magnesium in the dry-matter of the lamina of young (upper) leaves varied between 0.1 and 0.5%. The concentration of extractable magnesium in the dry-matter of the petioles was similar to that of the lamina.

There was consistently an inverse relationship between extractable magnesium and extractable potassium in the lamina of the young leaves. The very low levels of potassium found in young leaves sampled when the 4th - 7th trusses were in flower, were always accompanied by very high values for magnesium. Low levels of magnesium later in the season were associated with high concentrations of potassium. (See Diagrams 2, 3; 9, 10; 14, 15; 21, 22; 31, 32.)

The appearance of magnesium deficiency symptoms tended to coincide with low levels of magnesium in the tissue, but no satisfactory relationship between "checking" and leaf magnesium could be established. In particular, the amount of extractable magnesium in the lamina of young leaves analysed in the course of this work showed either a marked rise during the "check period" (Law, 1948) or an obvious lack of relation to "checking", well shown at Garrion (1950). These were centres/

centres and seasons which showed a definite "checking". At other centres (Springfield, and Kairn, 1949; Ravenswood, 1950) there was no well-marked "check period" and the levels of extractable magnesium were equivocal. Only at Ravenswood (1950) was there a minimum of extractable magnesium during a "check period".

So much for analytically-determined magnesium. Visual signs of magnesium deficiency were in no instance obtrusive during the "check period". Before the "check period" visible signs of magnesium deficiency were never more than slight; after the "check period" they were often severe.

Manganese: (1948 - 1950):

The percentage of manganese in the dry matter of the lamina of young (upper) leaves was found to vary between 0.01 and 0.1. There is considerable evidence to show that during periods of strain the manganese concentration in the lamina increases. At Garrion the young leaves associated with the high-yielding trusses had fairly low concentrations of manganese; but as the period of strain developed, the concentration increased until a maximum was reached at the height of the "check period". The concentrations of manganese during this period of strain were two or three times as great as during periods of/

of normal growth. This apparent connection between manganese increase and "check" or "physiological strain" was first observed in leaves from Law, in 1948, and was confirmed for leaf samples from the other five 1948 centres; and in 1950, at both centres where tissue analyses were done. (There was no marked check in 1949).

This question of manganese relationships in laminae appears very important. It is believed to be both diagnostic and prognostic.

The N/Mn ratio in the dry matter of the lamina of the upper leaves was found to be low during periods of poor fruiting and growth. Diagram 26 shows the variation in the N/Mn ratio of young leaves sampled during the season at Garrion (1950). High values were shown at periods of good growth and low values at periods of poor growth. The graph of N/Mn ratio in the leaf shows a very similar variation to the graph of truss yields (Diagram 18). Results at other centres show similar variation and correspondence.

Manganese concentration in the dry matter of the petiole of upper leaves was considerably lower than in the corresponding lamina (Table 45). A greater concentration of manganese was found in older leaves than in young leaves (of the same truss).

Calcium/

Calcium:

This was determined in 1950 only after confidence had been gained in the analytical method used and then published (Reprint 2 forming part V of this Thesis).

Concentrations of extractable calcium in the dry matter of the lamina of young (upper) leaves varied between 1 and 4%, lower values being found during mid-season and higher values at beginning and end of season. Older leaves had rather higher concentrations in the lamina, 4.5 - 5.5%. The percentage of extractable calcium in the dry matter of petioles of the upper leaves varied between 0.6 and 1.6%.

Sulphate:

This also was determined only in 1950, after the unpublished analytical technique (Appendix B) had been well tested.

High concentrations of sulphate ($-SO_4''$) were found in the lamina. At Ravenswood and Garrion, values ranged from 2 to 8% in the dry matter of the lamina of young leaves. At both centres the concentration of sulphate was higher in older leaves - in these it reached surprising concentrations; up to 12% of SO_4'' in the lamina dry-matter.

The/

The graph of sulphate concentration in the lamina of the young leaves during the season showed a very similar variation to that of manganese. High concentrations were noted at periods of poor growth and low concentrations during periods of normal growth.

N/SO_4 ratio in the dry matter of the lamina of the young leaves accordingly showed very similar variations to those found in the N/Mn ratio.

The P/S ratio was always less than 1, indicating that the uptake of sulphur was greater than that of phosphorus (cf. (17)).

CONCLUSIONS.

Many conclusions could be drawn from the analytical work on tomatoes. Each year, five or eight series of determinations of plant constituents were made. To discuss each of these in turn, and to make comparisons between pairs would be tedious.

Firstly, a fundamental point relating to tissue diagnosis in general is made. Then follow those conclusions which seem especially remarkable in relation to particular constituents of (usually) the lamina of young leaves associated with each truss. All of these comments are based on consistent findings: mostly over three seasons' work. However, the most novel work on a single constituent (sulphate) was done at two centres in 1950 only.

"Young" and "Old" leaves: relevance to tissue diagnosis

The comparison made at Garrion and Ravenswood between "young" and "old" leaves of the same truss - therefore comparable in position but differing slightly in age - brings out a point important for those concerned with foliar analysis for diagnostic purposes.

There/

There were somewhat similar trends during the season in young and old leaves, but the absolute magnitudes of concentrations of elements in the lamina often differed substantially in the two positions of leaves. Hence to posit a given concentration, or limits of concentrations, as indicating certain features of tomato nutrition or health, may be unwise. Such a postulate as that a certain condition in the plant is typified by a given concentration in the lamina may be true for a given set of experiments; but it seems evident that it probably cannot be verified, by another experimenter unless he works with leaves comparable in every respect. Also, the postulate should not be put out as guidance for diagnostic purposes, unless it is accompanied by an exact statement of the type and position of the leaf that was employed in establishing the postulate.

It is, therefore, strongly recommended that all work based on analysis of particular tissues should specify the exact type and location of the tissue used. It is also desirable that, whenever possible - as it usually is possible with tissue-analysis of dicotyledonous plants - at least a few parallel sets of analyses of leaves or tissues of corresponding type from at least two specified parts of the plant should be made, and/

and that such comparison results should be published. The art of tissue diagnosis is still young; and its development can be as much helped by comparative studies as it can be harmed by injudicious interpretation of work done without sufficient collation and comparison.

In this study the information derived from phosphate was small, though a rough correlation was observed of phosphate with growth and fruit-yield, and therefore presumably with well-being of the plant.

However, valuable information was obtained from constituents studied at the same time as phosphate.

Checking - meaning the arrest of fruit development - is clearly not related either to extractable magnesium or total nitrogen in either the younger leaves (1948 - 49-50) or the older leaves (1950).

Extractable potassium and extractable magnesium in the lamina of young leaves were always closely correlated inversely.

Consequently, no diagnostic or prognostic value can be attached - in relation to "the check" - to laminar total nitrogen or extractable magnesium or potassium.

A deficiency of (extractable) magnesium - and a potassium excess - accompanied, simultaneously or at a short interval of time, visible manifestations of magnesium deficiency.

While "check" occurred, a simultaneous increased level of total manganese was also found (1948, 1950); and a similar rise in extractable sulphate (1950). The magnitude of the rise in total manganese and extractable sulphate at each centre was qualitatively an indication of the severity of the check. When no marked check occurred (1949) there was no significant increase in total manganese.

The check periods were preceded by a marked rise in total manganese from a low level which presumably was a normal equilibrium level for tomato plants growing in a neutral soil or a soil maintained nearly neutral (pH 6). Excessive uptake of manganese, such as is associated with soil acidity (see Hunter and McGregor (9): attached Reprint III) is not here in question. It can therefore be fairly claimed that a new aspect of imbalance of manganese in plant nutrition has been revealed by this work.

It is further suggested that the amount of total manganese in tomato lamina may be practically diagnostic of/

of checking. For a soil closely approximating to neutrality, it appears that an amount of manganese (in the lamina) exceeding about 50 mg. of Mn per 100 g. of dry matter, check can be considered established. This is not very useful, since the check would then be evident.

As prognostic test, it is suggested to analyse the lamina of leaves associated with each new truss (when in flower) after about the third to the sixth (i.e., from mid-May onwards), still for a nearly neutral soil: if the amount of manganese (in dry matter) exceeds about 40 mg. per 100 g., and a fortiori if the figure is increasing, from a level of about 20 mg. per 100 g., check and loss of crop may be expected.

