A STUDY OF THE UPTAKE OF PHOSPHORUS BY THE POTATO (S. tuberosum)

By

RAVI DATT VERMA

B.Sc.(Pb)., B.Sc.,Hon.(Edin)., M.S.(Iowa)

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I. INTRODUCTION

The element phosphorus is so basic to the whole question of crop production that probably no other subject in the field of soil fertility has received more attention than the phosphorus problem in its various soil-plant and soil-animal relationships. Phosphorus is an essential constituent of the cell nucleus of all living organisms. In plants the deficiency of this element restricts cell division and consequently leads to weak and spindly growth of vegetative parts, poor root development and reduced yields of fruit or grain. Purplish or brown tints or spots on the dull bluish green foliage is a fairly characteristic, though not always specific, symptom of the deficiency of available phosphorus in the soil.

The essential role of phosphorus in plant nutrition has long been accepted. The popularity of bone meal as a manure among the farmers centuries ago, was in fact indirect recognition of the part played by phosphorus in crop production. Although it was not till 1769 that phosphorus was recognized as a constituent of bone and the manurial value of bones attributed to their phosphatic constituents, the use of bones as a fertilizer was probably quite common, in this country, long before that time. The use of bones steadily increased to such proportions, that in the early part of the last century, large quantities of bone were being imported into Great/

Great Britain from Europe. So much so that about a century ago, Liebig, the noted German chemist wrote with some alarm:-

"England is robbing all other countries of the conditions of their fertility. Already in her eagerness for bones she has turned up the battle fields of Liepzig, of Waterloo, and of Crimea; already from the catacombes of Sicily she has carried away the skeletons of many successive generations".

However, as a result of the restricted supplies of bones, the use of phosphorus necessarily remained limited, in the early days. The discovery of rock phosphate deposits, led to increased use of mineral phosphates; early work however showed that rock phosphate was not so good a source of available phosphorus as bone meal. It was not till 1843, therefore, when Sir John Lawes discovered that a more available source of phosphorus could be produced by treating rock phosphate with sulphuric acid, and actually set up a factory to manufacture superphosphate, that the foundation of the present vast phosphate industry, and widespread use of phosphatic fertilizers by farmers, was laid. Although the use of phosphatic fertilizers in agriculture increased steadily with increased production and improved quality of the superphosphate, yet, the really large expansion in consumption has come about in the last 10-15 years. For example the United States' annual total consumption on P_2O_5 equivalent basis was only 246,000 tons in 1900; by 1920 it had reached a total of 640,000 tons, and by 1940 to 894,000 tons. By 1950, it had risen to 2,434,000 tons and it is estimated/

estimated that the requirements during next 10-15 years may increase to twice this amount (Pierre 1953). In Great Britain, 50% increase in the consumption in post-war years as compared to pre-war years is estimated by Stewart (1953).

This tremendous increase in the consumption of phosphate fertilizers - particularly in the agriculturally advanced countries may be attributed partly to the mass of research work carried out during the last quarter of a century in all fields of phosphorus nutrition of crop plants and partly to meet the pressing need to feed and clothe the ever increasing population of the world.

The phosphorus nutrition of crops is a complex and broad problem. Unlike nitrogen and potassium where most of the applied nutrient can be accounted for, by the uptake by the crop and losses due to leaching, in the case of phosphorus only a small fraction - 5-20% of the applied phosphorus - is utilized by the crop in the year of application, and very little, if any, is leached away, under normal farming conditions. Most of it is fixed or retained by the soil, in the narrow region where the fertilizer comes in contact with soil. The mechanism, the nature and availability of this fixed phosphate has been and continues to be a subject of intense investigation by the Agricultural research workers. It is however now generally agreed that phosphates on addition to the soil are quickly absorbed by the soil particles. These absorbed forms are readily available to most crops. In time this initial form is converted to less soluble/

soluble forms. Usually the duration of this conversion is of the order of several months, depending on the conditions and nature of the soil, and concentrations involved.

Since the efficiency of applied phosphorus has long been known to be low, and supplies plentiful - there has been in the past a marked tendency - at least in some sectors of farming community - to apply far higher rates of phosphate fertilizer, than would seem justifiable from both the point of view of sound economics and judicious use of the present resources. For example Peech (1939 and 1949) who made an extensive study of the available phosphorus status of the potato growing areas of Atlantic and Gulf coast of U.S. found the level of available phosphorus of the cultivated soil at least 10-20 times than the comparable virgin soils. Obviously under such conditions, very little return, if any, could be expected from applied phosphorus. Furthermore there is a real possibility that due to the world shortage of sulphur, the production of superphosphate - which in 1950-51 accounted for 77% of the total consumption of P_2O_5 on world basis - may be seriously curtailed. This situation has lately focussed the attention of Agricultural research workers on two important questions: firstly are the farmers making judicious use of the present phosphate supplies? Secondly, in view of the possible shortage of superphosphate occuring, what other sources of phosphorus could be used as alternatives to superphosphate; in answer to the first question one can only say that without doubt many farmers could/

could greatly benefit by applying higher rates of phosphorus than they are doing at present; on the other hand there is some evidence to show that the practice in which some farmers indulge of applying luxury dressings of phosphate fertilizers to soils either already naturally rich in available phosphorus or made so through previous applications of phsophate fertilizers is not only grossly uneconomical and wasteful of limited supplies of phosphate fertilizers, but in certain cases instead of an increase may lead to a depression in yield. One such instance has been reported in the Edinburgh and East of Scotland College of Agriculture, Annual Report for 1953 (page 54). The results showed a significant depression in the yield of potato tubers when more than 3 cwt. of superphosphate was applied on a soil of moderate available phosphorus status and pH 5.7. The implications of these preliminary results are quite obvious. However, before any general conclusions could be drawn, it was felt that these results would require confirmation by further field experiments, and more detailed data would help to test the full significance of these results.

As for the alternative sources of phosphorus, considerable work has already been done and reported regarding the utilization of phosphorus from different sources by different crops. However, there are not enough detailed comparative data to support the generally held view that for the potato crop mineral phosphate is worthless and dicalcium phosphate just as good as superphosphate. Even if it were true, detailed data would be necessary to explain why it is so.

In order, therefore, to study the utilization of applied phosphorus by the potato crop in soils of high and low available phosphorus status four preliminary field experiments were conducted in the 1954 season. The programme included two experiments on high and one on low available phosphorus status soils, with superphosphate at different rates as source of phosphorus. A fourth experiment, with superphosphate, dicalcium phosphate, "hyper-phosphate" and gafsa mineral phosphate as sources of fertilizer phosphorus was conducted at one location with high available phosphorus status.

However as the basic interest in the present study was to find how much of the applied phosphorus was taken up by the plant, the radio tracer technique was introduced in the 1955 studies. With the use of P^{32} tagged superphosphate, it is now possible to trace the path of the fertilizer phosphorus in the plant and estimate the relative amounts of soil and applied phosphorus utilized by the crop. Extensive use of this comparatively new research technique has been made in U.S.A., and some other countries; but in this country, as far as the writer is aware, these are among the first field experiments to make use of the tracer technique. The reason for this has been due largely to the lack of radio-active phosphate fertilizers for agricultural research.

In 1955 two field experiments were carried out with potatoes, one on a soil of high available phosphorus and one on low phosphorus status. P^{32} tagged superphosphate was used/

used at different rates with two rates of nitrogen. Soil from these two centres was also used in the greenhouse for pot experiments of similar design but with oats as the crop. In addition the 1954 experiment with phosphorus from different fertilizer materials was repeated but this time on soil of low available phosphorus status.

II. REVIEW OF LITERATURE

Problems connected with the provision of adequate phosphate nutrition of the plants through the medium of soil are among the most complex and most widely investigated in the field of crop nutrition. Although these problems have received the attention of Soil scientists for a long time, it is, the intensive research programme carried out in this broad field in the last quarter of a century or so, which has greatly advanced our understanding of the efficient utilization of soil and fertilizer phosphorus in crop production. Some idea of the volume of work carried out in this field may be obtained from the fact that a total of 673 major articles covering this field were published in United States of America, alone, during the 16 year period 1935-1950 (Pierre 1953). It is obvious, therefore, that an extensive review of the published literature, is impossible and beyond the scope of the present work. Only a few selected references bearing directly, on the main factors which influence the utilization of the applied phosphorus are considered here. The various factors are so interdependent and interrelated that only an arbitrary grouping of these factors is possible. They are discussed under the following broad categories.

1. Climate.
2. Soil factors.
3. Crop factors.
4. Fertilizer factors.

5./

5. Management practices.

1. Climate

The important influence of climate, especially rainfall, on the utilization of applied phosphate fertilizer has been recognised for a long time. Higher rainfall is conducive to vegetative growth and delays ripening, higher rates of phosphate are, therefore required to counteract this tendency. Also because of the higher leaching rate of calcium under conditions of higher rainfall, extra applications of phosphate fertilizer may be necessary.

Crowther and Yates (1941) summarizing the results of all the major field experiments carried out in Great Britain during the present century, show that average responses to phosphorus in the south and east of England were only about two thirds of those in central and north England. In Scotland, Wales and west of England, on the other hand, average responses to phosphorus were about $1^2/3$ times as great as those in central and north England. Broadly these differences in average responses corresponded to differences in annual rainfall ranging from about 25 inches in south-east England to about 30 inches in the east of Scotland and rising to 60-70 and over in wetter western regions. In recent papers Smith and Simpson (1950); Simpson (1955) have correlated the yearly rainfall with percentage recovery of applied phosphorus from experiments conducted in the East of Scotland/

Scotland area. Considering the data for all experiments during the 14 year period, Simpson (1955) found practically no relationship between Spring (January to April) rainfall and recovery, but a very good positive correlation between recovery and both total (January to October) and Summer (May to October) rainfall.

Consideration of the data on an average yearly recovery from all the experiments conducted during the year and average rainfall for the year, he found that the correlation was barely significant, though it indicated that recovery of applied phosphorus increased with increase in rainfall. He further noted that recovery of phosphorus during the two wet years - 1948 and 1954 was high and during the only dry season - 1946 - the recovery in three out of four experiments was low.

2. Soil factors

The extent of utilization of applied phosphate fertilizer by the crop, is dependent on a great many factors. Some of these factors have been extensively studied and are well understood; others still remain to be thoroughly investigated. Of all the various factors phosphorus fixing capacity of the soil, and the amount of available phosphorus, in the soil, are probably the two with the most important effect on utilization of the applied phosphorus by the plant.

It is well known that when a phosphate fertilizer is applied to the soil, a certain amount becomes unavailable to plants. The process giving rise to the unavailability of phosphorus/

phosphorus is commonly designated by the term phosphorus "fixation". The literature dealing with phosphorus fixation is very extensive and dates back to 1850, when Way demonstrated by simple percolation experiments that solutions of phosphate of soda in water and phosphate of lime in dilute sulphuric acid lost their phosphate when passed through a soil. Reviews on the recent work on the retention of phosphate by the soil have been prepared by Midgley (1940); Dean (1949); Wild (1950). They show not only that phosphate is fixed by soils almost at the point at which it comes in contact with the soil particles, but also that clay soils fix phosphate more rapidly than sandy soils.

Penetration of applied phosphate fertilizer within the soil is of great importance, because unless the phosphate penetrates into the root zone, it cannot be utilized by the plant. Except in some cases, where serious loss may occur due to run off water, results of numerous investigations have shown that movement of phosphate in soils is limited to within a few inches from the point of application to soil, but varies to some extent according to soil texture, amount of phosphorus applied, rainfall. Dyer (1901); Gaarder et al (1930); Fleig (1935) and many other workers have noted that the penetration of applied phosphorus was greater when it was applied in conjunction with other fertilizer salts or farm-yard manure. Chaminade (1943), Chaminade and Blancher (1952) ascribe the beneficial effect of organic matter in making the soil/

soil phosphorus more available to plants to the formation of phosphohumic complexes. The phosphorus in these complexes is regarded as being more assimilable by plants than that of the less soluble soil phosphorus compounds.

Ford (1932) who analyzed seperates from the soil samples from an unfertilized plot and a corresponding plot which had received fertilizers for a number of years, showed that most of the added phosphorus had been fixed by the clay fraction. Walker and Brown (1936), who made a study of the phosphorus content of Carrington soils in U.S., found the phosphorus content of Carrington sand to be 800 pounds P_2O_5 per acre, as compared to 1288 pounds in the Carrington silt loam. From the findings of these and numerous other workers, it is evident that the phosphorus fixing capacity for a given type of soil will increase with the increase in the clay content of the soil.

The type of clay mineral is also of significant importance. Kaolinite has been shown to have much greater fixing capacity than other types of clay minerals. Opinions on the availability of the phosphate ions held by Kaolinite, however, differ. Murphy's (1939) experiments led him to believe that Kaolinite-held phosphate is relatively unavailable. Dickman and Bray (1941); Bray and Dickman (1941), on the other hand consider that the adsorbed phosphate ions held by clay minerals are readily available. Black (1942) from his work with Kaolinitic Cecil clay soil, has suggested that the Kaolinitic portion is capable of holding/

holding some phosphate in relatively available form, but that the unavailability of phosphate is high when the clay has been forced to combine with a large amount of this ion. The ability of clay minerals of the montromorillonite and hydrous mica type to fix phosphorus is not so great. Stout (1939) found very little fixation by bentonite. Murphy (1940) and Black (1942) have shown that phosphate ions added to this clay have a high availability to plants.

The nature of the compounds formed through fixation has been studied by numerous workers. Heck (1934) studied the nature of fixed phosphate by comparative solubilities in 0.002 N. H_2SO_4, of known compounds, and those formed in soil through fixation when a soluble phosphate was applied to the soil. His conclusions were, that the predominant form in which soluble phosphate is fixed depends on the relative abundance in the soil of the different materials capable of fixing phosphorus. If the ratio of active calcium to active iron and aluminium is high, the fixation will be in calcium form and the fixed phosphorus will be comparatively readily available. If reverse was true the fixation will be in the form of iron and aluminium compounds of phosphorus which are not nearly/so available

Many investigators have attempted to study in isolated systems the utilization by plants of the iron and aluminium compounds which are formed during phosphate fixation and have obtained very variable results. Truog (1916) working with chemically pure materials, obtained with aluminium phosphate, yields/

yields from 75 to 100 per cent as great as superphosphate. McGeorge and Breazeale (1932) found that freshly precipitated iron and aluminium phosphates gave relatively high yields and were quite different from mineral phosphates. On the other hand Dalton et al (1952) in sand cultures with corn plants obtained yields relative to soluble phosphate of the order of only 15 per cent from freshly precipitated iron and aluminium phosphates. Utilization by crops of phosphates adsorbed by gels of iron and aluminium hydroxides and the phosphate adsorbed by soil and clay particles have also been found to be high by various workers. Williams and Stewart (1943) from a study with a soil of acid igneous group found that fixation takes place very rapidly and is largely complete within 7 weeks with basic slag and probably within a few days with superphosphate. They found the general trend of the results and field behaviour to be compatible with an adsorption of the phosphate by ferric and aluminium complexes or clay minerals. "It is evident", they concluded "that anion exchange reactions are of considerable importance in the phosphorus relationship of the soil". Kurtz (1953) from his review of work done on the phosphorus in acid and neutral soils, came to the conclusion, that soil phosphorus is converted quickly to an adsorbed form which can be readily utilized by most crop plants. In time this initial form is gradually converted to less soluble form which is less available. The duration of this conversion depends on the concentrations involved, but it is usually of the order of several /

several months.

That the phosphorus status of the soil has a significant influence on the utilization of the applied phosphorus by crops has long been known. The long established practice of soil testing as a means of predicting the fertilizer requirements of a soil, is in fact recognition of the close relation-ship which exists between the soil and the applied phosphorus as a source of nutrient to the plant. Fried and Dean (1952) put this relationship in more concrete terms, when in suggesting the method of radio-chemical analysis of plant material for assessing the phosphorus status of the soil, they assumed that a plant presented with two sources of phosphorus, namely the soil and the fertilizer, will absorb phosphorus in direct proportion to the amounts of these respective supplies. The results of a large number of studies with radio-active phosphate fertilizers have generally confirmed this assumption to be correct. Dean et al (1949) from the greenhouse studies, using P^{32} tagged superphosphate, tricalcium phosphate, and hydroxy apatite, with soils of low, medium, and high available phosphorus status, found an inverse relationship between the soil phosphorus status and the percentage of phosphorus in the crop that is derived from the fertilizer. Nelson et al (1947), using a similar radio-tracer technique, and soils of different fertility status also found that the percentage of phosphorus absorbed from the fertilizer by the potato, corn and cotton crops decreased as the amount of native phosphorus increased. Similar results, using similar techniques, have been reported by/

by Woltz et al (1949) with tobacco; Jacob et al (1949) with potato and Nelson et al (1949) with cotton and corn. Verma (1953) using radio-active superphosphate, and oats as test crop and with three soils, of low, medium and high available phosphorus status, obtained similar results. The same trends were obtained among the soils - i.e. a progressive decrease in percentage of fertilizer phosphorus from the plots which had received progressivly heavy dressings of superphosphate in previous years,

3. Crop factors

The soil and the plant comprise a heterogeneous system. It is a dynamic, ever changing system. The roots of the seedling plants grow, bringing an increasing volume of soil into the system. In assessing the soil as a supplier of phosphorus, the plant can hardly be looked upon as a passive agent. To a degree, the plant influences the utilization of the soil and applied phosphorus. Generally it has been established that short duration crops utilize readily soluble phosphate more effectively than long duration crops. As phosphate is a mobile nutrient, crops such as cereals with a determinate type of growth absorb most of their requirements of phosphorus in the early stage of growth. For example Gericke (1924) found that full requirements of wheat plant for phosphorus could be satisfied by supplying phosphate to the plants only during the first four weeks of their growth. On the other hand in crops like tomato - with indeterminate type of growth characterised by a succession of new vegetative and fruit tissue, the uptake is spread over a much longer period. Nelson/

Nelson et al (1947) studied the uptake of phosphorus by four crops - potato, tobacco, corn and cotton, in the field using P^{32} labelled phosphate fertilizers. He found that these crops vary greatly in absorption of fertilizer phosphorus on soils of comparable native phosphorus content. Potatoes and corn represented the extremes; while potatoes absorbed a relatively high proportion from fertilizer throughout the growing period, corn absorbed a high proportion of its fertilizer phosphorus early and only small amounts in the later part of its growth period. They related phosphorus absorption to root extension. Potatoes have a limited root system and depend largely on the concentrated supply of applied phosphorus round the tuber; corn on the other hand develops a very extensive root system and hence absorbed a relatively high amount of soil phosphorus in the late stages of growth. Krantz et al (1949) using a similar technique compared the uptake of phosphorus by potatoes, corn and soya beans and obtained similar results. They also concluded that corn, potatoes, soya beans vary greatly in percentage of phosphorus derived from the fertilizer. Potatoes absorbed a relatively high proportion of fertilizer phosphorus throughout the growing season. They further found that potatoes absorbed the most fertilizer phosphorus and soya-beans the least. Corn however absorbed the greatest total amount of phosphorus and potatoes the least.

Of the common field crops, root crops - particularly swedes and turnips are relatively the most responsive to application/

application of phosphate fertilizers. Potatoes and mangolds come next and sugar beet is generally the least responsive of the root crops. Cereals, except in markedly deficient soils usually give only small percentage responses. Oats among the cereals, have usually shown the greatest response and wheat the least. Marked responses to the phosphate fertilizers have been reported from grasses and clovers in U.S.A.

Not only do different crops differ in the degree of utilization of a particular type of phosphate fertilizer, they also vary markedly in their power to utilize phosphorus from different sources of supply - particularly from less soluble phosphates. Rogers et al (1953) have reviewed phosphate fertilizers. They conclude that crops vary a great deal in their ability to feed on mineral phosphates. Russell (1950) classifies Lupins, lucerne, sweet clover, swedes, turnips, mustard, buck wheat and millet as most; and oats, wheat, barley, potatoes, maize, cotton, as least able to obtain phosphorus from relatively insoluble phosphates. Very little is know why crops differ in this respect. The nature and extent of excretions from the root system, may offer part of the explanation. For example Schander (1941) found that roots of lupins excrete an organic acid which may be responsible for their ability to utilize less readily available phosphorus in the soil. Earlier Domontovitch (1933) had found that this dissolving action is so strong that oats growing with lupins suffered less from phosphorus starvation than when grown alone in a soil deficient in readily/

readily available phosphorus. The activity of micro-organisms associated with a root system may also play an important role in increasing the availability of less available forms of phosphorus. Pikorskaya (1948) compared the phosphorus uptake by plants growing in sterile and non sterile cultures and showed more phosphorus to be absorbed from basic calcium phosphate in the presence of micro-organisms. Other unknown factors no doubt play their part in the differential behaviour of crops to utilize less available form of phosphorus .

Previous crops in the rotation have an indirect effect on the utilization of the phosphate by the crop to which it is applied. The nature and quantity of crop residues added to the soil by the crops in rotation may, not only appreciably alter the available phosphorus status of the soil and thus modify the uptake of the applied phosphorus, it may also directly influence the utilization of the added phosphorus. Through the use of plant materials containing phosphorus tagged with P^{32} Dean (1949) found that green manure phosphorus from wheat tops and roots was about 70 percent as efficient as superphosphate when these materials were mixed with the soils under greenhouse conditions. When the plant material was placed in layers to simulate field application the percent utilization of phosphorus exceeded that from superphosphate applied on equivalent phosphorus basis. The proportion of phosphorus present in inorganic form is of great importance as it has been shown that this phosphorus fraction/

fraction is as readily available to the crops as that from superphosphate and possibly less liable to fixation because of its intimate association with plant organic matter. If the residues are high in carbon and low in phosphorus as for example in straw, such residues not only would supply little phosphorus but as has been shown by Papadakis (1947), may appreciably reduce the supply of available soil phosphorus. In Finland, Kaila (1948) has shown that carbon/organic phosphorus ratio is roughly constant at 100-150, but if the ratio exceeds 200, inorganic phosphorus is liable to be biologically absorbed. Under such conditions the soil micro-organisms may compete with growing plants for the available supply from soil and fertilizer phosphorus and lead to reduced uptake of added phosphorus by the crop.

4. Fertilizer factors

In any consideration of efficient utilization of phosphorus, the role of added fertilizer is itself of utmost importance. Rate, time, method and frequency of application all have profound influence on the uptake, by the crop of the applied phosphorus. These factors influence phosphorus availability largely by affecting the degree and rate of fixation of applied phosphorus by the soil. Their effects are closely interrelated and any one of these factors may greatly affect the importance of others. For example, the time factor may be greatly influenced by the rate or method of application and vice versa.

Ideally, phosphate fertilizers should be applied at rates which/

which result in maximum financial returns. According to Crowther and Yates (1941) the optimum level of fertilization is reached when the value of the increase in crops resulting from a small additional increment of fertilizer is equal to costs involved in producing the extra increment of yield. Truog et al (1945), however advocate that the phosphorus status of the soil should at once be built up to some desired level, which may be considerably beyond that required for maximum yield. An attempt is then made to maintain this level by periodic applications of phosphate fertilizers. This concept has been justified on the basis that a heavy initial fertilizer application essentially constitutes a capital investment; and that residual effects from heavy application may be relied upon to supply phosphorus needs in cases of short fertilizer supply or adverse economic conditions. As may be expected, very conflicting results have been obtained by different workers experimenting under different soil and climatic conditions, on the residual value of applied phosphate fertilizer. To quote extreme examples, McAuliffe et al (1951) reported that application in 1941 of as high a rate as 1,000 to 2,000 pounds per acre of 20 per cent superphosphate on two silt loam soils showed very little residual effect in 1949, while, on the other hand Volk (1945) working on a loam soil found that cotton was responding to five annual dressings of 90 and 120 lbs. P_2O_5 per acre from superphosphate 10 years after the last application had been given. Response at the end of 10 years was larger, the larger the amount of phosphate that had been given. The results of experiments reported/

reported by Williams (1950) greatly help to clarify the position. These experiments were undertaken to measure the residual effects of relatively heavy dressings of superphosphate at rates supplying the equivalent of 200 lbs. and 500 lbs. P_2O_5 per acre. The results showed that these dressings did have very considerable residual effects in 12 to 24 month period and appreciable residual effects in 24 to 36 month period following application. The most striking feature of the results, however, was, that with phosphorus responsive crops of turnips and swedes the residues after even only one year had much lower value than that of a fresh dressing of 100-125 lbs. P_2O_5 per acre applied to the crop. The results indicated that the residues of 500 lbs. P_2O_5 per acre dressing in 12 to 24 month period following application were roughly equivalent in effect to only 80-100 lbs. P_2O_5 applied as a fresh dressing. The following advice given to farmers by Williams (1951a) probably sums up the present attitude of most of the soil scientists towards the problems of rate and frequency of application better than any other statement. His advice is "The rule in phosphate manuring should be "little" or at least not "too much" and often. Each crop should be given a dressing according to its needs and to the degree of shortage in the soil".

Although, utilization of the applied phosphorus has been a popular subject of investigation for a long time, the recent introduction of P^{32} tagged phosphate fertilizers has enabled the soil scientists to make direct and more accurate determinations/

determinations of the proportion of phosphorus taken up by the plant from different sources and when applied at different rates. The results of greenhouse experiments by Dean et al (1947), and fields studies by Nelson et al (1949) with potatoes, tobacco, corn and cotton; Woltz et al (1949) with tobacco; Jacob et al (1949) with potato crop; all using radioactive fertilizer, showed an increase in the uptake of fertilizer as well as soil phosphorus, with increase in the rate of application. Strzemienski (1948), through use of P^{32}, for example, found that on two phosphorus deficient soils from New Zealand, plants that received phosphorus fertilizer took up three to eight times as much soil phosphorus as did the control. According to Dion et al (1949) who likewise used P^{32} in their studies, a greater uptake of soil phosphorus is likely to occur when small amounts of fertilizer are used, but a lower phosphorus uptake from the soil when large amounts are used.

The method of application has recently attracted a good deal of attention as a means of reducing the fixation and improving the positional availability of applied phosphorus. Results of various workers have established beyond doubt the beneficial effects of placement as compared to broadcasting the phosphate fertilizers. For example the results of Crowther (1945); Stewart and Reith (1945); Reith (1952); showed that with cereals to give the same yield only about half as much of superphosphate was required if it was drilled with seed than if it was broadcast. Developments in the use of radiophosphorus in field investigations has given a great impetus/

impetus to research on placement methods. Until P^{32} tagged phosphate fertilizers came into use, it was not possible to evaluate clearly the relative or actual amounts of phosphorus obtained by the plant from different placements. Recent studies using radio-active fertilizers by Stanford _et al_ (1949) with corn; Nelson _et al_ (1949) with Cotton and corn; Olsen _et al_ (1949) with soya bean, and Pesek (1951) with oats, have clearly shown that crops generally derive a greater amount of phosphorus from localized placements such as banding or mixing with restricted amounts of soils than from broadcast applications. Olsen _et al_ (1949) reported an interaction between source of material and placement on sugar-beet. He found that more soluble phosphates such as superphosphate and metaphosphate showed a greater uptake from band placement whereas the less soluble phosphates - dicalcium and tricalcium phosphates - were more available in the rotiller placement.

Among the many factors which may determine the superiority of a particular type of placement over another, the kind of crop and its pattern of root distribution appear to be of particular significance. The studies reported by Hall (1951) using a technique involving injections of small quantities of radiophosphorus at various positions in the soil with respect to the plant, are particularly noteworthy. He found that corn relies heavily on the 3 inch layer of soil during the first four weeks of growth but not after this time. By the end of seven weeks the 8 inch and 13 inch horizons contribute substantially to the growth of the plant. Drake and/

and Stewart (1950) reported a significant positive interaction between 3 inch and 8 inch depth drill placement for Alfalfa, which illustrates a possible advantage of multiple band placement. More field experiments with different crops with multiple band placement versus placement at one depth, would be invaluable in determining the best method of applying fertilizers fully to meet the needs of the crop throughout its period of growth.

5. Management practices

Factors such as liming, availability of other nutrients and drainage all affect the utilization of applied phosphorus by the crop plants.

The liming of acid soils and its beneficial effect on the utilization of phosphorus has received the attention of investigators for over a hundred years. In 1849 Johnston wrote that the previous use of lime may lessen the need of phosphates - probably because of the lessened need for the calcium carried by manures. Watson and Stoddart (1907) studied the response of soils to applications of phosphate fertilizers and found that the acid soils with which they worked gave a much greater response to phosphate fertilizer than non acid soils. They suggested that in acid soils the phosphorus was largely present as iron and aluminium phosphates instead of the more available calcium phosphate. Salter and Barnes (1935) studied the effect of 11 different crops to application of superphosphate on soils which had been/

been brought to different pH values by previous liming. They found that on the soils that were medium to very slightly acid, superphosphate gave good increases in yield, but where lime had been used im amounts slighty greater than to neutralize all soil acidity, the yields were no higher than where no superphosphate had been used. They concluded that the lack of response to superphosphate was largely due to the fact that the lime had increased the availability of native soil phosphate to such an extent that the plants needed no additional amounts. Simpson (1955) from the 14 years work with acid soils on the recovery of applied phosphorus, obtained a highly significant correlation between per cent recovery and exchangeable calcium.

Deficiency of other nutrients may also greatly affect the efficient utilization of phosphorus. This principle has been more fully appreciated in recent years. Striking effects of an adequate supply of nitrogen on the efficiency of applied phosphorus have recently been reported by Coleman (1944); Dumenil and Nelson (1948); Smith et al (1950). For instance Dumenil and Hanway (1952) showed that for corn phosphate fertilizer alone gave no increase in yield, but when adequate amounts of nitrogen had been applied the increase was 10.2 bushels and where both nitrogen and potassium had been applied the yield increase from phosphorus was 23 bushels. Similarly phosphorus alone had no effect on the percentage phosphorus in the leaves, but the combination of phosphorus and nitrogen increased it from 0.22/

0.22 to 0.28 percent. Bennett *et al* also found that application of nitrogen fertilizers may increase the phosphorus content of the leaves. The reason for this effect of nitrogen, may be partly its effect in increasing the root growth and the forging power of roots for phosphorus.

In conclusion it may be stated that though the large volume of research work carried out in the last 30 years has greatly advanced our knowledge and understanding of the many complex problems connected with the phosphorus nutrition of the crops, yet, a great deal more still remains to be accomplished before the many problems related to efficient utilization of soil and fertilizer phosphorus are finally solved.

III. EXPERIMENTAL METHODS AND MATERIALS

Experimental programme:- 1954

Four field experiments were conducted with Potato Crop - three at different levels of phosphorus and one with phosphorus from different fertilizer materials. Of the former, two were on soil of high phosphorus availability (Shawfair and Dryden Mains) and one on low phosphorus status soil (Barbauchlaw). Fourth experiment with phosphorus from different fertilizer materials was located alongside the levels of phosphorus experiment at Dryden Mains.

Description of the Experiments 1954

A. Field operations

1. Selection of Site.

Preliminary selection of the site for each experiment was done the previous autumn from a large field which was to come under potatoes the following year, on consideration of uniformity of soil, drainage and phosphorus status. Twelve soil samples from different parts of the selected area were taken and analyzed to get an idea of the available phosphorus status, and if satisfactory, the area was pegged and the farmer requested not to apply farm yard manure to the experimental area. Before applying fertilizers at planting time soil samples were taken from each plot.

2. Description of Soils.

Shawfair

The farm is situated about a mile south east of

Portobello/

Portobello, Midlothian. The soil is derived from the highest of the four raised beaches which run along the Firth of Forth coast in this area. It is sandy in nature and freely drained. Average pH was 6.0 (range 5.8 to 6.2), easily soluble phosphate ($N/_2Hcl$) 220 p.p.m. (range 200-280 p.p.m.); available potassium high (Aspergillus niger method).

Dryden Mains

Situated about half a mile north east of Roslin, Midlothian. The soil is derived from parent material of fluvio-glacial sand with some gravelin the sub-soil. This material is some 10 ft. thick and overlies heavy glacial till, the surface of which has been water worked. The surface drainage is however very free. The soil had been worked for some years as a market garden and the Organic Matter was high. The average pH was 7.5 (range 7.0-8.0); easily soluble phosphate average 600 p.p.m. (range 500-700 p.p.m.); available potassium moderate.

Barbauchlaw Mains

Situated immediately west of Armadale, West Lothian. Soil is derived from sandy clay glacial till, and considering the high rainfall in this area would undoubtedly revert to peat under natural conditions. The area has however been well farmed for many years and the soil was of good structure and fairly good drainage. Average pH was 5.9 (range 5.6 to 6.2); easily soluble phosphate 25 p.p.m. (range 15 to 35 p.p.m.); available potassium moderate.

3./

3. Treatments and layout

Fertilizer treatments are shown in Table I.

Table I

Fertilizer Treatments

"Levels of phosphorus experiments" (Shawfair, Dryden Mains and Barbauchlaw).		"Phosphorus from different fertilizers" Experiment (Dryden Mains).	
Treatment	Rate (P_2O_5/acre as Superphosphate[1])	Source	Rate (P_2O_5/acre)
A	Check	-	Check
B	0.33 cwt.	Superphosphate	0.33 cwt.
C	0.66 cwt.	Superphosphate	0.66 cwt.
D	1.00 cwt.	Hyperphosphate[2]	0.50 cwt.
E	2.00 cwt.	Gafsa mineral phosphate[3]	0.50 cwt.
F	4.00 cwt.	Dicalcium phosphate[4]	0.50 cwt.

Total P_2O_5

1. 20 percent
2. 29.6 percent
3. 29.0 percent
4. 41.4 percent

Ammonium sulphate (21% N) at the rate of 5 cwt. per acre and Potassium chloride (60% K_2O) 2 cwt. per acre were applied to all plots. Fertilizers were well mixed and placed in the drills by hand.

Plot size gross - 13.5 ft. (six 27 rows) x 15 ft. long.

Net area harvested - 9 ft. (four 27 rows) x 11 ft. long.(11sq. yds.)

Layout adopted for all experiments was a randomised block design/

Fig. 1. Field plan[1] for 1954 and 1955, 6 (Treatments) x 4 (replications) experiments[1].

Shawfair 1954.

Replications	I	II	III	IV
	F	D	F	D
	B	A	D	F
	A	F	A	C
	E	C	B	A
	C	E	C	E
	D	B	E	B

1. Field lay outs similar to the above but with treatments randomised separately for each experiment were used for all the four experiments in 1954; and for the "phosphorus from different fertilizer materials" experiment of 1955 with the addition of one more replication.

design with 6 treatments and 4 replications.

Field plan for each experiment is shown in Fig. (1).

4. Cultural operations and harvesting.

Preparation of the field for planting was left to the farmer according to his normal practice. It usually consisted of a tractor ploughing either in autumn or spring, followed by one or two harrowings in spring before drawing the ridges 27" apart.

At each location, the gross plots were measured from the selected area and marked by canes. Fertilizer for each plot - which had been weighed and thoroughly mixed before hand - was then divided into six parts and spread by hand at the bottom of each furrow. Tubers (Kerr's Pink) were placed in position about 1 foot apart and covered by splitting the drill by tractor plough. The position of the experimental area was marked by pegs on the side of the field and the measurements recorded.

Normal cultural operations to keep the field clear of weeds were carried out. Ridging was done when the plants were about 9-12 inches high - between 5-6 weeks after planting. After ridging the plots were again measured and marked with canes.

Harvesting

The net area harvested was 4 middle rows, 11 ft. long, leaving two outside rows and 2 feet space at each end of the plot as guard area. The net area was lifted first, bagged and labelled, before the guard area was cleared as general crop./

crop. A week was allowed between lifting and riddling to allow any soil sticking to the tubers to dry off.

Grading was done by hand riddles. Produce from each plot was riddled separately into the following categories and weights recorded.

Ware - Above $2\frac{1}{4}$' mesh riddle

Seed - Between $1\frac{1}{4}$ and $2\frac{1}{4}$" mesh riddles

Chats - Below $1\frac{1}{4}$" mesh riddle

5. Dates of important field operations and observations

Table 2

	Shawfair	Dryden Mains[1]	Barbauchlaw
1. Layout	15. 4.54	25. 5.54	21. 4.54
2. Planting	15. 4.54	26-27. 5.54	8. 5.54
3. Ridging	1. 6.54.	7. 7.54	14. 6.54
4. Observations			
1st	15. 6.54	26-27. 7.54	7. 7.54
2nd	19. 7.54	29-30. 8.54	11. 8.54
3rd	16. 8.54	26-27. 9.54	7. 9.54
4th	15. 9.54	28-29.10.54	5.10.54
5. Harvesting	17. 9.54	29-30.10.54	6.10.54
6. Riddling &	24. 9.54	5- 6.11.54	14.10.54

1 includes "phosphorus from different fertilizer material" experiments.

From table 2 it may be noted that:-

1. Date of sowing at different locations varied rather widely. This happened because of the exceptionally wet weather/

weather at the planting season, with the result that at some places the farmer was able to prepare the land for planting earlier than at others.

2. First plant samples from the field were taken 8 weeks after planting in every case, and then onward at monthly intervals. The date of first sampling roughly corresponded to beginning of grand period of vegetative growth; the second when the growth processes were at their peak and onset of tuber formation; the third marked the end of grand period of vegetative growth, but rapid swelling of the tubers. The fourth observation represented the state of the plant at maturity.

3. Harvesting in every case was carried out at the end of 5 months from the date of planting

6. Sampling procedure.

For height measurements, 10 plants taken at random from the net plot area were marked with $2\frac{1}{2}$ ft. canes. One of the main shoots from each plant was tied loosely with cotton string to the cane and labelled. This procedure ensured that the same shoot was measured for height at successive observations. The labels were dipped in molten paraffin wax to prevent their being destroyed by rain or sun.

Dry weight data and samples for analysis were obtained from a composite sample of 2 plants randomly selected from each net plot

These plants were lifted out of the ground by two operators inserting forks full depth into the soil on each side/

side of the plant half way between the plant to be dug and the next plant in the row and levering it up along with the soil without breaking the roots. Each plant was put in a specially made large sized double-kraft paper bag, suitably numbered. The plants were then brought to the greenhouse for washing.

The plants were washed free of soil with a fine spray of water over a $\frac{1}{8}$" mesh sieve, resting on a large tank. It was found that if care was taken not to use the spray with a very strong pressure, very few roots were broken during this operation, and the ones that did, were collected from the sieve and weighed along with the rest of the underground portion of the plant. After washing, the two plants from each plot were combined and laid on numbered sheets of brown paper, on the greenhouse benches and left overnight for moisture to dry off.

Next day, the top portion of the plant was cut off from underground portion and their weights recorded separately.

The underground portion constituted the root system plus a small part of the stem, which being below the ground level, showed no development of chlorophyll. The number and fresh weight of tubers was also taken. Where the weight of any part of a plant was large, as in the case of shoot and tubers at the 2nd and 3rd observation, a representative sample of 100-150 g. was taken. Tuber sample was made up from as many tubers as possible and cut into small pieces to facilitate quick drying in the oven. Thus at each observation, three samples/

samples - one of shoot, one of underground portion of the plant and one of tuber - were obtained from each plot. Each sample was put into a separate numbered bag and transferred to the laboratory.

In the laboratory the samples were dried in a large electric oven fitted with a fan, at 95° - $100^{\circ}C$ for 48 hours, taken out of the oven and weighed as quickly as possible, for dry weight data. The samples were then milled in small laboratory mill and stored in 8 oz. labelled glass bottles with bakelite caps. Before weighing for chemical analysis, the ground material in the bottles was again dried at $100^{\circ}C$ in a small electric oven, for 24 hours, allowed to cool and thoroughly mixed.

B. Analytical methods

1. Total phosphorus determination.

For quantitative analysis of the milled plant material for total phosphorus, the procedure outlined by Piper in "Soil and Plant Analysis" (1950) pages 272-274 and 293-294, was followed. Sets of 10-12 samples were analysed at a time. However before adopting the above procedure as a standard method it was checked for accuracy and reproducibility. The results of several determinations of the percentage recovery from know standards, and from plant material showed that the method was highly satisfactory both in respect of accuracy of recovery of phosphorus and reproducibility. As a further check two determinations from the known standard were carried out with each/

each set of 10 plant samples. The method is described below briefly:-

A two gram sample was weighed and transferred to a Kjeldahl digestion flask. A mixture of 4 ml. perchloric acid (60%), 3 ml. of sulphuric acid (conc), and 23 ml. of nitric acid (S.G.1.42), was then added and the contents of the flask thoroughly mixed by agitation. The mixture was heated on a Kjeldahl rack, with a very low bunsen flame, cutting down most of the air intake. After about 5 minutes when the initial vigorous action had subsided the flame was slightly raised and the digestion continued. Dense white fumes of sulphuric acid appeared usually in 100-120 minutes. The digestion at low heat was continued for further 5-10 minutes and then completed by turning the flame on full for 2-3 minutes. A colourless or pale yellow liquid was obtained at the end of digestion. The Kjeldahl flask was then allowed to cool, 30 ml. of hot distilled water were added and the mixture shaken to get as complete a solution as possible. The liquid was then filtered through Whatman 44 filter paper into 250 ml. beaker, the digestion flask being washed twice with dil. nitric acid (one part conc. Nitric acid and 19 parts water), using about 20 ml. for each washing. The flask was finally rinsed with two washings with hot water. The filtrate was evaporated to about 5 ml. by standing the beaker in boiling water bath for about 2 hours. The beaker was removed from the bath and 50 ml. of dilute nitric acid (15 parts conc. Nitric acid: 34 parts water) were added. The contents/

contents were then heated just to boiling point, stirring well to dissolve any calcium sulphate, and 50 ml. of Lorenz Sulphate, molybdic acid reagent added (Piper (1950) pp. 152). The beaker was covered and left overnight for the ammonium phosphomolybdate precipitate to settle down.

Next day the precipitate was filtered through a Gooch crucible charged with asbestos and previously dried in an oven overnight at 100°C, cooled in a desiccator and weighed. The precipitate was washed 4 times with 2% ammonium nitrate - (made just acid with a few drops of conc. nitric acid) - three times with acetone, and then air was drawn through the precipitate for about one minute. Finally, the crucible was placed in a dessiccator without dehydrating agents, evacuated for about 5 minutes, and weighed after half an hour.

2. Preparation of standard solution.

The standard solution was prepared in accordance with the procedure laid down in Statutory Rules and Orders (1932) No. 658 (Fertilizers and Feeding Stuffs) pp. 16 for determination of total phosphoric acid.

Description of Experiments 1955.

Experimental programme:-

Radio-active superphosphate was used both in the field and in the greenhouse experiments this season. The high cost of radioactive fertilizer (£13 per kilogram); considerations of quantity which could be handled quickly and safely; the extra work involved in radio assay work, and the introduction of 2 levels of nitrogen, made some curtailment in the number/

number of field experiments necessary. The "levels of superphosphate" experiment was therefore conducted at two locations this year, as against three in 1954. One of these experiments was located at Boghall - a soil with a high content of available phosphorus the other on a soil of low available phosphorus status was at Barbauchlaw - on the same farm as in 1954 but on a different field. The experiment with phosphorus from different fertilizer materials was repeated, but this year on soil of low phosphorus status. It was located at Barbauchlaw alongside the "levels of phosphorus experiment". Soils from Boghall and Barbauchlaw experimental areas were used for pot experiments in the greenhouse at Boghall, with oats as test crop.

I. Field Experiments

A. Field Operations

1. Selection of Site.

Sites for the field experiments were selected the previous autumn in the same manner as in 1954.

2. Description of Soils.

The experiment was located in the Threshypark field of the Boghall experimental farm, which is situated 5 miles south of Edinburgh, in Midlothian. The soil is a medium loam derived from a 18 inch layer of water worked glacial till. The surface drainage is fairly good but there are signs of impedance at depth. Average pH of the experimental area was 6.2/

6.2 (range 6.0-6.3); average value for easily soluble phosphate 260 p.p.m. range (240 - 300 p.p.m.); available potassium moderate.

Barbauchlaw

The experimental area was only about 200 yards from the 1954 site, and the same geological description is applicable; but the average pH was 5.6 (range 5.4-5.8); the average available phosphorus 50 p.p.m. (range 40-60 p.p.m.); and the available potassium moderate to low.

3. Treatments and layout.

(a) Field Experiments.

In the light of the 1954 results and because of the introduction of radio-active superphosphate certain changes were made in the treatments. Fertilizer treatments for "levels of phosphorus experiment" at both locations were the same.

In the "phosphorus from different fertilizer materials" experiment "Hyperphosphate" used in 1954 was replaced by coarsely ground Gafsa mineral phosphate. Treatments for the two set of experiments are shown in table 3.

Table 3./

Table 3

Fertilizer Treatments

"Levels of Phosphorus" Experiment				"Phosphorus from Different Sources" Experiment		
P levels		N levels				
Treatment	P_2O_5/ac.	Treatment	N^6 per ac.	Treatment	Source	P_2O_5/ac.
P_0	Control	N_1	0.5 cwt.	A	-	Control
P_1^{*1}	0.25 cwt.	N_2	1.0 cwt.	B	Superphosphate[2]	0.33 cwt.
P_2^{*}	0.5 cwt.			C	Superphosphate	0.66 cwt.
P_3^{*}	1.0 cwt.			D	Gafsa mineral phosphate[3] (coarsely ground)	0.5 cwt.
P_4^{2}	2.0 cwt.			E	Gafsa mineral phosphate[4] (finely ground)	0.5 cwt.
				F	Dicalcium phosphate[5]	0.5 cwt.

Total P_2O_5

*1. P^{32} tagged superphosphate - 20% 2. 20% 3. 29.1% 4. 29.1% 5. 41.4% 6. From Ammonium Sulphate - 21% N

Fig. 2. Field plan[1] for "levels of phosphorus" experiments 1955.

Barbauchlaw

Replication					
I	A	D*	B*	C*	F
	G*	I*	E	H*	J
II	I*	G*	J	D*	F
	A	C*	B*	E	H*
III	B*	F	I*	A	J
	G*	D*	E	H*	C*
IV	A	J	E	I*	G*
	C*	H*	B*	F	D*
	E	H*	G*	D*	B*
	A	J	I*	F	C*[4]

Treatments

Phosphorus[2] (cwt. P_2O_5/ac.)

P_0 = Control

P_1 = 0.25

P_2 = 0.50

P_3 = 1.00

P_4 = 2.00

$A = N_1P_0$ $F = N_2P_0$

$B = N_1P_1$ $G = N_2P_1$

$C = N_1P_2$ $H = N_2P_2$

$D = N_1P_3$ $I = N_2P_3$

$E = N_1P_4$ $J = N_2P_4$

Nitrogen[3] (cwt. N./ac.)

N_1 = 0.5

N_2 = 1.0

1. Similar field plan used for Boghall with different randomization of the treatments.
2. From superphosphate. 3. From Ammonium Sulphate.
4. Radioactive superphosphate used in the sub-plot (Fig. 3)

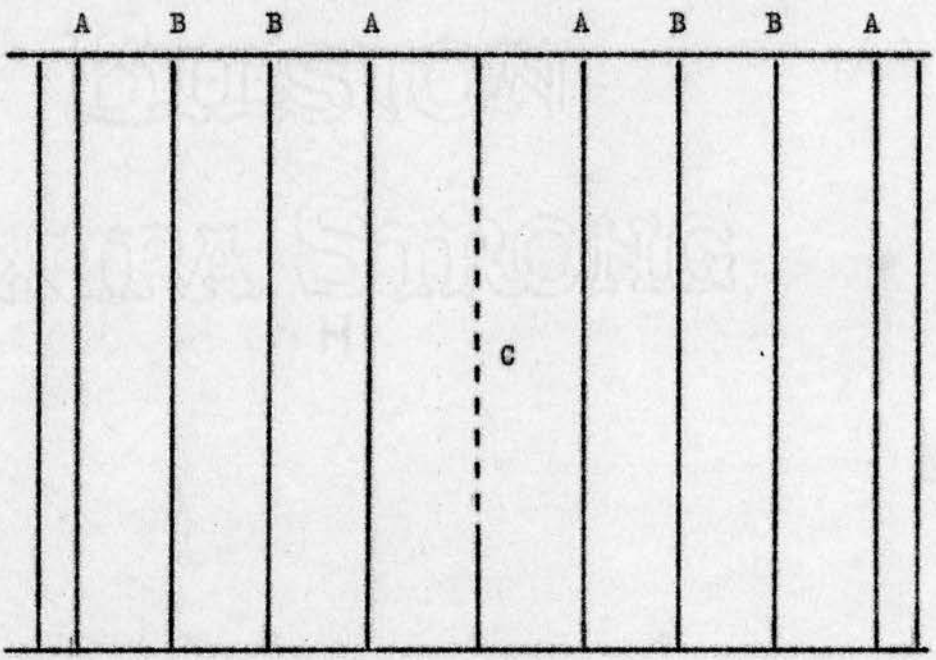
Five phosphorus and two nitrogen levels thus gave ten treatment combinations. A basal dressing of 168 pounds K_2O per acre as Potassium chloride (60%) was applied to all plots of the 3 field experiments.

The lay out was of randomised block design with 10 treatments and 5 replications. A new randomisation was made for each replication. The field plans for the three experiments are shown in Fig. 2. Each plot consisted of nine 27" wide drills 20 feet in length. In the plots where radioactive fertilizer was used, the nine drills included, one "radioactive" drill in the middle, four guard rows (two outside ones, and one on each side of the radioactive drill and four drills for taking the final yield. The actual field plan of one plot is shown in Fig. 3. From the four drills for yield, 3 feet guard area on each end of the plot was allowed at harvest. Thus the net plot lifted for yield was four drills (9 feet) by 14 feet long or 1/345 acre.

Radioactive superphosphate was applied to the 12 foot length in the middle of the "radioactive" row at the rates of 40, 80 and 160 g., equivalent to 0.25, 0.5 and 1.0 cwt. P_2O_5 per acre respectively. The specific activity of the superphosphate on 27th April was about 120 millicuries per kilogram of superphosphate. As the fertilizer was applied in the field within the next two days i.e. 28th and 29th April, this application resulted in approximate initial P^{32} concentration of 4.8, 9.6 and 19.2 millicuries per 12 feet row at 0.25, 0.5 and 1.0 cwt. P_2O_5 per acre rate of application respectively.

The/

Fig. 3. Plan of each individual plot used in the radioactive phosphorus field studies at Barbauchlaw and Boghall.



A. Guard rows.

B. Harvested for yield data. Ordinary superphosphate used at appropriate rate.

C. Radioactive row of 12 ft. length. P^{32} tagged superphosphate applied at an equivalent rate to the main plot treatment.

The application of ordinary superphosphate containing P^{31} to the other drills was completed in the same manner as in 1954, a day previous to the application of P^{32}. This enabled the ridging up by tractor plough immediately after the radioactive fertilizer had been applied and the tubers placed in position at a measured spacing of one foot apart.

Seed

A variety of short maturity period had to be used in 1955, because of the decay in the radioactivity of P^{32}. Craig's Royal which is a second early and heavy yielding variety therefore replaced Kerr's Pink used in 1954. Certified stock seed was obtained from the county of Fife. Although the "seed" was in excellent condition and of fairly uniform size, it was, considered that, as plant samples for various observations and analytical work would be drawn from the 12 foot radioactive row only, the elimination of the effect of seed size was necessary. The seed tubers for the radioactive rows were therefore specially selected. About 750 tubers - a little more than the actual requirement of 720 tubers (2 locations x 30 radioactive subplots x 12 tubers per subplot) - of average weight were hand picked. An approximate idea of the average weight was obtained by weighing 10 lots of 100 tubers each taken from the stock seed bags at random and taking the mean. The mean weight per tuber came to 90 g. About 750 sound tubers of good shape each weighing between 86 and 95 g. were picked from the rest of the seed and their individual weights recorded with waterproof India ink on the tuber/

tuber itself. These tubers were further subdivided into two categories, those between 86 and 90 g. and those between 91 and 95 g. per tuber, and were put in separate sprouting trays. At the time of planting tubers from each category were planted alternately in the row thus further eliminating the effect of tuber size.

The rest of the seed (34 cwt.) was also hand graded to remove any damaged tubers - which were very few in number - before putting them in the sprouting trays. These trays were put in a single layer on greenhouse benches. Due to the sunny warm weather, which luckily prevailed during practically the whole of April, good sturdy, sprouts about $\frac{1}{4}$ inch long were obtained in about 20 days i.e. from the time of receiving the "seed" and putting it in sprouting trays to the time of planting on 28th and 29th April.

4. Cultural operations and harvesting

Cultural operations before and after planting followed the same pattern as in 1954.

Harvesting was carried out on 12th September at Boghall and 16th at Barbauchlaw and grading a week later. The same procedure as in 1954 was followed. Tubers from the few plants still left in the radioactive subplots were harvested and bagged separately, and put away to be used as seed in 1956.

5. Dates of field operations

Table 4/

Table 4.

Operation	Date performed	
	Boghall	Barbauchlaw[1]
1. Layout	21.4.55	23.4.55
2. Application of fertilizers	28.4.55[2]	29.4.55[2]
3. Planting	28.4.55	29-30.4.55
4. Ridging	18.6.55	20.6.55
5. Observations		
1st	24.6.55	29-30.6.55
2nd	24.7.55	29-30.7.55
3rd	28.8.55	2- 3.9.55
6. Lifting	12.9.55	16.9.55
7. Riddling	19.9.55	20.9.55

1 includes "phosphorus from different fertilizer materials" experiment.

2 radioactive fertilizers applied a day earlier.

6. Sampling procedure

The same procedure as in 1954 was followed, except that the two plants for dry matter and chemical analysis were taken from the radioactive subplot. One plant at each end of the subplot was excluded, when removing two plants at different sampling dates. To avoid removing a plant lacking root competition on one side from where two plants for previous observation had been taken, one plant was left standing inbetween the two plants removed at successive observations.

B. Analytical/

B. Analytical methods

1. Total phosphorus determination

The same method as used in 1954 was adopted (Soil and Plant Analysis 1950 by C.S. Piper, pp. 272-274 and 293-295). However, where part of the sample was to be kept for radio-assay work, the material after digestion was filtered into a 100 ml. graduated flask. After completing the washing of the Kjedlahl flask, the filtrate in the graduated flask was allowed to stand overnight. Next morning about 30 ml. of the solution from the graduated flask was poured directly into a clean test tube for radio-assay work. Total phosphorus was determined from a suitable aliquot from the rest of the solution.

Because of the decay in the radioactivity with passage of time, it became necessary to increase the P^{32} concentration in the digested samples to facilitate counting. Therefore 8 g. samples were digested from the 2nd and 3rd sampling of potatoes and the final sampling of oats. In such cases, 12 ml. of perchloric acid (60%) 12 ml. sulphuric acid (conc) and 51 ml. of nitric acid (SG 1.42) were used for digesting each plant sample.

2. Measurement of P^{32}

From the solution set aside in test tubes for P^{32} determinations, 10 ml were transferred with a pipette (new pipette used for each sample) to a 20th Century Electronics liquid counter fitted to a standard scaling unit, and the counts/

counts were taken over a suitable period. The counting period varied with the activity of the sample and ranged from about 4 minutes for the first samplings to more than 30 minutes for the last samples of potatoes and oats. Between counting different samples, the liquid counter was cleaned by rinsing 12 times with distilled water and drying with strips of filter paper. Background was taken each day before and after counting. Net counts were corrected for background and two counters (J.N.1272 and L.D.479) were used but all corrected counts were converted to J.N. counters by multiplying L.D. counts by 0.04. This factor was obtained by comparing the counting rates of the two counters with a standard solution. Corrected counts were adjusted to a standard time - 12 o'clock each day. A standard solution was treated similarly and least squares analysis of the decay curve was carried out. The half life worked out to be 14.2 days. The least square curve was used to give the specific activity of the fertilizer as a function of time. The standard solution was counted over 3 months.

3. Preparation of standard solutions.

Radioactive superphosphate was analysed for water soluble and total P_2O_5 by the procedure laid down in Statutory Rules and Orders 1932, No. 658 for the Fertilizers and Feeding Stuffs Act. The average of several determinations gave water soluble P_2O_5 as 18.8 percent.

Standards to give 0.5% recovery of total P_2O_5 were prepared/

prepared from both the ordinary superphosphate (total P_2O_5 20%)and P^{32} tagged superphosphate. Several check determinations gave a recovery of between 98 to 100% from these standard solutions.

C. Precautions taken in handling the radioactive materials

1. Radioactive Superphosphate

The total quantity of P^{32} tagged superphosphate (6 kilograms), amounting to approximately 0.7 curie of radioactivity was manufactured on the previous day at the Radiochemical centre Amersham, Bucks and railed overnight to Edinburgh. It was split into 12 lots of about 500 g. each in 12 oz. glass bottles. Each bottle was housed in a tin container with a protective packing about ½" thick, and the tin containers were packed in a wooden case. At the time of weighing - which was done immediately on receipt of the fertilizer - only one bottle at a time was taken out from its protective casing; requisite quantities of fertilizer were weighed quickly and put in 8 oz. bottles in which the required quantities of nitrogen and potassium fertilizers had already been placed. The fertilizers were thoroughly mixed and the bottles put away in a cardboard box at the other end of the room. Weighing was done in a fume cupboard fitted with an exhaust fan. In addition the floor of the cupboard was covered with polythene sheeting to take any spillings of fertilizer during weighing. Little contamination occurred except/

except on polythene sheeting, balance pan and exhaust fan. Polythene sheeting was disposed of as radioactive waste. Balance pan weights, and other articles were thoroughly washed with water. Checked for radioactivity with portable scaler and reused in the laboratory for other work, only when free from contamination.

All operations in the field which involved handling of the radioactive fertilizers, were performed by three persons only, who wore protective clothing and face masks. After application of fertilizer in the 12 foot radioactive row tubers were planted and the drills immediately covered by hand-hoe to avoid any blowing away of the fertilizer by wind which was fortunately very slight. Slight stickiness of the fertilizer due to some absorbed moisture, also kept the fertilizer from blowing away during spreading in the drill.

All articles which were likely to get contaminated were checked for radioactivity with a portable scaler. Practically no contamination occurred except for the canes which marked the limits of 12 ft. radioactive row. These canes were washed with water and put away for use only next year. Similar precautions i.e. wearing protective clothing, gloves, face masks were observed when mixing radioactive superphosphate for pot experiments in the greenhouse. All mixing was done in a separate small section of the greenhouse.

2. Radioactive plants in the field and greenhouse.

When lifting two plant samples in the field, thick rubber gloves and protective clothing were worn. Two forks used/

used for lifting observational plants were kept exclusively for these experiments. While carrying plant samples from field to greenhouse for washing, paper bags were stood upright to avoid any contaminated soil being spilled in the van. New bags were used each time to collect plant samples.

During washing of the plants in the greenhouse the same precautions of wearing protective clothing, gloves were observed. The waste water from the washing of the plants was drained into the ground through a field drain. The soil accumulating in the bath tank during the washing was disposed of as radioactive waste some distance from the greenhouse. Similarly used paper bags, vegetative and tuber material remaining after representative samples had been taken, was removed to the radioactive waste dump and covered with soil. All the equipment used for weighing and other operations was kept separate in the greenhouse and used only for these experiments on successive observations.

3. Laboratory precautions.

Plant material was milled in a fume cupboard specially fitted for this purpose with a strong exhaust fan. Cleaning of the milling machine and thimble, between two samples, was done by light brushing of the parts with a small brush, and then using a vacuum cleaner. Vacuum cleaning proved very effective for cleaning of the mill and thimble and preventing radioactive plant material dust from getting into the air. In addition, the normal precautions of using a laboratory/

laboratory coat, reserved for this purpose, and wearing rubber glover whenever handling the radioactive material throughout the laboratory work.

The part of the radioactive solution used for radio-assay work (in the Bio-physics department building) was poured directly into clean test tubes from the 100 ml. graduated flask, to avoid any likelihood of contamination from one sample to another, which might have occurred if the solutions had been pipetted. A new 10 ml. pipette was used for each sample when transferring 10 ml. from the test tubes to the liquid counter of the Geiger counter.

Oral suction was avoided to eliminate the danger of sucking up some of the radioactive solution while pipetting.

II. Greenhouse Experiments

1. Experimental programme.

Two experiments - one with soil of high (from Boghall field experiment) and the other of low (from Barbauchlaw field experiment) available phosphorus status, were conducted to study the utilization of applied phosphorus at different levels by the oat crop. P^{32} tagged superphosphate was used as a source of phosphorus.

2. Greenhouse facilities.

A medium size greenhouse divided into a large and small section/

section at Boghall Experimental Station was used exclusively for accommodating the pot experiments and for washing and handling the material from the field samplings of the potato crops. It was connected to the water supply from the mains and fitted with a large tank which proved useful for washing the potato plants

3. Preparation of pots.

A representative sample of soil was spade dug from areas adjacent to the two field experiments under potatoes. They were brought to the greenhouse in clean gunny bags, mixed, and spread out in a thin layer on strong sheets of brown paper on the greenhouse benches, and air dried for 10 days with occasional stirrings to facilitate drying. The soils were then passed through a $\frac{1}{2}$ inch mesh sieve to remove stones and weeds. In the meantime 120 glazed earthenware 10 lb. pots were thoroughly washed and left to dry in the greenhouse.

Sieved soil at the rate of 5 lb. per pot was then thoroughly mixed with an equal quantity by weight of acid washed nutrient free sand. Thus each pot received 10 lb. of soil-sand mixture. The mixture was prepared for 5 pots at a time receiving the same rate of fertilizers. One third, i.e. 3.3 lb. of unfertilized mixture, was placed in each pot, the remaining two thirds was mixed thoroughly with the requisite quantities of fertilizers and added to the pot. The quantities of fertilizers which corresponded to the following treatments were calculated on the basis of 2,000,000 lb. of soil/

soil per acre, and were weighed for each lot of 5 replicates, in the laboratory, and thoroughly mixed in glass bottles.

4. Treatments and layout.

Table 4.

Fertilizer Treatments

P_2O_5[1] lb. per acre	N[2] lb. per acre	
P_0 - nil	N_0 - nil	K_2O[3] at the rate
P_1 - 40	N_1 - 40	of 60 lb. per acre
P_2 - 80	N_2 - 80	to all parts.
P_3 - 160		

1. from 20% P_2O_5 Radioactive superphosphate.
2. from 21% N Ammonium sulphate.
3. from 60% K_2O Potassium chloride.

After the 60 pots (12 treatment combinations x 5 replications) for each experiment had been prepared, they were arranged on single greenhouse bench in randomised block design. A new randomisation was made for each replication.

Pots were then watered (distilled water used for all waterings) to allow the soil to settle and the water to soak to the bottom of the pots.

5. Sowing and Sampling.

Sowing was done on 10th May. The top few inches of the soil was stirred and levelled to give a good seedbed. Forty dressed seeds of Blenda variety of oats per pot were sown about $\frac{3}{4}$ inch deep as evenly as possible and the pots lightly watered/

watered after sowing. Watering thereafter was done as required usually on alternate days, giving 250 ml. per pot in early stages and gradually increasing to 500 ml. at the height of vegetative growth. Plants started to emerge after about 7 days. Germination was complete by 24th May, when the plants were thinned down to 30 per pot.

The first samples of 10 plants per pot were taken on 10th June - one month after sowing - when the plants were 6-8 inches high. Plants were removed by cutting the stem just above ground level with small sharp pointed scissors. Harvested plants were immediately weighed for fresh weight, put in numbered paper bags, and later dried in the oven in the laboratory at 95-100°C for 48 hours for dry weight determination.

Because of the warm sunny weather which prevailed almost throughout the period of these experiments the plants made rapid and very satisfactory growth.

A second sample of 10 plants per pot was taken on 4th July - 54 days after sowing - just before the "shooting" stage. As in the case of the 1st sampling, fresh weight was taken immediately after removal and dry weight after oven drying for 48 hours at 95° to 100°C.

The remaining 10 plants were allowed to mature and finally harvested on 12th August - 3 months after sowing. Fresh and dry weights of shoot and grain were recorded separately in the usual way.

At all samplings, after the dry weight had been taken, the/

the 5 replicates were composited, milled and analysed for total P^{31} and P^{32} in the plant, following the same analytical procedures as for samples from the potato crop.

E. Data collected and statistical analysis

Following records[1] were maintained for all experiments for both the years:-

Observation

I. Field Experiments (Potato Crop)

A. Population.

B. Shoot

1. Number per plant.
2. Height per plant.
3. Fresh weight per plant.
4. Dry matter %
5. Total P_2O_5 (%)
6. Percent P_2O_5 from fertilizer[2]

C. Root

1. Fresh weight.
2. Dry matter %
3. Total P_2O_5 %
4. Percent P_2O_5 from fertilizer[2]

D. Tuber

1. Number per plant.
2. Fresh weight per plant.
3. Dry matter %
4. Total P_2O_5
5. Percent P_2O_5 from fertilizer[2]
6. Total yield (ware + seed + chats)
7. Ware.

8./

Observation (continued)
8. Seed.
9. Chats.
II. Greenhouse Experiments (Oats) 1955.
1. Fresh weight
2. Dry matter
3. Total P_2O_5 %
4. Percent P_2O_5 from fertilizer[2]

1. Records were maintained for 4 observations in 1954 and 3 observations in 1955. First observation 2 months after planting, others at monthly interval afterwards.
2. From studies with radioactive superphosphate.

Statistical analysis.

Mostly the data from 3rd or final observation were subjected to appropriate methods of analysis. Where considered necessary earlier observations were also analysed. Fisher and Yates (1943); Patterson (1939); Cochran and Cox (1950) were consulted for this purpose. Results are presented in the next section.

To avoid burdening the text with too many tables, complete plot data for all observations are given in appropriate appendicies. In the text, means of all replications at each observation are given as one table. Analysis of Variance of the data of the observations statistically analysed is given in appropriate appendicies.

Details of the procedure adopted for radio-chemical analysis is shown in Appendix XV.

As is conventional, in the Analysis of Variance table, the results significant at 1% and 5% level are marked by double (**) and single(*) asterisk respectively.

Table 4.a

Weather Data

1954

	Barbauchlaw				Boghall			
	Max.	Min.	Sun Shine Per day	Rain fall per month	Max.	Min.	Sun shine per day	Rain fall per month
	°F	°F	Hours	Inches	°F	°F	Hours	Inches
April	45.9	42.3	5.9	1.62	52.0	36.0	5.9	1.37
May	49.4	46.5	4.6	4.64	54.3	41.3	4.3	5.11
June	53.8	50.6	4.5	2.19	59.0	46.9	4.4	2.65
July	56.1	52.7	4.0	2.84	61.0	47.6	3.9	2.05
August	56.5	53.7	3.4	6.79	60.4	47.7	3.2	5.68
September	52.4	49.9	4.7	3.89	58.4	44.6	4.9	4.05
October	49.5	47.7	2.4	8.04	55.2	43.6	2.6	6.61

1955

April	55.5	38.6	6.0	1.08	53.0	36.1	6.2	0.72
May	55.2	38.1	7.5	3.25	53.0	37.7	7.2	2.45
June	61.7	45.6	5.9	1.74	61.0	42.5	5.8	0.69
July	71.4	50.0	9.0	1.21	67.6	50.3	8.9	2.14
August	70.0	49.3	6.7	1.28	69.3	50.7	5.5	1.15
September	62.7	45.7	5.0	2.38	60.6	48.3	5.1	1.80

Weather features

As the climate is known to influence the uptake of phosphorus by plants, it is pertinent to review the main features of the weather in the two seasons over which the experiments extended. The meteorological data relevant to the potato crop for 1954 and 1955 are given in Table 4.a. From this table it is evident that the climatic conditions in the two years differed widely. While 1954 was termed as "a particularly wet year", 1955 will long be remembered as a year of "sunshine and scanty rainfall".

The minimum temperatures right from April to October were consistently higher in 1954 than 1955 at Barbauchlaw but at Boghall the trend was not as consistent. Except for May at Boghall day temperatures (maximum) were considerably higher during the 1955 season than in 1954. During the critical months of June, July and August, when the vegetative and the tuber growth was at its height, the maximum temperatures were 8 to 16 degrees F higher at Barbauchlaw and 2 to 9 degrees at Boghall.

The daily hours of sunshine were also considerably higher in 1955 than in 1954 both at Boghall and at Barbauchlaw. For example Barbauchlaw had in 1955 compared to 1954, 31, 125 and 97% greater number of hours of sunshine in June, July and August. The position at Boghall was almost the same.

The total rainfall for the 6 months - April to October - was at Barbauchlaw 30 inches in 1954 and only 11 inches in 1955. The/

The corresponding figures for Boghall were 27.5 and 9 inches. Such large differences between the rainfall for two consecutive seasons are practically unprecedented in the records of the meteorological office. Figures for the three months June, July and August also show that little more than a third as much rain fell during 1955 as in 1954. Although these data show the extreme dryness of the summer of 1955, it must be recorded that winter and early spring of this year were very cool and moderately wet and planting of crops in many cases was delayed owing to the excess moisture present in the soil. Indeed it was planned to plant the potatoes in 1955 experiments fully two weeks after the normal planting time in order to secure early rapid growth for radioactive analysis work but in actual fact ploughing and cultivations were barely completed by the planting time. The soils in the early stages, therefore were very well supplied with moisture and long hours of sunshine in May brought the crop away very quickly. It was not until the time of final observation (end of August) that the soils appeared very dry and plants showed any signs of suffering from drought.

IV. RESULTS

1954 Season

The data and the main results of the 4 field experiments are presented in this section. Under the heading "levels of phosphorus" are included 2 experiments on soils of high available phosphorus at Shawfair and Dryden and one experiment on a soil low in available phosphorus at Barbauchlaw. Six treatments in all the 3 experiments were A, control; B, 0.33; C, 0.66; D, 1.0; E, 2.0; and F, 4.0; cwt. P_2O_5 per acre in the form of superphosphate.

Data and results for "phosphorus from different fertilizer materials" conducted at Dryden are presented separately. Treatments A, B and C were the same as for "levels of phosphorus" experiment, while D, E and F were Reno Hyperphosphate, Gafsa mineral phosphate and Dicalcium phosphate, respectively, applied at the equivalent of 0.5 cwt. P_2O_5 per acre. For comparison of the effect of superphosphate at equivalent rate with other fertilizer materials, the mean of B and C i.e. 0.33 and 0.66 cwt. P_2O_5 respectively is taken, though it is realized that this procedure is not always strictly accurate.

I. "Levels of phosphorus" Experiments

A. Effect of Treatments on plant development

Population

The mean population for each treatment at three locations (Barbauchlaw,/

Table 5.

Summary[1] of the data of the effect of the treatments on plant development

Barbauchlaw

Observation	A	B	C	D	E	F	S.E.[2]
a. Population per plot (15 sq. yd.)							
	45	47	48	47	46	46	N.S.
b. Sprouts per hill							
	3.2	2.8	2.7	2.6	2.8	2.7	N.S.
c. Shoot height[3] (cm)							
I	8	10	13	12	11	14	-
II	27	43	48	52	59	69	-
III	33	53	55	64	68	74	± 3.1
IV	36	54	56	65	73	76	-
d. Shoot fresh weight[3] (g/plant)							
I	36	68	96	95	118	121	-
II	96	162	203	331	322	403	-
III	105	243	230	432	407	432	±51.1
IV	40	65	89	111	102	139	-
e. Shoot, dry weight (%)							
I	17.9	13.2	11.4	11.8	11.4	11.5	-
II	20.7	19.1	18.5	16.5	17.0	15.2	-
III	15.7	14.8	16.4	14.2	12.6	12.6	± 0.65
IV	32.6	32.4	33.5	28.2	29.6	29.6	-
f. Root, fresh weight (g/plant)							
I	14.0	16.6	18.5	17.0	19.6	19.6	-
II	15.5	16.9	21.0	28.7	25.4	30.8	-
III	17.4	33.9	34.2	37.6	36.2	42.3	± 6.5
IV	11.6	17.7	22.9	27.6	19.8	23.2	-
g. Root, dry weight (%)							
I	26.3	22.8	21.4	20.5	17.8	18.5	-
II	35.8	35.1	33.1	32.5	30.7	29.3	-
III	22.3	20.0	24.3	23.3	21.2	19.2	± 0.027
IV	33.1	31.2	29.8	30.4	32.6	38.3	-

Shawfair

Observation	A.	B	C	D	E	F	S.E.[2]
a. Population per plot (15 sq. yd.)							
	37	38	36	38	38	29	N.S.
b. Sprouts per hill							
	3.0	2.9	3.0	2.9	3.3	3.9	N.S.
c. Shoot height[3] (cm)							
I	7	9	10	8	8	8	-
II	51	50	48	52	52	51	-
III	59	62	58	63	62	64	N.S.
IV	62	64	60	65	66	67	-
d. Shoot fresh weight[3] (g/plant)							
I	39	40	54	46	47	43	-
II	324	368	486	521	440	394	-
III	413	444	447	467	440	397	N.S.
IV	231	205	239	209	165	226	-
e. Shoot, dry weight (%)							
I	9.0	9.0	9.1	9.3	9.1	9.0	-
II	-	-	-	-	-	-	-
III	11.8	12.2	11.8	11.1	11.2	11.2	N.S.
IV	17.1	19.6	17.9	17.4	19.0	17.6	-
f. Root, fresh weight (g/plant)							
I	9.3	11.3	13.9	11.3	8.0	12.2	-
II	19.0	22.7	26.3	27.0	28.2	23.3	-
III	27.6	27.1	31.5	31.3	27.8	19.8	N.S.
IV	17.3	16.6	19.1	23.1	17.2	19.5	-
g. Root, dry weight (%)							
I	15.8	15.5	15.8	17.3	17.4	15.3	-
II	19.9	20.3	23.7	23.2	22.1	22.0	-
III	24.5	24.5	21.6	23.3	24.9	26.9	N.S.
IV	30.0	31.3	32.2	31.6	34.3	32.1	-

Dryden

Observation	A	B	C	D	E	F	S.E.[2]
a. Population per plot (15 sq. yd.)							
	48	48	46	48	49	45	N.S.
b. Sprouts per hill							
	2.8	3.0	2.8	2.8	3.2	2.9	N.S.
c. Shoot height[3] (cm)							
I	44	44	42	47	50	46	-
II	83	85	86	89	92	92	-
III	88	94	95	96	100	100	N.S.
IV	88	95	95	96	104	103	-
d. Shoot fresh weight[3] (g/plant)							
I	207	271	363	312	317	291	-
II	599	783	648	766	618	869	
III	382	314	280	354	382	307	N.S.
IV	63	72	103	79	108	105	-
e. Shoot, dry weight (%)							
I	16.7	14.6	15.3	15.4	16.2	15.5	-
II	10.9	12.1	12.2	12.1	11.5	11.8	-
III	22.3	20.9	19.4	20.3	20.1	18.0	N.S.
IV	-	-	-	-	-	-	
f. Root, fresh weight (g/plant)							
I	21.9	23.2	25.5	20.7	25.0	19.5	-
II	36.2	55.7	48.8	57.6	45.7	43.1	-
III	39.1	37.5	31.8	30.4	32.1	25.1	N.S.
IV	21.5	17.9	23.8	21.9	22.1	23.6	-
g. Root, dry weight (%)							
I	45.1	39.8	39.6	45.6	39.0	40.2	-
II	28.5	25.1	25.7	25.8	27.0	25.0	-
III	32.1	35.7	35.2	33.5	34.2	30.6	N.S.
IV	35.0	35.3	28.8	39.9	40.7	33.8	-

1. Each mean value in the table is the average of 4 replications.
2. S.E. multiplied by 2.131 and 2.947 gives least significant difference at the 5% and 1% level respectively.
3. Figures rounded off to nearest whole number.