Plants on slightly more acid soils (e.g. Ravenswood: soil pH about 5.8) had higher manganese levels throughout than would accord with the standards just proposed. The findings are consistent with what is known about increased uptake of manganese with increasing acidity. It looks, therefore, as if further work will be needed to determine the absolute levels of manganese that will be diagnostic at various ranges of soil acidity and in different varieties; nevertheless, the relative levels of manganese yielded at different times by any one system of soil management appear to be capable of giving quite valuable information.

This conclusion is supported by the facts that whereas total nitrogen alone gave no consistent clue to "check", the rise and fall of the ratio total N / total Mn showed a close relation to the variations in yields of fruit per truss.

The total nitrogen / extractable sulphate ratio behaved similarly.

Tentatively, it is suggested that determinations of extractable sulphate (SO_4) may prove equally apt for prognosis and diagnosis; but in view of the varying conditions of supply of sulphates in the soil, and in view of the possibility that the very high amounts of sulphate found in the plant may reflect "luxury consumption", rather than a physiological need of the plant, it is felt that further work will be needed to establish diagnostic levels of sulphate-sulphur.

The finding that tomato plants sustain large proportions of sulphate over a long period is new. Very few unexceptionable determinations of actual sulphate or other forms of sulphur in plants have been made. The only relevant published work seems to be that of Peterson (18) in 1914; he did not examine tomatoes, and his work, though valuable, was merely exploratory and can be regarded as indicative only. Peterson seems to have had no successor. Most other recorded analyses of plant

"sulphur"/

"sulphur" or sulphates were made before Peterson's time; and virtually all such analyses have been done on the basis of total sulphate in ash; this is probably subject to considerable error, and in any case is not very enlightening.*

The set of analyses and conclusions here presented for manganese in plants not subjected to gross soil acidity is also new.

It is also submitted that no comparable set of analyses of a crop plant or other plant for at least six constituents has been made before.

The analytical methods evolved and used have been found rapid and accurate, and therefore suitable for the purposes for which they were devised. For example, manganese in amounts of from 5 to 100 mg. per 100 g. of dry leaf-substance, or about 1 to 20 mg. per 100 g. of fresh leaf, can be determined singly or serially in one day on samples consisting of a single tomato leaf. Thus this method is well suited to the prognostic test outlined above; and the other techniques are no less appropriate.

* In March 1951, after this work was done, Hunter told me he had made some determinations of sulphate in tomatoes. This work is unpublished (Glasgow Ph.D. Thesis, 1948) and none of its conclusions are known to me.

The cause of "checking"

This work does not by itself indicate the cause or causes of checking. Valuable as the information seems about the variations in phosphate uptake from a soil well supplied with phosphate; and though the information found about manganese and sulphate concentrations in the plant may be even more instructive; yet the variations in amounts of P, Mn, and SO_4, and other constituents, are probably results rather than causes. They each indicate an imbalance in the plant during "checking", but do not point to its cause.

The fertiliser trials with nitrogen gave useful negative evidence that the total supply of nitrogen in the soil is not a determinant of the "check". Taken in conjunction with the nitrogen analyses of the lamina, and in view of the evidence that manganese is somehow associated with nitrogen metabolism in plants (19, 20, 21), the evidence strongly suggests that checking is associated with a deficient uptake of nitrogen from the soil.

The present work was not, of course, directed specifically to elucidating this question of the availability of soil nitrogen.

From general knowledge, it is tentatively suggested that the cause of checking is most likely a toxicity due to excessive/

excessive build-up of soil ammonia; and this in turn is ascribable to incomplete nitrification, brought about by poor aeration: this, finally, is induced by treading and compaction of the soil, which lead to poor aeration and drainage.

Experiments explicitly designed to put conditions of soil aeration under test are being undertaken this (1951) season.

It is submitted that if the foregoing hypothesis is right, all the work is fully in line with what is known about the importance of drainage and aeration in crop husbandry. The ideal is to provide conditions for the continual passage, and unimpeded exchanges, of air and water through the soil. The tomato work thus dynamically links up with the findings of the initial work on utilisation and fate of phosphate in soils having various degrees of natural drainage.

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PART V.

DETERMINATION OF CALCIUM IN PLANT-TISSUE EXTRACTS.

REPRINT II.

Reprinted from THE ANALYST, *the Journal of the Society of Public Analysts and Other Analytical Chemists, April*, 1950, *Vol.* 75, *No.* 889, *pp.* 211–215

A Colorimetric Method for the Micro-Determination of Calcium in Plant Tissue Extracts

BY A. J. McGREGOR

SYNOPSIS—Calcium is extracted from fresh or dried plant material by an acetate reagent and precipitated as oxalate. The washed and centrifuged precipitate is used to reduce the red colour of a standard ferric thiocyanate solution. The decrease in intensity of colour, measured absorptiometrically, is proportional to the calcium content of the extract. Magnesium does not interfere.

At very low concentrations the accuracy is of the order of 8 per cent., but over the range 24 to 60 parts of calcium per million the accuracy of repetition is within 2 per cent. Over a similar range of calcium concentrations the results are in close agreement with those obtained by permanganate titration. Added calcium is recovered to within about 2 per cent.

WHAT is known as "lime deficiency" in soils is a common cause of partial failures of crops. The calcium status of the soil is reflected in that of the crop. A deficiency of calcium not great enough to produce visible signs of crop failure may injure quality, *e.g.*, in peas, or lead to risk of calcium deficiency in animals consuming fodder crops. A prompt diagnosis of unsatisfactory nutrient levels in a crop may be important and can be most effectively ascertained by tests performed on the growing plants. The method described below is designed to determine colorimetrically the calcium extractable by a reagent solution from fresh or dried plant material. As the method is rapid and simple it may be found useful for control in vegetable-processing factories as well as for agricultural advisory purposes.

Essentially the method consists of precipitating the calcium as calcium oxalate, washing and centrifuging the precipitate and determining the amount of calcium by the reduction in colour of a standard ferric thiocyanate solution. The intensity of colour developed is measured in a Spekker absorptiometer. The method has proved satisfactory as a routine procedure and gives results that are ordinarily accurate to 2 per cent.

The ability of oxalates to reduce ferric thiocyanate was utilised by Marriott and Howland[1] in a method for the determination of calcium in blood. The method here described is a modification of this procedure and is applicable to plant extracts. The ferric thiocyanate reagent used is capable of estimating 0·05 to 0·6 mg. of calcium in 10 ml.

METHOD

REAGENTS—

(1) *Acetate reagent*—30 ml. of glacial acetic acid (A.R.) are dissolved in 1 litre of a solution containing 100 g. of hydrated sodium acetate (A.R.).

(2) *Oxalate reagent*—4 g. of ammonium oxalate (A.R.) are dissolved in 100 ml. of distilled water.

(3) *Wash solution*—Prepared by mixing together 2 ml. of concentrated ammonia solution (sp.gr. 0·88), 98 ml. of distilled water, 100 ml. of redistilled ether and 100 ml. of redistilled ethyl alcohol.

(4) *Diluted hydrochloric acid*—50 ml. of concentrated hydrochloric acid (A.R.) are dissolved in distilled water and made up to 1 litre.

(5) *Ferric chloride solution*—8 g. of hydrated ferric chloride (A.R.) are dissolved in 500 ml. of reagent (4), made up to 1 litre with that reagent and filtered through No. 42 Whatman filter-paper.

(6) *Potassium thiocyanate*—16 g. of potassium thiocyanate (A.R.) are dissolved in distilled water and made up to 1 litre.

(7) *Thiocyanate reagent*—10 ml. of ferric chloride reagent (5) and 10 ml. of potassium thiocyanate reagent (6) are measured into a 200-ml. volumetric flask and made up to volume with distilled water. The reagent is allowed to stand for half an hour before use.

(8) *Standard calcium solution*—1·4984 g. of calcium carbonate (A.R.) (oven-dried) are dissolved in acetate reagent (1) and made up to 1 litre with that reagent. The concentration of this solution is 600 parts of calcium per million. A 60-p.p.m. standard solution is prepared by suitable dilution with acetate reagent.