(Barbauchlaw, Shawfair and Dryden) is given in Table 5a. It will be seen from this table that treatments had no effect on the germination of the tuber except in the case of the highest rate of application of phosphorus (treatment F) at Shawfair. Here the number of plants per acre dropped to about 12,500, as compared to overall mean population of about 15,700. This depression in population is just significant at the 5% level. Whether this drop is due to the lack of development of some tubers because of too high a concentration of fertilizer around the tuber, or to some other unknown factor is difficult to say, because at Dryden - a soil of even higher available soil phosphorus status - no such marked effect was shown. Furthermore if F treatment had proved harmful for germination, it would be expected that the effects would be detectable in the number of sprouts per hill. No such effect was visible.

1. Shoot

i. Sprouts per hill

The number of sprouts per hill was fairly constant around 3 under different treatments and at all three locations, (Table 5b). It seems obvious from these two sets of data i.e. population and the number of sprouts per hill, that increasing rate of phosphorus application had very little if any effect on the development of the plant from the tuber.

ii. Height

The data for the effect of treatments on the mean height (mean of 40 plants) of the shoot at different dates of observation and at the three locations are presented in Table/

Table 5c. The differences in height at the first observation at the three locations was due largely to the differences in the date of planting. Planting was carried out earliest at Shawfair (15th April) and after two months when the first observation was taken the weather was still cold and wet and the plants had not much chance to develop. The Barbauchlaw experiment was planted next on 7th May and Dryden at the end of May. The crop at Dryden therefore had more favourable weather for growth before the first observation was taken. However, it is quite clear from Table 5c that the application of phosphorus had influenced the height of the plant. As may be expected it is less pronounced in soils of high phosphorus status. For example at Dryden only the highest two rates i.e. 2 and 4 cwt. P_2O_5 per acre application, showed a significant increase over the control; among the other treatments, the differences were not significant. At Shawfair too, the treatments produced no marked differences - except F treatment which just failed to record a significant increase over the control. The response is very different in the soil of low available phosphorus at Barbauchlaw. At the first observation, when the plant was dependent mainly on the mother tuber for its food supplies, no effect of fertilizer additions could be expected nor were any differences shown, but at the second observation the height of the plant, even at the lowest fertilizer rate i.e. 0.33 cwt. P_2O_5 per acre (treatment B), showed a remarkable increase of about 63% over the/

the control. Each successive increase in the rate of phosphorus application produced a progressive increase in height, though not nearly so great as that between control and B treatment. These differences in height due to different treatments were maintained more or less in the same order as at the second observation to the end. Statistical analysis of the third observation, when the plant had attained its maximum height, showed that each increase in the rate of fertilizer application led to a highly significant increase in height of plant due to the next but one lower rate e.g. C A, D B, F D. As compared with E, the increase in height due to F treatment failed to attain significance. Plot wise data for all the four observations and analysis of variance of the data of 3rd observation are given in Appendix I.a and I a 1 respectively.

iii. Fresh weight of shoot

As may be expected, in soils of high available phosphorus (Shawfair and Dryden), the application of phosphorus failed to increase, to any appreciable degree, the fresh weight of the shoot, (Table 5d). On the other hand in the low phosphorus soil (Barbauchlaw) even the lowest application of fertilizer (treatment B) increased the fresh weight almost 2$\frac{1}{2}$ times over the control at the third observation. The highest rate produced an increase of more than 300 per cent. At the 1% level, all rates showed a significant increase over the control. It is also note worthy that 1 cwt. P_2O_5 per acre (treatment D) proved very clearly superior to the others, in that/

that it improved the growth of the plant markedly as compared to the two lower rates of fertilizer application; but the two higher rates i.e. E and F failed to achieve any further increase in fresh weight of shoot over this rate i.e. D. Complete data for the four observations and analysis of variance of the data of third observations is given in appendix I.b and I.a 2 respectively.

iv. Dry weight (%) of shoot

From Table 5e it is clear that the increased rate of phosphorus led to increased absorption of water by the plants. At all three centres the percentage dry matter, generally tended to decrease with the increase in phosphorus application. Because of the already high phosphorus availability, this trend is not so marked in the Shawfair and Dryden data - except at Dryden in the third observation when F treatment produced a significant decrease as compared to no application of phosphorus. The phosphorus deficient soil of Barbauchlaw however shows the effect more clearly. Analysis of variance (Appendix I a.3) of the data of the third observation (Appendix I.c.) showed that A and C treatments gave higher percentage dry matter, - significant at 1% level - than B, D, E and F which is the reverse of the data of the green weight of the shoot at the same stage. High percentage of dry matter at 4th observation was, particularly at Barbauchlaw and Dryden, mainly due to the plants drying up because of the severe frost a few days earlier.

2. Root/

2. Root

i. Fresh weight

The effect of treatments on the total weight of the root followed practically the same pattern as the fresh weight of shoot. Both at Shawfair and Dryden the additions of fertilizer produced no significant increase in the root development (Table 5f). Supression of root development at the highest rate (F) is however quite noticeable, particularly at Shawfair when at third observation this reduction, compared to C treatment, just failed to reach significance at 5% level. Once again in the low phosphorus soil (Barbauchlaw) the beneficial effect of increasing rates of phosphorus on root development is quite evident, particularly between the control and B treatment. The increase in weight is almost 100 percent (Table 5f) and highly significant (Appendix I a 4). Each increase in the rate of application of fertilizer produced an increase in weight, except E treatment. However, none of the differences among the treatments proved statistically significant. The adverse effect on root [development] at the highest rate (4 cwt. P_2O_5 per acre), seems [t]o be indicated in the soils of high phosphorus status, though in the low available phosphorus soil, this high concentration of phosphorus around the root system had, evidently no harmful effect on root growth. The increase in the weight of root and shoot due to F treatment are not of the same order. While fresh weight of shoot recorded an increase of over 300 percent over the control (Table 5d), the increase in root weight/

weight is little over 150 percent (Table 5f).

ii. % Dry weight

As against % dry matter in the shoot, treatments had very little effect on the dry matter percentage of the root. At none of the locations were any significant changes produced by application of fertilizers (Table 5g). This is not unexpected. The root system is in close contact with the soil solution and as such the amount of water in the root tissue is unlikely to vary much under different treatments with phosphates and therefore dry weight would remain fairly constant under different treatments.

B. Effect of treatments on tuber development and final yield

I. Tuber development

i. Number of tubers per plant

It is recognised that lack of adequate supplies of phosphorus to the plant leads to reduction in cell division and activity of the cell protoplasm. Additions of readily available phosphorus to the soil may therefore be expected to increase both the vegetative growth and the number of tubers per plant. This latter effect is clearly borne out from the data for Barbauchlaw in Table 6a. The average number of tubers per plant was almost doubled at the highest rate of phosphorus application compared to control. This increase is far more pronounced with treatment B than with further additions/

Table 6

Summary[1] of the data of the effect of the treatments on tuber development and final yield

	Barbauchlaw							Shawfair							Dryden						
	Treatment						S.E.[2]	Treatment						S.E.[2]	Treatment						S.E.[2]
ervation	A	B	C	D	E	F		A	B	C	D	E	F		A	B	C	D	E	F	
								a. Number (per plant)[3]													
I	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	20	15	15	16	17	-
II	10	15	17	22	16	21	-	8	12	18	18	23	15	-	11	18	15	16	17	17	-
III	10	15	12	16	16	17	± 2.95	12	13	14	21	13	14	N.S.	15	16	16	20	19	21	N.S.
IV	11	15	17	17	17	19	± 1.94	17	15	15	17	16	21	N.S.	15	17	18	18	22	22	N.S.
								b. Fresh weight (g/plant)[3]													
I	-	-	-	-	-	-	-	-	-	-	-	-	-	-	109	146	164	122	138	149	-
II	173	328	345	441	386	429	-	81	117	266	297	262	265	-	534	1116	941	1052	859	842	-
III	282	726	697	732	667	781	-	773	964	950	10	926	866	-	1038	1258	1091	1211	1054	813	-
IV	399	673	1026	929	923	952	± 98.2	1119	1075	1306	1362	1020	1141	N.S.	1120	1312	1282	1223	1112	1083	N.S.
								c. Dry matter (%)													
I	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.9	16.7	17.0	17.0	16.9	16.8	-
II	18.4	17.9	18.5	18.2	18.9	19.2	-	14.1	14.2	16.0	14.6	15.3	15.4	-	17.1	17.5	17.3	17.2	17.6	16.3	-
III	17.6	17.9	18.4	19.2	19.5	20.2	-	18.3	18.6	17.9	17.8	18.5	19.7	-	19.2	19.9	19.1	19.2	20.1	19.9	-
IV	19.6	20.9	21.4	21.5	21.6	21.9	± 0.66	18.8	19.7	19.0	17.2	18.8	18.8	N.S.	20.2	19.3	20.9	20.4	20.3	19.9	N.S.
								d. Ware (tons/ac.)													
	0.05	0.75	1.00	0.80	0.75	0.70	± 0.23	3.30	3.70	2.90	3.60	2.70	3.80	± 1.69	2.00	2.30	1.90	2.50	1.10	1.20	± 0.48
								e. Seed (tons/ac.)													
	3.1	6.4	8.8	8.5	8.6	9.4	± 0.66	7.9	7.4	7.9	7.8	8.3	6.9	N.S.	7.3	8.2	7.7	7.5	7.8	7.4	± 0.61
								f. Chats (tons/ac.)													
	0.29	0.37	0.39	0.32	0.32	0.47	± 0.095	0.44	0.41	0.46	0.59	0.61	0.44	N.S.	0.30	0.33	0.33	0.33	0.42	0.33	± 0.21
								g. Total yield (tons/ac.)													
	3.5	7.5	10.1	9.6	9.6	10.6	± 0.67	11.7	11.6	11.3	11.9	11.6	10.2	N.S.	9.6	10.7	9.9	10.3	9.3	8.8	± 0.93

1. Each mean value in the table is the average of 4 replications.
2. S.E. multiplied by 2.131 and 2.947 gives least significant difference at the 5% and 1% level respectively.
3. Figures rounded off to nearest whole number.

additions. Analysis of variance (Appendix IIa 1) of the third observation (Appendix IIa) showed a significant increase over control for all rates except C where for some unknown reason there was a reduction in the number of tubers, which failed to reach a significant level over control. The number of tubers per plant at the final observation showed the treatment effects even better. All the treatments except B gave an increase, significant at 1% level over the control while B was superior to A at 5%. Although each increase in the rate of phosphorus application, generally increased the number of tubers, none of the differences among the treatments was significant except the difference between B and F.

In soils of high available phosphorus (Dryden and Shawfair) phosphorus application up to about 1 cwt. per acre level produced very little increase in the number of tubers at the third and fourth observations. At Shawfair, at the second observation an increase from 8 to 23 tubers per plant with A and E treatments respectively is notable, though this result is not confirmed at third and fourth observations. These results indicate that in these two soils the available supply of phosphorus from the soil was adequate to meet all requirements of the plant and the additions of phosphorus, as in the growth of plant, made no difference in the final development of tubers.

ii. <u>Total weight tubers per plant</u>

Summary of results in table 6b, show that treatments had little/

little effect on the weight of tubers per plant in the phosphorus rich soils. Generally there was a small increase over the control with B and C treatments at Shawfair and with B treatment at Dryden, but the increase in weight then gradually drops with increase in the amount of phosphorus applied. A sharp increase in the weight due to fertilizer application, compared with control, is evident at the first and second observations both at Dryden and Shawfair. But this is mainly accounted for by the increase in number of tubers. These differences disappear at maturity (fourth observation).

At Barbauchlaw all additions produced an increase in the weight of the tubers compared to control but the magnititude of increase gradually decreased as the phosphorus rate increased. At the final observation all treatments except B proved significantly better (at 1% level) than the control, and B was better than A at 5% level (Appendix IIa 2).

iii. Dry weight tubers (%).

Fertilizer treatments brought about no change in the dry matter percentage at Shawfair and Dryden, but at Barbauchlaw the dry matter increased steadily with each increase in the phosphorus applied (Table 6c). The increase was more marked between control and B treatment, than among the other treatments. Increases in the dry matter percentage, however, were not significant among themselves, but D, E and F treatments significantly improved the % dry matter as compared with control.

2. Final/

2. Final Yield

The ultimate effect of phosphorus treatments on the tuber crop like potato must be judged not only on the total yield of tubers, but also on the changes in the different grades of tubers. The three recognised grades (Ware, Seed and Chats) are discussed first and the total yields (Ware + Seed + Chats) later.

i. Ware (Above 2¼" mesh riddle)

The effect of increasing rates of applied phosphorus in decreasing the total amount of ware is evident from the data in Table 6d. In the phosphorus rich soils of Dryden and Shawfair the two highest rates i.e. E and F, significantly reduced the yield of ware as compared to B and D treatments (Appendix IIa 4). Rates of application of phosphorus up to 1 cwt. P_2O_5 per acre (treatment D) showed no significant difference among themselves.

In the case of the low phosphorus soil (Barbauchlaw) in three out of 4 replications on control plots, tubers failed to achieve the ware size. Obviously lack of readily available phosphorus in the soil restricted the development of the tubers. The amount of ware increased with the first two rates of phosphorus application but steadily decreased thereafter. All rates of fertilizer application increased significantly the amount of ware in total yield.

ii. Seed (Between 2¼" and 1¼" mesh riddles)

At Shawfair and Dryden, treatments brought about no significant changes in the total amount of seed sized tubers (Table/

(Table 6e). But at Barbauchlaw the amount of seed tubers produced showed a highly significant increase at all levels of phosphorus application compared to the control. This increase is particularly sharp with the lowest rate of application i.e. o.33 cwt. P_2O_5 per acre, when the yield is more than twice that of control. Treatment C gave a further increase over B, significant at 1% level. Further additions of fertilizers (treatments D, E and F) however failed to record any significant effect over other fertilizer treatments.

iii. Chats

From Table 6f it will be seen that no differential effect on the total yield of chats is revealed by any fertilizer treatment at any of the three locations, possibly because of the very small weight of chats obtained at all the locations.

iv. Total yield

Data on the effect of treatments on the total yield (ware + seed + chats) are presented in Table 6g. In both soils of high available phosphorus (Shawfair and Dryden) additions of fertilizer made no difference in the total yield. In fact a depression in yield due to F treatment (4 cwt. P_2O_5 per acre) at Dryden when compared to B treatment (0.33 cwt. P_2O_5 per acre) just failed to reach significance level (Table 19a).

At Barbauchlaw, all treatments produced a marked increase in yield (significant at 1%) over the control. The addition of/

of a dressing as small as 0.33 cwt. P_2O_5 per acre (B treatment) doubled the yield compared with control. Another addition of 0.33 cwt. P_2O_5 per acre ~~in~~ treatment C produced a further highly significant increase. Rates higher than 1 cwt. P_2O_5 per acre (treatment D) failed to show any further benefit. Treatment F does show an increase of about 0.49 tons per acre over C (difference not significant) but at a cost of about 17 cwt. of superphosphate (20% P_2O_5).

C. Effect of Treatments on uptake of P_2O_5

1. Shoot

From the data in Table 7a it is evident that treatments exerted a marked influence on the P_2O_5 percentage in the shoot at all stages of growth and at all locations. Generally, each increase in the rate of phosphorus increased the amount of P_2O_5 in the plant at all stages except the fourth observation at Barbauchlaw when plants were dying. The treatment effects in the early stages are far more marked at Barbauchlaw than at Shawfair or Dryden. For example at Barbauchlaw at the first observation the P_2O_5 percentage more than doubled, with F treatment compared to control while similar comparisons at Shawfair and Dryden show increases of only 21 and 43 percent respectively. This is also true for the second observation. But at the final observation the picture is very different. While in soil of low available phosphorus (Barbauchlaw), there is a decrease, particularly sharp with B treatment, with phosphorus/

Table 7

Summary[1] of the data of the effect of treatments on the uptake of total P_2O_5 (% of dry matter)

	Barbauchlaw							Shawfair							Dryden						
	Treatment						S.E.[2]	Treatment						S.E.[2]	Treatment						S.E.[2]
Observation	A	B	C	D	E	F		A	B	C	D	E	F		A	B	C	D	E	F	
I																					
										a. Shoot											
I	0.59	0.81	0.99	1.02	1.21	1.31	-	1.53	1.49	1.59	1.51	1.78	1.85	-	0.83	0.99	0.94	1.06	1.05	1.20	-
II	0.48	0.48	0.50	0.59	0.83	0.82	-	-	-	-	-	-	-	-	0.67	0.63	0.81	0.86	0.88	1.09	-
III	0.53	0.44	0.41	0.44	0.57	0.64	± 0.044	0.67	0.59	0.66	0.71	0.73	0.68	± 0.05	0.49	0.50	0.67	0.65	0.64	1.09	± 0.087
IV	0.38	0.30	0.25	0.25	0.28	0.30	-	0.44	0.46	0.46	0.54	0.49	0.70	-	0.29	0.27	0.35	0.43	0.42	0.50	-
										b. Root											
I	0.43	0.57	0.64	0.66	0.86	0.98	-	1.12	1.00	1.08	1.04	1.55	1.44	-	0.70	0.79	0.79	0.91	0.91	1.09	-
II	0.30	0.29	0.32	0.35	0.43	0.62	-	0.60	0.64	0.69	0.65	0.76	0.86	-	0.60	0.54	0.68	0.66	0.81	1.03	-
III	0.33	0.27	0.29	0.31	0.35	0.48	± 0.027	0.44	0.41	0.50	0.62	0.59	0.61	N.S.	0.38	0.34	0.46	0.45	0.57	0.67	± 0.089
IV	0.20	0.19	0.16	0.17	0.18	0.28	-	0.34	0.34	0.43	0.47	0.42	0.71	-	0.21	0.17	0.30	0.18	0.27	0.27	-
										c. Tuber											
I	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.70	0.85	0.76	0.92	0.91	0.92	-
II	0.38	0.31	0.34	0.44	0.50	0.60	-	0.83	0.83	0.80	0.78	0.85	0.87	-	0.64	0.62	0.73	0.72	0.77	0.90	-
III	0.31	0.31	0.37	0.35	0.45	0.53	± 0.026	0.59	0.54	0.57	0.69	0.64	0.64	± 0.10	0.59	0.56	0.69	0.75	0.67	0.75	± 0.026
IV	0.31	0.34	0.36	0.38	0.51	0.64	-	0.68	0.64	0.65	0.68	0.68	0.83	-	0.63	0.64	0.69	0.68	0.74	0.86	-

1. Each mean value is the average of 4 replications.
2. S.E. multiplied by 2.131 and 2.947 gives least significant difference at the 5% and 1% level respectively.

phosphorus application, in soils of high phosphorus status at Shawfair and Dryden the % phosphorus in the shoot increased almost to double with F treatment compared to control. Obviously at Barbauchlaw uptake of phosphorus by the plant has not been proportional to the large increases in vegetative and tuber development due to fertilizer application and therefore the position of P_2O_5 percentage in the shoot is almost reversed between the first and the fourth observation. On the other hand phosphorus not being the limiting factor at Shawfair and Dryden, plants receiving successive increases of phosphorus, accumulated increasingly greater amounts in their plant tissues and therefore showed a higher percentage of P_2O_5 with increasing rates of application.

Analysis of variance (Appendix IIIa 1) of the third observation (Appendix IIIa) showed some significant increases due to all treatments over control. At Dryden F treatment produced increase in P_2O_5 content of shoot, significantly (1%) higher than all other treatments, while D was superior to A and B treatments at 5% level. At shawfair D, E and F treatments proved better (at 5% level) than B and C. At Barbauchlaw, the position was very similar to that at Shawfair compared to control. There was an almost significant depression with the lowest rate (B treatment) which reached significant level with the next higher rate i.e. treatment C, but thereafter P_2O_5 percentage rises and the two highest rates show a highly significant increase over B and C treatments.

2. <u>Root</u>

2. Root

More or less similar trends as in shoot though not as well defined are shown by P_2O_5 in the root data in Table 7b. In soils of high phosphorus status increases in the rate of fertilizer application; generally resulted in increasing the P_2O_5 percentage in the root. At Dryden, for example, at the third observation, F treatment almost doubled the P_2O_5 content compared to B. The two highest treatments were significant over B, while F proved better than all other treatments except E. At Barbauchlaw, again the picture is the same as for the shoot data. At early stages, the percent P_2O_5 in the root increased with each increase in rate of phosphorus applied, with the result that it was more than doubled with F treatment compared to B. As in the case of the shoot, these differences vanished at the fourth observation. Analysis of variance (Appendix IIIa 2) of the third observation (Appendix IIIb) showed, as in case of shoot, a significant depression with treatment B. In the root however the P_2O_5 content started rising with the next treatment, i.e. C, till E and F were superior to B, and F superior to all others except E.

3. Tubers

From the data in Table 7c, it will be observed that tubers from the two soils rich in available phosphorus i.e. Shawfair and Dryden, contained a considerably higher percentage of P_2O_5 at all stages of development than those from Barbauchlaw. Broadly, the highest rate of fertilizer application/

application (F treatment) at Barbauchlaw, brought up the P_2O_5 content of the tubers to about the same level as B treatment at Shawfair and Dryden. It is also noteworthy that at maturity (4th observation) except the F treatment at Shawfair and E and F at Dryden, other treatments had not improved the P_2O_5 content of tuber compared to control as much as in the case of Barbauchlaw. At Barbauchlaw, first observation, there was a slight depression in P_2O_5 percentage with B treatment but thereafter the amount of P_2O_5 rose steadily till it reached a figure about 80% higher than the control. The magnitude of the increase possibly because of much greater concentration of P_2O_5 in shoot and root at earlier stages is higher with E and F than with lower rates. At fourth observation F treatment more than doubled the P_2O_5 percentage compared with control. Statistical analysis (Appendix IIIa 3) of the data from the third observation (Appendix IIIc) showed the position for percent P_2O_5 as follows:- At Dryden D and F treatments proved superior to all others. All other treatments proved better than A and B, while there was no difference between A and B, C was significantly superior to B; D to C and F to E. Shawfair data showed D, E and F to be better (5% level) than B treatment. D was also superior to A. Other comparisons showed no significant differences. At Barbauchlaw, as has already been remarked, treatments produced wider differences. At 1% level of significance E and F treatments were superior to all other treatments and F was better than E. At 5% level, treatments/

treatments C, E and F proved superior to control and B.

II. "Phosphorus from different fertilizer materials" experiment

This experiment was conducted at Dryden - a soil of high available phosphorus status - with the purpose of comparing the relative values of the following fertilizers as a source of phosphorus for the potato crop.

Treatments included, A, control; B and C, superphosphate at 0.33 and 0.66 cwt. P_2O_5 per acre; D, Reno Hyperphosphate; E, Gafsa mineral phosphate; and F, Dicalcium phosphate. The last three i.e. D, E, F were applied at the equivalent of 0.5 cwt. P_2O_5 per acre. Mean of B and C is throughout used (though this procedure not always strictly accurate) for comparison at equivalent rate with D, E and F treatments.

1. Effect of treatments on plant development

As will be seen from the data in Tables 8a and b, neither population nor number of sprouts per hill, showed any effect of the treatments on the development of the plant from the mother tuber. The population was fairly constant around an overall mean of about nineteen thousand plants per acre and sprouts around three per hill. Lack of response to treatments by aerial parts is further evident from the mean height (mean of 40 plants) of the shoot (Table 8c) as well as from the fresh weight of shoot, (Table 8d). Some increase both in height and green weight is noticeable at the first observation between superphosphate and other treatments but/

Table 8

Summary[1] of the data on the effect of treatments on plant development

Observation	A	B	C	D	E	F	S.E.[2]
	a. Population per plot (15 sq. yd.)						
I	43	43	45	44	46	43	N.S.
	b. Number of sprouts per hill						
	3.0	3.1	2.9	2.6	2.9	3.0	N.S.
	c. Shoot Height (cm.)[3]						
I	39	44	43	36	42	43	-
II	89	92	90	88	83	83	-
III	98	97	97	97	89	89	N.S.
IV	99	100	98	98	91	90	-
	d. Shoot fresh weight (g/plant)[3]						
I	351	523	377	339	334	309	-
II	601	563	574	526	568	569	-
III	493	426	513	436	394	327	N.S.
IV	82	59	73	61	62	70	-
	e. Shoot dry matter (%)						
I	12.0	11.2	11.5	12.2	12.5	12.2	-
II	11.5	11.0	11.8	10.8	10.8	11.2	-
III	18.0	16.2	18.0	18.8	18.0	18.0	N.S.
IV	46.5	56.8	49.2	44.0	49.0	50.0	-
	f. Root fresh weight (g/plant)[3]						
I	40	48	39	29	29	27	± 6.1
II	42	55	45	48	47	45	-
III	36	34	34	34	30	34	N.S.
IV	31	26	19	27	24	28	-
	g. Root dry matter (%)						
I	26.5	24.0	28.8	26.8	27.5	28.2	-
II	26.0	24.3	26.8	25.5	27.3	26.5	-
III	25.8	25.8	28.0	27.5	30.0	24.0	N.S.
IV	30.8	31.5	33.3	30.5	30.3	30.3	-

1. Each mean value is the average of 4 replications.
2. S.E. multiplied by 2.131 and 2.947 gives significant difference at the 5% and 1% level respectively.
3. Figures rounded off to nearest whole number.

but none of these differences was statistically significant at any stage of growth. Percent dry weight also showed no influence of the treatments. Beneficial effects of more readily available phosphorus from superphosphate (mean of B and C treatments) compared to other fertilizer materials used are however, shown in the early stage (first observation) of root development. Analysis of variance (Appendix IVa 4) of plot data (Appendix IVd) showed that superphosphate significantly increased the weight of root compared to others. A significant effect of Dicalcium phosphate (F treatment) compared to control is also indicated Hyperphosphate, Gafsa mineral phosphate, and Dicalcium phosphate, i.e. treatments D, E and F respectively, showed no differential influence. This initial beneficial effect of superphosphate, vanished at later stages possibly because by that time root systems had sufficiently developed and penetrated the soil, already high in reserves of available phosphorus, and therefore became practically independent of fertilizer phosphorus supplies. As might have been expected, dry weight (%) of root showed no influence of treatments and was fairly constant at all stages of growth.

2. Effect of treatments on tuber development

The data for tuber development are presented in Table 9. It is evident from this table that generally "Hyperphosphate" (treatment D) recorded a lower number of tubers per plant than other fertilizers. Though differences were not significant at earlier stages, at maturity i.e. fourth observation, E and F/

Table 9

Summary[1] on the data on the effect of treatments on tuber development and final yield

Observation	A	B	C	D	E	F	S.E.[2]
a. Tubers: number per plant							
I	18	15	16	12	15	15	-
II	13	17	18	15	17	16	-
III	15	16	17	15	17	16	-
IV	12	16	17	13	18	18	± 1.76
b. Tubers: fresh weight (g/plant)[3]							
I	114	261	114	151	157	126	-
II	697	825	754	897	794	794	-
III	813	857	921	1014	980	1015	-
IV	1037	960	1171	972	1175	1199	N.S.
c. Tubers: dry weight (%)							
I	16.6	15.8	15.6	16.1	15.7	16.9	-
II	16.3	17.7	17.6	16.7	18.2	16.6	-
III	18.0	19.1	19.8	18.9	20.5	19.2	N.S.
IV	18.9	19.7	18.9	19.8	19.9	18.9	-
d. Ware (tons/ac.)							
	1.9	1.9	1.6	1.9	2.3	1.4	N.S.
e. Seeds (tons/ac.)							
	6.8	6.9	6.8	5.2	7.4	6.8	± 0.46
f. Chats (tons/ac.)							
	0.2	0.3	0.3	0.2	0.3	0.3	N.S.
g. Total Yield (tons/ac.)							
	8.9	9.0	8.6	7.2	8.9	8.3	± 0.75

1. Each mean value is the average of 4 replications.
2. S.E. multiplied by 2.131 and 2.947 gives significant difference at the 5% and 1% level respectively.
3. Figures rounded off to nearest whole number.

F treatments (Gafsa mineral phosphate and Dicalcium phosphate) produced significantly higher numbers of tubers than control, superphosphate and Hyperphosphate.

The total weight of tubers showed greater treatment variations at the first observation than at later stages. More readily available phosphorus from superphosphate at this stage resulted in more than 50% increase in weight over control and little less over Dicalcium phosphate. These differences however were not significant, as was also the case with the fourth observation.

As in the case of shoot and root, percent dry weight of tuber was in no way seriously altered by treatments.

Data on the total yield as well as ware seed and chats is shown in Table 9 and analysis of variance (Appendix Va 4 to Va 7.) The data for total yield showed that all treatments except Dicalcium phosphate (F) gave a significant increase in yield compared to Hyperphosphate (D). It is also noteworthy that Hyperphosphate significantly (at 5% level) depressed the yield compared to control. Amongst the other treatments i.e. A, mean of B and C, E and F there were no marked differences.

As far as ware sized tubers were concerned treatments produced no significant differences. The percentage of ware in the total yield however varied considerably. The highest proportion was produced by "Hyperphosphate" (26.4%) and lowest by Dicalcium phosphate (16.7%). The percentages for the other treatments were, control, 21.3, superphosphate 19.8 and Gafsa mineral phosphate 23 percent.

Total/

Table 10

Summary[1] of the data on the effect of treatments on the uptake of P_2O_5

Observation	A	B	C	D	E	F	S.E.[2]
			Treatments				
			a. Shoot: % P_2O_5				
I	0.91	1.07	1.12	0.70	1.05	0.99	-
II	0.65	0.67	0.67	0.67	0.67	0.70	-
III	0.48	0.55	0.61	0.49	0.44	0.45	N.S.
IV	0.26	0.34	0.31	0.32	0.31	0.27	-
			b. Root: % P_2O_5				
I	0.65	0.74	0.89	0.95	0.84	0.69	-
II	0.54	0.51	0.60	0.48	0.56	0.53	-
III	0.40	0.47	0.49	0.37	0.32	0.32	± 0.063
IV	0.12	0.18	0.18	0.13	0.14	0.15	-
			c. Tuber % P_2O_5				
I	0.79	0.82	0.93	0.83	0.81	0.84	-
II	0.49	0.68	0.67	0.72	0.57	0.58	-
III	0.53	0.68	0.67	0.52	0.51	0.49	N.S.
IV	0.54	0.63	0.64	0.57	0.57	0.58	-

1. Each mean value is the average of 4 replications.
2. S.E. multiplied by 2.131 and 2.947 gives significant difference at the 5% and 1% level respectively.

Total seed which accounted for between 70 and 82% of the total yield followed the same trend as the total yield. Hyperphosphate gave a significantly lower amount of seed size tubers than other treatments. It also showed a lower figure for seed as a percentage i.e. 72% of total yield compared to 77.9; 74.7; 81.9 by superphosphate, Gafsa mineral phosphate and Dicalcium phosphate respectively.

The yield of chats showed no significant differences due to treatments and as could be expected control produced the lowest, 8.9, and Dicalcium phosphate highest, 14.4 percentage of chat size tubers in the total yield.

3. Uptake of P_2O_5

Data on the percent P_2O_5 in shoot, root and tuber at different stages of growth are presented in Table 10.

From these data it is evident that the P_2O_5 content of the shoot (Table 10a) was higher at all stages with superphosphate treatment (mean of B and C treatments), than when other fertilizers were the source of phosphorus. It is clear that excepting superphosphate, other fertilizers brought about no notable change in the amount of P_2O_5, compared with the control. Analysis of the third observation showed that even the difference produced by superphosphate was not significant over the control or any other fertilizer treatment. This is obviously due to the fact that the soil had supplies of available phosphorus too great for the fertilizer treatments to be effective.

The/

The trend of increased P_2O_5 from superphosphate application is also evident in the root data (Table 10b) and this increase (third observation) reached 5% level of significance in comparison with E and F treatments i.e. Gafsa mineral phosphate and dicalcium phosphate. Comparisons between the other treatments showed no differences.

Similar trends are shown by data for P_2O_5 percentage in tubers. At all stages of tuber development, application of fertilizers improved the P_2O_5 content, and superphosphate proved best in this respect. At no stage, however, did these differences, either among the fertilizer treatments or the control and the fertilizers reach a significant level.

1955 Season

The data and the main results presented in this section are arranged in an order similar to those for 1954. Under the heading "Levels of phosphorus" are included 2 field experiments with the potato crop - one on high (Boghall) and the other on low (Barbauchlaw) available phosphorus status soil. Treatments were the same for both experiments and included, in addition to control, all combinations of phosphorus at 4 levels (P_1, 0.25; P_2, 0.5; P_3, 1.0 and P_4, 2.0 cwt. P_2O_5 per acre as superphosphate) with nitrogen at 2 levels (N_1, 0.5 and N_2, 1.0 cwt. N per acre as ammonium sulphate). P^{32} tagged superphosphate at equivalent rate to treatments P_1, P_2 and P_3 was applied to a small subplot (12 ft. row) in the main plot, for the study of the uptake of phosphorus, derived from fertilizer, by radio tracer technique.

The data and results of a single field experiment conducted at Barbauchlaw with the potato crop to study the comparative merits of four phosphate fertilizers are presented under the heading "Phosphorus from different fertilizer materials" in subsection II, details of treatments are given.

Finally in subsection III, under the heading "Greenhouse experiments", are presented the data and results of two pot experiments, with soils obtained from the sites of the Boghall and Barbauchlaw field experiments, and oats as the crop. Treatment details are given under subsection III.

I. "Levels of phosphorus" experiments

A. Effect of treatments on plant development

1. Population and number of sprouts per hill.

Both at Boghall (soil of high available phosphorus) and Barbauchlaw (low available phosphorus), germination of the tubers was very satisfactory and regular, around an overall mean of about nineteen thousand plants per acre. From the data in Table 10a it is evident that treatments had no influence on the development of the plant from the mother tuber.

The number of sprouts per hill - another index of harmful or beneficial effect of treatments if any - varied only very slightly from an overall mean of 2.1 per hill for both locations (Table 10b), but these differences proved non-significant (Appendix VIIb and VIIa 2).

2. Shoot

i. Height

Data on the effect of treatments at the 3 observations are summarised in Table 10c. Complete data are presented in Appendix VIIc and the Analysis of variance of data from the third observation in Appendix VIIa 3. From Table 10c it is evident that both phosphorus and nitrogen treatments influenced the height of the plant. Even at Boghall, in soil of high available phosphorus, additions of phosphorus at all levels improved significantly the height of the plant (third observation) compared to control but the rate at which phosphorus was applied made very little difference.

The/

Table 10

Summary[1] of results of the effect of treatments on plant development

Observation	Barbauchlaw Treatment P_o	P_1	P_2	P_3	P_4	S.E.[2]	Treatment N_1	N_2	S.E.[2]	Boghall Treatment P_0	P_1	P_2	P_3	P_4	S.E.[2]	Treatment N_1	N_2	S.E.[2]
a. Population per plot[3] (30 sq. yd.)																		
	110	112	109	114	112	N.S.	111	111	N.S.	102	109	105	108	105	N.S.	106	105	N.S.
b. Sprouts per hill																		
	2.0	2.1	2.3	2.2	2.3	N.S.	2.7	2.7	N.S.	2.4	2.4	2.8	2.7	2.7	N.S.	3.3	3.2	N.S.
c. Shoot - Height[3] (cm.)																		
I	19	36	44	47	50	-	39	38.3	-	25	33	32	34	33	-	32	30	-
II	40	47	51	58	59	-	50	52	-	61	67	67	68	69	-	65	68	-
III	41	48	53	60	60	± 1.6	50	53	± 1.03	62	67	68	68	69	± 1.8	65	68	± 1.1
d. Shoot - Fresh weight[3] (g/plant)																		
I	52	124	171	217	247	-	163	161	-	140	207	200	231	236	-	210	208	-
II	120	183	259	297	331	±33.7	235	241	N.S.	297	372	347	335	366	N.S.	329	357	N.S.
III	69	72	88	74	114	-	79	88	-	267	263	304	290	284	-	260	308	-
e. Shoot dry matter (%)																		
I	13.8	10.9	10.6	9.9	9.2	-	10.8	11.1	-	9.1	8.1	7.9	7.0	7.0	-	7.8	8.1	-
II	10.9	9.1	9.6	9.3	9.7	N.S.	10.1	9.7	N.S.	12.3	11.2	11.7	11.8	11.6	N.S.	11.6	11.9	N.S.
III	18.9	21.4	19.6	20.9	20.6	-	21.5	19.1	-	10.7	10.0	9.8	10.1	10.6	-	10.4	10.1	-
f. Root - fresh weight (g/plant)																		
I	13.2	15.3	21.2	23.0	18.1	-	19.2	17.0	-	17.5	22.6	23.1	27.0	24.5	-	23.1	20.6	-
II	18.2	23.4	28.4	29.6	26.0	± 2.69	25.2	25.0	N.S.	24.7	26.6	25.3	23.9	23.0	N.S.	25.1	24.0	N.S.
III	11.8	15.7	16.7	15.6	15.4	-	15.3	14.9	-	45.3	55.0	65.4	58.8	60.4	-	55.5	58.9	-
g. Root - dry matter (%)																		
I	18.4	18.4	15.9	15.3	17.4	-	17.3	16.8	-	17.1	15.3	15.5	13.2	13.5	-	15.4	14.5	-
II	13.1	13.1	12.9	12.5	13.8	N.S.	13.5	12.6	N.S.	20.8	19.2	19.5	19.3	20.8	N.S.	19.1	20.7	N.S.
III	23.4	20.0	20.1	21.9	22.6	-	21.1	22.0	-	18.6	16.0	16.0	15.2	17.0	-	16.4	16.8	-

1. Each mean value is the average of 5 replications.
2. S.E. multiplied by 2.030 and 2.724 gives the least significant difference at the 5% level and 1% level respectively.
3. Figures rounded off to nearest whole number.