PROCEDURE

Preparation of the extract—Prepare the extract by treating 10 g. of finely chopped fresh plant tissue with 200 ml. of acetate reagent in a Waring blendor and decolorising with 1 g. of purified carbon (not bone charcoal). After 3 minutes, filter the extract through a No. 42 Whatman filter-paper. (Extracts of dry material can be prepared by shaking 1 g. of dry matter with 100 ml. acetate reagent (1) in a to-and-fro shaker for 1 hour, and then clarifying and filtering as above.)

The extract volume—The standard extract volume is 10 ml. Place this volume in a 25-ml. centrifuge tube. (The volume of extract taken should contain between 0·05 mg. and 0·6 mg. of calcium. For samples containing greater amounts of calcium a suitable volume is diluted to 10 ml. with acetate reagent.)

Precipitation of calcium—Heat the centrifuge tube containing the extract volume in a water-bath to a temperature of 80° to 90° C. Add 1 drop of methyl red indicator, followed by 2 ml. of warm oxalate reagent (2). Add diluted aqueous ammonia (1 in 4) drop by drop until the acidity is nearly neutralised and the solution is faintly acid. Mix the contents of the tube thoroughly by rotating it between the hands. Allow to stand for an hour before centrifuging.

Washing the precipitate—Centrifuge the contents of tube at 3000 r.p.m. for 10 minutes. Suck off the supernatant liquid by means of a fine-bore glass tube connected to a water pump. Remove excess of oxalate and acetate reagents by two washings with the wash solution (3).

Drying the precipitate—After washing the precipitate, place the tubes in an electric oven at 90° C. till dry. Avoid over-heating.

Development of colour—Add 1 ml. of the hydrochloric acid reagent (4), accurately measured, to each tube and dissolve the precipitate completely by shaking the tube. If the precipitate is difficult to dissolve the tube can be placed in a water-bath for 2 or 3 minutes. Add 10 ml. of the thiocyanate reagent (7) and mix thoroughly. Allow the colours to develop for 30 minutes. It is convenient to develop colours in 20 to 25 tubes at a time.

Measurement of colour intensity—Measure the intensity of the colour by means of a Spekker absorptiometer. Use the 1-cm. cell, heat filters H503 and green filters No. 5. Set the drum at 1·00 against distilled water.

Calibration—Take 2, 4, 6, 8 and 10 ml. of the 60-p.p.m. calcium standard in centrifuge tubes, make up to 10 ml. with acetate reagent and treat as described above. Re-calibration is required when new potassium thiocyanate, ferric chloride or hydrochloric acid solutions are prepared.

NOTES—

Range of the method—When the concentration of calcium ions in the extract volume (10 ml.) is greater than 60 parts per million inaccurate results are obtained. If the concentration is between 60 and 120 p.p.m., the colours may be adjusted by the addition of a further 1 ml. of reagent (4) and 10 ml. of reagent (7). It may also be possible to measure higher concentrations of calcium by altering the strength of the thiocyanate reagent. This however has not been found necessary for most plant extracts. For extracts containing more than 60 p.p.m., a suitable aliquot is diluted to the extract volume with acetate reagent. The method is therefore capable of measuring concentrations of calcium of from 10 to 600 p.p.m.

Precipitation of calcium—Under the conditions of precipitation calcium is precipitated quantitatively. In the presence of excess of ammonium oxalate, magnesium ions in the extract do not interfere. The method has been tested with concentrations of magnesium higher than are normally found in plant extracts but no error resulted in the determination of calcium (Table I). The precipitation is usually complete within half an hour (Table II), but it is convenient to standardise the time at 1 hour.

TABLE I

THE EFFECT OF MAGNESIUM

Concentration, p.p.m.		Spekker reading (average of three determinations)
Calcium	Magnesium	
12	—	0·205
12	6	0·205
12	20	0·200
12	160	0·210
36	—	0·510
36	80	0·510

TABLE II

THE EFFECT OF PRECIPITATION TIME

Concentration of calcium, p.p.m.	Time between precipitating and centrifuging	Spekker reading
12	10 min.	0·185
60	10 "	0·765
12	20 min.	0·190
60	20 "	0·765
12	30 min.	0·195
60	30 "	0·780
12	1 hour	0·205
60	1 "	0·790
12	2 hours	0·205
60	2 "	0·785
12	18 hours	0·205
60	18 "	0·785

Washing the precipitate—Thorough washing of the precipitate is essential if accurate results are to be obtained. The wash solution recommended by Le Fevre and Nicholson[2] was found to be satisfactory and much superior to washing with dilute ammonia, alcohol and ether. The latter technique required three washings and four centrifugings, which make it a long, tedious process. Inaccurate results were obtained owing to the difficulties of centrifuging the calcium oxalate precipitate from these liquids. Two washings with the "wash solution" (3) were found to be satisfactory. Furthermore, solution (3) gives a suspension which is easily centrifuged at 3000 r.p.m.

The effect of acidity on intensity of colour—With increasing concentration of hydrochloric acid in the final solution, the sensitivity of the method is decreased (Table III). Various concentrations of hydrochloric acid were tried for dissolving the calcium oxalate precipitate. Reagent (4), 5 per cent. v/v hydrochloric acid gave the most satisfactory range of colours. With concentrations below this, difficulty was experienced in dissolving the precipitate.

The concentration of ferric thiocyanate was chosen to give a suitable range of Spekker readings under the conditions of the method. This was found to be 0·08 per cent. of potassium thiocyanate and 0·04 per cent. of ferric chloride, which gives a Spekker reading of about 0·04 in the absence of calcium and 0·75 with 60 p.p.m. of calcium in the extract volume.

The graph of calcium concentration against the Spekker drum reading is linear up to approximately 0·7. With increasing calcium concentration above this point, the reduction

in colour becomes less rapid and the graph curves rapidly, owing to interference by the yellowish colour of reduced iron thiocyanate.

The sensitivity of the method is increased by increasing the proportion of potassium thiocyanate to ferric chloride. A point is reached, however, at which further increases cause a serious reduction in the range of the method. The concentration of potassium thiocyanate

TABLE III

THE EFFECT OF HYDROCHLORIC ACID

Concentration of "concentrated" hydrochloric acid (v/v), %	Concentration of calcium in extract volume, p.p.m.	Spekker reading	Difference
5	12	0·205	0·585
	60	0·790	
10	12	0·255	0·490
	60	0·745	
15	12	0·315	0·415
	60	0·730	
20	12	0·350	0·365
	60	0·715	

and of ferric chloride prescribed for reagent (7) was found to give the maximum sensitivity for the range of calcium concentration required in this method.

Development of colour—The development of the thiocyanate colour is almost instantaneous, but it is advisable to allow the solutions to stand for several minutes in order to ensure that equilibrium has been reached. It was found convenient to read the colours half an hour after development. The colours are stable up to 1½ hours after development.

RESULTS

The method was checked by determining the calcium contents of typical plant extracts; a known amount of calcium was then added to fresh samples of each extract and the calcium contents re-determined. The percentage recovery of calcium was calculated and was found to be satisfactory (Table IV). In addition some acetate extracts of plant tissue were made and the calcium concentration in each determined in 5 ml. and in 10 ml. of the extract. Agreement was good; the results for four samples are shown in Table V.

TABLE IV

THE RECOVERY OF CALCIUM

	Calcium in extract volume, mg.			Calcium added, mg.		
Extract	Determined	Originally present plus amount added (calculated)	Re-determined	Known	Determined	Difference as % of the amount added
1	0·452	0·572	0·572	0·12	0·12	—
2	0·399	0·519	0·522	0·12	0·123	+2·5
3	0·259	0·499	0·495	0·24	0·236	−1·7

The accuracy of the method was also tested by comparison with the standard volumetric procedure of titrating the calcium oxalate with standard potassium permanganate solution

TABLE V

THE DETERMINATION OF CALCIUM IN 5 AND 10 ML. OF EXTRACT

Results for four samples

Volume of extract used	Concentration (p.p.m.) of calcium in extract volume (determined)			
	1	2	3	4
5 ml.	46·0	39·6	36·2	41·2
10 ml.	45·2	39·0	36·4	39·9
Difference, % ..	1·7	1·5	0·55	2·9

(Table VI). Eleven typical plant extracts were used for this comparison. The values obtained by the two methods were in close agreement. The coefficient of correlation was found to be +0·996.

TABLE VI

COMPARISON OF THE COLORIMETRIC METHOD AND VOLUMETRIC POTASSIUM PERMANGANATE METHOD

Sample	Concentration of calcium, mg. per 100 ml.	
	Thiocyanate	Permanganate
1	5·20	5·30
2	8·30	8·28
3	9·88	9·92
4	11·56	11·58
5	15·12	15·12
6	10·00	9·98
7	7·04	7·14
8	7·12	7·04
9	19·32	19·38
10	14·84	14·80
11	8·96	8·88
Mean	10·67	10·67

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2. Le Fevre, M. L., and Nicholson, E., *J. Dental Research*, 1938, **17**, 31; as quoted by Kochakian, C. D., and Fox, P. R., *Ind. Eng. Chem., Anal. Ed.*, 1944, **16**, 762.

THE WEST OF SCOTLAND AGRICULTURAL COLLEGE
6, BLYTHSWOOD SQUARE, GLASGOW, C.2

May, 1949

DETERMINATION OF CALCIUM *

Analyses of standard solutions conducted throughout a period of two weeks.

Concentration (p.p.m.) of Ca in extract volume	6	12	24	36	48	60
Number of samples	20	20	20	20	20	20
Mean Spekker reading	0.105	0.168	0.317	0.472	0.624	0.754
Concentration (p.p.m.) determined using graph of mean Spekker readings.	6.0 6.5 6.0 5.6 5.6 6.0 6.5 7.0 6.0 6.0 6.0 5.6 5.0 6.5 6.0 5.6 6.0 5.6 6.5 6.0	11.8 11.8 11.4 12.2 12.6 12.6 11.8 12.2 11.8 11.8 12.2 12.6 11.8 11.8 11.8 12.2 12.2 11.8 11.4 12.2	24.2 23.9 24.2 24.2 25.0 23.5 24.2 24.2 23.2 23.2 23.9 24.2 24.6 24.2 23.9 23.9 24.2 24.2 23.9 23.5	36.2 36.6 36.2 36.2 36.2 36.2 35.6 35.8 35.6 35.6 36.2 36.6 35.6 36.2 37.0 36.2 36.2 35.8 35.8 35.6	48.4 48.4 48.9 48.9 47.3 48.4 48.1 48.1 47.0 48.4 47.3 48.9 47.7 47.3 48.1 47.7 47.7 47.7 47.7 48.1	60.7 60.7 61.2 60.2 59.7 59.7 60.2 59.2 59.7 59.7 59.7 60.2 60.7 60.2 61.2 59.7 59.7 59.7 60.2 59.7

DETERMINATION OF CALCIUM*

Results of analyses of standard solutions, continued

Mean determined concentration p.p.m.	6.0	12.0	24.0	36.07	48.0	60.1
Standard Deviation	0.44	0.36	0.43	0.39	0.56	0.55
Coefficient of Variation	7.33	3.0	1.8	1.1	1.1	0.92

* Omitted from published work.

ACKNOWLEDGMENTS

In addition to giving thanks already to certain helpers and colleagues, special thanks are recorded to:

Sir George Wilson, M.A., Ll.D., Chairman of Governors, West of Scotland Agricultural College, for allowing use of land for experiments on penetration of phosphate in grassland. To him and to other farmers for allowing access to their land for the phosphate experiments with swedes.

To the owners and managers of the commercial glasshouses at the five centres named for their kind co-operation in providing space and facilities for the conduct of trials; and to other growers who have allowed samples to be taken.

To the Horticulture Dept. of the West of Scotland Agricultural College and especially to Mr. J.B.R. Anderson for facilitating the choice of sites and conduct of the tomato experiments; and also for much assistance with the recordings of fruit yield and condition of the plants, as well for his valued assistance in laying out the manurial plots in tomato houses.

To Mr. R.H. Alexander for much assistance with the recordings of fruit yield and other greenhouse work, including valued assistance in laying out the plots; and further for much help in the photography of the diagrams included herewith.

To present and former colleagues of the Chemistry Dept. for help in laying out field plots and giving assistance with analyses: notably the laboratory assistants who did much of the routine analytical work.

To my director, Professor Hugh Nicol, Advisory Agricultural Chemist, West of Scotland Agricultural College, I would like to express my sincere appreciation of his guidance and criticism, during the progress of this work.

PART VI.

APPENDIXES

APPENDIX A.

REPRINTS III AND IV.

REPRINT III.

[*Reprinted from* SCOTTISH AGRICULTURE, *Vol. XXVI., No.* 1, *July* 1946, *by permission of the Controller of H.M. Stationery Office.*]

SOME ABNORMALITIES IN THE NUTRITION OF CROPS.

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IN July 1945 the writers gave a preliminary account in the *Journal* of an investigation of several cases of partial or complete failure of the potato crop that were found to be due to nutritional deficiencies. Further work has been undertaken during the past season on similar examples of crop failures, and the method of determining the status of mineral nutrition by the extraction of soluble constituents from plant tissues has been developed and extended. The present report describes the more important points which have been established during the season from this work in the West of Scotland College area. It should be understood, however, that a complete survey of crop failure cases in the area could not be undertaken and that the extent and economic significance of some of the deficiency conditions here discussed cannot as yet be accurately established. There is no doubt, however, that on particular farms the diseases may lead to serious loss.

Diseases associated with deficiency of the major food elements.—In the early part of the season, some cases of poor and sickly growth in cereal crops were found to be due to a temporary deficiency of either nitrogen or magnesium. These were no doubt due to the cold and wet spring affecting the rate of root development and hence the ability of the plant to obtain its required food supply. The occurrence was more pronounced on heavy, poorly drained soils, and more or less complete recovery followed an improvement in the weather conditions.

A deficiency of nitrogen was occasionally noted in crops later in the season which was not related to weather conditions, but was due to an actual soil deficiency of available nitrogen. Several poor crops were also proved to be due to insufficient phosphorus and potassium, but these were more frequent in the case of root crops than with cereals. More adequate use of farmyard manure and fertilisers would have prevented these deficiencies: the cure is always straightforward. Deficiency of phosphates and of potash must always be a possibility so long as fertilisers are in short supply and insufficient for the needs of all the crops on the farm.

Diseases associated with soil acidity.—As a result of this season's work it has been possible to form a clearer picture of the effects of soil acidity and to define this effect in terms of mineral absorption. In cases of extreme acidity or sourness the crop may suffer from a deficiency of lime or magnesium or from an accumulation in the plant of toxic amounts of manganese.

A deficiency of calcium (lime) in crops such as oats and potatoes, which are generally supposed to be remarkably tolerant of soil acidity, was again found in several cases. It is advisable, therefore, to apply lime to extremely acid soils even for such crops, and this is particularly important when the soils are light in texture. In certain cases where lime had not been applied to very acid soils and calcium deficiency symptoms appeared, con-

siderable improvement in crop growth was obtained when top-dressings of hydrated lime were applied while the plants were still young.

A deficiency of magnesium in the soil and in the plant appears to be much more widespread in this area than was suspected up to now. Instances were found in the counties of Ayr, Dunbarton, Lanark, Renfrew, Stirling and in West Perth, and they occurred on more than one soil type. In some cases the soils were not extremely acid and the need for liming might not have been too obvious.

Magnesium deficiency associated with acid soil conditions can frequently be counteracted by applying ordinary lime materials such as burnt lime or ground limestone, but occasionally the use of ordinary lime may intensify the magnesium deficiency. Treatment with dolomitic limestone or magnesium marl will always prevent the trouble provided that the lime or marl has been applied some time before the crop is sown and has been worked into the surface soil. Some evidence was obtained that potatoes are particularly susceptible to magnesium deficiency and they may require relatively more magnesium than other crops. Dressings of dolomitic limestone or magnesium marl may be specially suitable for the potato crop on very acid soils.