The higher rate of nitrogen application (N_2) gave a significant increase over N_1. Interaction between P and N treatments was completely lacking.

The influence of treatments was even more pronounced in the low available phosphorus soil of Barbauchlaw (third observation). All phosphorus treatments increased the height of the plant over the control, the difference being significant at the 1% level. Among the treatments, P_1 gave a significant increase over P_o; P_2 over P_1; and P_3 and P_4 over P_2. Application of phosphorus at a rate higher than 1 cwt. P_2O_5 per acre (P_3), failed to cause any further improvement in the height. As at Boghall, the higher rate of nitrogen, improved the mean height of the plant, differences between N_2 and N_1 treatments being significant at the 1% level. Interaction between phosphorus and nitrogen treatments again lacked any significance, though it was noted that the higher rate of nitrogen always improved the height in combination with phosphorus at all levels compared to the lower rate (N_1).

ii. Fresh weight per plant

Data for the effect of treatments on the fresh weight of the 3 observations are summarized in Table 10d. Complete data are contained in Appendix VIId and the analysis of variance of the data of the second observation in Appendix VIIa 4.

At the second observation, when the plants were at the height of vegetative growth neither phosphorus nor nitrogen treatments/

treatments showed any influence at Boghall (high available phosphorus). At Barbauchlaw the addition of phosphorus exerted a marked influence in increasing the shoot weight. Even a low dressing of 0.25 cwt. P_2O_5 per acre (P_1) increased the weight by over 50%, the highest rate (P_4) showed an increase of 178% over the control. Each alternate increase (i.e. comparisons between P_0 and P_2; P_1 and P_3) in the rate of application of phosphorus improved the weight of the shoot - significant at the 5% level. Nitrogen treatments alone or in combination with phosphorus failed to produce any marked differences in the weight of the shoot.

iii. Dry weight (%)

Data in summarized form are presented in Table 10e, and plot wise in Appendix VIIc. Analysis of variance of the data of the second observation is shown in Appendix VIIa 5.

From the data in Table 10e it will be seen that at the first observation there was a regular decline in the percent dry matter in the shoot, at both locations with increase in rate of P or N . It was more pronounced at Barbauchlaw than at Boghall. At the height of vegetative growth i.e. second observation, though variations existed statistical analysis of the data showed them to be nonsignificant.

3. Root

i. Fresh weight per plant

Data for the effect of treatments on the weight of the root/

root, at both locations and at the three observations, are summarized in Table 10f. Complete data and the analysis of variance of the data of the second observation are given in Appendix VIIf and VIIa 6 respectively.

Like the fresh weight of shoot, the root reflected practically no influence of treatments in soil of high available phosphorus (Boghall). Slight increases in weight due to fertilizer treatments at the earliest stage, had practically completely disappeared at second observation. On the other hand the marked beneficial effect of phosphorus application on root development in soil of low available phosphorus is quite evident from the Barbauchlaw data in Table 10f, even with a small application of fertilizer (treatment B). Study of the Barbauchlaw data also reveals another interesting point. At all three observations the highest rate i.e. 2 cwt. P_2O_5 per acre application of fertilizer checked the development of root as compared with the next lower rate i.e. 1 cwt. P_2O_5 per acre application (P_3). This is particularly marked at the earliest stage. It seems probable that the high concentration of phosphate around the root system at the 2 cwt. P_2O_5 per acre application (at the earliest stage), checked the development of the root in the early stages. Analysis of the data of the second observation showed that all treatments except P_1, significantly (1% level) improved the weight of the root compared to the control. P_1 just failed to reach significant level (at 5%) compared to control. Among the rates of application comparisons, P_3 significantly increased/

increased the weight compared to P_1 but the improvement from P_2 to P_3 was not significant.

The two levels of nitrogen, either alone or in combination with the phosphorus treatments, exerted no marked influence.

ii. Dry matter (%)

Summarized data are given in Table 10g. Complete data and analysis of variance of the data of second observation are in Appendices VIIg and VIIa 7 respectively.

It is clear from Table 10g that the percent dry matter remained fairly constant at both locations and showed no influence of the phosphorus treatments at the height of the vegetative growth of the plant i.e. second observation. At the earlier stage, however, except for the P_4 treatment at Barbauchlaw, there was a marked trend, at both Boghall and Barbauchlaw, for the percent dry matter to decrease with the increase in the rate of phosphorus application. Root material from the control plots showed the highest percentage of dry matter.

Nitrogen proved ineffective at Barbauchlaw but at Boghall higher rate (N_2) increase the dry weight percentage, the difference between N_2 and N_1 being significant at the 5% level. Any indication of interaction between P and N treatments was completely absent.

B./

Table 11

Summary[1] of results of the effect of treatments of tuber development and final yield

	Barbauchlaw									Boghall								
	Treatment					S.E.[2]	Treatment		S.E.[2]	Treatment					S.E.[2]	Treatment		S.E.[2]
Observation	P_0	P_1	P_2	P_3	P_4		N_1	N_2		P_0	P_1	P_2	P_3	P_4		N_1	N_2	
	a. Number (per plant)																	
I	5.6	7.3	7.7	8.2	9.7	-	7.8	7.5	-	4.9	6.5	7.7	9.2	7.9	-	8.0	6.5	-
II	9.2	6.1	16.0	16.4	16.9	-	14.8	15.3	-	10.1	12.6	11.8	11.9	14.6	-	12.3	12.1	-
III	10.3	16.7	17.6	16.5	18.5	± 2.3	16.7	15.9	N.S.	9.5	10.3	11.6	10.0	12.5	N.S.	11.0	10.5	N.S.
	b. Fresh weight[3] (g/plant)																	
I	88	132	182	169	117	±22.15	136	138	N.S.	30	45	51	67	52	±10.1	52	46	N.S.
II	265	437	548	592	516	-	450	454	-	489	612	539	502	556	-	561	499	-
III	453	709	760	774	755	±52.3	698	701	N.S.	801	887	907	804	795	N.S.	870	844	N.S.
	c. Dry matter (%)																	
I	16.7	17.1	16.5	17.0	15.0	-	16.3	16.7	N.S.	14.9	14.1	14.6	14.9	14.1	-	14.6	14.2	-
II	19.2	21.7	20.8	21.9	20.6	-	20.6	21.0	N.S.	20.3	21.1	21.1	21.2	21.8	-	21.3	20.9	-
III	21.3	21.6	22.0	22.0	23.1	± 0.138	21.7	22.3	± 0.276	22.4	21.5	21.9	21.3	22.1	N.S.	21.8	21.9	N.S.
	d. Final Yield of tubers (tons/ac.)																	
	Ware																	
	5.69	8.39	9.25	9.56	8.29	± 0.62	7.74	8.71	± 0.39	9.54	11.51	10.73	10.49	10.36	± 0.56	9.99	11.06	± 0.358
	Seed																	
	4.16	4.72	5.19	5.67	6.64	± 0.34	5.59	4.96	± 0.21	4.94	5.85	5.87	6.32	5.83	N.S.	5.80	5.70	N.S.
	Chats																	
	0.15	0.18	0.20	0.23	0.32	± 0.036	0.21	0.23	N.S.	0.13	0.17	0.17	0.18	0.21	N.S.	0.17	0.18	N.S.
	Total																	
	9.60	13.22	14.29	15.28	14.14	± 0.95	13.34	13.67	N.S.	14.61	17.65	16.76	16.97	16.36	± 0.87	15.98	16.95	± 0.55

1. Each mean values is the average of 5 replications.
2. S.E. multiplied by 2.030 and 2.724 gives the least significant difference at the 5% level and 1% level respectively.
4. Figures rounded off to nearest whole number.

B. Effect of treatments on tuber development and the final yield

1. Tuber development

i. Number per plant

The data on the effect of treatments on the number of tubers per plant at the three observations are summarized in Table 11a. Plot wise data for all observations and the analysis of variance of data for the third observation are presented in Appendices VIIIa and VIIIa 1 respectively.

From Table 11a, it is evident that even at 2 months from planting (first observation) the numbers of tubers per plant were already showing a beneficial influence of fertilizer treatments. It is also noteworthy that the difference in the available phosphorus status of the soil at the two locations, at the earliest stage, had practically no influence. At the second observation, the effect of available phosphorus status of the soils, as well as that of the added phosphorus was clearly seen. At this stage the numbers of tubers showed a big increase, due to fertilizer application over the control, particularly on the soil of low available phosphorus (Barbauchlaw). The increase in the number of tubers per plant was over 50% at Barbauchlaw but only 25% at Boghall. Statistical analysis of the third observation, which represented the number of tubers that matured, showed no significant difference at Boghall. At Barbauchlaw, all treatments produced significantly higher numbers of tubers per plant compared to control but among the treatments there were no marked differences.

Nitrogen/

Nitrogen rates, alone or in combination with phosphorus, failed to reveal any influence on the number of tubers per plant at either location.

ii. Fresh weight per plant

The data of the treatment effects on the weight of tubers produced per plant at the three observations are summarized in Table 11b. Detailed data for the three observations and the analysis of variance of the data of the third observation are given in Appendices VIIIb and VIII a 2 respectively.

The data of Table 11b showed that at the first observation, the weight of tubers under every treatment was considerably higher at Barbauchlaw than at Boghall. As the planting of the crop was done at the two locations with only one day elapsing, and as the number of tubers at this stage (first observation) also showed no marked difference between the locations, it can only be concluded that tuber swelling started earlier at Barbauchlaw than Boghall, where possibly due to high availability of phosphorus, the vegetative growth period was prolonged at the cost of tuber development. This difference almost disappeared at the second observation and at maturity (third observation) the yield of tubers per plant at Boghall exceeded that of Barbauchlaw at all levels of fertilizer application. As might be expected, at Boghall, at the first observation, there was a sharp increase of 50% (significant at the 5% level) with even the 0.25 cwt. P_2O_5 per acre (treatment P_1) application compared to control. At later/

later stages, however, no marked differences due to any of the treatments were observed. At Barbauchlaw the position was interesting. There was a marked increase in the weight, due to all fertilizer treatments, over the control, at all three observations. Among the treatments the weight of the tubers rose steadily, except in the first observation, with each increase in the rate of phosphorus application up to P_3 treatment (1 cwt. P_2O_5 per acre rate), but with the highest there was a decline in yield. At the first observation the yield began to decline after the P_2 treatment. Analysis of variance of the first observation, showed the depression in yield due to highest rate of phosphorus application (P_4) to be significant at the 1% level compared to P_2 and at the 5% level compared to P_3. At the final observation, though the P_4 treatment still showed a drop in yield compared to P_3, the difference was not statistically significant. At this stage i.e. third observation, all fertilizer treatments proved better (at the 1% level) than the control, but the differences among the treatments were not significant.

iii. <u>Dry matter (%)</u>

The data are presented in summarized form in Table 11c. Complete data for the three observations, and analysis of variance are given in Appendices VIIIc and VIIIa 3 respectively.

From the data in Table 11c it is clear that in the high available phosphorus soil of Boghall the treatments had no influence on the percent dry matter of the tuber. Analysis of/

of the data of the third observation from Barbauchlaw experiment showed that phosphorus as well as nitrogen treatments had shown considerable influence. Each increase in the rate of phosphorus application led to a significant increase in dry matter content of the tuber, except, that P_2 and P_3 showed no such difference.

The higher rate of nitrogen (N_2) proved better than the lower rate (N_1) at the 5% level but showed no interaction with phosphorus treatments

2. Final Yield.

i. Total (Ware + Seed + Chats)

Summary of the data of the effects of treatments on the total yield of tubers are presented in Table 11d (total). Plot wise data and the analysis of variance of these data are shown in Appendices VIIId and VIIIa 4 respectively.

From the data in Table 11d (total), it will be seen that phosphorus treatments showed considerable influence on the total yield at Boghall, as well as at Barbauchlaw. At Boghall - the high available phosphorus soil - it will be noticed that the maximum increase (significant at the 5% level) on yield over the control was obtained with application on only 0.25 cwt. P_2O_5 per acre (P_1), further additions tended to depress the yield. Compared with control both P_2 and P_3 were significantly better. With the highest rate i.e. P_4 the drop in yield compared to P_1 very nearly reached the significance level at 5%. Differences among the fertilizer treatments however were not significant.

In/

In the low available phosphorus soil of Barbauchlaw the results show that maximum yield was obtained with the P_3 treatment i.e. an application of 1.0 cwt. P_2O_5 per acre. Though not significantly the P_4 treatment even here reduced the total yield slightly compared to P_3. Analysis of variance of the data showed that each successive increase in the rate of phosphorus application up to the P_3 level, increased the yield significantly.

Nitrogen treatments alone or in combination with phosphorus showed no effect at Boghall. At Barbauchlaw, however, though nitrogen alone had no effect, it showed significant interaction with phosphorus. The higher rate of nitrogen (N_2) with no phosphorus depressed the yield but each increase in the rate of phosphorus application in combination with N_2 gave a higher yield than with lower rate of nitrogen i.e. N_1.

ii. Ware (above 2¼" mesh riddle)

Data of the effect of treatments on the amount of ware in the total yield are summarized in Table 11d (ware). Plot data and analysis of variance of this data are shown in Appendicies VIIId and VIIIa 4 respectively.

Ware constituted about 75% of the total yield. The effect of phosphorus treatments were more or less the same as shown by total yield. In the soil of high available phosphorus status, phosphorus application at all levels improved the yield compared to control, but among the rates of/

of application there were no significant differences. In fact as in the case of total yield, the quantity of ware decreased steadily up to the highest dressing (P_4) which showed a significant depression in yield when compared with P_1.

At Barbauchlaw too, the effect of phosphorus treatments on the yield of ware was almost similar to their effect on total yield. Each increase up to P_3 produced a highly significant increase in yield compared to control. Among P_1, P_2 and P_3 treatments, though the differences were substantial they just fell short of the 5% level of significance. Similarly, the depression in yield of 1.27 tons per acre from P_4 as compared with P_3 fell short just by 0.03 tons from attaining a significant level.

Application of nitrogen at the N_2 level improved the yield of ware more markedly at Boghall than at Barbauchlaw, though at both places the increases due to the higher rate of application were significant. The increase of 1.07 tons per acre at Boghall due to N_2 treatment was significant at the 1% level while at Barbauchlaw the increase of 0.97 tons was significant at the 5% level. At neither location was interaction between P and N treatments significant. It therefore seems clear that while phosphorus increased the number of tubers, the main effect of nitrogen was to improve the size of the tuber.

iii. <u>Seed (Between 2¼" and 1½" mesh riddle)</u>

Data are summarized in Table 11d (Seed). Plot wise data/

data and analysis of variance of these data are presented in Appendices VIIId and VIIIa 4 respectively.

As might be expected, the Barbauchlaw experiment showed a very pronounced influence of phosphorus treatments. All treatments except P_1 produced a highly significant increase over the control; the increase due to P_1 just failed to achieve significance. Among the treatments, the amount of seed produced increased with the increase in the level of phosphorus application, these differences when compared among alternate treatments i.e. P_1 with P_3 and P_2 with P_4 proved significant at the 1% level. Increase from P_3 to P_4 was also highly significant. On the high available phosphorus soil of Boghall, phosphorus treatments failed to show any significant influence. However the trend of increased production of seed size tubers with increasing rate of phosphorus is quite evident.

As has been pointed out before, nitrogen seems to influence the size of the tuber. This is evident from the Barbauchlaw data where the higher rate of nitrogen decreased the amount of seed size tubers, this reduction of 0.63 tons per acre proved to be highly significant compared to N_1. No effect of nitrogen was shown at Boghall. Interaction between P and N treatment was absent at both locations

iv. Chats (Below $1\frac{1}{4}$" mesh riddle)

A summary of relevant data is given in Table 11d (Chats). Plot wise data and analysis of variance of this data are shown in Appendices VIIId and VIIIa 4 respectively.

The amount of chat size tubers in the total yield was very/

very small. Nevertheless the effect of phosphorus is quite marked in the Barbauchlaw data. Increasing amounts of added phosphorus increased the amount of chats in the produce progressively. This effect is particularly pronounced at highest rate i.e. P_4, when compared even to P_3, the difference almost reached the 1% level of significance. The increase with P_4 treatment was highly significant compared to the rest of the treatments. Even on a soil of high available phosphorus (Boghall) the same trends are clearly seen - but the differences proved statistically nonsignificant.

Nitrogen alone or in combination with phosphorus treatments proved ineffective.

C. Effect of treatments on the uptake of P_2O_5

The uptake of phosphorus by the plant was studied by two methods. Total P_2O_5 (expressed as percentage of the dry matter) was determined by a chemical method described the section on Materials and Methods.

The part of the total P_2O_5 derived from the fertilizer as distinct from that derived from the soil reserves, was determined by the radio chemical technique, using P^{32} tagged superphosphate as a source of phosphorus. It is expressed as a percentage of the total P_2O_5 determined by the chemical method. Data for the total phosphorus in the different parts of the plant are presented first, followed by data for the P_2O_5 derived from the fertilizer.

1. Total/

1. Total P_2O_5

i. Shoot

Data on the effect of treatments on the percentage of P_2O_5 in the shoot at the three observations are summarized in Table 12a. Detailed data and the analysis of variance of these data are presented in Appendices IXa and IXa 1 respectively.

Data in Table 12a show a much higher percentage of P_2O_5 in the shoots from Boghall than from the low available phosphorus soil of Barbauchlaw, at the earliest stage. The differences were reduced considerably at the height of the vegetative growth (second observation) and had practically vanished at maturity.

Since there was comparatively little difference at the first observation in the weight of shoot material at the two locations, the higher uptake of P_2O_5 at Boghall resulted in much higher accumulation of P_2O_5 in the shoot. With the development of the plant, the vegetative parts generally showed an increase according to the amount of available phosphorus, both from the soil and the fertilizer sources and therefore the amount of P_2O_5 in the shoot tended to level off at later stages.

It is also quite evident that at both locations each increase in the rate of phosphorus application led to a distinct increase in the percent of P_2O_5 in the shoot at the first observation. At Barbauchlaw the increase is comparatively more marked and the highest rate (P_4) almost doubled/

Table 12

Summary[1] of results of the effect of treatment on the uptake of P_2O_5 (total and percent of total, derived from fertilizer

	Barbauchlaw										Boghall								
	Treatment					S.E.[3]	Treatment		S.E.[3]		Treatment					S.E.[3]	Treatment		S.E.[3]
Observation	P_0	P_1	P_2	P_3	P_4		N_1	N_2			P_0	P_1	P_2	P_3	P_4		N_1	N_2	
Total P_2O_5 (%)[2]																			
a. Shoot																			
I	0.50	0.60	0.65	0.70	0.98	-	0.67	0.71	-		0.88	1.08	1.22	1.20	1.40	-	1.18	1.19	-
II	0.54	0.40	0.38	0.36	0.45	-	0.40	0.45	-		0.55	0.53	0.61	0.59	0.59	-	0.53	0.63	-
III	0.39	0.28	0.31	0.30	0.32	± 0.024	0.30	0.34	± 0.023		0.36	0.34	0.34	0.35	0.33	N.S.	0.34	0.34	N.S.
b. Root																			
I	0.28	0.35	0.37	0.49	0.81	-	0.42	0.49	-		0.53	0.74	0.76	0.86	1.10	-	0.78	0.81	-
II	0.34	0.27	0.22	0.25	0.38	-	0.29	0.29	-		0.47	0.50	0.50	0.48	0.64	-	0.48	0.55	-
III	0.31	0.23	0.22	0.24	0.26	± 0.023	0.25	0.26	N.S.		0.26	0.26	0.27	0.27	0.29	N.S.	0.25	0.30	± 0.012
c. Tuber																			
I	0.32	0.41	0.45	0.52	0.77	± 0.029	0.49	0.49	N.S.		0.60	0.76	0.85	0.88	0.89	-	0.78	0.80	-
II	0.35	0.29	0.30	0.32	0.40	-	0.34	0.32	-		0.50	0.44	0.47	0.50	0.53	-	0.48	0.50	-
III	0.33	0.28	0.29	0.32	0.35	± 0.015	0.32	0.30	± 0.009		0.39	0.34	0.45	0.49	0.45	± 0.022	0.44	0.44	N.S.
Percent P_2O_5 derived from fertilizer[2]																			
d. Shoot																			
I		45	57	67		± 2.4	55	58	N.S.			25	40	48		± 4.3	41	34	± 3.5
II		26	40	58		-	41	42	-			14	24	40		-	26	26	-
III		19	33	42		± 3.1	31	32	N.S.			11	17	26		± 2.6	16	20	N.S.
e. Root																			
I		35	50	61		± 2.18	47	51	N.S.			19	30	39		± 3.03	31	27	N.S.
II		19	34	48		-	32	34	-			10	20	33		-	21	22	-
III		16	23	33		-	22	26	-			9	14	23		± 1.11	15	16	N.S.
f. Tuber																			
I		43	58	68		± 2.99	55	58	N.S.			21	36	41		± 3.14	34	32	N.S.
II		30	49	64		-	45	50	-			16	29	39		-	30	37	-
III		30	50	62		± 2.58	46	49	N.S.			15	23	37		± 1.66	26	24	N.S.

1. Each mean value is the average of 5 replications. 2. Total P_2O_5 is the percentage of dry matter and the P_2O_5 derived from fertilizer is the percentage of total P_2O_5. 3. S.E. multiplied by 2.030 and 2.724 gives the least significant difference at the 5% level and 1% level respectively. S.E. for tables d, e and f multiplied by 2.086 and 2.845 gives the significant difference at the 5 and 1% level respectively.

doubled the percentage of phosphorus compared to control. Analysis of variance of the data of the third observation showed no effect of the treatments at Boghall, but at Barbauchlaw both phosphorus and nitrogen treatments brought about significant changes. Due to the very poor all round development of the plants in the control plots, the shoot showed, at the final observation, the highest concentration of P_2O_5, the difference being highly significant compared to all other treatments. Though among the treatments the differences failed to reach significant level, it is worth noting that the P_1 treatment, which showed the greatest comparative increase in the vegetative growth with the successive increaments in fertilizer application, showed the lowest P_2O_5 percentage in the shoot tissue.

At the third observation, nitrogen showed no effect, at Boghall, but at Barbauchlaw the higher rate of nitrogen (N_2) significantly improved the percentage of P_2O_5 in the shoot. No interaction between P and N treatments was evident.

ii. Root

The data of the effect of the treatments on the P_2O_5 (%) in the root are summarized in Table 12b. Complete data are given in Appendix IXb and the analysis of variance of the data of third observation in Appendix IXa 2.

From the data in Table 12b, it is evident that the percentage of P_2O_5 in the root followed the same pattern as that in the shoot. The root material from the soil of high available/

available phosphorus (Boghall) showed considerably higher percentage of P_2O_5 at all observations and at all levels of phosphorus treatments. Like the shoot, at first observation, each increase in the phosphorus application increased the P_2O_5 percentage in the root at both locations. Compared to control, the increase due to P_4 treatment amounted to 189 and 104 percent at Barbauchlaw and Boghall respectively. At the height of the vegetative growth these differences in the P_2O_5 due to treatments were reduced considerably, both at Boghall and Barbauchlaw.

Statistical analysis of the data of the final observation showed no significant differences due to the phosphorus treatments at Boghall, but at Barbauchlaw though among the fertilizer treatments there were no significant differences, control showed significantly higher amount of P_2O_5 percentage, than all other treatments.

Nitrogen rates failed to show any effect at Barbauchlaw, but at Boghall N_2 treatments significantly (1% level) improved the percentage of P_2O_5 compared to N_1.

iii. Tuber

Summarized data on the effect of treatments on the total P_2O_5 percentage in tuber are shown in Table 12c. Complete data and the analysis of variance of the first and third observation are given in Appendices IXc and IXa 3.

Like the shoot and root, tubers from the high available phosphorus soil of Boghall showed a higher percentage of

P_2O_5/

P_2O_5 than those from Barbauchlaw. While these differences between the two locations vanished at later stages in shoot and root, they were maintained up to maturity in the tubers. It is also noticeable that at the second and third observations, at both locations, there was a considerable drop in the P_2O_5 content of the tuber with P_1 treatment as compared to control, possibly because of the comparatively large increase in the yield of tubers, due to this (P_1) treatment. After the initial drop due to P_1 treatment, the P_2O_5 content of the tuber then rose steadily and at the highest rate, it was invariably higher than the control. Statistical analysis of the data of the third observation at Barbauchlaw showed a significant increase between alternate fertilizer treatments i.e. P_3 P_1, P_4 P_2. P_4 just failed to be significantly (at the 5% level) better than P_3, but the control was significantly better than P_1 and P_2. At Boghall all treatments markedly improved the P_2O_5 content compared to control, but among the rates of application of phosphorus there was no significant difference.

There was no response to nitrogen at Boghall. At Barbauchlaw the higher rate increased the P_2O_5 percentage, and this difference proved highly significant. No interaction between P and N treatments was shown.

2. <u>P_2O_5 derived from fertilizer.</u>

For the study of the uptake of P_2O_5 derived from P^{32} tagged superphosphate, the phosphorus treatments were limited to/

to three levels, (P_1, P_2 and P_3). Nitrogen treatments were the same. Plant samples from individual plots were analysed for first and third sampling. Second observation values are from composite sample from 5 replications.

Shoot

The data of the effect of the treatments on the uptake of P_2O_5 by shoot, root and tuber (expressed here as percentage of the total P_2O_5) from the fertilizer at the three observations are summarized in Table 12d, e and f respectively.

From the data of these tables the following points stand out clearly. Firstly, there was a much greater proportion of fertilizer phosphorus taken up by the plant in the soil of low available phosphorus (Barbauchlaw) than from soil already high in available phosphorus (Boghall). The magnitude of this increase varied between 50 to 100% under the same treatments, at the two locations.

Secondly each increase in the rate of application of phosphorus, invariably increased the percentage of P_2O_5 derived from fertilizer. This percentage increase was always less between P_2 and P_3 than between P_1 and P_2.

Thirdly the application of nitrogen at the two levels used in this experiment i.e. 2.5 and 5.0 cwt. ammonium sulphate per acre, showed practically no influence, on the utilization of fertilizer phosphorus at any stage of plant or tuber development except in the case of shoot, at Boghall, at the first observation.

i. Shoot/

i. Shoot

Relevant data are summzrized in Table 12d. Complete data for first and third observation and analysis of variance of these data are given in Appendices IXc and IXa 4 respectively.

Analysis of variance of the data of first observatimn showed that even in soil of high phosphorus status (Boghall), phosphorus treatments exerted a marked influence, on the utilization of applied phosphorus. Each increase in the rate of phosphorus application, increased the percentage of phosphorus derived from the fertilizer highly significantly. While the increase from P_1 to P_2 rate of fertilizer application was 64%, doubling of P_2 rate i.e. from 0.5 to 1.0 cwt P_2O_5 per acre (P_3) resulted in a further increase of only 20%. At the second observation the percentage of fertilizer derived P_2O_5 in the shoot tissue dropped almostto half at the two lower rates of application (P_1 and P_2), but at the P_3 rate the drop was only slight. As the growth progressed the percentage of fertilizer derived phosphorus decreased till at maturity (third observation), it was less than half compared to the first observation at the two lower rates of fertilizer application i.e. P_1 and P_2. The differences between each increasing treatment effects, at the third observation, were still, highly significant.

At Barbauchlaw as far as effects of phosphorus were concerned, they were similar to Boghall results, but the magnitude of differences due to treatments varied. For example/

example at the first observation while at Boghall the uptake of fertilizer phosphorus dropped from 64% between P_1 and P_2 to 20% between P_2 and P_3, corresponding comparisons for Barbauchlaw show a drop from 27 to 18% only. Analysis of variance of the data of first and third observation showed that at both stages each increment in the rate of phosphorus application increased the amount of P_2O_5 derived from fertilizer - these differences being significant at the 1% level.

Nitrogen alone or in combination with phosphorus treatments failed to show any effect.

ii. Root

The data of the effect of treatments are summarized in Table 12e. Complete data for first and third observation for Boghall, and first observation for Barbauchlaw are given in Appendix IXe. Analysis of variance of the data of Appendix IXe is given in Appendix IXa 5.

From the data of Table 12e it will be seen that treatment effects produced results similar to those for the shoot, except that, at all observations and at both locations the percentage of phosphorus derived from fertilizer was lower than that in the shoot.

Analysis of variance of the data of first and third observation of Boghall and first observation of Barbauchlaw showed the same results as in case of shoot, that is successive increases in the rate of phosphorus application led to progressive and highly significant increases in the percentage/

percentage of phosphorus derived from fertilizer.

The two rates of nitrogen application singly or in combination with phosphorus treatments failed to show any effect in soil of high available phosphorus (Boghall). At Barbauchlaw, the higher rate of nitrogen increased the percentage of fertilizer derived phosphorus from 46.7 to 50.5, this difference was significant at the 5% level. No interaction between phosphorus and nitrogen treatments was shown.

iii. Tuber

Relevant data are summarized in Table 12f. Plot data of the first and third observation and analysis of variance of these data are presented in Appendices IXf and IXa 6 respectively.

From the data of Table 12f it is clear that the effect of treatments is similar to that on shoot and root. Each increase in the rate of fertilizer application invariably increased the percentage of fertilizer derived phosphorus in the tuber. It will also be observed, that compared to shoot and root, tubers showed comparatively very small decreases in the percentage of fertilizer derived phosphorus at the later stages; particularly between second and third observations.

Statistical analysis of the data of first and third observations, at both locations again showed a highly significant increase with each increment in the rate of application of fertilizer.

Nitrogen rates alone or in combination with phosphorus treatments showed no influence on the percentage of phosphorus derived from fertilizer.

II. "Phosphorus from different fertilizer materials" experiment

In this section, the data and the main results of a single experiment, conducted with the potato crop on a soil of low available phosphorus status at Barbauchlaw, are reported. Treatments included, A, control; B, 0.33 and C, 0.66 cwt. P_2O_5 per acre from superphosphate; D and E, coarsely ground (100 mesh) and finely ground (300 mesh). Gafsa mineral phosphate; and F, dicalcium phosphate, each at the equivalent of 0.50 cwt. P_2O_5 per acre. For comparisons of superphosphate with other fertilizers on an equal P_2O_5 basis, the mean of B and C treatments was taken - though it is realized that this procedure is not always strictly accurate.

1. Effect of treatments on the development of the plant

Population and number of sprouts per plant may be taken as a reasonable indication of the effect - harmful or beneficial - of the treatments on the development of the young plant from the mother tuber. In this experiment, neither the population (Table 13a) nor the number of sprouts per plant (Table 13b) showed any marked variations, indicating thereby that treatments exerted no influence on the normal development of the mother tuber into a plant. Population was constant around about 19,000 plants per acre and number of sprouts averaged 2 per plant (range 1.9 to 2.1).

Height, considered along with the fresh weight of the shoot provides a good measure of the extent of the development/

Table 13

Summary[1] of the data on the effect of treatments on plant development

Observation	Treatments A	B	C	D	E	F	S.E.[2]
a. Population (30 sq. yd.)							
	118	119	119	117	118	120	
b. Number of sprouts per hill							
	2.0	1.9	1.9	2.2	2.1	1.9	
c. Height (cm.)[3]							
I	18	33	35	29	27	39	-
II	37	51	56	43	45	52	-
III	40	52	58	46	47	56	± 2.5
d. Shoot fresh weight (g/plant)[3]							
I	36	132	161	62	78	167	-
II	82	160	258	96	127	213	±19.0
III	64	79	135	88	102	110	-
e. Shoot dry matter (%)							
I	18.0	13.3	12.3	16.3	14.3	12.7	-
II	13.7	12.6	11.6	13.3	13.7	11.6	± 0.25
III	17.9	21.4	20.8	18.5	19.6	20.6	-
f. Root fresh weight (g/plant)							
I	7.4	11.2	14.2	6.5	7.6	12.2	-
II	12.2	15.4	20.8	11.8	14.2	19.8	± 2.8
III	11.0	12.2	13.4	10.8	11.0	12.0	-
g. Root dry matter (%)							
I	30.6	22.3	20.8	32.3	29.8	20.3	-
II	17.2	16.8	16.1	17.5	19.4	17.2	N.S.
III	21.6	24.7	29.2	23.6	25.9	24.8	-

1. Each mean value is the average of 5 replications.
2. S.E. multiplied by 2.086 and 2.845 give significant difference at the 5% and 1% level respectively.
3. Figures rounded off to nearest whole number.

development of the plant, once it has established itself in the soil. In this experiment the influence of the treatments on the height of the shoot was clearly shown even at the first observation (Table 13c). Plants from the control plots (treatment A) showed less than half the height of that induced by Dicalcium phosphate (treatment F). Superphosphate (mean B and C) was only very slightly less effective than dicalcium phosphate, but Gafsa mineral phosphate (D and E treatments) proved much inferior. The increase in height over the control induced by the less readily available phosphorus from Gafsa mineral phosphate was only about 50% of that induced by Dicalcium phosphate. Neither was there any marked visual difference due to the fineness of grinding of the Gafsa mineral phosphate. More or less the same relative positions, as far as the height of the shoot was concerned, were maintained by the different treatments throughout the life of the plant. Statistical analysis (Appendix Xa 3) of the data of the final observation (Appendix Xc) when the plants had attained their maximum height, showed that the effect of superphosphate (mean B and C) and Dicalcium phosphate (F) in inducing a greater height of the shoot was highly significant, as compared to the control and both treatments of Gafsa mineral phosphate (D and E). In turn the application of both the grades of Gafsa mineral phosphate did help the plant to attain a significantly greater height than the control. The differences between superphosphate and dicalcium phosphate proved nonsignificant.

Superiority/

Superiority of superphosphate and dicalcium phosphate as vegetative growth promoters was further evident from the fresh weight of the shoot data, summarized in Table 13d. The relative positions of the effect of treatments at the second observation was almost the same as shown by final height data. Both superphosphate and dicalcium phosphate produced significantly (1% level) greater weight per plant than did Gafsa mineral phosphate (treatments D and E), and the control, but there was no significant difference in the weight per plant from the superphosphate (mean B and C) and dicalcium phosphate (F) treated plots. Although the fineness of grinding of Gafsa mineral phosphate had shown practically no effect on the height of the plant, finely ground material proved more effective in increasing the weight of the shoot per plant.

Compared to control,E treatment (finely ground Gafsa mineral phosphate) gave a significant increase at the 5% level, while the coarsely ground product (D) failed to achieve significance.

Weights recorded at the final observation though showing similar trends to the ones described above for second observation, were misleading as indicative of treatment effects on vegetative growth. In fact, in a rough way, the data of the third observation reflected the effect of treatments in inducing early maturity of the vegetative parts. For example, while the fresh weight of the plants from superphosphate and dicalcium phosphate treated plots showed a drop/

drop in weight of almost 50% from the second to the third observation, the corresponding decrease in weight per plant from the control and Gafsa mineral treated plots is only between 10 to 20%. This effect of superphosphate and dicalcium phosphate in inducing early maturity of shoot, was also observed visually in the field and is further reflected in the third observation of % dry matter data, a summary of which is presented in Table 13c. Plot wise data and analysis of variance of the data of the second observation are shown in Appendices Xe and Xa 5 respectively. From the data in table 13e it will be seen that at the first and second observation superphosphate and dicalcium phosphate treatments showed a lower percentage of dry matter than the control or the Gafsa mineral phosphate, but at the final observation the position is reversed - due, as has been said before, to the effect of superphosphate and dicalcium phosphate in inducing early maturity of the shoot.

Analysis of variance of % dry matter at the second observation showed a significantly lower value for plants receiving dicalcium phosphate and superphosphate as sources of phosphorus than other treatments. Comparison between superphosphate and dicalcium phosphate showed that the former produced just significantly higher dry weight than the latter. Differences between other treatments were not significant.

The effect of treatments on root development follows a similar/

similar pattern to that of shoot (Table 13f). Superiority of superphosphate and dicalcium phosphate over Gafsa mineral phosphate is clearly evident at all the three observations. For example at the first observation treatment D produced only about half the weight of root compared to superphosphate and dicalcium phosphate. Slight superiority due to fineness of grinding of Gafsa mineral phosphate, at all the three observations was also evident though these differences between D and E treatments never reached a significant level. At the height of root development i.e. second observation analysis of variance (Appendix Xa 6), of the plot data (Appendix Xf) showed superphosphate and dicalcium phosphate to be significantly superior to treatments A and D.

At the first observation of the roots there was a considerably higher dry matter percentage in treatments which produced smaller amounts of fresh root i.e. treatments, A, D and E. These differences narrowed down considerably at the second observation. Analysis of variance of the data at this stage (second observation) showed no statistical significance between the treatment effects.

2. Effect of treatments on tuber development

The effect of readily available phosphorus in inducing greater numbers of tubers per plant in clearly seen from the summary of data of the effect of treatments on the number of tubers per plant in Table 14a. Both the control and the Gafsa mineral phosphate produced smaller numbers of tubers per plant/

Table 14

Summary[1] of the data on the effect of treatments on the tuber development and final yield

Observation	A	B	C	D	E	F	S.E.[2]
			a. Number per plant				
I	5.6	7.6	8.6	5.0	5.6	6.0	N.S.
II	5.4	6.6	9.0	5.2	6.4	10.0	-
III	5.8	6.4	8.6	5.6	6.0	7.8	N.S.
			b. Fresh Weight (g/plant)[3]				
I	59	110	120	63	190	129	-
II	195	381	571	267	281	474	-
III	405	638	897	666	741	837	± 151
			c. Dry weight (%)				
I	18.2	17.9	17.6	18.9	17.9	17.8	-
II	20.5	21.0	20.9	20.0	18.5	21.1	-
III	20.6	21.6	22.1	21.4	22.1	22.0	N.S.
			d. Total yield (tons/ac.)				
	8.5	13.0	13.8	10.4	10.7	14.1	± 0.81
			e. Ware (tons/ac.)				
	4.3	9.3	9.9	6.7	7.5	11.0	± 0.69
			f. Seed (tons/ac.)				
	4.1	3.7	3.8	3.4	3.1	3.5	N.S.
			g. Chats (tons/ac.)				
	0.06	0.06	0.12	0.06	0.07	0.06	N.S.