A magnesium-deficient crop can always be treated by spraying with a solution of magnesium sulphate (Epsom Salts or Kieserite), but the treatment is effective only when applied during the early stages of growth. It may sometimes be possible to save an affected crop in this way, but the more satisfactory and more permanent cure is to apply a magnesium limestone or marl to the soil before planting.

The association between certain types of crop abnormality or failure on acid soils and the presence in the crop of unusually high concentrations of manganese does not seem to have been recorded previously in this country.[1] A number of cases of this kind were observed in Dunbartonshire, Lanarkshire, Renfrewshire and Stirlingshire on swedes and oats, and the examination of the tissues showed the presence of comparatively large total amounts of manganese. These amounts were of the order of 500-1,500 parts per million of the dry matter compared with usual level of 50-200 parts per million. The soils in such cases also showed an abnormally high concentration of water-soluble manganese.

The solubility of manganese in the soil is governed by a number of factors, the more important of which are the degree of acidity and the amount of soil organic matter. As the acidity increases, the solubility tends also to increase, particularly where organic matter is not too plentiful. In a very acid soil the plant may absorb more manganese than it requires for normal metabolism, and the excess may lead to abnormality in growth.

In some cases the affected crop also showed a deficiency of magnesium or calcium, and the acidity effect was therefore due to a combination of the previously mentioned factors.

Adequate liming with the right type of material is, of course, the practical cure for acidity failures on the farm, whether the effect of the acidity shows itself in a deficiency of either calcium or magnesium or in an accumulation of manganese. Ordinary lime materials are probably satisfactory in the majority of cases, but farmers should consider using either dolomitic limestone or magnesium marl where there is any reason to suspect that the soils or crops suffer from a deficiency of magnesium.

[1] Since this article was submitted, Wallace, Hewitt and Nicholas have published in *Nature* (Volume 156, page 778) an account of a similar effect on the runner bean and cauliflower, and Hale and Heintze (*Nature*, Volume 157, page 554) have drawn attention to it on agricultural crops.

Diseases associated with trace element deficiencies.—The West of Scotland area seems to be more fortunate than other areas in the country in that serious deficiencies of trace elements are not very frequent. In addition to boron deficiency in the root crops, a number of instances of manganese deficiency in oats have been confirmed. This deficiency disease must be clearly distinguished from the acidity condition previously mentioned due to an accumulation of manganese. The manganese deficiency disease in oats is called "Grey Speck," and the symptoms are the appearance on the young oat foliage of yellowish grey streaks or specks which may develop into streaks of brown dead tissue, and the tips of affected leaves generally bend downwards in a characteristic manner. The disease is associated with slightly acid, neutral or alkaline soil conditions and the presence of abundant organic matter.

The deficiency can be counteracted by spraying the growing crop with a 1 per cent. solution of manganese sulphate at the rate of about 200 gallons per acre, or by applying a dressing of solid manganese sulphate immediately before sowing at the rate of ½-1 cwt. per acre. The spray treatment is the more effective in the majority of cases. Basic slag, which contains appreciable amounts of manganese, has proved effective under certain conditions in controlling the deficiency.

It should be noted that most nutritional deficiency diseases are less severe where generous dressings of farmyard manure have been used, although manure, by itself, will not often be a complete cure for the trouble. Much of the value of farmyard manure as a plant food is due to its content of phosphates and potash, but it may supply some of the necessary amounts of other elements such as magnesium. It may also enable the plant to obtain a larger supply of nutrients from the soil by encouraging a more active root growth or by its effect on biochemical reactions in the soil.

Deficiency diseases may lead to serious reduction in crop yields, even where complete failure does not result. In the case of potatoes a further complication arises from the fact that certain deficiencies produce abnormalities in growth and some of these resemble closely the symptoms of virus diseases. The occurrence of such abnormalities may mean that where it is desired for seed, a proportion of the crop is destroyed in roguing. It is very desirable, therefore, that farmers should report cases of crop failure to the College authorities as soon as suspicious symptoms appear. Our knowledge of crop nutrition is steadily growing, and the use of soil analysis supplemented by the recently developed technique of tissue or foliar analysis means that correct diagnosis of abnormal nutritional conditions should generally be possible. In this, as in other matters, prevention is better than cure, but early diagnosis may mean the saving of the crop.

It is with pleasure that the authors acknowledge that Dr D. N. M'Arthur, Director, The Macaulay Institute for Soil Research, and Dr R. Stewart, recently Professor of Agricultural Chemistry, The West of Scotland Agricultural College, have been closely associated with this work.

(868) Wt 72925/34 8/46 L. & Co. Ltd. Gp 167.

REPRINT IV.

[*Reprinted from* THE SCOTTISH JOURNAL OF AGRICULTURE, *Vol. XXV., No.* 3, *July* 1945, *by permission of the Controller of H.M. Stationery Office.*]

AN INVESTIGATION OF DISEASES RESULTING FROM INADEQUATE NUTRITION OF THE POTATO PLANT.

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CERTAIN failures of the potato crop in parts of Perthshire and Stirlingshire have been investigated in the past two seasons. It has been found that although sometimes the plants seemed to be affected by ordinary disease organisms, such as the leaf roll virus and mosaic virus, the trouble really was due to the absence of sufficient supplies of certain nutrients, namely, calcium, magnesium, or nitrogen. The affected plants vary in appearance, but three main types have been distinguished.

In the first of these, a good example of which occurred at a farm in Perthshire, the plants were very dwarfed and the leaves, when young, had a slight upward roll which increased as the plants grew older. In August, at which time the haulms were only about six inches high, the older leaves were blotched yellow and brown and dead patches were present on them. This marking of the leaves was particularly evident at the margins and at the tips, though in the oldest leaves it extended right between the veins. The leaves died prematurely and dropped off so that the haulms tended to be bare. The younger leaves were a pale, unhealthy green colour. The tubers were small and the yield poor.

When the soil on which these potatoes were growing was examined it was found to be extremely acid. Last season it was decided to try the effect of liming, and so groups of twelve drills received ground shell lime at various rates (see table), while some received none. The lime was broadcast over the drill and the potatoes were planted four days later. A few drills also received dung, while still others received lime and dung. The whole field received a dressing of potato manure at the rate of 6 cwt. per acre.

In the areas which had received nothing but potato manure, the potatoes were diseased. Where lime, lime and dung or dung alone had been applied, the soil was found to be less acid than before, and the potatoes grew well and gave fair yields. The potatoes in the lime plots had very little scab, although they were planted right in the lime. It is probable that even better results would have been obtained had ground limestone been used and cultivated into the soil earlier

in the season. It is hoped to continue the investigation next year.

Potatoes were also grown on a neighbouring field, the soil of which was very acid, and after they were planted the farmer top-dressed the drills with lime. The crop grew normally, although yields were not so large as those in the lime plots of the experiment.

Samples of the leaf blades and haulms were taken from diseased and normal plants growing in the experimental areas, and these were examined by a special rapid technique so that the amounts of soluble minerals present in them were determined. The soluble minerals are those which can be removed from the tissue by an extracting solution containing the substances sodium acetate and acetic acid. A deficiency of any one of the soluble minerals in a plant tissue indicates that the plant is not receiving sufficient of that mineral for normal development.

When the figures for the soluble minerals were compared, it was found that the leaf blades of normal plants contained about four times as much calcium as those of the diseased plants. The amount in the haulms of normal plants was also greater than that in abnormal ones, though the difference was not so marked. The amount of soluble magnesium was also found to be smaller in diseased plants than in normal, though the difference was relatively not so important as that in the case of calcium. Since there was no significant difference in the values received for the other soluble minerals in the tissues, it was deduced that the cause of the disease was primarily a serious deficiency of calcium in the soil. It was also considered that the disease was aggravated by low supplies of magnesium. Examination of the soil confirmed that the amounts of exchangeable calcium and magnesium were small where the plants were diseased. These deficiencies were probably produced by the extremely acid state of the soil. The effects of adding lime and dung would result from the presence of sufficient calcium and magnesium for the growth of the plants.

The second main type of disease was well illustrated at a farm in Stirlingshire, where, although adequate supplies of a potato manure had been given, the growth was very poor. The haulms in August were only 12-18 inches high and very bare, due to the premature death and shedding of many of the older leaves.

In the early stages the margins of the leaves had a slight upward curl. A yellowing of the margins and tips soon developed, and in time this changed to an orange-yellow colour which extended from the margins to the veins and midribs. Sometimes the only green parts left on a leaf were small patches between the veins. Brownish-purple areas were usually present between the veins and were sometimes surrounded by an almost normal green colour and at others by yellow tissue. Brown dead patches were often present on various parts of the leaves. The tubers here were not so badly affected as those of the first type, but the yield was considerably reduced.

The plant tissue was examined for soluble minerals as before and this time it was found that the only soluble mineral deficient was magnesium and that there was only one-seventh as much of it in the leaf blades of the diseased plants as was in those of the healthy. The disease was therefore assumed to be due to a deficiency of magnesium, and examination of the soil confirmed this. In this case also the soil

was found to be extremely acid, which probably accounted for the deficiency.

The best means of preventing such a deficiency is to apply lime (particularly dolomitic limestone, which contains magnesium compounds) or to utilise dung. This should ensure the presence of sufficient magnesium in the soil for the growth of the plants. An alternative means would be to apply suitable dressings of magnesium salts.

In another type of potato disease which was studied, the plants were stunted and parts of the leaves were a yellow-green colour, although, unlike the previous types, the peculiar marginal effect was absent. The extreme edges of the leaves were brownish and there was a very slight upward curl. The tuber yield was reduced.

When plants suffering from this type of disease were examined by the methods previously stated, it was found that their nitrate content was considerably lower than that of normal plants. The disease, therefore, appears to be caused by a deficiency of those nitrogenous compounds which can be absorbed by the plants.

This disease may be prevented from appearing by application of suitable amounts of nitrogenous manures.

The first two types of disease were associated with extreme acidity, and liming of the soil, in conjunction with application of farmyard manure, seems to be the remedy. The main purpose of this article, however, is not to advocate extensive liming of soil in which potatoes have to be grown, but to point out that in certain cases liming will prevent failure of the potato crop.

TABLE.

Yield of tubers from lime experiment, Perthshire.

Treatments per acre in addition to potato manure	Approximate yields per acre
Nothing	1 ton
5 cwt. ground shell lime	4 tons
10 cwt. ground shell lime	4½ tons
20 cwt. ground shell lime	5½ tons
10 tons farmyard manure	5½ tons
10 cwt. ground shell lime and 10 tons farmyard manure	8½ tons

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APPENDIX B.

CHEMICAL METHODS.

Dry Matter.

When the percentage dry matter of plant tissue was required, 50 g. samples were weighed out in duplicate and dried in an oven at 90°C. The samples for dry-matter estimation must be weighed out as soon as possible, otherwise considerable loss of weight will occur and high answers will be obtained. After being in the oven for 48 hours, the dry matter was weighed and the dry matter calculated. Any surplus of the sample may be dried in the same way, without weighing.

After drying the dry matter was milled and stored in glass bottles.

Preparation of Extract.

a. Extract of Fresh material:- The fresh material was finely chopped, thoroughly mixed and a 10 g. representative sample weighed out. This process must be done as quickly as possible to prevent excessive loss of weight by evaporation. The 10-g. sample was extracted with 200 ml. Morgan's reagent in a Waring Blendor for 3 minutes. The extract was then decolorised by adding 1 - 2 g. of purified carbon and macerating for a further half minute. The extract was filtered through a Whatman No. 42, 18.5 cm. filter paper.

b. Extract of Dried material:- The dried material

after/

after milling was thoroughly mixed and returned to the oven for 1 hour. 1 g. of the sample was weighed out and extracted by shaking for 1 hour with 100 ml. Morgan's reagent. Approximately 1 g. of carbon was added and the extract shaken for a further 5 minutes. The extract was then filtered through a Whatman No. 42, 18.5 cm. filter paper.

Reagents:-

Morgan's Reagent. 100 g. hydrated sodium acetate (A.R.) are dissolved in water, 30 ml. glacial acetic acid (A.R.) added and the mixture made up to one litre with water.

Carbon. Activated charcoal must be purified before use. This is done by extracting with hot 50% hydrochloric acid, followed by repeated washing with water. The carbon is then dried. The purity is checked by extracting about 2 g. with 100 ml. Morgan's reagent and testing the extract for phosphate; the phosphate concentration must be small.

Determination of Potassium in plant tissue extracts.

Reagents.

1. Cobaltinitrite reagent:-

a. 50 g. sodium nitrite are dissolved in water and diluted to 150 ml.. 25 g. of sodium cobaltinitrite are added and dissolved.

b. 40 g. silver nitrate are dissolved in water and diluted to 100 ml..

c. Glacial acetic acid.

5 ml. of reagent b. are added to reagent a. and the mixture diluted to 200 ml.. 2 ml. of reagent c. are then added and a current of air passed through the mixture for one hour to remove nitrous fumes. The reagent is kept at about 5°C. for at least 12 hours and then filtered through a No. 42 Whatman filter paper. It is stored at about 5°C. for not longer than two weeks and is centrifuged immediately before use, only the supernatant layers being used in the determination.

2. 30% Acetone:- 300 ml. acetone diluted to 1 litre with water.

3. Nitric acid reagent:- 200 ml. of nitric acid (A.R.) are diluted with 800 ml. of water, two drops of Lyssapol-N are added and mixed.

4. Thiocyanate reagent:- 20 g. of ammonium thiocyanate

are/

are dissolved in 1 litre rectified industrial spirits.

5. Potassium stock solution:- 3000 p.p.m. potassium. 7.757 g. potassium nitrate (A.R.) are dissolved in Morgan's reagent and diluted to 1 litre with Morgan's reagent.

6. Potassium standard solution:- 150 p.p.m. potassium. 50 ml. potassium stock solution are diluted to 1 litre with Morgan's reagent.

Procedure.

An aliquot of the extract (containing 0.075 to 0.75 mg. K) is diluted to 5 ml. with Morgan's reagent in a centrifuge tube and 2 ml, of the cobaltinitrite reagent are added. The contents are mixed and the tube kept about 5°C. for at least an hour after which it is centrifuged for five minutes at 6000 r.p.m.. The clear solution is then sucked off leaving the precipitate undisturbed. The precipitate is washed two or three times with 5 - 10 ml. of 30% acetone reagent, and once with pure acetone, centrifuging and sucking off as before after each washing. The final washing must be practically colourless.

The tube is then supported by a stand so that it almost touches the surface of a hot plate, until all the acetone has evaporated. 1 ml. of the nitric acid reagent

is/

is then added and the tube heated in boiling water until the cobaltinitrite portion of the precipitate (including any on the side of the tube) has dissolved; evaporation of the contents of the tube is kept at a minimum. A residue of silver chloride usually remains after this treatment.

The tube is cooled and 10 ml. of the thiocyanate reagent are added, shaken and left for at least 20 minutes, during which time any turbidity due to silver chloride separates out (centrifuging is permissable).

The intensity of the blue colour is then determined using the Spekker absorptiometer. The 1 cm. cell, heat filters H503 and red filters No. 1 are used.

Calibration:-

0,1,2,3,4,5 ml. of the potassium standard solution are put in centrifuge tubes and diluted to 5 ml. with Morgan's reagent. The colours are developed as above.

The Spekker drum readings are plotted against the concentration of potassium in p.p.m., the 5 ml. standard being equivalent to 150 p.p.m. potassium. The graph value multiplied by 5 and divide by the volume of the aliquot gives the concentration of potassium as p.p.m. in the extract.

Notes:-

Iron must not be present in the reagents and apparatus/

apparatus because of the red colour formed with the thiocyanate reagent. A faint pink colour in this reagent itself does not interfere.

Source of Method.

A private communication from Dr. T.W. Walker, Advisory Chemist, West Midland Province, N.A.A.S.

Determination of Magnesium in Plant Tissue Extracts.