1. Each mean value is the average of 5 replications.
2. S.E. multiplied by 2.086 and 2.845 gives significant difference at the 5% and 1% level respectively.
3. Figures rounded off to nearest whole number.

plant than the superphosphate and dicalcium phosphate, at all the three observations, but the differences are particularly pronounced at the second observation. Analysis of variance of the first and third observations however showed that these differences failed to reach significant level.

Very marked superiority of readily available phosphorus from superphosphate and dicalcium phosphate in increasing the weight of tubers per plant, as compared to Gafsa mineral phosphate and control is further evident in the data of Table 14b. Even at the earliest stage dicalcium phosphate more than doubled the weight of tubers as compared to control or coarsely ground Gafsa mineral phosphate; a slightly less marked increase was shown by superphosphate. Althougth the increase due to fineness of grinding of Gafsa mineral phosphate (E) at no stage proved large enough to be significant compared to D treatment (coarsely ground Gafsa mineral phosphate), it is however noteworthy that E treatment at all three observations increased the weight of tubers compared to treatment D. Statistical analysis of the data of the third observation (Appendix Xlb) showed that all treatments except D, increased the weight of tubers produced per plant significantly compared to control. The differences among the fertilizer treatments though quite marked, failed to reach significant level.

At all three observations, treatments showed very little influence on the percent dry matter in the tuber (Table 14c).

Statistical/

Statistical analysis of the data of the third observation showed no significant difference due to effect of the treatments.

Total yield (Ware + Seed + Chats)

A summary of the data on the effect of treatments on the total yield is given in Table 14d. Complete data and the analysis of variance of this data are presented in Appendices XId and XIa 4.

It is evident from the data in Table 14d that the application of phosphorus, irrespective of the source from which it is supplied, greatly improved the yield on this soil of low available phosphorus. As might be expected, Gafsa mineral phosphate (treatments D and E) proved less effective than either superphosphate or dicalcium phosphate. Statistical analysis showed that all treatments produced significant increases in yield over the control. While the differences between control on the one hand and the two Gafsa mineral phosphate treatments on the other were significant at the 5% level, the increases over the control due to superphosphate (mean of B and C) and dicalcium phosphate were significant at the 1% level. Comparisons among the treatments revealed that compared to the two Gafsa mineral phosphate treatments, superphosphate as well as dicalcium phosphate produced highly significant increases in yield. Although dicalcium phosphate showed an increase of about 0.7 tons of tubers per acre compared to superphosphate, this difference was not significant.

Ware/

Ware sized tubers contributed well over 50% to the total yield, and the effect of treatments are very similar to the effects on the total yield. For example the application of phosphorus, irrespective of the source, improved the yield of the total amount of ware; the differences being significant at the 1% level. Again superphosphate and dicalcium phosphate proved far superior (significant at the 1% level) in increasing the yield of ware compared with Gafsa mineral phosphate (D and E). As for the total yield, dicalcium phosphate produced a higher yield of ware than superphosphate, but the difference just failed to reach significance at the 5% level.

The percentage weight of seed in the total yield varied greatly the range being almost 50% in case of control to less than 25% with dicalcium phosphate. The largest amount of seed tubers was produced in the control and the least by finely ground Gafsa mineral phosphate, but none of the differences was significant.

A very small quantity of chats was produced in the experiment as a whole and the mean yields showed very little variation due to treatments, except superphosphate, which showed a marked increase over the other treatments. No significant differences were produced.

3. Effect of treatments on the uptake of P_2O_5

The study of the effect of treatments on the percentage of phosphorus in the plant at different stages was limited to chemical/

Table 15

Summary[1] of the data on the effect of treatments on the uptake of P_2O_5

Observation	A	B	C	D	E	F	S.E.[2]
	a. Shoot						
I	0.48	0.79	0.83	0.66	0.66	0.87	-
II	0.58	0.45	0.44	0.51	0.48	0.48	-
III	0.44	0.34	0.33	0.39	0.37	0.35	± 0.026
	b. Root						
I	0.28	0.50	0.62	0.36	0.40	0.64	-
II	0.66	0.31	0.33	0.38	0.30	0.30	-
III	0.34	0.28	0.29	0.31	0.30	0.30	± 0.018
	c. Tuber						
I	0.32	0.48	0.59	0.36	0.40	0.57	-
II	0.34	0.29	0.33	0.34	0.32	0.31	-
III	0.35	0.31	0.32	0.35	0.28	0.28	± 0.018

1. I and II from composite sample, II mean of 5 replications.
2. S.E. multiplied by 2.086 and 2.845 gives significant difference at the 5 and 1% level respectively.

chemical analysis for total P_2O_5 in composite samples from five replications at the first and second observations. Shoot, root and tuber samples for each plot were analysed individually only for the final observation. Summarized data are presented in Table 15a, b and c. Plot wise data for the third observation and analysis of variance of these data are given in Appendices XIIa, b and c and XIIa. 1, 2 and 3 respectively.

From the data for the first observation in Table 15a it is clear that different fertilizer materials exerted, at a very early stage, strong influences on the percentage of P_2O_5 in the shoot. From the two readily available sources of phosphorus i.e. superphosphate and dicalcium phosphate, the P_2O_5 content of the shoot tissue was 68 and 81% higher respectively than from the control. While the increase in the percentage P_2O_5 due to the application of phosphorus from less readily available source, i.e. Gafsa mineral phosphate, amounted to only about 38% compared to control. As is apparent from the data of the first observation (Table 15a) both superphosphate and dicalcium phosphate improved the P_2O_5 percentage in the shoot quite considerably compared with the two Gafsa mineral phosphate treatments and control. The differences among the treatment effects more or less disappeared by the time second observation was taken. It is further noticeable that the drop is more marked in the superphosphate and dicalcium phosphate treatments than in the Gafsa mineral phosphate treatments, which invariably showed the/

the poorest all round development of the plant as well as tubers among the fertilizer treatments. Statistical analysis of the data from the third observation showed a development of the trends shown in the second observation, that is lesser percentage of P_2O_5 under treatments which improved the growth better than others. At the final stage, therefore, the control showed a significantly higher percentage of P_2O_5 in the shoot than the treated plots except for D treatment. Among the other comparisons, the D treatment showed a significantly higher amount than the superphosphate treated plots.

The effect of treatments on the amount of P_2O_5 in the root Table 14b follows a pattern more or less similar to that for the shoot. For instance at the first observation the application of superphosphate and dicalcium phosphate showed 100% and 129% increases respectively compared to control. Very much lower percentages of P_2O_5 in the tissue are also noticeable from the Gafsa mineral phosphate treated plots compared to superphosphate and dicalcium phosphate. Again like the shoot, at the second observation, while the root material from fertilizer treated plots showed a decrease in the percentage P_2O_5, the control showed considerable increase. The decrease in the P_2O_5 (%) was much greater under superphosphate and dicalcium phosphate, which induced greater development of the plant. Statistical analysis of the data of the third observation (Appendix XIIb) showed a significantly higher amount of P_2O_5 in the control than in any/

any other treatment except treatment D. Neither among the two treatments of Gafsa mineral phosphate nor between treatments E, F and mean B and C were the differences significant.

At the first observation, except for the control the percentage of P_2O_5 in the tuber was very nearly the same as in the root tissue (Table 15c). Tubers from superphosphate and dicalcium treated plots had higher percentages of P_2O_5 than the other treatments. The drop in P_2O_5 percentage from first to second observation is very nearly of the same order as in the root, except that the control did not show a very marked increase as in the case of the root.

Statistical analysis of the data of the third observation (Appendix XIIa 3) showed that the P_2O_5 percentage in the tuber from the treatments A and D was significantly higher than from E and F at the 1% level and higher at the 5% level from plots receiving superphosphate (mean B and C). Other comparisons proved to be nonsignificant.

III. Greenhouse Experiments

The data and results of two subsidiary pot experiments conducted in the greenhouse at Boghall, with oats as the crop, are presented in this section. Soils for these experiments were obtained from the sites of the field experiments with the potato crops at Boghall and Barbauchlaw. Details of procedures used in conducting these experiments have already been/

been given in "Methods and Material" section, but for convenience the treatments are again mentioned. They included, in addition to control, phosphorus from radioactive superphosphate at three levels - P_1, P_2 and P_3 equivalent to 40, 80 and 160 lb. P_2O_5 per acre respectively. Nitrogen, in addition to control, was applied in all combinations with phosphorus treatments at 40 and 80 lb. N per acre as ammonium sulphate.

On account of the large number of samples analysed by chemical and "radio chemical" methods from the field experiments with potatoes, it was found possible to analyse only composite samples from 5 replications both for total P_2O_5 (by chemical method) and percentage of phosphorus derived from fertilizer (by radio chemical method).

1. Effect of treatments on the plant development and uptake of P_2O_5

a. Fresh weight

The data are summarized in Table 16a. Complete data and analysis of variance of these data are presented in Appendix XIIIa and XIIIa 1 respectively.

The data in Table 16a show that both phosphorus and nitrogen treatments exerted a marked influence on the growth of the plant in the low available phosphorus soil of Barbauchlaw. In the soil, already high in available phosphorus, from Boghall, phosphorus treatments failed to show/

Table 16

Summary[1] of the data of the effect of treatments on the plant development and uptake of P_2O_5 - Oats

	Barbauchlaw									Boghall								
	Treatments				S.E.[2]	Treatments			S.E.[2]	Treatments				S.E.[2]	Treatments			S.E.[2]
Observation	P_0	P_1	P_2	P_3		N_0	N_1	N_2		P_0	P_1	P_2	P_3		N_0	N_1	N_2	
								a. Fresh weight (g/10 plants)										
								Shoot										
I	7.3	8.2	8.9	9.6	± 0.34	8.5	8.3	8.8	N.S.	9.5	9.9	10.2	10.7	± 0.13	9.6	10.1	10.6	± 0.11
II	16.5	15.8	16.6	17.8	N.S.	14.3	17.2	18.3	± 0.41	19.7	21.3	20.6	21.1	N.S.	19.1	21.0	22.9	± 0.7
III	13.0	14.2	14.5	14.9	± 0.5	13.3	14.0	15.3	± 0.85	23.4	22.9	22.9	23.7	N.S.	20.3	23.9	26.8	± 1.3
								b. Dry matter (%)										
I	13.2	13.6	13.5	14.1	N.S.	13.4	13.6	13.8	N.S.	12.0	11.8	11.7	12.6	N.S.	12.1	12.0	12.0	N.S.
II	17.8	18.9	19.3	20.5	± 1.3	19.5	19.1	18.8	N.S.	17.6	18.2	18.2	18.6	N.S.	18.4	18.5	17.6	± 0.35
III	34.6	34.4	35.3	34.3	N.S.	31.4	35.5	34.9	± 0.42	32.2	32.5	32.0	32.0	N.S.	31.6	32.1	33.8	± 0.43
								c. Total P_2O_5 (%)										
I	0.46	0.42	0.47	0.59		0.52	0.50	0.46		0.70	0.67	0.73	0.89	-	0.81	0.71	0.73	
II	0.45	0.39	0.39	0.42		0.43	0.40	0.41		0.52	0.49	0.51	0.63		0.63	0.51	0.48	
III	0.15	0.12	0.14	0.15		0.19	0.12	0.11		0.24	0.22	0.25	0.38		0.45	0.23	0.15	
								d. P_2O_5 derived from fertilizer (% of total)										
I	-	12.6	27.4	41.1		26.4	27.9	26.7		-	9.7	18.2	20.5		14.4	16.8	17.1	
II	-	10.4	21.7	39.4		22.9	23.6	25.2		-	4.9	8.4	10.6		7.9	8.0	8.0	
III	-	8.0	13.5	25.5		14.7	16.0	16.3		-	7.1	14.2	15.1		10.6	13.0	13.0	

1. Each mean value is the average of 5 replications.
2. S.E. multiplied by 2.014 and 2.690 gives significant difference at the 5 and 1% level respectively.

show any significant effect, except at the earliest stage, but nitrogen proved very effective.

At the first observation, when the plants were 8-10 inches high, increase in phosphorus application increased significantly the fresh weight of the plant in both soils. The effect was more marked in the Barbauchlaw soil than in that from Boghall. For example the percentage increase, with P_3 treatment compared to control was 32% and 12% for soils from Barbauchlaw and Boghall respectively. Nitrogen at this stage proved ineffective in the Barbauchlaw soil but in Boghall soil the weight of the plant was increased significantly with each increase in the rate of application.

At the height of vegetative growth of the plant (second observation), the effect of phosphorus treatments was considerably reduced and though plants receiving fertilizer still showed greater weight than the control, these differences failed to reach the 5% significant level. The influence of nitrogen was very prominent at this stage in both soils. Each increase in nitrogen application led to a highly significant increase in the weight of the plant in both soils.

At maturity (third observation), the weight of plants varied very little in the Boghall soil, but in the Barbauchlaw soil there was a significant increase over control due to all phosphate treatments but among the fertilizer treatments the differences failed to reach a significant level. Nitrogen continued to show its effect at both/

both locations. In the Boghall soil, 40 lb. N per acre rate (N_1) showed a highly significant increase over the control while the increase from N_1 to N_2 was significant at the 5% level. In the soil from Barbauchlaw, the N_2 treatment gave a significant increase over the control but the differences between control and N_1 and between N_1 and N_2 failed to reach significant level.

b. Dry matter (%)

The data are summarized in Table 16b. Complete data and the analysis of variance of the data are presented in Appendices XIIIb and XIIIa 2 respectively.

It will be seen from the data in Table 16b that phosphorus showed very little influence on the percentage of dry matter in the plant in soils from either location. The only time it showed any significant influence was in the Barbauchlaw soil at the height of the vegetative growth of the plant (second observation). At that stage, only the difference between the control and the highest rate of phosphorus application (P_3) reached a significant level; other comparisons showed no statistical differences.

Nitrogen proved to be relatively more effective than phosphorus. Though at the first observation no significant effects were shown, at the second observation in the Boghall soils, the higher rate of nitrogen (N_2) caused a depression in dry matter percentage, significant at the 5% level, compared to the control and N_1 treatment. This position was reversed at the third observation when the highest rate gave a significantly/

significantly higher percentage of dry matter than N_0 or N_1 treatments. In the Barbauchlaw soil at the third observation, both N_1 and N_2 rates of application increased the dry matter percentage highly significantly compared to control, but between the two nitrogen treatments the difference was not statistically significant.

c. Uptake of P_2O_5 (%)

The data on the effect of treatments on the uptake of total P_2O_5 (expressed as percentage of dry matter) by the plant at the three observations are summarized in Table 16c. Complete data are presented in Appendix XIIIc.

Data in Table 16c show that at all three stages and at all levels of phosphorus and nitrogen treatments, plants in the Boghall soil had 25 to 50% more P_2O_5 than those grown under the same treatments in the soil from Barbauchlaw. Another striking feature which the data in Table 16c show, was that the lowest phosphorus treatment (P_1), and both rates of nitrogen invariably recorded, in soils from both locations, a lower percentage of P_2O_5 than the control. Among the phosphorus treatments at both locations increases in the rate of application improved the percentage of P_2O_5 in the shoot. The magnitude of this increase was generally greater between treatments P_2 and P_3 than between P_1 and P_2. Between the two nitrogen rates, though differences occurred, the variation was very small compared to that between phosphorus treatments. Further, it will be seen from this table (16c) that the percentage/

percentage of P_2O_5 in the shoot decreased with age, but the extent of the decrease was much greater between the second and third observations - the period of grain formation - than between the first and second observations - vegetative growth period of the plant. The shoot at maturity contained only between a third to one quarter of the amount of P_2O_5 shown at the first observation.

d. Percent P_2O_5 derived from fertilizer.

The data on the effect of the treatments on the percentage of P_2O_5 derived from fertilizer are summarized in Table 16d. Complete data are given in Appendix XIIId.

From the data in Table 16d it is clear that the plants derived a much higher percentage of their total phosphorus from the fertilizer in the soil of low available phosphorus (Barbauchlaw) than in the soil already high in available phosphorus (Boghall). Again, irrespective of the soil available phosphorus, each increase in the rate of fertilizer application - both phosphorus and nitrogen - invariably led to an increase in fertilizer phosphorus uptake. Another feature which the data in Table 16d show was that the first increment in the application of phosphorus i.e. from P_1 to P_2 (40 to 80 lb. P_2O_5 per acre), gave, for both soils and at all three observations, an increase of about 100% in the percentage of fertilizer - derived P_2O_5. But further doubling of the rate of application from 80 lb. to 160 lb. P_2O_5 per acre (P_2 to P_3), considerably reduced the response in the Boghall soil compared to that in the Barbauchlaw soil. Another/

Another very prominent feature of the pattern of the uptake of fertilizer phosphorus in the two soils was that the drop in the amount of P_2O_5 derived from fertilizer between the first and second observations was less than 20% in the soil from Barbauchlaw, whilst the reduction was almost to half in the soil from Boghall. Comparison between second and third observations revealed that at Barbauchlaw the fertilizer derived P_2O_5 dropped further varying from 17% in treatment P_1 to about 36% in treatments P_2 and P_3, but the Boghall data showed an increase ranging between 40 to 70% in the percentage of P_2O_5 derived from fertilizer.

More or less similar trends were shown by the nitrogen treatments, though the magnitude of difference between the treatment effects was much smaller.

2. Effect of treatments on the grain weight and uptake of P_2O_5

a. Fresh weight

Data on the effect of treatments on the fresh weight of grain are summarized in Table 17a. Complete data are given in Appendix IXa.

The data in Table 17a show that except for a slight increase with P_1 treatment (40 lb. P_2O_5 per acre), in Barbauchlaw soil, compared to the control, the increasing rate of application of phosphorus decreased the fresh weight of the grain in both soils. In comparison with the control, the yield obtained with the highest rate, i.e. P_3, showed a depression/

Table 17

Summary of the data of the effect of treatment on grain weight and uptake of P_2O_5 - Oats

	Barbauchlaw Soils							Boghall Soil						
	Treatments							Treatments						
	P_0	P_1	P_2	P_3	N_0	N_1	N_2	P_0	P_1	P_2	P_3	N_0	N_1	N_2
a. Weight (gm./10 plants)														
Fresh weight (g/10 plants)	23.1	23.5	21.1	21.2	19.2	23.9	23.6	22.7	21.4	21.3	19.1	16.9	20.2	26.3
b. Dry weight (%)														
Dry weight (%)	89.0	89.1	89.6	89.4	89.4	89.1	89.3	87.9	88.0	88.2	88.6	88.0	88.1	88.4
c. Total P_2O_5 (%)														
Total P_2O_5 (%D.M.)	1.10	1.06	1.12	1.13	1.13	1.09	1.09	1.19	1.18	1.16	1.22	1.22	1.19	1.16
d. Percent P_2O_5 derived from fertilizer														
P_2O_5 derived from fertilizer (% of total P_2O_5)	-	7.4	14.3	28.3	16.5	16.9	16.4	-	7.07	14.0	15.2	10.3	13.0	12.9

depression of 8% in Barbauchlaw soil and almost double this amount (15.8%) in Boghall soil. Application of nitrogen on the other hand showed a markedly beneficial effect on the grain yield in both soils. Compared to control the N_1 treatment improved the yield by 24% and 20% in Barbauchlaw and Boghall soils respectively. Doubling the nitrogen rate, i.e. N_2, made no difference at Barbauchlaw, but in Boghall soil it increased the yield by a further 30%. From these data it appears that under greenhouse conditions, in both these soils, the requirements of phosphorus for a grain crop like oats, were fully met, by the available phosphorus already in the soil, but the yield of the grain greatly benefited by the application of nitrogen.

b. Dry matter (%)

Neither phosphorus nor nitrogen treatments produced an effect on the dry matter percentage of the grain (Table 17b). A slightly higher dry matter content in the grain was shown by the Barbauchlaw soil than the grain from the crop grown in soil from Boghall.

c. Total P_2O_5 %

Data are summarized in Table 17c and complete data are shown in Appendix IXb.

The percentage of total P_2O_5 in the grain did not show any great variations due to treatments. Like the shoot data, there was a trend in both soils for the P_2O_5 percentage to fall slightly with the P_1 treatment, compared to control;

but/

but then rise with P_2 and P_3 treatments. P_3 treatment, showed the highest percentage in the grain. On the other hand, each increase in nitrogen rate produced a slight decline in the P_2O_5 percentage.

d. Percent P_2O_5 derived from fertilizer.

Summarized data are presented in Table 17d and complete data are given in Appendix IXd.

In contrast to total P_2O_5, the percentage derived from fertilizer showed a very pronounced influence of phosphorus treatments and very little of nitrogen application.

In the low available phosphorus soil from Barbauchlaw each increase in the rate of phosphorus application led to a proportional increase in the percentage of fertilizer derived P_2O_5. The highest rate of phosphorus application i.e. P_3, compared to P_1, increased the percentage of P_2O_5 from 7.4% to 28.3% - almost 300% increase - the same as the increase in the rate of fertilizer application i.e. 40 to 160 lb. P_2O_5 per acre. In the soil already high in available phosphorus the doubling (P_2) of the lowest rate (P_1) led to 100% increase, but when the P_2 rate of application was further doubled to P_3 rate i.e. from 80 lb. P_2O_5 per acre to 160 lb., the increase in the uptake of fertilizer derived P_2O_5 was only 9%.

Nitrogen treatment though they produced no marked differences, did show its influence more in the Boghall soil than in the Barbauchlaw soil - N_1 rate increased the percentage of fertilizer derived phosphorus by about 26%, but further increase to N_2 rate produced no effect.

V. DISCUSSION

Without phosphorus, the present high level of crop yields in agriculturally advanced countries is inconceivable. It is this realization of the essential role of phosphorus in crop production which has led,in the last half a century,to the vast expansion in the programme of research carried out in the field of phosphorus nutrition of crop plants and a simultaneous rapid expansion in the use of phosphatic fertilizers. The increase in the use of phosphatic fertilizers had been particularly large in the last 10-15 years. For example, the consumption in the United States between 1940 and 1955 increased more than 2½ times while Stewart (1952) estimates that the British farmer is using 50% more phosphatic fertilizer now than in prewar years.

This rapid increase in consumption inevitably led to the indiscrimate use of fertilizers by some sections of the farming community - as a means of getting higher and higher yields. While there is no doubt that many farmers are not using enough phosphate to get maximum return quite a few are using what has come to be known as "luxury dressings", year after year,without due regard to the economics of the practice. As generally only 10-20 percent of the applied phosphorus is recovered by the crop in the first year, and the rest is slowly fixed in the soil in less readily available forms, it is evident that heavy dressings of phosphatic fertilizers applied over a number of years would inevitably/

inevitably lead to large accumulations of phosphorus in the soils, only a small fraction of which would be available to plants - a very uneconomic way of supplying phosphorus to the plant.

This injudicious use of limited phosphate reserves has in recent years attracted the attention of agricultural research workers. Before the farmer can be persuaded to put his phosphate manuring schedule on a sounder economic basis, it would be necessary to have many more experimental data than are available at present, on the utilization of applied phosphorus by crops grown on soils of different available phosphorus status. This study was undertaken with the above object in view.

The data and results of 7 field experiments with the potato crop and 2 greenhouse experiments with oats have been presented in the previous section. The salient findings are discussed below.

Effect of treatments on the plant development.

Plant growth is governed by numerous environmental and nutritional factors. If one or other of these factors is lacking or inadequate, the result is reflected in the poor growth of the plant. The purpose of manuring is to provide as far as is possible, the optimum plant growth under any given set of environmental and soil conditions. Obviously, the reactions of the plant to any additions of fertilizers will/

will depend largely on the degree of availability of that particular nutrient already present in the soil. This is amply borne out from the data presented in Tables 5 and 10, on the effect of additions of phosphorus to two types of soils - one high in available phosphorus and the others deficient in this nutrient.

From the data in these tables from the three trials on "good" soils (high available phosphorus) (Shawfair and Dryden in 1954 and Boghall in 1955) it is quite evident that additions of phosphorus generally showed no effect as far as the growth of the plant was concerned. Slight initial advantages of the placed easily available phosphorus at the earlier stages of growth are apparent, as might be expected, particularly in the case of root development. Once the plants were well established these differences vanished.

The effects of treatments are very pronounced on "poor" soils (low in available phosphorus). The data from the two trials at Barbauchlaw in Tables 5 and 10 show a regular and highly significant influence of all phosphate treatments in all phases of plant growth. Gains in height for example, due to the highest rate of phosphorus application ranged from 50 to 300 percent increase over the control - comparative differences being naturally higher in earlier stages of growth and with lower levels of phosphorus application. The gains in shoot weight and the weight of

the/

the root, present an equally impressive picture and were highly significant.

The fresh weight of the shoot presents another interesting indication. In the Barbauchlaw data of 1955 (Table 10.f) it will be noticed that there is a drop in the fresh weight of the root - more marked at the first observation than at the second - with P_4 treatment (2 cwt. P_2O_5 per acre) compared to P_3 (1 cwt. P_2O_5 per acre). This drop was not recorded at the third observation;considered in conjunction with the similar trends of the drop in the fresh weight of the root between the highest (F) and the next lower rate (E) in the cases of Shawfair, Dryden and Boghall data, one is tempted to infer that some check to the free development of the root occurred in the early stages of root development. A more detailed study over a number of years, of the effect of high rates of phosphorus application on root development would, it is felt, yield valuable and interesting data, which might explain the depressing influence on yield of high rates of phosphorus application observed by some workers (Simpson 1953).

The Dry matter percentages of shoot and root showed no effect of treatment in "good" soils in either season. The two trials on the "poor" soil of Barbauchlaw showed a regular trend, the dry matter percentage falling with increased rates of phosphorus application. It is interesting to note that while in the wet season of 1954, these differences between control and higher rates of fertilizer/

fertilizer application achieved significant levels, they were not so marked in the drier season of 1955. Obviously the level of soil moisture played an important role in the two seasons. In 1954, the increase in the fresh weight of root was accompanied by greater amounts of water in the root tissues. On the other hand in 1955 although the influence of phosphorus did lead to increases in the root system, the restricted supplied of soil moisture limited the differences in the dry matter percentage between plants from control and other plots.

Effect of the treatments on tuber development and the final yield.

Development of tubers followed closely the pattern set out for vegetative growth. Application of phosphorus to "good" soils brought about no marked changes in the weight or the percent dry matter in the tubers. It is by no means implied that the factors influencing vegetative growth and tuber development bear any close relationship. In fact the contrary may be true. For example Roberts and Struckmeyer (1938) found that conditions most suitable for potato haulms are long warm days of moderate light intensity. Tuber formation (Driver 1943) is more efficient if the days are shorter, when a small proportion of the carbohydrates is used for haulm growth and the surplus is available for tuber formation between 15°C to 20°C. It is quite possible, that the climatic conditions in the two years were such that they did/

did not materially influence one way or the other, the growth of the plant or tuber development. As these were the wettest and driest seasons on record for some time it may be inferred that in the area concerned, with a soil of reasonable drainage and good water holding capacity, seasonal climatic differences should not effect the yield of potatoes.

The great benefit exhibited by the growth in "poor" soils due to the treatments was equally well reflected in the tuber development. The number of tubers per plant (Tables 6 and 11) lend strong support to the conclusion arrived at by Russell and Garner (1941 part III) that phosphates, when used with adequate quantities of potassium and nitrogen, increase the numbers, rather than the size of the tubers. Even though in "good" soils the differences in the number of tubers failed to reach significant level at maturity, a substantial increase, particularly with higher rates and at early stages, was quite evident. For example, the percentage increase produced by highest rate over the control was at the first observation, 87, 54 and 61 at Shawfair, Dryden and Boghall respectively, while the same comparisons at the final observation showed an increase of about 11, 46 and 31%. As can be expected in the two trials on "poor" soils, all fertilizer treatments produced a significantly greater number of tubers per plant.

The total yield showed no beneficial influence of the added phosphorus in soils already rich in available phosphorus. In fact among the fertilizer applications there was/

Table 18

Effect of treatments on the percentage of grades in the total produce

Treatments (lb. P_2O_5 per acre)

Year and Location	Grade	Control	0.33	0.66	1.0	2.0	4.0
1954							
	Ware	28	31	25	25	23	27
Shawfair	Seed	67	64	69	70	72	68
	Chats	4	4	4	5	5	5
	Ware	20	21	19	14	11	11
Dryden	Seed	76	76	77	82	83	84
	Chats	3	3	3	3	5	6
	Ware	4	10	10	8	8	7
Barbauchlaw	Seed	88	85	87	89	70	88
	Chats	8	5	4	3	3	4

Year and Location	Grade	Control	0.25	0.5	1.0	2.0	-
1955							
	Ware	65	64	63	61	62	
Boghall	Seed	33	34	35	37	36	
	Chats	1	1	1	2	1	
	Ware	55	64	63	62	55	
Barbauchlaw	Seed	43	35	36	37	43	
	Chats	2	1	1	1	2	

was a tendency for the yield to drop with the increased rates of application. It is noteworthy that at Shawfair and Dryden the highest rate (4 cwt. P_2O_5 per acre) gave a yield, 12.8 and 8.3 percent, lower even than the control. In the "poor" soils the beneficial effects noted, on plant growth and tuber development, were fully maintained. The yield increased sharply to about the 1 cwt. P_2O_5 rate, but then declined slightly with higher rates. As has been pointed out before, Russell and Garner observed that the effect of phosphorus is in the direction of increasing the number of tubers rather than on the size. It could therefore be expected that a phosphorus application would decrease the percentage of ware and increase that of seed and chats in the total yield. This is quite evident from the data in Table 18. The effect is far more marked in the soil richest in available phosphorus (Dryden) where the proportion of ware dropped from 20% to 11%, the proportion of seed increased by 8 percent. This effect of phosphorus on the grades in the total yield has generally been recognised as of considerable agricultural value. In the past, it has generally been advocated that if the crop is grown primarily for seed, phosphorus should be applied at a higher rate to produce a greater proportion of seed size tubers and vice versa if the crop is intended for Ware production. As far as the effect on the grades only is considered, this recommendation seems to be applicable even up to the high rate of phosphorus used in/

in 1954 i.e. 4 cwt. P_2O_5 per acre, but from the point of view of "net profits" as will be seen later in this discussion, the above advice is applicable only to the limit, or a little beyond, at which phosphorus application leads to an increase in total yield. As applications of phosphorus beyond a certain rate - depending on the phosphorus status of the soil - may lead to a marked depression in the yield, the net profits become progressively less, with additions beyond this limit, inspite of the continued effect of phosphorus on the size of the tubers.

Effect of treatments on the uptake of phosphorus.

Before the results are discussed it is appropriate to mention, that, in the interpretation of the data on the uptake of phosphorus derived from the fertilizer, it has been assumed, as accepted by Fried and Dean (1952), that a plant presented with two sources of phosphorus, namely the soil and the fertilizer, will absorb phosphorus from each in direct proportion to the amounts of these respective supplies. Recently Scott Russell *et al* (1954) have raised doubts about the validity of this assumption. They consider that isotopic exchange must be taken into account in interpreting the radio-chemical data on the uptake of fertilizer phosphorus. The opinions of various workers are conflicting on this subject. Spinks and Barber (1947) concluded that such an exchange did not affect the interpretation of their data. MacAuliffe *et al* (1947) believe that isotopic exchange would decrease the/

the apparent utilization of labelled phosphate. Scott Russell et al (1954) state that in the majority of experiments, it is expected that the exchangeable soil phosphate will be less available than fertilizer phosphate, and therefore an under-estimation of fertilizer uptake should be the more common error. However, as the pH values of the soils were neutral or slightly alkaline, in the experiments reported here, it may be taken with some confidence that most of the soil phosphate was of the calcium phosphate type and of comparable availability to the added superphosphate. Further, Hendricks and Dean (1950) were of the opinion that exchange was so slight that it could not cause any large errors in the estimation of fertilizer absorption in normal circumstances. Since no measurements of isotopic exchange in soils of normal water content are available, the extent of this effect cannot be assessed. In the present study, therefore, the radiochemical data are discussed on the original assumption made by Fried and Dean and stated earlier in this section.

The general effect of the phosphorus treatments on both types of soils was to raise the percent P_2O_5 in the plant as a whole. As has been discussed before, this increased uptake in a "poor" soil led to a vast improvement both of vegetative growth and tuber yields. In the case of "good" soils, however, increased phosphorus uptake was reflected only in a higher percentage of P_2O_5 in the plant,

particularly/

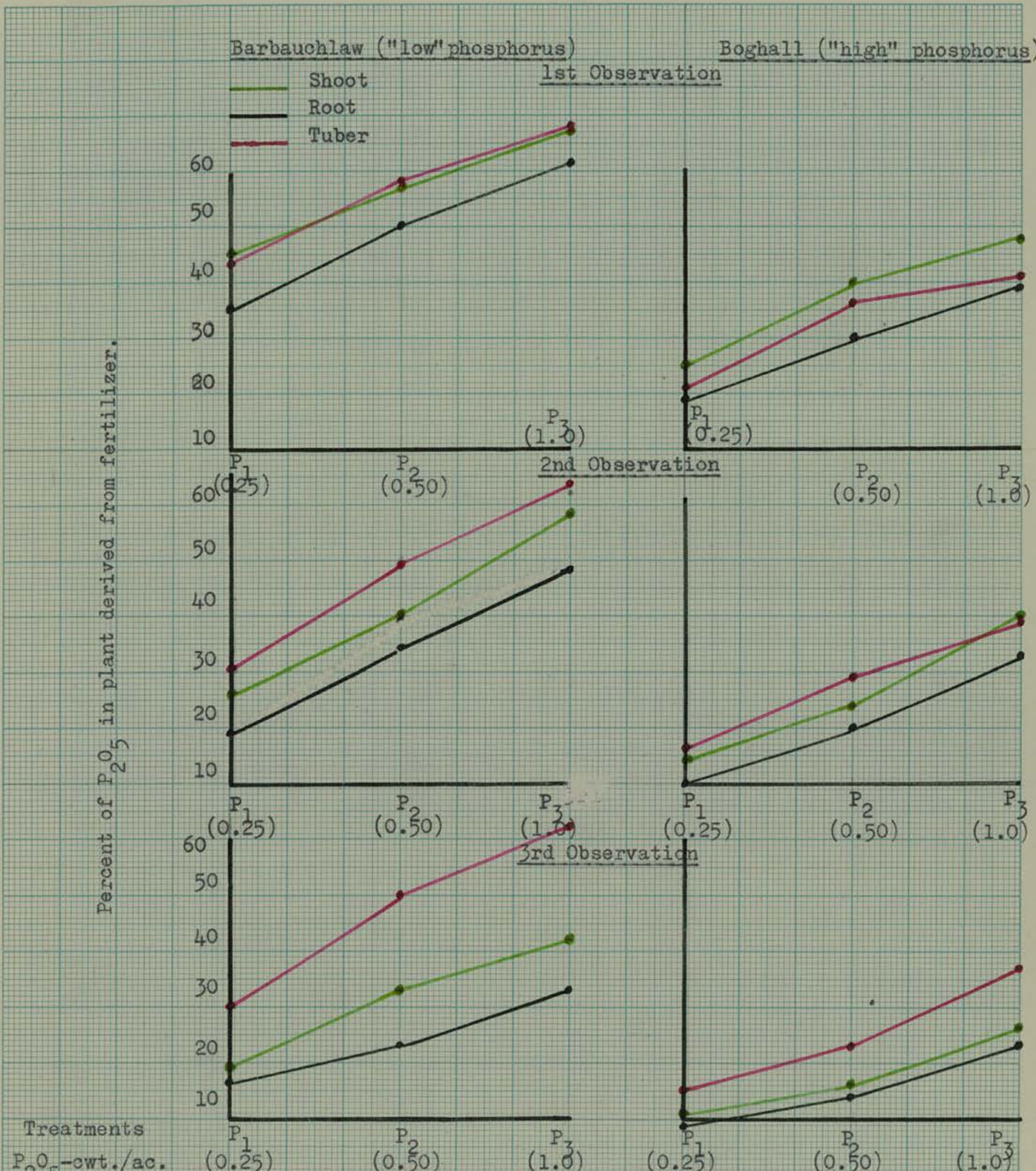


Fig. 4. Percentage of phosphorus in the plant (shoot, root, tuber) derived from the fertilizer as affected by the rate of applied phosphorus and level of available phosphorus in the soil.

particularly tubers. It had no effect on yield. For instance tubers at the final stage showed an increase in phosphorus content of 22, 37 and 15 percent at Shawfair, Dryden and Boghall respectively, with the highest rate of fertilizer application, compared to the control, while the yields were only equal to or less than the control yield.

The percentage of phosphorus derived from the fertilizer presents an interesting picture (Table 12 d, e and f). The fertilizer derived phosphorus increased with the increase in the rate of application irrespective of phosphorus availability status of the soil. The law of diminishing returns was clearly demonstrated here, in that the increase from 0.25 cwt. P_2O_5 per acre rate to 0.5 cwt. P_2O_5 rate led to a much greater increase in the percentage of fertilizer-derived phosphorus than when the rate was increased to 1.0 cwt. P_2O_5 per acre. Again the poor utilization of added phosphorus in "rich" soils is well demonstrated by the fact that generally the amount of fertilizer-derived phosphorus at all stages was only about half as much in the "good" soil as in "poor" soil. For example, the percentage of fertilizer-derived phosphorus in the tuber at maturity was, at Barbauchlaw 30, 50 and 62 compared to 15, 23, and 37 at Boghall with the application of 0.25, 0.5 and 1.0 cwt. P_2O_5 per acre rates of application respectively (Table 12 f).