REAGENTS:-

1. Oxalic acid reagent:- 15 g. oxalic acid (hydrated) are dissolved in water and made up to 1 litre.
2. Tartrate reagent:- Prepared by mixing the following together and making up to 1 litre with Morgan's reagent.

   a. 15 g. sodium hydrogen tartrate are dissolved in about 400 ml. warm Morgan's reagent and cooled.

   b. 15 g. mannitol are dissolved in about 200 ml. warm Morgan's reagent and cooled.

   c. 4 g. hydrazine sulphate are dissolved in boiling Morgan's reagent and cooled.
3. Titan Yellow reagent:- 0.8 g. titan yellow are dissolved in 1 litre water and filtered.
4. Sodium hydroxide reagent:- 180 g. sodium hydroxide are dissolved in 1 litre of water. This reagent is used at temperature between 50 and 70°C. and is added by a fairly rapidly emptying pipette (not automatic) with a protection bulb on mouthpiece.

PROCEDURE:-

An aliquot of the extract (containing 0.03 - 0.2 mg. Mg) is diluted to 20 ml. with Morgan's reagent in a 100 ml. conical/

conical flask. 5 ml. of oxalic acid reagent are then added, mixed and left for 1 hour or more at room temperature.

The following are then added in succession, the contents of the flask being mixed after each addition.

5 ml. tartrate reagent.

1 ml. (exactly) titan yellow reagent.

20 ml. sodium hydroxide reagent.

The mixture is allowed to cool to room temperature and two hours after the addition of sodium hydroxide reagent it is shaken with 50 ml. (added from 50 ml. measuring cylinder) absolute iso-propyl alcohol for 30 seconds.

The two phases are allowed to separate. The alcohol layer is decanted into a 4 cm. Spekker cell and reading taken using heat and violet filters.

CALIBRATION:-

Magnesium Stock Solution:- 400 p.p.m. Magnesium.

4.054 g. $MgSO_4.7H_2O$ (A.R.) are dissolved in Morgan's reagent and diluted to 1 litre with Morgan's reagent.

Magnesium Standard Solution:- 20 p.p.m. Magnesium.

50 ml. magnesium stock solution are diluted to litre with Morgan's reagent.

Calcium/

Calcium Compensating Stock Solution:- 4000 p.p.m. Ca. 10 g. $CaCO_3$ (A.R.) are added to about 100 ml. water in a covered beaker and about 10 ml. glacial acid added. The mixture is warmed and about 500 ml. Morgan's reagent added and warmed until the carbonate has dissolved. The solution is cooled and made up to 1 litre with Morgan's reagent.

Calcium Compensating Solution:- 200 p.p.m. Calcium. 50 ml. of calcium stock solution are diluted to 1 litre with Morgan's reagent.

Calibration Graph is prepared as follows:-

0,2,4,6,8 and 10 ml. of magnesium standard solution are measured into 100 ml. conical flasks, 5 ml. of calcium compensating solution are added to each and diluted to 20 ml. with Morgan's reagent. Oxalic acid is added and the rest of the procedure is the same as before.

The Spekker drum-readings are plotted against the concentrations of magnesium, the 10 ml. standard being equivalent to 20 p.p.m. Mg. The graph value multiplied by 10 and divided by the aliquot volume gives the concentration of magnesium as p.p.m. in the extract.

SOURCE OF METHOD:-

A private communication from Dr. J.G. Hunter, Plant Physiology Department, Macaulay Institute for Soil Research.

Determination of Phosphorus in Plant Tissue extracts.

Reagents:-

1. Ammonium molybdate:- 2.5% ammonium molybdate (A.R.) in 6N sulphuric acid.
2. Aminonaphtholsulphonic acid:- 0.5 g. 1: amino-2:naphthol-4:sulphonic acid dissolved in 180 ml. 15% sodium meta-bisulphite. 30 ml. 20% sodium sulphite added slowly with constant stirring.
3. Phosphate Stock Solution:- 400 p.p.m. phosphorus. 1.754 g. of dry potassium dihydrogen phosphate dissolved in Morgan's reagent and diluted to 1 litre.
4. Phosphate Standard Solution:- 20 p.p.m. phosphorus. 50 ml. of the phosphate stock solution diluted to 1 litre with Morgan's reagent.

Procedure:-

An aliquot, containing 0.04 - 0.40 mg. phosphorus is measured into a 100 ml. conical flask and made up to 20 ml. with Morgan's reagent. 4 ml. ammonium molybdate reagent are then added, followed by 1 ml. aminonaphtholsulphonic acid reagent. The colour is allowed to develop for 1 hour after the addition of the sulphonic acid reagent. The intensity of the blue colour is determined in the Spekker absorptiometer, using a 1 cm. cell/

cell, blue filters No. 6 and heat filters No. H503.

Calibration:-

0,2,4,6,8,10,12,14,16,18 and 20 ml. of the phosphate standard solution are measured into 100 ml. conical flasks and diluted to 20 ml. with Morgan's reagent. The procedure is then as above.

The Spekker readings are plotted against phosphorus concentration in the standards, the 20 ml. being equivalent to 20 p.p.m. phosphorus.

Source of Method:- This method was evolved by Dr. J.G. Hunter, when working at Chemistry Dept., West of Scotland Agricultural College.

Determination of Manganese in Plant material.

This method is a modification of the usual method of estimating manganese in plant material. It is suitable as a routine procedure giving results of a fairly high standard of accuracy.

Reagents:-

1. Manganese-free concentrated nitric acid.
2. Concentrated sulphuric acid.
3. Perchloric acid 60%.
4. Phosphoric acid Sp.Gr. 1.75.
5. Sodium or potassium periodate.

Precautions:-

All wash-bottles must be free from rubber fittings. Glassware must be rinsed with distilled water before use. It is important that the order of addition of acids be nitric, sulphuric, perchloric, to prevent the possibility of an explosion.

Method:-

1. Digestion:- 1 - 5 g. of dry matter are weighed into a kjeldahl flask, concentrated nitric acid is then added 15 ml. for quantities up to 2 g. and a further 7 ml. for each additional g. of dry matter. 5 ml. sulphuric acid followed by 4 ml. perchloric acid are then added. The contents/

contents of the flask are mixed and heated gently at low heat for 2 or 3 minutes until dense brown fumes appear. The heating is continued with a slightly larger flame until white fumes appear (if 25-30 ml. nitric acid have been used this should take $1\frac{1}{2}$ - $1\frac{3}{4}$ hrs.). Digestion is continued at low heat for 5-10 minutes after white fumes appear and then heated strongly until colourless. If the contents of the flask are yellow when cold, the flask should be reheated until the contents are colourless. The flask is then allowed to cool and 5-10 ml. distilled water are added.

2. Development of colour:- The contents of the flask are filtered through a sintered glass crucible (No. 3) into a 100 ml. beaker and the flask washed several times with hot distilled water. Care should be taken to ensure that filtrate runs through clear of rubber fittings. The total filtrate should be about 70 ml.. 2 ml. phosphoric acid and 0.3 g. sodium periodate are added and the contents are heated to boiling. The boiling is continued for 2 minutes and the beaker is then placed on a hot plate at medium heat for 20 minutes to ensure complete development of colour. The beaker is then cooled and the contents are made up to 100 ml. with distilled water. The liquid is decanted from a white crystalline ppte.

and/

and the intensity of colour is measured in a Spekker absorptiometer using 4 cm. cell, green filter No.5, heat filters H503, water as standard and drum-reading of 1.00.

3. Dilution of colour:- For concentrations of manganese greater than 1.2 mg. per 100 ml. a dilution may be made. An aliquot of the final colour is taken and made up to 100 ml. with distilled water.

4. Standard solution:- The standard manganese solution may be prepared as follows. Dissolve 0.2878 g. potassium permanganate (A.R.) in 250 ml. distilled water. Add 40 ml. conc. sulphuric acid and reduce the permanganate by the careful addition of sodium metabisulphite solution until the liquid just becomes colourless. Oxidise excess sulphurous acid by addition of a little nitric acid (or boil off excess sulphur dioxide). When cool, dilute to 1 litre with distilled water.

1 ml. of this solution is equivalent to 0.1 mg. Mn.

Calibration:- 1-15 ml. of standard solution are measured into 100 ml. beakers. 10 ml. concentrated sulphuric acid and 2 ml. phosphoric acid are added to each. The contents of the beakers are diluted to about 60 ml. with distilled water and the colours are developed as before.