It is interesting to note that though the plants contained much higher percentages of fertilizer phosphorus at the earlier/

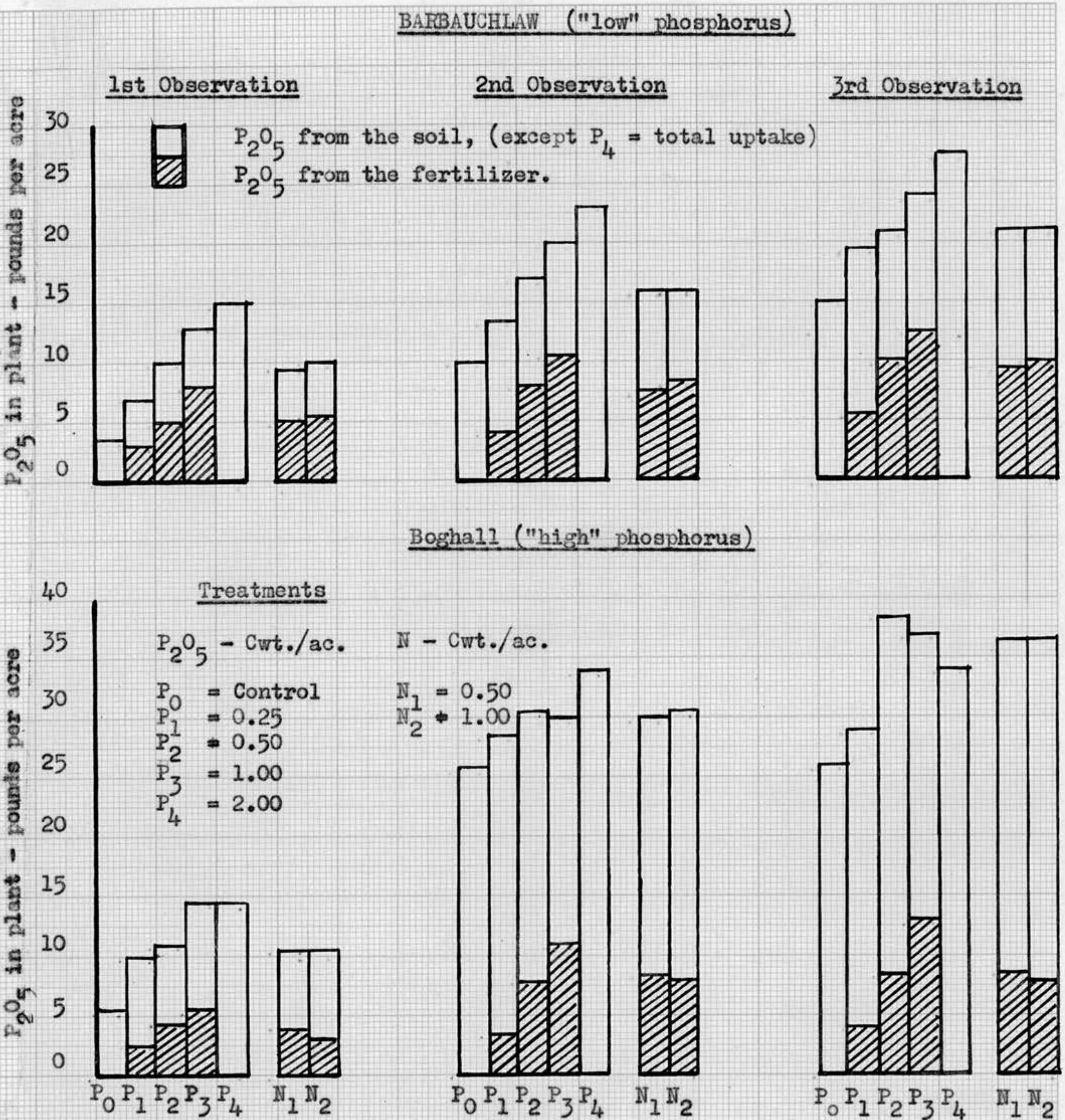


Fig. 5. Total uptake of P_2O_5 from the fertilizer and from the soil as affected by the rate of applied phosphorus and level of available phosphorus in the soil.

earlier stage, even at maturity the root and shoot contained more than a quarter of fertilizer-derived phosphorus at Boghall and about a third at Barbauchlaw. It is therefore apparent that the potato continues to be dependent on fertilizer phosphorus, till late in life because of the limited root system and indeterminate type of growth. Krantz et al (1949) in a similar study on the uptake of phosphorus by corn, potatoes and cotton, observed that potatoes absorbed a relatively high proportion of fertilizer phosphorus, throughout the season.

The amounts of P_2O_5 applied exerted a major influence on the amount of P_2O_5 absorbed from fertilizer. As the application of phosphorus increased the number of pounds absorbed by the plants per acre also increased (Table 18). Usually the amount almost doubled with the initial increase i.e. from 0.25 to 0.5 cwt. rate, but only a 50 percent increase resulted with a further doubling (1.0 cwt P_2O_5) of the rate of application.

Although the number of pounds of P_2O_5 absorbed increased, the percent recovery of the applied phosphorus decreased with the increase in the rate of application. For example at the final observation at Barbauchlaw the total fertilizer phosphorus increased from 5.5 lb. to 14.5 lb. per acre with an increased rate of application from 0.25 to 1.0 cwt. P_2O_5 but the recovery of added phosphorus decreased from 19.6 to 12.9 percent. It is obvious that with increasing amounts of readily available phosphorus, placed in the root zone, as is done/

Table 19

Effect of treatments on the recovery of soil and fertilizer phosphorus by the crop[1 & 2]

		Barbauchlaw P_2O_5-lb./ac.				Boghall P_2O_5-lb./ac.			
Observation	Treatment	Total Recovery	Derived from fertilizer	Derived from soil	% Recovery of fertilizer	Total Recovery P_2O_5	Derived from fertilizer	Derived from soil	% Recovery of fertilizer
I	P_0	3.5	-	3.5	-	5.7	-	5.7	-
	P_1	7.2	3.0	4.2	10.7	9.9	2.3	7.6	8.3
	P_2	10.3	5.1	5.2	9.1	10.7	4.4	6.3	7.9
	P_3	12.9	8.5	4.4	7.6	12.0	5.4	6.6	4.8
	P_4	15.3	-	-	-	12.3	-	-	-
II	P_0	10.1	-	10.1	-	26.1	-	26.1	-
	P_1	13.7	4.1	9.6	14.5	28.8	3.6	24.7	13.6
	P_2	17.1	8.0	9.1	14.3	30.4	8.2	22.2	14.7
	P_3	21.2	13.3	7.9	11.8	30.2	11.8	18.4	10.5
	P_4	23.1	-	-	-	34.4	-	-	-
III	P_0	14.7	-	14.7	-	26.6	-	26.6	-
	P_1	19.3	5.5	13.8	19.6	29.4	4.2	25.2	15.1
	P_2	21.1	10.0	11.1	17.9	38.6	8.5	30.1	15.2
	P_3	24.3	14.5	9.8	12.9	37.0	13.1	23.9	11.7
	P_4	27.6	-	-	-	34.3	-	-	-

1. Percent P_2O_5 in the plant derived from the fertilizer (Table 12 d, e and f) is graphically represented in Fig.4.
2. The data of first three columns for both locations are also represented in a Histogram form in Fig.5.

done in the potato crop, it can be expected that the plant will rely more and more on this source of supply rather than forage from the soil. This is clear from the data on the amounts of phosphorus derived from the soil, obtained by deducting from the total uptake the portion derived from the fertilizer (Table 19). With increasing rates of fertilizer application the plant contained less and less P_2O_5 derived from the soil. The results discussed in this section are in agreement with the findings of other workers like Jacob et al (1949), Nelson et al (1947) who conducted similar studies using labelled superphosphate.

Effect of nitrogen.

In the 1955 potato experiments two rates of nitrogen at 0.5 and 1.0 cwt. N per acre were introduced. Contrary to expectation nitrogen applications showed very little influence on the vegetative growth of the plant even in the poor soil of Barbauchlaw. Neither was a marked interaction shown between nitrogen and phosphorus treatments. The only significant and important effect was on the tuber size. As far as the limited data of these two field experiments show, there was considerable improvement in size as revealed by ware yields. For instance the higher rate of application led at Barbauchlaw to a 13% and at Boghall to a 10% increase (Table 11). Similar effect of nitrogen on the improvement of the size of the tuber has been noted by Singh (1947).

It must be remembered that during the summer of 1955 conditions/

conditions were at an optimum for the conversion of the reserve of soil nitrogen into the available nitrate form, and such lack of response might not occur in a "normal" season.

Financial returns

As manuring is carried out primarily to increase profits, "net profit" must, ultimately be the yard stick to measure the value of any fertilizer treatments.

The profits obtained and loss statement due to different treatments in the five experiments already discussed are given in Table 20. Ware and seed have been valued at the prevailing rate of £13 and £19 per ton on the farm. The price of superphosphate at £2.4 per cwt. P_2O_5 has been deducted from the gross income.

The very obvious differences in the profits obtained from the high phosphorus and low phosphorus soils may be seen in Table 20. For example at Shawfair in 1954 no fertilizer dressing yielded a profit, at Dryden and Boghall the greatest profit was from the lowest dressings - i.e. 0.33 and 0.25 cwt. P_2O_5 per acre respectively.

The picture is very different with the phosphorus deficient soils in both seasons. In 1954 the largest profit (£119 per acre) was shown by the 0.66 cwt. P_2O_5 per acre dressing and in 1955 by the 1 cwt. P_2O_5 per acre rate.

It is obvious from these figures that the most profitable rate for a fertile soil is little more than a cwt. of superphosphate per acre while for a deficient soil dressings of up to 5 cwt. per acre may still yield profitable returns.
These/

Table 20

Net Profits[1] under different treatments (£ per acre)

Treatments (P_2O_5 cwt./ac.)

Year and Location	Soil phosphorus status	0.33	0.66	1.0	2.0	4.0
1954						
Shawfair	"high"	- 5	- 7	- 0.2	- 5	- 22
Dryden	"high"	+ 20	+ 5	+ 8	- 1.8	- 18.1
Barbauchlaw	"low"	+ 71	+119	+110	+ 74	+118
		0.25	0.5	1.0	2.0	-
1955						
Barbauchlaw	"low"	+ 44	+ 65	+ 77	+ 75	
Boghall	"high"	+ 44	+ 33	+ 37	+ 24	

1. Ware and seed calculated at £13 and £19 per ton on the farm. Price of superphosphate at £2.4 per cwt. P_2O_5 deducted from gross income.

These conclusions do not appear to be affected by local extremes of climate.

"Phosphorus from different fertilizer Materials". Experiments

Since its introduction over a hundred years ago, superphosphate has reigned supreme as a phosphatic fertilizer. Knowing the resources of sulphur, and hence to sulphuric acid used in the manufacture of superphosphate to be limited, agricultural scientists have been, for quite some time, in search of another source of phosphorus, as good if not better than superphosphate. Recent curtailment of supplies of sulphur from U.S.A. has intensified the search for a suitable alternative to superphosphate.

It was with the above object in view, that the experiments, the results of which are discussed here, were conducted. Superphosphate, Reno Hyperphosphate, Gafsa mineral phosphate (coarse and fine) and dicalcium phosphate were tried over two seasons (1954 and 1955) to assess their comparative values as a source of phosphorus for the potato crop. The results have been given in the previous section. Outstanding findings are briefly discussed.

Effect of treatments on plant and tuber development and final yield:-

In a soil of high available phosphorus status (Dryden) in which the experiment was conducted in 1954 season, vegetative development of the plant showed practically no differential response to different sources of phosphorus (Table 8). Evidently already high availability of phosphorus in this soil masked any influence of the treatments. This supposition/

supposition is supported by the data of 1955 experiment (Table 13) from which it will be seen that Gafsa mineral phosphate - irrespective of the fineness of grinding - produced much poorer vegetative growth than the two more readily available sources namely superphosphate and dicalcium phosphate. For example, mineral phosphate proved no better than the control for fresh weight of shoot and root. Superphosphate and dicalcium phosphate showed almost the same effects in greatly improving the growth of the plant. It is also noteworthy from the dry matter percentage data in Table 13 that treatments which induced greater growth, produced a higher amount of water in the plant tissues. In the shoot for instance, at the peak of the growth period (2nd observation Table 13), control and the Gafsa treatments produced dry matter figures about 15 percent higher than superphosphate or dicalcium treatments.

From the data on tuber development in 1954 i.e. the number of tubers and the weight per plant in Table 9, the marked inferiority of Reno Hyper-phosphate as a source of phosphorus to the potato crop is at once evident. Both the number and the weight of tubers showed no improvement over the control. The effect of readily available phosphorus in increasing the number of tubers per plant, already noted in the "levels of phosphorus experiments", even in high-available-phosphorus soils, is again evident from Table 9. The number of tubers per plant with superphosphate and dicalcium/

dicalcium phosphate, for example, showed an increase of 41 and 50 percent over the control.

For some unknown reason finely ground Gafsa mineral phosphate (300 mesh) proved just as good as superphosphate in 1954, both as regards number and the weight of the tubers per plant, although Williams (1951) and many others consider mineral phosphate practically useless for potatoes. The data for the same observations for 1955, however show this conclusion to be quite sound. The wet weather in 1954 may be partly responsible for such a good response to Gafsa mineral phosphate by the potato crop. This assumption is fully supported by the 1955 data (Table 14), where it will be seen that Gafsa mineral phosphate produced considerably less weight of tubers per plant and a slight reduction in number of tubers per plant.

The final yields reflect the trends already set up by the weight of the tubers per plant. It is particularly noteworthy that in 1954 , Reno-Hyper phosphate produced a yield significantly less even than the control. The other treatments namely superphosphate, dicalcium phosphate, and Gafsa mineral phosphate produced almost the same quantities of tubers as the control. Obviously the high availability of phosphorus in the soil made the application of fertilizers completely ineffective. Consideration of the 1955 results (Table 14) clearly shows that dicalcium phosphate was fully as good if not better than the superphosphate for the potato crop/

crop. This finding accords with the results obtained by many other workers. For example Hoogland et al (1942) reporting the results of field experiments with the potato crop, found dicalcium to be practically as effective as concentrated superphosphate. Williams (1951), too, considers that citric soluable phosphate like dicalcium phosphate "give good results on potatoes - a crop known to require quick acting phosphate". It is also worth noting that on the phosphorus deficient soils even the application of mineral phosphate improved the yield by almost 2 tons per acre compared to the control.

The strikingly large proportion of ware (Table 21) in the total yield under the mineral phosphate treatments (Hyper phosphate and Gafsa mineral phosphate), in soil of high-available phosphate, is noteworthy; though almost the reverse is the position in the case of soil low in available phosphate. Obviously in Barbauchlaw the phosphorus was the limiting factor in tuber swelling as is shown by the very low percentage of ware obtained from the control. Readily available phosphorus from superphosphate and dicalcium phosphate on the other hand not only improved the total yield but also the grade.

Because, in 1954, the experiment was located in soil already high in available phosphorus, no marked differences in the uptake of P_2O_5 could be expected nor are they shown in the data of Table 10. In the low phosphorus soil the position is

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Table 21

Effect of treatments on the percentage of the three grades of tuber in the total yield

Year and Grade 1954	Control	Super 0.33	Super 0.66	Hyper 0.5	Gafsa 0.5	Dical. 0.5
Total						
Ware	21	21	19	26	26	16
Seed	76	76	79	72	71	81
Chats	3	3	3	3	2	4

1955	Control	Super 0.33	Super 0.66	Gafsa coarse	Gafsa fine	Dical. 0.5
Total						
Ware	51	71	72	64	70	78
Seed	48	28	27	33	29	22
Chats	1	0.5	0.9	0.6	0.7	0.4

very different and interesting. In the earlier stages, particularly the first observation, the plants showed a considerably higher percentage of P_2O_5 in their tissue when superphosphate or dicalcium phosphate was the source of supply than when the source was mineral phosphate. As the plant advanced in age these differences decreased, till at maturity (third observation) the treatments which produced more growth and tuber yield, namely superphosphate and dicalcium phosphate, showed lower percentages of P_2O_5. Obviously because of the considerable increase both in the vegetative growth and tuber development the total uptake of phosphorus from the limited application of 0.5 cwt. P_2O_5 per acre was distributed over larger volumes of plant tissue and therefore showed lower amounts of P_2O_5 per unit of the tissue at maturity.

Greenhouse experiments

Some striking effects of adequate nitrogen fertilizer application on the efficiency of applied phosphorus have recently been reported by several workers Smith <u>et al</u> (1950); Dumenil and Hanway (1952); Bennet (1953). As oats is one of the important cereal crops and compared to some other cereals more responsive to applications of phosphorus, greenhouse experiments to study the utilization of applied phosphorus, in soils of high and low available phosphorus status, were conducted in 1955, using different levels of radioactive superphosphate in combination with two rates of nitrogen. The major points arising from the results already given in the previous section are briefly discussed here.

Application of both phosphorus and nitrogen greatly improved the growth of the plant, as is evident from Table 16. It was interesting to note that while the beneficial effect of readily available phosphorus was visible soon after the germination of the seed the response to nitrogen was not clear till after about three weeks. The differences in the growth of the plants due to phosphorus treatments were so prominent at two weeks after germination, that it was possible to tell the phosphorus treated pots by visual observation. At the second observation it was similarly possible to pick out the different nitrogen treatments, but the effect of phosphorus was considerably masked. At maturity, as is shown in/

in the data of Table 16, both nitrogen and phosphorus proved effective in increasing the fresh weight of the plant in the low phosphorus soil, but only the effects of nitrogen lasted till the end. Apparently it took more than three weeks for the re-establishment of the soil micro-organism population in the soil - which must have been reduced drastically by air drying of the soil - and the conversion of ammonium in the ammonium sulphate to nitrate which the plants could utilize. It is also interesting to note that at maturity the effect of phosphorus is much more pronounced in the "poor" soil of Barbauchlaw and that of nitrogen in the "good" soil of Boghall.

Generally, phosphorus treatments did not materially affect the dry matter percentage. Nitrogen on the other hand - by inducing more luxuriant and softer growth tended to give smaller dry matter percentages.

The total phosphorus percentage of the dry matter of the plants showed a marked improvement with increasing rates of phosphorus application at the earliest stage of plant growth which, as has been pointed out earlier, was fully reflected in the vigour and the size of the plants. For example, at the first observation the plants supplied with 160 lb. P_2O_5 per acre had 28 and 27 percent more phosphorous than the control in Barbauchlaw and Boghall soils respectively, than those receiving only 40 lb. P_2O_5. These differences were, however, considerably reduced with development of the plant/

plant, till at maturity only the highest rate of phosphorus application in Boghall soil produced any marked accumulation. Nitrogen applications tended to depress quite markedly the percentage of phosphorus in the shoot. For example, compared to control, the 80 lb. rate showed only about half as much P_2O_5 in Barbauchlaw soil and only a third in Boghall soil. This depression in P_2O_5 percentage in the shoot, is however fully accounted for, partly by the increased vegetative growth, but mainly by the very remarkable increases in grain weight under the influence of nitrogen treatments.

From the uptake of fertilizer phosphorus data in Table 16.d it is abundantly clear, that because of the high level of available phosphorus in the Boghall soil the plants absorbed considerably less fertilizer phosphorus than those grown in the Barbauchlaw soil. The amount of fertilizer phosphorus absorbed however, increased in both soils with increase in the rate of added phosphorus. Generally, the uptake almost doubled with the initial application but further doubling of the rate of application resulted in smaller increases.

It was further interesting to note that in the two soils the pattern of fertilizer phosphorus uptake is very different. While in the case of low phosphorus soil from Barbauchlaw uptake showed only a slight decrease between first and second observations and a sharp drop during the seed formation phase (between second and third observation), in the/

the soil from Boghall the demand of the plants for fertilizer phosphorus dropped sharply between the beginning and the end of the vegetative growth period (first and second observation) but the uptake rose sharply again during the seed formation time. Similar trends are to be seen in the data obtained by Stanford et al (1949), but the authors offer no explanation. It appears, that at least part of the explanation of this renewed demand by the plants for fertilizer phosphorus may be in the fact that there was a large increase in the weight of the grain due to nitrogen treatments and the plant increased its absorption of fertilizer phosphorus to meet this requirement.

Though phosphorus application made very little difference to grain formation, nitrogen increased the grain weight very strikingly - particularly in the phosphorus rich soil from Boghall. Here the 40 and 80 lb. nitrogen rate increased the yield of grain by 20 and 50 percent respectively. It is realized that it is not possible to make a reliable estimate of field behaviour from the results of a single greenhouse experiment, but there is no doubt that interesting results would be obtained by a field trial based on similar treatments.

Finally, it is worth noting that though neither phosphorus nor nitrogen treatments made any notable difference in the percentage of total phosphorus in the seed, the contribution from the fertilizer phosphorus increased in the same proportion as the phosphorus added, except that in the high phosphorus soil the highest rate of phosphorus application proved less effective in this respect.

VI. SUMMARY

During the Seasons 1954 and 1955, seven field experiments with the potato crop and two experiments in the greenhouse with the oat crop, were conducted on soils of high and low available phosphorus status. The object of the investigation was to study the effect of applications of phosphorus at different levels, and from different fertilizer materials on the uptake of phosphorus and its effect on the growth of the plant and the final yield.

The 1954 programme included two field experiments on soils rich in available phosphorus and one on a "poor" soil. Treatments included, control, 0.33, 0.66, 1.0, 2.0 and 4.0 cwt. P_2O_5 per acre. Nitrogen and potassium were applied as basal dressing to all plots. Another field trial compared at equivalent rates of 0.5 cwt. P_2O_5 per acre, superphosphate, Reno Hyperphosphate, Gafsa mineral phosphate and Dicalcium phosphate.

In 1955, the above experiments were repeated with slight modifications in the treatments. In the "levels of phosphorus" experiment, the 0.33 and 0.66 rates were reduced to 0.25 and 0.50 cwt. P_2O_5 per acre respectively and the 4.0 cwt. rate was excluded. Nitrogen at two levels - 0.5 and 1 cwt. N per acre was introduced. In the phosphorus from "different fertilizer materials" experiment, Reno Hyperphosphate was replaced by coarse Gafsa mineral phosphate.

The treatments for the two pot experiments conducted in 1955/

1955 in the greenhouse, using soils from the field experiment areas, included all combinations of phosphorus at 0, 40, 80 and 160 lb. P_2O_5 per acre with nitrogen at 0, 40, 80 lb. per acre.

Radioactive superphosphate was used in 1955 to study the fertilizer phosphorus uptake, by potatoes and oats at different levels of application.

<u>The five trials on soils of high and low available phosphorus status, with phosphorus applied at different levels showed</u>:-

1. Application of phosphorus, at rates higher than 0.25 cwt. and 1.0 cwt. P_2O_5 per acre in soils of high and low phosphorus status respectively, proved to be of no benefit to the crop either in the growth of the plant, or in tuber development and final yields.
2. There were indications that the 4 cwt. P_2O_5 rate in the wet season (1954) and the 2 cwt. P_2O_5 per acre rate in the dry season (1955), hindered the free development of the root, particularly in the early stages of growth. This effect was more marked in "high" than in the "low" phosphorus soils.
4. Uptake of phosphorus increased with the increase in the rates of application, but resulted in the case of high-phosphorus soils only in a higher percentage of P_2O_5 in the plants - particularly in the tubers. It had no effect on yields. In the low phosphorus soils responses in yield to the uptake of phosphorus were observed up to about/

about the 1 cwt. P_2O_5 per acre rate of application.

4. Increasing the rate of phosphorus application generally led to an increase in the number of tubers per plant, irrespective of the phosphorus status of the soils.
5. The total yield of tubers was markedly depressed by applications of phosphorus beyond 1.0 cwt. P_2O_5 per acre. In phosphorus rich soils the 4 cwt. P_2O_5 rate (1954), in one trial, gave a yield significantly lower even than the control. This effect of reduction of yields at high rates appeared to be related to the root injury noted in paragraph 2 above. More detailed data over a number of years, would, it is felt lead to fruitful results and may confirm this finding.
6. In high-phosphorus soils, rates higher than about 0.25 cwt. P_2O_5 per acre resulted in reduced profits or even in a loss. In low phosphorus soils about 1 cwt. P_2O_5 per acre proved to be most profitable.
7. The only marked influence that the application of nitrogen showed on the potato crop in these two soils was on the size of the tuber. The quantity of ware in the total yield was significantly increased with higher rates of nitrogen application.

<u>Results for the uptake of fertilizer phosphorus, with radioactive superphosphate, in the case of the potato crop showed:-</u>

8. The plants grown on high phosphorus soils generally contained/

contained only about half as much fertilizer phosphorus as those grown on low phosphorus soils.

9. The percentage of phosphorus derived from the fertilizer increased with the increase in the rate of fertilizer application irrespective of the phosphorus status of the soil. This difference was much higher with the initial increase than when the rate of application was further raised.

10. The quantity of phosphorus absorbed from the fertilizer increased with the increase in the rate of application but the percentage of added phosphorus utilized decreased.

11. The plants continued to absorb comparatively high amounts of fertilizer phosphorus throughout their period of growth.

12. Recovery of added phosphorus varied between 11.7 to 15.1 percent in high-phosphorus soil and between 12.9 to 19.6 percent in low phosphorus soils.

<u>The two trials with the phosphorus from different fertilizer showed</u>:-

13. Mineral phosphate (Reno Hyperphosphate and Gafsa mineral phosphate) proved of no value as a source of phosphorus for the potato crop. Gafsa mineral phosphate proved better under wet (1954) than dry (1955) weather conditions.

14. Fineness of grinding of Gafsa mineral phosphate proved of no avail in increasing the yield of tubers.

15./

15. Dicalcium phosphate was more effective in the drier than in the wet season. In the dry season (1955) it proved as effective as superphosphate at an equivalent rate of application.

<u>The results of the greenhouse experiments with oat crop showed</u>:-

16. The general pattern of fertilizer phosphorus utilization to be similar to that noted for potato i.e. higher uptake of fertilizer phosphorus from soils of low phosphorus status than from high phosphorus soils; decrease in uptake with increase in the rate of phosphorus application with both high and low phosphorus soils. The percentage of fertilizer phosphorus in the plant was, however, much lower than in the potato.

17. There appeared to be a renewed demand on fertilizer phosphorus at the time of grain formation when the conditions favoured attainment of high grain yields. This finding however needs confirmation from field trial results.

18. Nitrogen, though proved to be ineffective with the potato crop in the field, improved the uptake of fertilizer phosphorus by the oat crop in the greenhouse. But the most marked effect of nitrogen was on yield of grain which improved greatly with increasing rate of nitrogen application.

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IX. APPENDICIES

1954. "Levels of phosphorus" experiments

Appendix Ia

Shoot: effect of treatments on the height. (cms.)

		Barbauchlaw						Shawfair						Dryden					
		Treatments						Treatments						Treatments					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
I	I	11	13	13	14	11	15	8	10	10	9	8	8	50	45	41	46	46	43
	II	8	10	11	11	13	14	7	8	11	9	7	9	41	45	44	45	51	47
	III	8	8	12	12	10	12	7	8	9	8	8	9	36	42	39	42	49	42
	IV	9	10	14	12	11	15	8	10	9	7	10	8	47	44	44	52	54	52
II	I	31	49	50	60	67	67	48	48	51	53	58	52	88	89	92	89	98	93
	II	24	41	45	48	54	67	53	52	41	52	46	51	85	85	81	87	89	97
	III	26	45	52	51	58	57	48	50	48	50	49	50	79	84	83	89	95	87
	IV	28	26	45	49	55	55	54	51	53	52	55	48	80	82	88	89	86	89
III	I	40	65	60	72	72	76	56	57	61	63	71	64	91	96	97	95	103	101
	II	27	50	49	55	65	78	58	66	52	62	56	64	87	89	90	92	102	107
	III	32	54	61	64	72	76	58	59	57	63	57	68	83	101	96	103	103	96
	IV	34	44	50	63	61	64	64	66	63	64	65	62	89	88	95	95	93	94
IV	I	41	68	58	74	82	80	63	59	64	66	79	66	92	98	98	96	105	103
	II	31	45	53	57	67	82	60	68	53	63	58	66	88	91	92	94	106	111
	III	34	58	62	64	77	77	59	61	57	66	60	72	83	101	95	105	108	100
	IV	39	44	51	63	65	65	64	66	64	67	67	63	89	89	95	96	95	98

1954. "Levels of phosphorus" experiments

Appendix I.b

Shoot: Effect of treatments on the fresh weight (g.)

		Barbauchlaw						Shawfair						Dryden					
		Treatments						Treatments						Treatments					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
I	I	32	64	122	86	95	82	33	84	103	79	92	39	263	404	522	392	306	350
	II	40	48	61	89	158	128	54	41	33	54	21	60	121	272	276	329	235	216
	III	32	98	114	84	109	124	27	32	58	67	56	54	188	179	229	290	336	312
	IV	41	61	87	119	110	151	83	42	80	29	65	62	254	232	427	240	391	287
II	I	168	236	189	335	375	343	305	443	925	801	430	651	516	1011	512	1003	710	853
	II	70	147	262	349	376	446	489	401	208	779	353	432	864	995	696	626	646	667
	III	45	147	182	380	290	472	450	432	488	515	716	287	609	634	553	558	628	1077
	IV	103	120	178	262	248	351	374	566	809	512	703	601	410	573	833	877	488	881
III	I	97	243	224	543	474	607	542	704	352	761	537	586	471	560	394	404	626	295
	II	76	200	183	312	266	282	455	426	409	566	393	752	323	331	187	307	278	276
	III	107	291	289	418	491	384	435	618	566	631	719	316	388	206	198	381	309	227
	IV	139	241	225	453	299	402	634	475	910	381	549	281	346	161	344	325	317	432
IV	I	54	75	108	116	150	151	231	205	221	495	197	226	94	65	125	114	116	98
	II	16	47	42	46	72	242	175	220	276	128	168	174	62	61	103	58	108	139
	III	24	82	110	109	83	108	341	198	243	672	135	261	56	76	65	88	44	70
	IV	61	54	94	172	105	53	177	197	217	344	161	244	40	85	119	57	163	113

1954. "Levels of phosphorus" experiments

Appendix I.c

Shoot: effect of treatments on the % dry matter.

		Barbauchlaw						Shawfair						Dryden					
		Treatments						Treatments						Treatments					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
I	I	17.8	11.8	11.2	10.4	10.7	10.6	9.1	7.9	8.1	8.9	8.3	10.8	12.9	12.8	11.2	12.3	13.3	11.7
	II	13.7	14.5	12.6	11.7	10.2	9.7	8.9	9.4	10.7	9.1	10.4	7.8	12.5	10.5	18.2	15.4	19.6	17.9
	III	23.4	10.5	12.3	12.4	12.7	14.2	8.9	9.0	8.2	9.3	9.4	9.4	19.8	20.3	20.0	18.3	16.2	16.8
	IV	16.8	15.9	9.6	12.8	12.1	11.8	9.1	9.7	9.2	10.0	8.4	7.8	21.4	14.9	11.9	15.4	15.8	15.5
II	I	15.9	13.1	17.9	14.5	13.3	12.8							9.6	10.9	14.6	10.7	8.7	10.9
	II	23.7	20.3	17.2	15.3	14.7	13.8							10.0	10.5	10.9	11.4	10.2	10.5
	III	23.4	22.6	19.3	17.4	18.4	16.3							10.0	13.2	11.4	11.8	13.1	11.3
	IV	19.7	20.4	19.4	18.6	21.8	18.0							13.8	13.6	12.0	14.3	13.9	14.3
III	I	14.8	14.7	14.2	11.6	9.8	10.5	9.5	11.7	12.1	11.1	9.6	12.9	17.9	17.2	15.6	17.7	16.6	16.4
	II	16.1	14.1	16.5	13.8	13.1	11.5	12.7	13.1	11.2	10.9	12.3	11.4	21.6	17.0	20.9	18.1	18.9	15.1
	III	16.3	16.1	18.1	16.3	13.7	13.7	13.0	12.2	12.4	12.0	11.2	14.3	23.0	23.7	22.1	18.3	19.4	20.1
	IV	15.6	14.2	16.6	14.9	13.6	14.5	12.1	11.9	11.4	10.5	11.7	13.4	26.4	25.8	19.0	27.0	25.6	20.4
IV	I	25.2	28.1	30.1	22.5	24.0	26.9	12.1	22.7	13.6	13.9	13.6	15.5						
	II	40.9	36.2	42.9	34.5	35.5	23.8	19.2	16.6	16.9	20.1	18.0	18.9						
	III	32.5	27.2	30.4	32.2	35.6	29.6	17.2	20.1	18.0	16.4	22.8	17.7						
	IV	31.9	38.1	35.4	23.6	23.4	39.3	19.8	19.3	23.1	19.0	21.5	18.4						

1954. "Levels of phosphorus" experiments

Appendix I.d

Root: effect of treatment on the fresh weight. (g.)

		Barbauchlaw						Shawfair						Dryden					
		Treatments						Treatments						Treatments					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
I	I	13.8	16.8	27.1	14.3	18.4	13.9	9.3	13.0	16.6	13.1	10.1	15.2	22.3	27.5	31.6	24.6	19.9	23.2
	II	19.8	12.4	11.5	13.8	23.4	19.5	14.8	7.6	8.1	11.8	4.2	16.7	21.9	20.7	17.9	13.9	21.9	15.9
	III	8.8	24.2	22.4	16.0	15.3	19.1	4.1	11.0	12.1	14.1	7.0	6.1	14.1	14.8	25.0	23.7	23.7	19.5
	IV	13.8	12.8	12.8	13.9	21.2	23.7	13.0	13.5	19.1	6.3	10.8	11.0	29.5	19.9	27.5	20.7	34.6	19.5
II	I	20.9	19.5	17.2	19.4	31.3	26.5	16.9	20.7	34.5	28.2	29.5	31.0	28.6	90.3	38.4	77.2	41.0	59.6
	II	17.1	17.5	26.5	37.6	29.8	34.3	15.5	16.9	14.7	19.9	16.8	24.4	40.7	70.8	50.9	45.4	37.4	38.2
	III	7.7	16.7	18.4	31.9	16.6	30.7	27.2	22.7	19.9	15.1	42.2	13.0	37.5	53.4	38.3	39.9	57.5	72.3
	IV	16.3	14.2	21.9	26.2	23.9	31.9	16.5	30.5	26.2	35.0	24.5	24.7	38.1	48.3	67.5	68.0	47.0	45.2
III	I	14.0	26.4	31.5	43.6	34.3	44.3	28.8	31.2	23.7	27.3	28.2	20.8	44.6	65.8	50.7	25.8	24.8	30.6
	II	13.6	34.8	39.5	26.4	21.5	21.4	28.5	16.9	28.4	38.5	19.4	22.8	41.1	36.9	24.6	32.5	30.3	16.5
	III	21.3	46.2	30.1	49.0	54.1	38.8	19.3	33.0	27.3	38.4	37.7	19.1	35.3	26.8	21.4	30.4	36.4	28.3
	IV	20.8	28.4	36.1	31.3	35.0	64.8	33.8	27.1	46.5	21.1	25.9	16.6	35.7	20.4	30.4	32.8	36.7	25.1
IV	I	8.9	15.9	32.8	32.6	22.4	28.3	17.3	10.6	17.0	28.2	14.0	29.3	22.4	18.5	30.4	27.8	26.9	22.9
	II	8.1	13.7	12.3	10.2	19.1	42.1	15.6	13.6	12.3	15.5	18.1	14.7	21.5	18.6	21.7	19.9	15.5	27.9
	III	14.7	20.0	24.3	30.9	21.4	13.8	22.2	16.5	15.7	17.0	19.7	22.6	21.9	22.4	19.6	17.6	13.9	12.8
	IV	14.8	21.1	22.1	37.2	16.3	8.7	14.2	25.6	31.3	31.5	17.0	11.5	20.3	30.0	23.3	22.5	32.1	30.8

1954. "Levels of phosphorus" experiments

Appendix I.e

Root: effect of treatments on the % dry matter

		Barbauchlaw						Shawfair						Dryden					
		Treatments						Treatments						Treatments					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
I	I	28.2	19.3	20.5	17.5	17.5	17.9	15.1	12.6	13.9	16.3	16.2	15.9	30.2	26.1	25.6	29.6	31.5	28.9
	II	21.2	24.1	19.3	20.3	16.6	15.3	15.8	18.2	21.1	20.2	18.8	12.8	59.5	39.9	49.7	56.3	46.1	47.1
	III	27.2	19.0	20.9	20.6	18.3	18.8	15.9	14.7	13.2	15.6	18.5	20.3	52.6	56.8	47.6	48.1	44.9	46.5
	IV	28.9	28.9	25.0	24.7	18.8	21.9	16.5	16.6	15.0	16.9	16.2	12.2	37.9	36.8	35.6	48.4	33.6	48.2
II	I	27.8	25.1	33.1	35.6	25.3	27.3	14.6	20.4	21.9	15.5	16.4	20.4	22.2	22.9	22.4	21.6	24.6	21.3
	II	42.7	34.8	30.2	29.1	27.2	25.6	24.9	24.1	22.7	29.2	24.2	26.9	30.9	24.6	26.9	24.9	29.9	28.3
	III	41.6	28.3	35.9	31.7	33.7	34.2	20.0	16.5	27.2	25.1	21.3	19.3	34.5	26.9	27.4	30.8	27.4	26.8
	IV	31.3	42.3	33.3	33.6	36.4	29.9	19.9	20.3	22.9	23.0	26.3	21.5	26.8	26.0	25.9	26.9	26.2	23.6
III	I	24.3	20.9	25.1	17.4	21.1	19.4	21.9	24.2	21.8	23.9	24.9	26.5	28.5	26.1	28.9	32.4	37.8	26.8
	II	24.3	18.7	25.9	25.7	26.5	21.9	26.0	27.4	19.5	22.2	26.9	25.5	26.3	28.6	36.9	32.8	34.3	29.7
	III	16.3	16.1	18.1	16.3	13.7	13.7	25.3	21.7	23.6	23.4	21.4	30.0	34.5	33.6	36.9	30.8	26.6	32.5
	IV	24.5	24.6	28.7	33.8	23.4	21.9	24.8	24.8	21.4	23.7	26.4	25.7	38.9	54.4	37.9	38.1	38.0	33.4
IV	I	31.5	38.1	26.2	26.3	30.4	29.3	25.6	33.4	36.8	29.3	29.6	29.2	29.6	30.8	27.9	57.2	48.9	38.9
	II	35.8	31.4	39.0	33.3	33.5	26.8	29.1	30.0	30.7	32.9	33.8	30.2	37.9	43.7	28.8	36.3	29.8	26.6
	III	33.3	24.6	33.3	30.7	35.1	53.6	30.4	33.7	31.8	34.4	38.8	29.0	38.8	39.3	35.7	36.3	45.6	37.5
	IV	32.4	30.6	20.8	31.9	31.7	43.6	34.9	28.0	29.3	29.8	34.8	40.3	33.7	27.3	22.7	29.9	38.6	32.4

1954. "Levels of phosphorus" experiments

Appendix II.a

Tuber: effect of treatments on number per plant

		Barbauchlaw						Shawfair						Dryden					
		Treatments						Treatments						Treatments					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
I	I													10	11	17	15	10	16
	II													14	20	15	15	15	11
	III													11	19	15	16	18	24
	IV													10	30	13	12	19	15
II	I	13	12	10	16	19	18	6	12	18	23	10	20	10	24	10	19	18	20
	II	15	13	19	27	20	22	6	4	11	18	18	19	10	18	19	17	11	12
	III	10	20	18	25	10	23	10	20	17	16	32	10	8	15	8	13	21	19
	IV	11	13	20	19	15	22	10	13	26	15	30	12	15	14	21	16	17	16
III	I	6	16	11	21	10	18	12	11	14	17	14	11	15	16	18	14	20	16
	II	15	13	11	12	22	10	12	13	10	23	15	17	13	14	16	16	18	18
	III	10	16	14	19	18	15	8	16	16	26	16	12	22	20	13	29	19	19
	IV	7	13	13	13	14	26	16	13	14	17	13	12	11	12	16	19	20	31
IV	I	11	12	17	16	12	23	14	12	21	14	18	33	12	19	12	19	22	19
	II	11	12	12	12	16	17	15	13	10	14	15	15	11	19	22	19	18	24
	III	11	18	19	19	21	21	19	18	13	15	12	16	18	18	24	16	18	22
	IV	9	18	19	22	17	17	20	16	17	24	17	18	19	13	15	18	30	24

1954. "Levels of phosphorus" experiments

Appendix II.b

Tuber: effect of treatments on fresh weight per plant. (g)

		Barbauchlaw						Shawfair						Dryden					
		Treatments						Treatments						Treatments					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
I	I													157	142	132	111	183	169
	II													124	121	125	121	119	202
	III													47	148	257	140	124	108
	IV													109	175	142	119	124	118
II	I	229	394	268	313	303	354	38	86	270	364	59	403	396	1539	687	1362	686	706
	II	208	321	387	427	352	458	135	135	26	449	81	474	551	1530	579	769	462	749
	III	80	354	353	550	320	409	109	1137	176	64	457	87	539	770	1440	565	1267	1277
	IV	174	243	371	354	270	497	43	108	595	312	451	136	753	626	1056	1512	1022	635
7 III	I	224	639	499	758	503	805	462	1429	694	1022	626	1009	975	1503	1235	1126	1277	612
	II	228	558	497	714	566	492	898	899	1523	422	893	1120	1105	1738	1295	1173	966	496
	III	400	676	953	733	895	833	531	786	953	1322	967	818	1014	1541	732	1119	856	465
	IV	276	682	840	727	706	992	1199	743	631	1386	1219	518	1057	584	1103	1427	1117	1682
IV	I	460	473	974	880	1062	862	464	1605	1201	1485	1496	1262	1460	1402	1286	1393	654	1523
	II	316	665	739	377	911	981	1032	962	1192	1167	585	734	772	1148	1373	1336	1076	774
	III	383	767	1272	1281	1085	1081	1523	786	1047	1165	56	993	1301	1526	1628	875	1323	1012
	IV	436	788	1119	1180	633	885	1457	950	1784	1634	1435	1577	947	1171	840	1286	1396	1042

1954. "Levels of phosphorus" experiments

Appendix II.c.

Tuber: effect of treatments on % dry matter.

		Barbauchlaw						Shawfair						Dryden					
		Treatments						Treatments						Treatments					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
I	I													18.0	16.2	15.2	17.2	15.0	16.3
	II													19.7	16.7	17.7	17.2	17.2	16.2
	III													18.8	17.7	16.3	17.6	16.9	17.6
	IV													19.2	16.3	18.9	16.1	18.5	17.1
II	I	17.4	17.1	18.2	18.1	18.5	19.6	13.5	13.9	15.9	14.5	14.1	16.1	17.6	16.8	16.8	17.0	15.9	16.9
	II	18.1	18.3	18.9	18.9	20.8	18.6	14.8	13.7	16.0	15.6	16.8	16.3	15.1	18.7	17.4	18.0	17.2	16.2
	III	19.4	18.0	18.4	17.0	18.0	18.0	13.8	14.7	15.0	11.5	15.4	14.4	16.8	17.5	16.2	16.1	19.0	15.9
	IV	18.5	18.1	18.5	18.8	18.3	20.5	14.1	14.5	17.2	16.7	14.7	14.9	18.7	17.0	19.0	17.7	18.2	16.4
III	I	17.1	17.1	17.8	19.8	18.5	19.9	16.4	18.4	18.2	16.9	20.4	18.7	18.8	19.7	19.9	18.6	22.0	18.7
	II	18.1	18.2	19.0	19.9	19.5	20.4	18.8	17.6	19.5	18.4	19.0	18.4	19.2	20.8	20.3	18.7	18.4	18.0
	III	18.2	17.8	18.0	19.1	19.5	19.5	17.4	18.6	18.3	18.0	19.1	21.4	19.6	18.8	18.9	20.6	20.4	19.6
	IV	17.3	18.6	19.0	17.8	20.6	20.8	20.4	19.7	15.4	18.0	15.7	20.4	19.1	20.5	17.4	18.8	19.8	23.5
IV	I	20.3	21.6	21.4	22.2	19.9	23.0	17.8	18.5	18.9	15.7	17.4	18.8	19.7	18.4	20.5	20.2	21.2	21.1
	II	20.9	21.4	22.3	21.1	22.9	22.4	18.8	17.2	19.2	16.5	18.8	20.2	20.6	20.3	21.5	20.3	19.8	20.5
	III	18.6	19.8	20.6	20.6	22.5	20.9	19.3	19.9	21.3	17.2	20.2	17.3	19.7	19.8	21.5	19.1	20.0	18.7
	IV	18.6	20.9	21.3	21.9	21.2	21.4	19.3	23.0	16.7	19.5	18.6	18.8	19.9	18.9	20.1	21.2	20.1	19.3

1954. "Levels of Phosphorus" experiments

Appendix II.d

Tubers: effect of treatments on:

		Barbauchlaw						Shawfair						Dryden					
		Treatment						Treatment						Treatment					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
Ware (tons/acre)																			
IV	I	0.2	1.6	0.7	0.7	1.0	1.2	2.6	3.1	2.2	2.7	2.4	2.4	2.6	2.6	1.8	2.7	2.1	1.0
	II	-	0.8	1.5	0.8	1.0	0.6	4.1	4.3	3.3	4.7	2.4	3.5	1.9	2.0	1.2	3.3	-	1.0
	III	-	0.2	0.9	1.0	0.6	0.3	2.4	2.7	2.7	2.9	2.6	2.0	1.7	1.6	1.8	2.4	2.0	1.2
	IV	-	0.4	0.9	0.7	0.4	0.7	0.1	4.7	3.5	3.9	2.7	3.3	1.9	2.9	2.8	1.6	0.3	1.5
Seed (tons/acre)																			
IV	I	4.2	6.5	8.8	8.6	9.1	9.5	5.2	6.9	8.0	8.7	8.5	8.4	0.44	0.44	0.39	0.39	0.29	0.39
	II	2.4	8.2	7.9	7.8	8.9	9.8	8.7	7.0	6.5	7.4	8.3	7.1	0.19	0.29	0.19	0.29	0.49	0.25
	III	2.7	7.9	8.8	9.2	7.4	10.7	8.5	8.6	8.4	6.0	9.5	5.9	0.29	2.39	0.35	0.19	0.39	0.39
	IV	3.2	5.0	9.5	8.5	8.8	7.7	8.8	6.9	8.6	8.4	6.9	6.3	0.29	0.19	0.39	0.44	0.79	0.29
Chats (tons/acre)																			
IV	I	0.20	0.20	0.59	0.29	0.39	0.39	0.29	0.39	0.59	0.59	0.79	0.49	0.44	0.44	0.39	0.39	0.29	0.39
	II	0.29	0.29	0.29	0.20	0.29	0.39	0.49	0.49	0.29	0.29	0.39	0.39	0.19	0.29	0.19	0.29	0.49	0.25
	III	0.49	0.69	0.29	0.39	0.29	0.69	0.49	0.49	0.39	0.69	0.49	0.39	0.29	0.39	0.34	0.19	0.39	0.39
	IV	0.20	0.29	0.39	0.39	0.39	0.30	0.49	0.29	0.59	0.59	0.79	0.49	0.29	0.19	0.39	0.44	0.49	0.29
Total Yield (tons/acre)																			
IV	I	4.6	8.3	10.1	9.6	10.5	11.1	8.1	10.4	10.8	12.0	12.4	11.4	10.6	9.6	7.5	11.1	9.8	9.3
	II	2.7	7.3	9.6	8.7	10.2	10.8	13.0	12.0	10.0	13.0	11.0	11.2	8.8	11.2	11.5	10.9	7.8	9.2
	III	3.1	8.8	10.0	10.6	8.3	11.7	11.4	12.0	11.6	9.6	12.4	8.2	9.6	10.6	9.1	7.9	10.5	7.9
	IV	3.4	5.7	10.6	9.5	9.5	8.7	13.6	12.0	12.6	13.0	10.4	10.2	9.2	11.6	11.6	11.4	8.9	9.0

1954. "Levels of phosphorus" experiments

Appendix III.a

Shoot: effect of treatments on uptake of total P_2O_5 (% dry matter)

		Barbauchlaw						Shawfair						Dryden					
		Treatments						Treatments						Treatments					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
I	I	0.59	0.81	0.99	1.02	1.21	1.31	1.53	1.49	1.59	1.51	1.78	1.85	0.83	0.99	0.94	1.06	1.05	1.21
II		0.48	0.48	0.50	0.59	0.83	0.72							0.67	0.63	0.81	0.68	0.88	1.09
III	I	0.52	0.51	0.39	0.46	0.68	0.62	0.73	0.58	0.60	0.70	0.65	0.73	0.58	0.45	0.55	0.75	0.74	1.15
	II	0.57	0.44	0.41	0.43	0.61	0.73	0.57	0.59	0.66	0.69	0.61	0.68	0.50	0.46	0.83	0.50	0.68	1.22
	III	0.53	0.38	0.52	0.41	0.50	0.64	0.69	0.61	0.57	0.52	0.63	0.58	0.46	0.57	0.51	0.45	0.55	1.13
	IV	0.49	0.43	0.33	0.46	0.50	0.59	0.71	0.58	0.82	0.95	1.04	0.74	0.42	0.52	0.78	0.52	0.59	0.85
IV		0.38	0.30	0.25	0.25	0.28	0.30	0.44	0.46	0.46	0.54	0.49	0.70	0.29	0.27	0.35	0.44	0.32	0.50

N.B. Figures rounded to two decimal places

1954. "Levels of phosphorus" experiments

Appendix III.b

Root: effect of treatments on the uptake of total P_2O_5 (% dry matter)

		Barbauchlaw						Shawfair						Dryden					
		Treatments						Treatments						Treatments					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
I		0.43	0.57	0.64	0.66	0.86	0.98	1.12	1.00	1.08	1.04	1.55	1.44	0.70	0.79	0.79	0.91	0.91	1.09
II		0.30	0.28	0.32	0.35	0.43	0.62	0.60	0.64	0.69	0.65	0.76	0.86	0.60	0.54	0.68	0.66	0.81	1.03
III	I	0.35	0.31	0.29	0.28	0.45	0.50	0.45	0.38	0.40	0.63	0.31	0.53	0.33	0.33	0.47	0.64	0.54	0.43
	II	0.32	0.27	0.30	0.33	0.33	0.53	0.35	0.42	0.54	0.68	0.49	0.85	0.32	0.23	0.42	0.22	0.70	0.79
	III	0.29	0.27	0.31	0.29	0.34	0.48	0.46	0.41	0.38	0.41	0.58	0.43	0.53	0.37	0.38	0.43	0.50	0.63
	IV	0.35	0.26	0.28	0.35	0.30	0.43	0.51	0.42	0.70	0.79	0.98	0.66	0.36	0.42	0.58	0.51	0.55	0.82
IV		0.20	0.19	0.16	0.17	0.18	0.28	0.34	0.34	0.43	0.47	0.42	0.71	0.21	0.17	0.30	0.18	0.27	0.27

N.B. Figures rounded to two decimal places.

1954. "Levels of phosphorus" experiments

Appendix III.c

Tuber: effect of treatments on uptake of total P_2O_5 (% dry matter)

		Barbauchlaw						Shawfair						Dryden					
		Treatments						Treatments						Treatments					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
I														0.70	0.85	0.76	0.92	0.91	0.92
II		0.38	0.31	0.34	0.44	0.50	0.60	0.83	0.80	0.80	0.78	0.85	0.87	0.64	0.62	0.73	0.72	0.77	0.90
III	I	0.35	0.37	0.45	0.40	0.58	0.54	0.69	0.53	0.53	0.79	0.54	0.61	0.61	0.58	0.60	0.81	0.67	0.91
	II	0.30	0.32	0.36	0.36	0.45	0.53	0.48	0.56	0.58	0.70	0.53	0.73	0.47	0.45	0.68	0.97	0.76	0.63
	III	0.28	0.27	0.38	0.32	0.40	0.55	0.53	0.49	0.44	0.55	0.64	0.57	0.71	0.63	0.71	0.52	0.54	0.75
	IV	0.30	0.28	0.28	0.34	0.38	0.52	0.66	0.57	0.75	0.71	0.86	0.66	0.57	0.58	0.78	0.71	0.73	0.72
IV		0.31	0.34	0.36	0.39	0.51	0.65	0.68	0.64	0.65	0.65	0.68	0.83	0.53	0.64	0.69	0.68	0.74	0.86

N.B. Figures rounded to two decimal places

1954 "Phosphorus from different fertilizer Materials"

Effect of treatments on

		Appendix IV Population (15 sq. yds.) Treatments						Appendix IV Sprouts per hill Treatments					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F
I	I	43	47	39	40	43	43	3.3	3.9	3.0	2.9	3.4	3.3
	II	44	50	45	43	46	44	3.2	3.1	3.2	2.4	3.2	3.1
	III	44	45	42	46	47	39	2.8	2.6	2.4	2.3	2.5	3.3
	IV	42	40	48	46	48	45	2.5	2.9	2.9	2.4	2.6	2.9

		Appendix IV.a Height (cms.) Treatments					
Observation	Replication	A	B	C	D	E	F
I	I	43	52	42	36	46	47
	II	42	50	45	47	44	49
	III	33	36	41	33	32	33
	IV	39	39	42	36	44	41
II	I	89	86	89	91	83	84
	II	89	97	80	76	74	82
	III	80	90	100	91	81	80
	IV	98	96	89	91	91	83
III	I	95	91	96	101	90	91
	II	108	103	88	88	86	95
	III	83	86	108	99	87	86
	IV	104	99	94	98	95	86
IV	I	96	93	98	102	91	92
	II	109	105	89	89	87	94
	III	85	97	110	101	88	87
	IV	106	103	95	99	97	87

1954. "Phosphorus from different fertilizer Materials".

Effect of treatments on:

Appendix IV.b

Shoot fresh weight (g)

Observation	Replication	A	B	C	D	E	F
		Treatments					
I	I	350	531	318	335	376	403
	II	385	426	306	322	216	466
	III	361	564	455	327	384	164
	IV	306	492	449	375	358	201
II	I	575	457	436	684	911	549
	II	859	633	559	513	402	472
	III	439	436	686	625	358	591
	IV	533	728	617	281	600	865
III	I	392	399	571	246	260	227
	II	728	328	243	135	403	332
	III	137	466	435	611	262	496
	IV	716	519	806	771	251	254
	I	66	37	63	111	54	58
	II	91	56	54	46	48	52
	III	99	83	98	43	68	95
	IV	71	58	76	43	78	73

Appendix IV.c

Shoot dry matter (%)

Observation	Replication	A	B	C	D	E	F
		Treatments					
I	I	10	11	13	10	12	11
	II	11	11	11	13	14	13
	III	13	11	13	13	13	12
	IV	15	11	10	13	12	13
II	I	11	11	11	11	10	11
	II	11	12	11	9	11	10
	III	13	11	11	13	12	15
	IV	11	10	14	10	10	9
III	I	17	16	18	20	21	20
	II	16	16	21	23	13	18
	III	24	16	16	17	22	17
	IV	15	17	17	15	16	17
	I	45	56	44	34	56	55
	II	47	63	55	33	40	55
	III	43	50	42	55	54	44
	IV	51	58	62	54	46	46

Appendix IV.d

Root fresh weight (g)

Observation	Replication	A	B	C	D	E	F
		Treatments					
I	I	65	55	36	27	40	38
	II	30	37	40	31	20	35
	III	43	49	47	29	32	16
	IV	21	30	34	28	25	18
II	I	38	53	43	71	68	46
	II	78	54	50	44	48	44
	III	27	48	34	60	39	47
	IV	23	63	53	19	31	43
III	I	32	49	38	19	28	32
	II	53	30	34	25	31	42
	III	22	24	32	34	26	37
	IV	38	34	31	58	35	23
	I	27	14	17	23	30	26
	II	40	28	20	54	20	26
	III	40	27	21	14	22	30
	IV	18	20	17	18	22	28

Appendix IV.e

Root dry matter (%)

Observation	Replication	A	B	C	D	E	F
		Treatments					
I	I	23	25	25	27	27	25
	II	27	26	33	25	27	26
	III	25	21	30	25	30	32
	IV	31	24	27	30	26	30
II	I	23	22	24	23	23	24
	II	24	23	29	29	25	28
	III	28	27	26	28	34	29
	IV	29	25	28	22	27	25
III	I	25	27	29	32	30	25
	II	24	24	29	29	32	21
	III	28	23	27	26	31	29
	IV	26	29	27	23	27	21
	I	31	42	45	31	33	30
	II	31	28	31	29	29	32
	III	30	28	27	32	31	30
	IV	31	28	30	30	28	29

1954. "Phosphorus from different fertilizer Materials"

Effect of treatments on:

		Appendix V.a						Appendix V.b						Appendix V.c					
		Number of tubers per plant						Tuber fresh weight (g)						Tuber dry matter (%)					
		Treatments						Treatments						Treatments					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
I	I	26	17	18	13	18	24	203	315	203	167	316	124	14.8	15.9	16.4	17.0	15.5	16.7
	II	19	12	10	9	20	17	189	205	106	147	146	262	16.1	16.0	14.5	15.3	16.6	17.3
	III	17	18	19	13	11	10	164	301	148	134	64	55	17.0	15.1	15.6	16.5	15.5	16.7
	IV	9	14	16	14	10	10	101	221	197	156	102	61	18.3	16.2	15.9	15.4	15.3	17.0
II	I	9	17	18	23	26	12	612	874	706	1030	1083	699	14.0	18.5	19.5	17.8	17.3	16.4
	II	24	15	17	12	17	18	1369	874	804	690	807	970	18.1	18.7	16.9	14.1	18.8	17.9
	III	8	15	14	19	19	13	397	643	619	970	743	727	15.6	16.7	16.9	19.9	18.7	16.4
	IV	10	22	21	7	11	21	413	910	890	896	544	779	17.6	16.9	17.1	14.9	17.8	15.5
III	I	24	22	21	13	19	22	1304	1018	792	1192	984	1079	17.3	19.8	20.1	17.7	20.2	20.6
	II	12	15	18	22	19	16	645	839	1062	740	1596	1462	18.2	19.5	19.6	18.6	19.3	20.3
	III	6	8	15	11	12	13	285	693	613	957	455	845	16.9	18.8	20.2	20.2	20.5	17.4
	IV	16	14	15	15	19	12	1019	879	1217	1166	887	676	18.8	18.1	19.4	17.7	20.1	18.4
IV	I	16	11	16	11	19	19	1308	996	1478	972	1328	1049	20.6	21.0	21.3	19.3	18.8	19.4
	II	13	14	14	18	16	17	844	1106	941	1698	777	1047	17.6	20.2	18.5	22.3	20.4	20.6
	III	12	11	12	8	18	18	1211	916	1078	704	1383	1369	18.8	19.5	17.1	18.4	20.1	18.6
	IV	7	9	13	13	16	19	785	822	1187	912	1213	1332	18.5	18.4	18.9	19.3	20.4	20.0

1954. "Phosphorus from different fertilizer Materials"

Effect of treatments on tuber

Appendix V.d Ware (tons per acre) Treatments						Appendix V.e Seed (tons per acre) Treatments						Appendix V.f Chats (tons per acre) Treatments						Appendix V.g Total yield (tons per acre) Treatments					
A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
2.2	1.0	1.2	1.6	1.4	0.4	6.3	8.6	6.9	5.5	8.1	7.9	0.2	0.4	0.2	0.2	0.4	0.6	8.7	10.0	8.3	7.3	9.9	8.8
2.0	2.0	0.8	2.6	3.1	1.6	6.9	8.6	8.1	4.9	9.2	8.1	0.2	0.4	0.2	0.2	0.4	0.2	9.1	11.0	8.7	7.7	12.7	9.9
2.0	2.6	2.4	1.8	2.0	1.0	7.1	5.5	6.3	4.9	6.1	4.9	0.2	0.2	0.2	0.2	0.2	0.2	9.3	8.3	8.9	6.9	8.3	6.1
1.4	1.8	2.0	1.4	2.6	1.8	6.9	4.7	5.9	5.5	6.1	6.3	0.2	0.2	0.2	0.2	0.2	0.2	8.5	6.7	8.3	7.1	8.9	8.3

1954. "Phosphorus from different fertilizer Materials"

Effect of treatments on uptake of P_2O_5

Observation	Replication	Appendix VI.a Shoot Treatments A	B	C	D	E	F	Appendix VI.b Root Treatments A	B	C	D	E	F	Appendix VI.c Tuber Treatments A	B	C	D	E	F
I		0.91	1.07	1.12	0.70	1.05	0.99	0.65	0.74	0.89	0.95	0.84	0.69	0.79	0.82	0.93	0.83	0.81	0.84
II		0.65	0.67	0.67	0.67	0.67	0.70	0.54	0.51	0.60	0.48	0.56	0.53	0.49	0.68	0.67	0.72	0.57	0.58
III	I	0.41	0.35	0.56	0.49	0.40	0.53	0.37	0.28	0.50	0.40	0.23	0.26	0.55	0.49	0.66	0.46	0.45	0.67
	II	0.44	0.40	0.46	0.48	0.55	0.27	0.42	0.38	0.31	0.33	0.36	0.18	0.56	0.84	0.61	0.51	0.48	0.67
	III	0.45	0.66	0.76	0.48	0.38	0.53	0.36	0.55	0.51	0.36	0.38	0.42	0.59	0.68	0.72	0.51	0.47	0.49
	IV	0.60	0.79	0.68	0.52	0.42	0.45	0.43	0.65	0.63	0.38	0.31	0.42	0.42	0.70	0.70	0.60	0.65	0.57
IV		0.26	0.34	0.31	0.32	0.31	0.27	0.12	0.18	0.18	-	0.14	0.15	0.54	0.63	0.64	0.57	0.57	0.58

1955. "Levels of Phosphorus" experiments

Appendix VII.a

Effect of treatments on population.

	Barbauchlaw Treatment										Boghall Treatment									
	N_1					N_2					N_1					N_2				
Replication	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4
I	111	103	93	119	120	116	112	108	115	110	105	112	112	112	99	95	113	107	112	109
II	110	113	117	119	114	107	116	106	108	112	106	114	100	102	109	101	101	108	109	106
III	112	117	119	117	101	108	110	120	115	109	104	112	102	107	105	99	108	108	108	101
IV	118	117	112	116	107	103	108	106	115	119	105	110	104	107	102	100	106	107	109	105
V	107	106	103	110	105	104	115	105	107	120	105	112	101	108	104	100	103	106	105	105

Appendix VII.b

Effect of treatments on number of sprouts per hill

	Barbauchlaw Treatment										Boghall Treatment									
	N_1					N_2					N_1					N_2				
Replication	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4
I	1.7	2.6	2.5	2.0	2.0	2.1	1.6	1.9	2.1	1.7	2.4	2.2	3.2	3.0	2.2	2.5	1.9	2.6	2.7	1.8
II	1.6	2.0	2.5	2.6	2.4	2.0	2.6	1.9	2.7	2.1	2.5	2.9	3.0	2.5	2.9	3.1	2.9	2.4	2.8	2.6
III	1.9	2.0	3.0	2.7	2.4	2.4	1.9	2.8	1.9	3.2	2.3	2.4	2.8	2.8	2.7	2.3	2.8	2.8	2.6	2.5
IV	2.3	1.4	1.8	1.9	2.1	2.1	2.3	2.5	2.1	2.4	2.1	2.4	2.5	2.4	3.0	2.5	2.9	2.4	3.3	2.8
V	2.1	2.3	1.8	1.9	1.9	2.2	2.3	1.8	1.7	2.3	2.4	2.0	3.4	3.0	2.6	2.5	1.9	3.1	1.9	2.6

1955. "Levels of Phosphorus" experiments

Appendix VII.c

Shoot: effect of treatments on height (cms.)

		Barbauchlaw Treatment										Boghall Treatment									
		N_1					N_2					N_1					N_2				
Observation	Replication	P_o	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4
	I	22	35	39	49	54	19	37	45	49	54	29	30	33	39	40	40	31	42	27	33
	II	20	39	44	48	50	18	36	40	49	50	24	33	27	34	32	22	41	30	26	28
I	III	20	40	40	50	49	19	40	44	41	49	28	35	29	38	36	26	27	27	35	31
	IV	20	32	43	47	50	20	39	40	43	49	32	27	34	30	37	33	35	28	37	31
	V	18	27	35	49	47	17	30	40	45	45	33	34	34	34	31	27	32	38	33	31
	I	38	37	46	58	58	45	52	54	60	64	59	70	64	67	65	64	67	64	65	61
	II	41	48	55	54	61	45	42	50	60	59	56	64	62	67	66	68	68	72	63	66
II	III	40	50	45	59	62	40	50	55	57	57	53	67	62	70	67	58	64	67	69	75
	IV	42	46	54	57	59	40	47	55	60	61	58	60	63	68	63	70	67	78	67	64
	V	35	45	45	58	58	30	45	55	57	55	59	71	66	66	63	62	69	71	67	65
	I	39	39	47	55	56	43	54	54	62	61	64	70	69	73	69	72	67	64	73	66
	II	43	51	52	54	62	47	44	52	66	60	57	66	63	67	67	61	74	67	63	65
III	III	42	53	46	56	63	44	53	56	61	63	56	62	63	73	71	60	67	69	70	77
	IV	43	47	53	66	58	38	50	56	63	62	64	61	64	60	66	68	68	71	68	70
	V	34	44	52	59	58	35	47	57	58	60	57	64	70	68	68	62	69	68	69	71

1955. "Levels of Phosphorus" experiments

Appendix VII.d

Shoot: effect of treatments on fresh weight (g)

		Barbauchlaw Treatment										Boghall Treatment									
		N_1					N_2					N_1					N_2				
Observation	Replication	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4
	I	56	133	213	275	207	84	159	211	250	142	79	143	243	271	191	293	234	277	205	220
	II	32	138	137	241	164	24	152	230	184	223	113	144	102	239	208	122	319	114	230	185
I	III	41	165	158	250	313	21	121	82	192	285	115	129	265	194	242	71	224	187	237	163
	IV	68	40	178	233	244	59	91	214	148	230	157	206	199	193	184	92	180	201	155	232
	V	35	121	200	181	252	103	122	83	220	404	183	303	237	261	347	179	189	179	223	384
	I	127	196	286	379	273	146	244	230	317	342	208	379	374	361	259	443	373	347	298	310
	II	92	225	243	332	202	115	215	278	320	257	287	285	261	373	410	372	393	344	197	493
II	III	102	185	203	273	527	112	155	327	361	406	291	326	346	356	393	213	396	302	265	298
	IV	110	126	215	260	526	132	120	312	236	294	251	363	325	275	331	275	418	417	500	426
	V	93	231	333	197	144	170	132	163	292	341	228	424	425	253	431	398	358	328	472	308
	I	100	47	40	133	57	47	107	68	90	110	366	217	329	238	125	167	315	374	202	298
	II	25	93	62	46	103	100	62	46	86	29	202	214	377	289	334	370	390	240	334	445
III	III	66	40	52	39	145	50	88	124	84	54	284	259	204	289	258	369	214	272	364	398
	IV	48	89	99	94	163	128	57	97	90	145	239	281	339	234	146	197	302	284	359	320
	V	50	24	146	29	192	75	112	145	47	145	250	189	393	281	175	227	251	235	313	355

1955. "Levels of Phosphorus" experiments

Appendix VII.e

Shoot: effect of treatments on dry matter(%)

		Barbauchlaw Treatment										Boghall Treatment									
		N_1					N_2					N_1					N_2				
Observation	Replication	P_o	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4
	I	13.8	9.1	9.1	9.1	10.1	12.2	10.6	10.3	10.3	9.6	9.4	8.6	6.1	5.3	7.2	8.2	8.6	6.9	6.7	7.8
	II	14.0	12.2	11.1	8.9	9.3	16.5	10.4	9.9	9.7	9.3	8.6	8.1	7.9	7.8	6.9	8.9	7.1	8.5	8.6	7.5
I	III	13.9	11.3	10.4	9.2	9.3	15.9	11.9	11.7	11.2	9.0	9.3	8.5	8.9	7.4	7.8	9.5	9.1	8.6	9.3	6.6
	IV	12.7	12.9	11.0	8.9	8.3	11.5	12.0	10.6	10.8	8.3	10.5	7.3	7.6	7.0	7.5	10.6	9.0	8.0	6.8	7.5
	V	15.0	10.4	10.7	10.9	9.4	11.9	12.5	10.8	10.2	9.4	8.2	7.1	7.4	7.2	6.4	8.4	8.4	8.0	6.6	7.6
	I	12.0	8.7	8.2	9.5	9.6	10.9	7.7	9.1	8.2	10.7	12.7	10.4	11.5	10.5	11.3	11.5	10.0	11.9	12.2	12.1
	II	11.8	9.8	10.1	8.1	10.4	12.1	8.0	9.8	9.2	9.9	13.7	11.8	12.0	12.1	12.5	12.6	11.2	13.3	13.3	11.7
II	III	12.3	10.5	9.8	7.6	9.5	10.8	9.9	8.4	8.8	8.0	13.2	11.1	10.1	12.0	10.4	12.1	11.2	11.0	12.3	12.6
	IV	9.5	10.5	12.9	12.0	6.5	10.2	12.0	8.9	9.9	11.1	13.3	10.9	11.1	10.7	11.1	11.2	11.7	12.4	11.6	11.7
	V	10.7	10.4	9.4	10.9	11.8	8.8	11.6	9.1	8.9	9.8	10.7	11.6	11.7	11.7	11.4	11.9	11.9	12.6	11.6	10.0
III	I	14.3	20.3	26.2	14.8	28.0	22.0	15.7	19.4	13.9	18.0	10.9	9.8	9.7	8.3	8.8	10.9	9.1	11.5	7.4	11.2
	II	29.3	19.2	17.9	29.0	12.8	15.6	17.0	29.1	14.3	46.0	12.1	11.1	9.6	11.3	9.8	10.2	8.6	8.0	10.4	10.2
	III	20.2	24.8	23.0	27.6	18.2	18.2	22.1	14.5	20.1	23.8	9.7	8.5	10.1	12.9	11.1	10.5	9.3	8.8	10.0	10.9
	IV	17.9	23.0	24.9	14.3	15.3	11.0	19.6	13.1	17.1	16.4	10.4	10.3	9.3	10.7	11.7	11.3	11.5	10.3	9.5	10.4
	V	20.4	32.0	14.6	36.4	14.6	20.3	21.0	13.5	21.7	12.6	10.8	11.2	10.1	9.5	11.0	10.5	10.6	9.8	10.5	11.1

<u>1955. "Levels of Phosphorus" experiments</u>

<u>Appendix VII.f</u>

<u>Root: effect of treatments on fresh weight (g)</u>

		Barbauchlaw Treatment										Boghall Treatment									
		N_1					N_2					N_1					N_2				
Observation	Replication	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4
I	I	13	21	25	39	16	17	15	19	15	13	12	20	31	27	23	29	25	25	28	20
	II	6	16	19	26	19	9	17	26	17	14	16	16	18	33	23	18	28	22	28	18
	III	12	15	22	24	28	8	18	19	19	21	12	19	25	20	21	9	22	22	25	19
	IV	17	7	27	22	14	11	12	23	18	16	19	24	27	25	30	12	21	20	22	26
	V	9	18	24	29	14	29	14	8	21	25	21	29	24	30	33	27	19	17	32	32
II	I	16	30	34	43	25	16	26	26	37	25	15	22	29	26	20	25	28	19	25	18
	II	13	26	27	32	35	17	29	43	23	17	22	20	25	20	28	26	29	30	14	35
	III	13	26	27	28	25	29	24	32	23	34	28	26	19	29	24	16	31	24	15	11
	IV	16	17	23	39	32	17	23	25	24	27	35	32	19	22	26	17	22	33	35	23
	V	16	17	28	23	19	29	16	19	24	21	28	34	35	21	22	35	22	20	32	24
III	I	16	20	20	16	20	22	15	12	25	16	64	69	80	69	61	36	62	82	56	56
	II	6	21	16	11	19	11	16	17	14	8	28	45	90	69	50	60	76	49	58	74
	III	8	15	10	18	14	14	15	14	11	9	38	47	55	44	45	52	56	56	54	91
	IV	13	12	17	23	15	11	14	21	11	13	43	23	71	61	47	28	38	70	66	54
	V	8	12	24	11	18	9	17	16	16	25	40	71	49	53	64	64	56	52	58	67

1955. "Levels of Phosphorus" experiments

Appendix VII.g

Root: effect of treatments on dry matter (%)

		Barbauchlaw Treatment										Boghall Treatment									
		N_1					N_2					N_1					N_2				
Observation	Replication	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4
	I	18.5	16.9	14.6	13.9	19.8	17.7	16.8	15.6	18.3	17.8	14.9	13.2	13.9	13.4	13.6	14.8	13.9	14.8	14.4	14.9
	II	22.2	18.1	14.9	13.1	17.3	18.4	16.4	14.4	16.1	14.8	16.8	14.5	12.7	12.6	15.1	15.3	13.8	13.5	13.1	13.4
I	III	17.6	17.8	15.7	15.3	16.8	20.6	19.3	12.2	16.4	17.5	21.0	13.9	16.1	14.8	14.5	20.4	13.6	13.7	12.4	13.7
	IV	16.3	21.8	16.9	14.1	17.1	15.8	20.8	16.4	13.8	15.1	18.3	14.7	15.2	12.4	10.6	17.0	13.1	16.9	13.5	12.9
	V	20.0	18.1	16.8	16.6	22.3	16.9	18.1	21.7	15.9	15.4	14.9	15.9	13.6	12.2	13.1	18.2	15.6	13.9	12.0	13.8
	I	18.1	10.6	13.4	12.8	13.9	11.9	13.1	11.1	9.8	16.1	19.6	18.9	18.6	19.5	22.5	23.3	21.4	24.0	16.8	21.8
	II	14.8	13.3	13.5	11.9	8.6	11.7	10.6	11.7	12.4	15.8	21.6	20.2	18.1	17.9	21.3	20.9	18.5	18.6	22.6	19.0
II	III	13.8	12.5	13.9	12.0	15.9	11.7	11.2	12.3	13.8	11.9	18.6	18.4	18.1	17.0	19.3	20.8	17.5	20.8	24.7	26.1
	IV	12.1	15.9	14.5	12.3	12.6	12.1	13.0	13.5	12.9	12.0	21.8	15.3	19.0	16.7	17.9	21.7	24.1	19.0	19.2	20.8
	V	13.8	16.0	12.2	12.0	17.9	11.4	14.5	13.1	14.1	13.2	19.3	17.3	18.9	20.8	20.7	20.8	20.1	19.5	17.9	18.8
	I	20.1	13.9	13.2	34.3	28.0	19.1	23.7	27.1	12.9	19.8	18.0	12.2	15.2	13.7	15.2	19.8	15.2	18.3	13.6	16.7
	II	27.6	14.7	19.9	23.4	15.8	25.3	17.6	19.6	20.9	28.0	20.6	15.8	13.9	16.3	18.1	18.8	14.5	15.2	16.3	16.1
III	III	26.6	16.8	27.3	20.4	21.7	24.1	23.8	21.6	27.8	29.5	19.1	14.6	14.2	14.0	18.6	17.8	15.3	16.1	15.3	16.9
	IV	20.4	24.7	19.2	14.7	22.3	20.7	19.7	14.7	24.1	21.4	16.2	16.6	15.6	15.1	20.7	18.7	18.8	16.0	15.6	16.9
	V	22.1	18.1	17.4	24.5	21.9	27.8	27.2	21.1	16.6	17.4	20.3	16.4	17.4	16.6	14.8	16.3	15.8	16.6	16.4	16.0