The/

The graph of manganese concentration against Spekker drum-reading is nearly linear up to 1-1.2 mg. Mn. but colours more intense give a rapidly curving graph.

References:-

1. Cook, J. W., 1941, Ind. and Engng. Chem. Anal. Ed., 13, 48.

2. Peech, M. , 1941, Ind. and Engng. Chem. Anal. Ed., 13, 436.

3. Piper, C. S., 1944, "Soil and Plant Analysis", Adelaide; p.346.

Determination of Sulphate in Morgan's extracts of plant tissue.

Reagents:-

1. Barium Chloride Reagent: 10 g. barium chloride dissolved in water and diluted to 1 litre.

2. 0.2% Hydrochloric acid: 2 ml. concentrated hydrochloric acid diluted with water to 1 litre.

3. Precipitating Reagent:

(a) 0.4 g. of bacteriological beef peptone dissolved in 100 ml. barium chloride reagent and sufficient 0.2% hydrochloric acid added to give a pH of 5.0 (determined by a glass electrode). 20 g. sodium chloride added, dissolved, and the solution made up to 200 ml. The solution is heated in a boiling water bath for 15 minutes, cooled, and a few drops of chloroform added. It is then stored in a refrigerator and can be used long after the date of preparation.

(b) 2 g. ground gum ghatti dissolved in barium chloride reagent and diluted with water to 1 litre. This reagent cannot be used beyond one week from date of preparation.

(c) The precipitating reagent is prepared immediately before use by mixing one volume (a) with 50 volumes (b).

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4. Sulphate Stock Solution: 5000 p.p.m. sulphate. 11.14 g. K_2SO (analytical reagent) dissolved in Morgan's reagent and diluted to 1 litre with Morgan's reagent.

5. Sulphate Standard Solution: 250 p.p.m. sulphate. 50 ml. sulphate stock solution diluted to 1 litre with Morgan's reagent.

Procedure.

An aliquot of the extract (containing 0.25 - 2.50 mg. sulphate) is pipetted into a test tube and diluted to 10 ml. with Morgan's reagent. 5 ml. dilute hydrochloric acid (1:4) are added and the contents of the tube shaken, 3 ml. of the precipitating reagent are then added and the contents of the tube shaken vigorously and left for 1 hour. The tube is then shaken vigorously, air bubbles allowed to disperse and the intensity of the turbidity determined.

Calibration Graph.

0,2,4,6,8,10 ml. of the sulphate standard solution are diluted to 10 ml. with Morgan's reagent, 5 ml. dilute hydrochloric acid added and the determination completed as above.

The intensity readings are plotted against the concentration of sulphate, the 10 ml. standard being equivalent to 250 p.p.m. sulphate. The graph reading multiplied/

multiplied by 10 and divided by the aliquot volume gives the concentration of sulphate as p.p.m. in the extract.

Source of Method.

Private communications from Dr. J. G. Hunter, Plant Physiology Dept., Macaulay Institute for Soil Research, Aberdeen. It is a modification of a method by Milton, Hoskins and Jackman (1).

(1) Milton, R., Hoskins, J.L., and Jackman, W.H.F.; Analyst (1944) 69 : 299.

Determination of Total Nitrogen in Dry Matter.

Reagents:-

1. Catalyst:- Prepared by grinding together -
   32 parts potassium sulphate
   5 parts mercuric sulphate
   1 part selenium powder.
2. Caustic Soda:- 1 lb. commercial sodium hydroxide + 50 g. sodium thiosulphate dissolved in 1 litre water.
3. Boric acid:- 30 g. boric acid (A.R.) dissolved in water and diluted to 1 litre.
4. Hydrochloric acid:- Standardised N/10 HCl.

Procedure:-

A ½ g. sample of the dry matter is accurately weighed into a 300 ml. Kjeldahl flask and about 1 g. of the catalyst added. 10 ml. concentrated nitrogen-free sulphuric acid are then added, care being taken to wash down any dry matter in the neck of the flask.

The flask is heated fairly vigorously until the contents of the flask become clear or straw coloured. The flask is allowed to cool and 40 - 50 ml. water added, again washing down the neck of the flask. The contents of the flask are mixed and boiled until all the water has/

has boiled off. The remaining liquid in the flask is boiled for another 30 minutes, and allowed to cool.

The contents of the flask are diluted to about 100 ml. and 60 ml. of the caustic soda reagent added carefully down the side of the flask. The flask is then fitted to a condenser and the contents of the flask mixed. The ammonia is distilled over into a flask containing boric acid.

The amount of ammonia trapped in the boric acid is determined by titrating with standard hydrochloric acid. About 1 ml. of a mixed indicator (20 ml. 0.1% methyl red in 95% ethyl alcohol + 100 ml. 0.1% bromo cresol green in 90% ethyl alcohol), is used.

Note:- This method does not take into account any nitrate present in the dry matter. Owen (3) estimated nitrogen in the dry matter of tomato plants by a similar method. He states. "Good agreement was obtained in all duplicate determinations. This points to the homogeneity of the material and suggests that the amount of nitrate nitrogen present and of compounds to which the Kjeldahl method is not applicable is negligible."

RÉSUMÉ

RÉSUMÉ

This describes three years' work on the penetration of phosphate into the top 7 inches of grassland after superphosphate had been applied once as top-dressing. The originality of the work consists in:

i) its being the only study of phosphate mobility in grassland soil whereby the effects of degree of natural drainage have been considered and investigated.

ii) the evolution of a method for conveniently estimating total phosphate in soil.

Allied to this was a study of yield-responses, after various modes of phosphate dressing, of swedes grown on soils differing in type of natural drainage. No similar work is known to have been published.

In addition, three years' work on the seasonal fluctuation of phosphate and several other nutrients in tomato plants, pointed to the importance of the (necessarily artificial) conditions of drainage and aeration. Detailed study of these factors was outwith the scope of the investigation, but the work has suggested/

suggested fresh lines of investigation which are being followed up.

The study of tomatoes revealed no special role for phosphate; but it led to several conclusions which are wholly or substantially new in relation to plant metabolism. Among these is a new role for manganese (and the sulphate ion) as indicators of "physiological strain" such as tomatoes commonly incur when grown under commercial conditions (of, presumably, poor drainage and aeration).

This strain was indicated by an increase of total manganese (and a corresponding increase in extractable sulphate) in laminae. These increases are phenomena not previously recorded.

As regards the increase of manganese, the phenomenon is distinct from that (which the candidate was among the first to make known) whereby the concentration of manganese in a plant increases with increasing soil acidity. Additional evidence of this tendency for manganese to produce "acid-toxicity" has been found. The original finding here is that for any soil almost or quite neutral, and presumably at a constant pH throughout the season, there were variations of manganese-concentration in the lamina; and these variations so closely reflected the general imbalance

and poor health and productivity of the plant as to be virtually diagnostic.

As regards sulphate, a similar variation was found. Hardly any determinations of actual sulphate in plants have been published. The novelty of the present work lies therefore i) in its having systematically revealed very large proportions of extractable sulphate throughout a season; ii) in revealing the existence of fluctuations in sulphate-content which have paralleled these of manganese - and presumably for the same reason.

Sulphate has thus been shown to be large in amount and to occur in relative quantities indicative of "physiological strain".

There was consistently more extractable sulphur (as sulphate) than extractable phosphorus (as phosphate) in the lamina - the ratio attaining 9:1.

A new method has been evolved for determination of calcium in vegetable material. No special significance, however, could be attached to variations in the amounts of calcium in the tomato plant.

Three season's work on the amounts of magnesium and potassium in tomato laminae and on their ratios have shown an inverse relationship to each other and

close relationships of either to signs of magnesium deficiency. This, while not original, is believe not to have been elsewhere investigated with similar minuteness.

As a new result it is possible to say with much confidence that neither potassium nor magnesium was related directly or causally to the condition of "physiological strain", wherein manganese certainly, and sulphate probably, appear to reflect a defective uptake of nitrogen from the soil.

The analytical method for total phosphate, first evolved for determining phosphate in soils, has been found also convenient for determining phosphate in fertilisers, turnips, liquid manure and other materials. It thus appears to be generally applicable to materials of agricultural interest.