1955. "Levels of Phosphorus" experiments

Appendix VIII.a

Tuber: effect of treatments on number of tubers per plant

		Barbauchlaw Treatment										Boghall Treatment									
		N_1					N_2					N_1					N_2				
Observation	Replication	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4
	I	7	7	11	11	13	7	7	7	10	7	6	6	9	14	5	12	7	8	10	8
	II	4	9	4	12	9	4	6	10	7	7	5	4	5	6	3	2	7	4	12	9
I	III	4	6	8	7	11	2	8	3	9	9	6	5	10	7	10	3	8	6	7	4
	IV	8	4	11	5	9	5	10	11	5	9	4	13	15	7	13	4	2	9	8	8
	V	4	9	8	6	4	11	7	4	10	14	5	9	8	12	12	2	4	3	9	7
	I	7	15	26	19	18	7	17	21	20	15	10	9	11	12	14	11	11	8	17	11
	II	5	16	18	19	10	7	27	13	8	16	13	17	7	18	19	15	13	13	9	22
II	III	6	13	7	24	19	9	17	10	19	21	7	13	12	13	17	3	13	18	5	10
	IV	9	20	17	17	20	13	9	22	10	19	10	11	14	9	14	12	16	12	10	15
	V	14	15	13	13	9	25	11	10	15	22	9	12	14	9	14	11	11	9	17	10
	I	19	18	17	20	21	6	15	24	22	13	8	12	17	6	16	8	12	20	10	17
	II	8	19	24	14	18	5	24	17	15	17	9	7	14	10	7	11	13	6	7	11
III	III	7	9	23	17	13	14	13	15	14	14	10	16	7	11	13	13	8	12	8	13
	IV	10	12	12	14	25	24	14	13	13	14	10	9	13	15	15	8	8	7	14	10
	V	12	25	13	22	25	18	18	18	14	25	9	8	11	11	11	9	10	9	8	12

1955. "Levels of Phosphorus" experiments

Appendix VIII.b

Tuber: effect of treatments on fresh weight per plant (g)

		Barbauchlaw Treatment										Boghall Treatment									
		N_1					N_2					N_1					N_2				
Observation	Replication	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4
	I	104	127	214	174	83	138	111	232	161	107	28	20	54	95	53	68	63	25	35	85
	II	60	195	164	197	189	60	168	239	173	105	41	33	53	21	50	6	58	15	102	52
I	III	71	166	184	148	158	62	120	110	169	125	37	19	149	52	32	5	78	16	90	14
	IV	126	33	255	105	104	69	83	218	152	83	24	70	43	65	74	36	7	70	69	53
	V	66	141	126	186	26	126	173	73	221	188	22	70	41	86	56	36	32	41	55	47
II																					
	I	229	448	662	551	511	301	471	464	594	473	254	435	467	628	407	530	668	589	496	518
	II	149	577	614	746	383	178	421	476	547	382	465	562	461	475	651	346	813	444	261	502
II	III	159	457	528	522	686	335	463	389	684	660	590	510	505	542	530	180	554	565	415	365
	IV	269	409	627	634	689	294	311	606	532	402	494	750	671	407	576	417	565	408	611	555
	V	311	363	670	599	450	424	449	445	509	528	668	679	740	657	903	553	585	456	530	556
	I	595	761	700	890	763	305	845	789	887	437	818	709	873	775	1113	566	620	1166	458	783
	II	367	723	689	680	759	468	618	807	643	864	486	885	1043	943	1052	669	1045	668	751	1040
III	III	433	713	795	639	875	480	696	807	679	693	807	729	738	762	945	999	788	940	1067	1198
	IV	389	637	605	733	722	534	499	693	927	773	1298	858	1124	908	722	655	843	1269	898	823
	V	422	755	915	807	627	534	844	809	855	1033	734	854	938	1054	1088	1285	743	316	822	1084

1955. "Levels of Phosphorus" experiments

Appendix VIII.c

Tuber: effect of treatments on dry matter (%)

		Barbauchlaw Treatment										Boghall Treatment									
		N_1					N_2					N_1					N_2				
Observation	Replication	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4
	I	16.5	16.9	16.1	16.5	15.1	17.5	17.7	16.6	16.4	16.3	14.9	13.2	13.9	13.4	13.6	14.8	13.9	14.8	14.4	14.9
	II	16.6	17.3	16.5	16.6	15.5	15.7	16.9	17.3	16.3	15.6	15.1	14.5	14.4	14.2	14.3	14.4	13.8	14.8	15.0	14.0
I	III	16.7	16.1	16.6	19.5	15.6	16.4	17.3	17.1	17.1	15.1	15.3	14.1	15.9	15.0	13.8	14.7	14.2	[illegible]	14.4	13.1
	IV	16.6	16.3	15.5	16.0	15.5	16.8	17.8	17.9	18.7	15.4	15.2	15.9	16.4	14.8	14.4	15.4	12.8	13.3	13.9	14.5
	V	17.0	16.8	15.8	16.6	14.3	16.8	17.5	15.2	16.7	15.1	14.8	13.9	15.2	14.8	14.9	14.3	14.8	14.2	15.0	13.6
	I	18.1	21.1	19.2	24.1	21.6	18.8	24.4	23.0	24.4	20.8	20.9	21.9	19.4	20.7	23.0	19.1	20.0	20.4	20.8	21.9
	II	18.9	21.0	22.5	20.0	20.6	18.9	21.2	20.6	22.7	19.8	20.3	22.1	20.5	19.3	21.3	19.0	20.8	20.7	20.9	21.1
II	III	20.7	21.3	19.7	21.6	19.7	20.3	22.3	22.7	22.0	22.3	20.9	21.0	21.1	21.3	20.4	20.0	21.7	21.4	19.6	17.9
	IV	19.8	20.9	22.5	21.0	19.6	19.2	19.6	20.3	21.7	20.6	20.7	21.4	20.8	21.5	23.0	21.7	20.7	23.7	20.9	21.1
	V	19.2	22.7	18.6	20.8	20.1	17.8	21.2	18.6	21.1	20.3	20.7	20.8	20.5	23.2	23.7	19.9	20.9	22.4	23.4	22.7
	I	20.5	21.2	22.3	19.7	23.4	21.8	22.8	22.9	23.6	21.9	23.7	19.8	22.0	21.0	21.7	20.8	21.6	19.7	19.8	21.2
	II	20.8	22.9	20.5	19.7	22.5	22.8	21.0	22.7	23.2	23.9	21.1	21.0	20.3	20.7	22.2	22.1	21.8	23.1	22.2	23.0
III	III	22.0	20.9	20.2	21.5	24.9	22.2	21.6	22.4	21.3	22.3	23.0	21.1	23.3	21.7	23.8	22.4	22.7	21.6	22.5	21.6
	IV	20.8	21.3	22.2	23.3	23.4	20.2	22.6	22.4	23.3	23.5	22.7	21.0	21.7	20.9	21.7	22.4	21.3	22.1	21.3	21.6
	V	21.3	20.4	21.6	21.8	22.9	20.8	20.8	22.8	22.3	21.9	23.2	22.8	22.6	20.3	22.3	22.9	22.2	22.5	22.6	22.3

1955. "Levels of Phosphorus" experiments

Appendix VIII.d

Tuber: effect of treatments on:

Total yield (tons per acre)

		Barbauchlaw Treatment										Boghall Treatment									
		N_1					N_2					N_1					N_2				
Observation	Replication	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4
	I	11.6	11.4	11.9	14.6	12.9	8.3	14.0	16.2	15.6	16.3	15.4	19.2	17.6	20.5	17.2	15.9	24.6	15.0	14.4	16.9
	II	9.9	14.5	13.7	14.5	13.9	9.4	12.9	14.0	14.3	15.6	15.7	17.4	15.1	17.3	15.0	14.8	19.6	18.3	20.1	20.1
IV	III	10.2	13.7	13.7	15.1	14.5	10.5	13.9	14.8	17.9	15.6	13.8	15.4	15.6	15.9	16.2	14.9	16.0	17.5	16.4	20.2
	IV	10.6	13.2	15.9	15.4	16.6	8.3	14.3	13.9	14.8	15.9	12.1	17.0	14.9	17.2	12.6	15.8	13.2	18.6	15.4	15.2
	V	9.7	12.1	15.1	14.3	14.5	7.5	12.2	13.7	16.3	15.6	13.5	16.8	18.1	15.6	14.6	14.2	17.3	16.9	16.9	15.6

Ware (tons per acre)

	I	7.1	4.9	7.5	8.5	5.5	4.5	9.7	11.6	11.6	10.3	10.8	12.6	10.6	11.3	11.1	11.5	14.9	10.2	9.9	11.1
	II	5.9	10.6	8.3	7.7	7.1	5.5	6.6	9.9	9.1	9.7	9.8	9.5	9.3	10.4	10.2	8.9	14.1	11.9	12.7	14.6
IV	III	6.3	8.8	7.2	8.5	8.2	7.5	10.5	9.5	12.0	8.6	9.1	10.0	10.9	9.4	9.0	9.2	11.7	12.3	10.1	11.7
	IV	6.0	8.3	10.5	9.5	8.0	6.0	9.2	8.9	9.1	9.5	7.5	11.0	8.5	11.1	8.0	10.5	9.1	10.8	9.4	9.8
	V	4.9	8.1	10.6	8.3	7.4	3.2	7.2	8.6	10.9	8.6	9.0	10.2	11.7	10.0	8.9	9.1	12.0	11.1	10.6	9.2

Seed (tons per acre)

	I	4.5	6.3	7.4	6.2	7.1	3.9	4.3	4.6	3.9	5.7	4.5	6.3	6.8	8.9	5.9	4.3	9.2	4.8	4.5	5.6
	II	3.9	3.7	5.2	6.8	6.6	3.9	5.9	4.2	5.1	5.5	5.9	6.9	5.7	6.8	4.7	5.9	5.2	6.2	7.2	5.4
IV	III	3.7	4.8	6.3	6.5	6.3	4.5	3.4	5.1	5.9	6.8	4.6	5.2	4.6	6.5	7.1	5.5	4.2	5.1	6.4	8.2
	IV	4.5	4.9	5.2	5.9	8.5	3.9	5.1	4.8	5.5	6.2	4.5	5.9	6.2	5.8	4.2	5.0	4.1	7.6	5.8	5.2
	V	4.6	4.0	4.2	5.7	6.9	4.2	4.8	4.9	5.2	6.8	4.3	6.4	6.4	5.3	5.8	4.9	5.1	5.3	6.0	6.2

Chats (tons per acre)

	I	0.15	0.31	0.15	0.15	0.46	0.15	0.15	0.15	0.15	0.46	0.08	0.20	0.15	0.23	0.23	0.08	0.23	0.08	0.08	0.23
	II	0.15	0.15	0.15	0.15	0.31	0.15	0.31	0.15	0.31	0.31	0.08	0.23	0.08	0.05	0.08	0.08	0.15	0.23	0.23	0.15
IV	III	0.15	0.15	0.31	0.15	0.15	0.15	0.15	0.15	0.31	0.31	0.08	0.08	0.15	0.08	0.15	0.15	0.08	0.08	0.15	0.23
	IV	0.15	0.15	0.15	0.31	0.15	0.15	0.15	0.31	0.31	0.46	0.15	0.15	0.23	0.23	0.39	0.24	0.15	0.15	0.23	0.23
	V	0.15	0.15	0.31	0.31	0.31	0.15	0.15	0.15	0.31	0.31	0.15	0.24	0.15	0.15	0.23	0.24	0.15	0.39	0.23	0.23

1955. "Levels of Phosphorus" experiments

Appendix IX.a

Shoot: effect of treatments on uptake of total P_2O_5 (% dry matter)

		Barbauchlaw Treatment										Boghall Treatment									
		N_1					N_2					N_1					N_2				
Observation	Replication	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4
	I	0.52	0.60	0.51	0.84	0.79	0.40	0.62	0.63	0.63	0.94	0.78	1.17	1.23	0.90	0.99	0.81	0.98	1.01	1.02	1.28
	II	0.53	0.55	0.55	0.61	0.96	0.58	0.54	0.59	0.76	1.28	1.02	1.22	1.31	1.15	1.60	0.90	0.87	1.33	1.14	1.57
I	III	0.57	0.61	0.54	0.76	0.76	0.55	0.54	0.65	0.72	1.11	0.92	1.05	0.99	1.05	1.21	0.86	0.90	1.16	1.36	1.77
	IV	0.52	0.74	0.51	0.78	0.85	0.43	0.64	0.55	0.62	1.16	0.78	1.12	1.05	1.20	1.28	0.94	1.01	1.36	1.32	1.57
	V	0.53	0.63	0.62	0.58	0.84	0.43	0.71	0.87	0.67	1.07	1.05	1.03	1.22	1.25	1.33	0.74	1.46	1.30	1.33	1.37
II	*	0.52	0.38	0.35	0.34	0.41	0.55	0.42	0.41	0.37	0.49	0.56	0.50	0.57	0.53	0.49	0.63	0.55	0.64	0.66	0.69
	I	0.38	0.23	0.18	0.37	0.23	0.45	0.28	0.28	0.33	0.43	0.38	0.35	0.34	0.32	0.35	0.33	0.37	0.34	0.41	0.40
	II	0.27	0.27	0.31	0.19	0.26	0.42	0.29	0.29	0.33	0.27	0.41	0.33	0.38	0.38	0.42	0.39	0.32	0.31	0.37	0.39
III	III	0.43	0.25	0.24	0.28	0.36	0.41	0.28	0.31	0.35	0.24	0.40	0.37	0.33	0.32	0.31	0.31	0.33	0.39	0.39	0.28
	IV	0.38	0.28	0.28	0.32	0.33	0.41	0.37	0.38	0.30	0.36	0.40	0.30	0.28	0.38	0.31	0.31	0.39	0.37	0.32	0.29
	V	0.39	0.24	0.41	0.25	0.35	0.42	0.28	0.35	0.26	0.37	0.36	0.34	0.32	0.30	0.25	0.29	0.28	0.32	0.33	0.34

* Composite sample

Appendix IX.b

Root: effect of treatments on uptake of total P_2O_5 (% dry matter)

	I	0.27	0.33	0.31	0.50	0.72	0.29	0.36	0.37	0.49	0.69	0.45	0.74	0.76	0.75	0.90	0.56	0.60	0.61	0.97	1.17
	II	0.29	0.28	0.37	0.41	0.47	0.31	0.29	0.37	0.59	1.16	0.46	0.66	0.78	0.89	1.08	0.63	0.70	0.73	0.76	1.27
I	III	0.26	0.36	0.36	0.57	0.72	0.36	0.34	0.39	0.49	0.73	0.44	0.78	0.63	0.84	1.07	0.53	0.66	0.70	0.84	1.21
	IV	0.26	0.43	0.35	0.47	0.80	0.25	0.34	0.34	0.44	1.14	0.53	0.84	0.66	0.86	1.03	0.59	0.69	0.96	0.84	1.07
	V	0.28	0.35	0.37	0.49	0.61	0.26	0.38	0.46	0.42	1.04	0.67	0.74	0.85	0.96	1.08	0.46	0.97	0.84	0.91	1.00
II	*	0.37	0.28	0.20	0.26	0.36	0.31	0.25	0.24	0.24	0.39	0.47	0.56	0.46	0.40	0.52	0.47	0.43	0.54	0.56	0.76
III	I	0.35	0.18	0.13	0.37	0.20	0.29	0.23	0.23	0.23	0.35	0.23	0.24	0.18	0.30	0.27	0.20	0.29	0.35	0.30	0.30
	II	0.27	0.23	0.24	0.14	0.23	0.32	0.24	0.31	0.24	0.20	0.22	0.24	0.26	0.22	0.27	0.32	0.25	0.25	0.38	0.38
	III	0.32	0.26	0.15	0.26	0.32	0.30	0.26	0.23	0.24	0.17	0.24	0.17	0.28	0.21	0.22	0.24	0.25	0.29	0.29	0.25
	IV	0.32	0.23	0.24	0.20	0.28	0.31	0.27	0.26	0.30	0.30	0.25	0.25	0.27	0.25	0.24	0.34	0.38	0.31	0.30	0.33
	V	0.35	0.19	0.27	0.18	0.32	0.29	0.23	0.28	0.19	0.25	0.24	0.23	0.26	0.25	0.38	0.29	0.29	0.29	0.23	0.28

1955. "Levels of Phosphorus" experiments

Appendix IX.c

Tuber: effect of treatments on uptake of P_2O_5 (% dry matter)

Barbauchlaw Treatment

Observation	Replication	N_1 P_0	N_1 P_1	N_1 P_2	N_1 P_3	N_1 P_4	N_2 P_0	N_2 P_1	N_2 P_2	N_2 P_3	N_2 P_4
I	I	0.29	0.37	0.41	0.47	0.71	0.27	0.38	0.43	0.53	0.64
	II	0.31	0.38	0.45	0.52	0.59	0.38	0.33	0.44	0.60	0.92
	III	0.33	0.48	0.51	0.60	0.69	0.37	0.36	0.43	0.50	0.80
	IV	0.31	0.59	0.45	0.55	0.81	0.30	0.44	0.39	0.43	0.88
	V	0.31	0.41	0.47	0.47	0.86	0.32	0.35	0.54	0.49	0.75
II	*	0.36	0.30	0.30	0.33	0.40	0.33	0.27	0.30	0.31	0.39
III	I	0.40	0.27	0.32	0.37	0.33	0.36	0.27	0.27	0.31	0.43
	II	0.34	0.30	0.36	0.33	0.36	0.29	0.26	0.26	0.31	0.40
	III	0.39	0.30	0.33	0.37	0.30	0.29	0.23	0.25	0.29	0.25
	IV	0.29	0.30	0.28	0.29	0.31	0.33	0.25	0.29	0.31	0.41
	V	0.30	0.33	0.26	0.29	0.33	0.33	0.27	0.26	0.35	0.37

Boghall Treatment

Observation	Replication	N_1 P_0	N_1 P_1	N_1 P_2	N_1 P_3	N_1 P_4	N_2 P_0	N_2 P_1	N_2 P_2	N_2 P_3	N_2 P_4
I	I	0.54	0.75	0.74	0.86	0.98	0.63	0.70	1.08	0.84	0.69
	II	0.50	0.71	0.78	1.01	1.03	0.82	0.78	0.95	0.76	0.83
	III	0.50	0.85	0.66	0.90	0.95	0.60	0.61	0.91	0.80	0.98
	IV	0.55	0.74	0.78	0.86	0.78	0.55	0.78	0.89	0.91	0.83
	V	0.76	0.77	0.76	0.87	0.97	0.50	0.89	0.90	0.90	0.88
II	*	0.50	0.43	0.45	0.50	0.50	0.50	0.45	0.48	0.50	0.55
III	I	0.32	0.52	0.43	0.50	0.42	0.50	0.39	0.47	0.59	0.46
	II	0.43	0.36	0.50	0.51	0.47	0.34	0.40	0.45	0.46	0.44
	III	0.40	0.44	0.40	0.45	0.41	0.34	0.44	0.44	0.40	0.48
	IV	0.37	0.46	0.45	0.54	0.48	0.41	0.49	0.45	0.43	0.42
	V	0.40	0.49	0.38	0.50	0.48	0.35	0.47	0.59	0.47	0.43

* Composite sample

Appendix IX.d

Shoot: effect of treatments on uptake of P_2O_5 from fertilizer (% of total)

Observation	Replication	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
I	I	53	58	61	49	68	79	31	27	48	21	30	43
	II	45	55	65	48	57	79	31	41	38	18	23	46
	III	52	52	73	37	52	65	37	39	68	25	52	45
	IV	40	56	57	42	51	69	20	63	42	10	33	46
	V	45	52	56	37	65	67	36	46	51	19	41	53
II	*	21	43	60	31	-	55	15	24	38	13	24	41
III	I	16	37	43	29	36	49	7	21	15	13	16	42
	II	17	50	39	20	33	38	7	13	21	6	24	24
	III	20	40	34	20	33	38	14	6	25	14	19	24
	IV	17	26	40	18	25	59	11	17	28	17	13	31
	V	17	23	40	23	26	45	7	25	21	9	18	30

1955. "Levels of Phosphorus" experiments

Appendix IX.e

Root: effect of treatments on uptake of P_2O_5 from fertilizer (% total)

		Barbauchlaw Treatment						Boghall Treatment					
		N_1			N_2			N_1			N_2		
Observation	Replication	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
	I	31	49	51	43	58	72	10	24	47	18	26	21
	II	36	43	61	38	50	69	27	30	43	18	18	36
I	III	39	46	65	30	51	65	24	33	57	20	45	41
	IV	32	47	54	35	46	56	17	36	38	15	28	43
	V	34	55	58	31	51	62	25	29	29	19	26	35
II	*	14	34	49	23	33	47	9	21	33	12	20	33
	I							8	16	20	9	13	31
	II							17	12	19	8	15	20
III	III*	12	24	29	19	21	37	10	10	21	9	14	21
	IV							8	13	25	12	15	23
	V							8	18	23	10	12	29

* Composite sample

Appendix IX.f

Tuber : effect of treatments on uptake of P_2O_5 from fertilizer (% total)

	I	43	59	69	51	58	82	12	55	41	16	28	43
	II	42	52	74	49	62	71	24	29	41	17	39	33
I	III	40	58	70	41	54	65	31	32	40	24	38	38
	IV	27	59	48	42	60	60	20	42	39	20	26	48
	V	52	67	61	42	50	76	28	40	38	22	32	53
II	*	22	49	64	38	49	64	16	31	41	16	27	37
	I	32	51	63	43	60	71	19	25	37	12	16	34
	II	28	44	70	39	59	57	13	20	33	9	23	40
III	III	25	57	58	24	43	65	15	21	40	16	21	36
	IV	34	47	58	27	50	73	20	26	39	19	22	37
	V	21	42	54	28	44	54	10	33	36	19	19	36

1955. "Phosphorus from different fertilizer Materials"

Effect of treatment on:

		Appendix X.a						Appendix X.b						Appendix X.c					
		Population						Sprouts per hill						Height (cms.)					
		Treatments						Treatments						Treatment					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
	I	119	117	124	122	123	120	2.2	2.4	1.9	2.2	2.5	2.5	19	29	24	29	27	40
	II	119	122	116	118	120	119	1.7	1.8	2.1	2.2	1.8	2.1	18	31	38	39	25	42
I	III	117	124	116	112	107	120	2.7	1.2	1.4	2.2	2.6	1.6	19	37	37	27	26	36
	IV	121	117	126	118	116	122	1.6	1.6	2.2	2.3	1.8	1.9	18	34	39	28	29	36
	V	113	117	115	112	122	117	1.8	1.9	1.9	2.0	1.8	1.4	18	36	38	24	28	40
	I													35	53	59	39	42	49
	II													38	50	55	42	42	59
II	III													40	53	56	45	49	50
	IV													37	50	54	45	48	53
	V													36	47	59	43	43	53
	I													38	55	61	41	43	51
	II													41	50	59	45	45	65
III	III													41	55	56	47	55	53
	IV													40	52	56	49	52	54
	V													42	49	60	46	42	57

1955. "Phosphorus from different fertiliser Material"

Effect of treatments on:

		Appendix X.d Shoot fresh weight (g)						Appendix X.e Shoot dry matter (%)						Appendix X.f Root fresh weight (g)						Appendix X.g Root dry matter (%)					
		Treatment						Treatment						Treatment						Treatment					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
I	I	50	197	213	73	62	157	15.2	11.6	11.6	14.6	15.4	12.1	8	14	18	8	6	8	27.6	20.0	19.3	20.3	26.5	22.5
	II	55	86	116	97	54	147	14.0	13.8	11.8	14.9	16.6	13.3	12	10	6	9	3	12	26.6	17.1	23.7	33.2	48.8	22.3
	III	32	175	148	50	145	195	20.9	12.6	13.8	17.2	10.8	13.8	7	12	17	4	16	16	33.2	26.2	17.2	43.2	16.6	19.5
	IV	23	54	213	49	51	119	19.8	16.6	12.3	17.0	13.9	13.4	6	4	20	4	4	12	29.4	26.0	18.4	36.6	34.1	17.1
	V	22	147	117	44	76	218	20.2	11.9	11.8	17.9	14.9	11.0	4	16	10	7	9	13	36.0	22.3	25.5	28.4	22.9	20.0
II	I	109	139	262	74	135	179	11.8	13.3	12.6	10.9	12.8	12.0	15	11	23	17	12	8	15.3	15.9	14.6	12.6	19.3	23.6
	II	105	178	244	98	199	284	12.3	10.6	11.1	15.1	14.9	11.8	18	20	17	11	17	29	15.9	15.1	17.5	19.9	20.5	14.5
	III	58	185	266	102	136	256	14.6	12.1	11.2	14.3	12.9	11.0	7	16	24	10	14	21	20.3	18.8	15.2	19.5	19.3	16.8
	IV	67	119	260	113	67	154	16.2	13.6	11.9	12.2	14.1	11.6	13	13	18	12	11	18	15.6	15.5	17.3	16.6	17.3	13.7
	V	71	180	259	94	98	193	13.7	13.2	11.4	13.9	13.7	11.6	8	17	22	9	17	19	19.0	18.6	15.7	19.0	18.8	17.2
III	I	42	44	122	79	130	67	17.2	28.7	18.7	16.8	16.6	18.5	14	12	8	12	11	9	17.9	23.0	48.2	20.7	21.3	20.3
	II	79	54	113	109	102	181	15.1	20.2	18.0	16.5	20.6	14.9	15	13	10	16	8	18	16.6	21.2	26.1	22.0	29.9	19.3
	III	70	94	163	62	140	81	21.6	16.6	18.7	18.6	20.6	18.1	7	13	18	9	19	10	29.3	26.0	22.6	25.1	25.3	24.2
	IV	50	137	148	82	93	72	18.3	15.3	16.9	20.7	19.5	24.0	8	12	19	6	8	12	22.6	25.6	20.3	23.6	26.2	27.1
	V	78	65	127	110	43	72	17.4	26.2	21.9	20.0	25.7	25.1	11	11	12	11	9	11	21.5	27.9	28.6	26.4	26.8	33.0

1955. "Phosphorus from different fertilizer Materials"

Appendix XL.a | Appendix XI.b | Appendix XI.c

Tuber: effect of treatments on:

		Number						Fresh weight (g.)						Dry matter (%)					
		Treatment						Treatment						Treatment					
Observation	Replication	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
	I	7	8	7	5	5	6	35	158	167	52	74	85	18.5	17.8	16.7	19.8	18.3	17.2
	II	6	6	5	8	6	6	103	63	67	101	64	128	17.4	17.9	17.1	20.6	17.7	17.2
I	III	7	13	5	3	10	5	62	79	143	35	156	173	17.8	18.3	18.0	18.9	17.8	18.3
	IV	3	3	16	4	4	5	55	58	199	50	63	118	18.5	17.3	18.1	17.6	18.2	18.4
	V	5	8	10	5	3	8	42	194	22	77	92	139	18.8	18.1	18.2	17.9	17.9	17.7
	I	6	5	7	7	10	6	330	372	665	258	248	384	20.5	21.4	20.6	19.8	19.8	17.4
	II	8	9	7	3	5	15	192	410	480	302	240	692	20.8	21.8	19.8	20.0	18.2	23.8
II	III	7	9	11	4	6	12	124	419	690	270	409	457	20.6	22.4	20.9	20.7	19.6	21.4
	IV	3	3	9	6	5	7	176	265	497	274	195	361	18.8	20.2	21.8	20.1	17.2	21.9
	V	3	7	11	6	6	10	154	485	522	229	162	474	21.8	19.6	21.3	19.5	17.6	21.0
	I	6	5	8	7	9	14	291	565	862	568	622	1461	15.0	21.2	23.4	19.5	22.4	20.5
	II	6	9	7	5	5	5	458	564	747	892	741	924	21.3	21.0	22.3	23.3	20.9	23.2
III	III	7	8	10	6	7	6	458	557	992	629	1185	502	22.9	24.1	22.1	22.2	22.4	20.7
	IV	4	5	12	5	4	8	396	604	1039	534	780	710	22.4	21.9	21.4	21.3	23.8	24.0
	V	6	5	6	5	5	6	424	900	844	706	377	590	21.2	21.0	21.6	20.6	21.3	21.6

1955. "Phosphorus from different fertilizer materials"

Tuber: effect of treatment on:

Appendix XI.d — Total yield (tons per acre)

Replication	Treatment A	B	C	D	E	F
I	8.0	14.0	15.1	9.9	9.9	14.4
II	8.3	11.1	14.1	11.3	11.5	15.4
III	9.2	13.2	14.0	10.7	10.9	14.1
IV	8.3	12.9	13.8	10.0	11.1	10.7
V	8.8	13.3	12.1	10.1	9.9	16.1

Appendix XI.e — Ware (tons per acre)

Replication	Treatment A	B	C	D	E	F
I	3.4	10.0	9.6	6.2	6.5	10.6
II	3.8	7.2	10.3	5.2	7.5	11.7
III	4.5	10.3	11.0	6.6	8.5	9.9
IV	5.7	10.2	9.9	6.4	9.0	10.5
V	4.3	8.9	9.3	9.3	6.1	12.4

Appendix XI.f — Seed (tons per acre)

Replication	Treatment A	B	C	D	E	F
I	4.5	3.9	5.3	3.7	3.4	3.7
II	4.5	3.7	3.7	3.0	3.9	3.7
III	4.6	3.5	2.9	4.6	2.4	4.1
IV	2.5	2.7	3.7	3.5	2.1	2.2
V	4.4	4.4	3.2	2.7	3.7	3.6

Appendix XI.g — Chats (tons per acre)

Replication	Treatment A	B	C	D	E	F
I	0.08	0.08	0.23	-	0.08	0.08
II	-	0.08	0.08	0.08	0.11	0.04
III	0.08	0.08	0.08	0.08	0.04	0.08
IV	0.08	0.04	0.15	0.08	0.04	-
V	0.08	-	0.08	0.08	0.08	0.08

Effect of treatment on uptake of total P_2O_5 (% dry matter)

Appendix XII.a — Shoot

Observation	Replication	Treatment A	B	C	D	E	F
I	*	0.48	0.79	0.83	0.66	0.66	0.87
II	*	0.58	0.45	0.44	0.51	0.48	0.48
III	I	0.47	0.32	0.37	0.38	0.35	0.36
	II	0.42	0.37	0.35	0.35	0.42	0.40
	III	0.44	0.32	0.36	0.38	0.32	0.36
	IV	0.44	0.38	0.25	0.39	0.41	0.37
	V	0.45	0.33	0.34	0.46	0.35	0.29

Appendix XII.b — Root

Observation	Replication	Treatment A	B	C	D	E	F
I	*	0.28	0.50	0.62	0.36	0.40	0.64
II	*	0.66	0.31	0.33	0.38	0.30	0.30
III	I	0.33	0.24	0.30	0.33	0.27	0.30
	II	0.35	0.30	0.28	0.34	0.31	0.32
	III	0.37	0.26	0.36	0.33	0.31	0.32
	IV	0.32	0.30	0.27	0.29	0.30	0.28
	V	0.37	0.31	0.28	0.27	0.30	0.25

Appendix XII.c — Tuber

Observation	Replication	Treatment A	B	C	D	E	F
I	*	0.32	0.48	0.59	0.36	0.40	0.57
II	*	0.34	0.29	0.33	0.34	0.32	0.31
III	I	0.33	0.28	0.31	0.37	0.30	0.26
	II	0.35	0.44	0.26	0.29	0.28	0.26
	III	0.36	0.30	0.36	0.56	0.29	0.34
	IV	0.34	0.25	0.35	0.27	0.27	0.26
	V	0.36	0.26	0.32	0.25	0.24	0.28

* composite sample of 5 replications.

1955. Greenhouse Experiments

Appendix XIII.a

Shoot: effect of treatments on fresh weight (g) - 10 plants

		Barbauchlaw Soil												Boghall Soil											
		Treatment				Treatment				Treatment				Treatment				Treatment				Treatment			
		N_0				N_1				N_2				N_0				N_1				N_2			
Observation	Replication	P_0	P_1	P_2	P_3	P_0	P_1	P_2	P_3	P_0	P_1	P_2	P_3	P_0	P_1	P_2	P_3	P_0	P_1	P_2	P_3	P_0	P_1	P_2	P_3
	I	5.5	7.6	8.8	9.1	6.5	7.8	9.0	9.8	7.8	8.6	8.0	10.0	10.1	9.0	8.1	9.2	10.1	8.1	8.1	8.7	7.7	6.7	8.6	11.2
	II	9.0	8.3	10.0	10.0	7.1	7.3	8.6	8.1	7.9	7.9	9.8	9.6	10.0	10.0	7.9	10.1	9.5	11.3	12.2	12.5	9.2	12.2	11.9	12.1
I	III	6.7	11.0	9.0	9.5	6.9	8.4	9.0	10.3	8.8	9.8	9.0	9.3	8.9	11.2	9.7	10.6	10.2	9.2	11.2	11.1	8.7	9.6	11.1	9.2
	IV	6.6	7.9	9.6	9.0	6.9	7.5	9.2	9.5	7.0	8.7	10.3	12.0	8.8	9.5	9.1	9.5	9.0	10.2	11.5	9.5	10.7	10.2	11.9	12.6
	V	6.8	8.0	7.1	9.8	7.5	8.8	8.5	9.2	8.2	7.4	7.8	8.9	9.5	9.7	11.0	9.8	8.6	9.9	10.5	11.1	11.6	11.8	10.8	13.4
	I	18.0	22.6	21.2	23.4	23.4	23.0	21.5	21.8	19.8	26.6	20.2	25.7	21.0	16.4	18.1	21.6	25.9	22.8	21.9	24.6	28.5	36.0	21.8	34.7
	II	16.3	18.1	20.4	21.3	16.5	22.4	25.1	20.5	25.1	27.2	21.1	21.5	18.6	23.0	18.8	18.7	28.7	27.5	24.7	24.4	29.5	26.3	24.0	36.6
II	III	18.0	19.5	16.4	14.2	21.4	23.3	22.0	22.2	20.9	21.0	24.0	25.2	16.9	18.7	23.3	23.7	22.9	24.3	26.3	25.9	23.5	21.2	25.9	24.2
	IV	18.0	17.3	20.8	19.8	19.2	18.0	21.4	17.2	20.1	19.3	18.5	21.1	21.8	20.7	23.6	23.3	21.6	20.8	25.6	23.2	22.8	25.1	24.8	25.4
	V	17.5	20.8	17.4	21.2	20.0	21.2	20.9	19.0	21.6	19.0	18.2	22.6	19.5	18.8	17.0	22.2	18.6	22.0	23.0	24.4	31.5	20.3	21.8	32.8
	I	11.5	12.2	13.7	14.0	12.1	13.5	14.5	15.6	14.9	15.4	16.7	16.7	13.6	14.9	12.0	12.6	13.2	17.7	20.2	18.4	17.1	22.5	16.7	18.8
	II	11.7	13.0	16.3	14.9	16.1	13.4	14.7	13.0	14.0	16.5	15.7	17.3	14.3	14.5	13.2	14.9	17.1	14.8	15.1	18.2	17.5	17.4	17.5	19.9
III	III	11.7	14.6	10.8	13.8	15.7	15.1	16.7	14.1	13.2	16.3	13.4	12.7	12.6	13.4	17.9	14.4	16.5	16.6	20.1	19.8	17.7	18.2	16.1	23.5
	IV	11.0	14.3	13.5	12.8	12.2	13.0	13.7	13.5	14.2	14.5	15.6	19.6	16.0	12.2	19.7	17.2	16.9	15.9	18.1	17.6	19.5	18.3	19.6	19.4
	V	10.8	14.4	13.8	16.6	12.9	12.7	14.2	12.5	13.0	14.8	14.5	16.0	13.0	11.9	12.9	15.9	17.1	15.6	17.3	17.0	21.4	12.7	12.8	20.0

1955. Greenhouse Experiments

Appendix XIII.b

Shoot: effect of treatments on dry matter (%)

		Barbauchlaw Soil												Boghall Soil											
		Treatment				Treatment				Treatment				Treatment				Treatment				Treatment			
		N_0				N_1				N_2				N_0				N_1				N_2			
Observation	Replication	P_0	P_1	P_2	P_3	P_0	P_1	P_2	P_3	P_0	P_1	P_2	P_3	P_0	P_1	P_2	P_3	P_0	P_1	P_2	P_3	P_0	P_1	P_2	P_3
	I	13.5	14.5	13.8	13.9	19.4	13.1	12.3	14.1	13.8	12.8	13.7	15.2	12.5	13.2	12.8	12.2	12.9	12.9	10.4	12.0	12.0	11.1	13.7	12.9
	II	11.8	14.7	13.0	13.3	13.6	14.1	12.3	14.9	13.1	12.3	13.5	14.9	11.1	11.6	11.8	13.1	10.8	11.6	10.7	12.5	11.1	11.2	10.9	12.5
I	III	12.7	11.7	14.4	13.3	13.1	12.8	13.9	12.1	13.4	13.9	13.8	16.2	15.1	9.0	11.1	11.7	11.8	11.0	11.0	12.3	10.9	10.9	12.0	15.5
	IV	12.4	12.5	13.1	13.3	14.2	14.1	12.7	15.3	13.9	13.6	13.9	12.1	11.8	13.2	11.3	11.4	11.5	12.4	12.0	13.3	12.1	11.8	11.1	12.3
	V	14.0	14.7	14.0	13.5	12.5	14.3	12.3	15.1	12.3	14.2	15.8	13.8	12.4	12.4	12.1	12.7	12.9	11.7	12.7	12.9	10.4	13.1	12.2	11.9
	I	18.2	18.8	19.4	20.2	15.6	17.4	18.8	20.0	19.0	17.7	17.6	19.6	19.4	18.1	18.7	17.3	19.2	18.9	17.8	20.9	17.3	16.4	17.7	18.1
	II	17.2	18.9	18.4	21.1	16.6	20.9	18.7	21.2	15.4	16.9	18.9	19.3	16.8	17.6	20.3	19.0	16.6	17.5	19.0	18.6	15.5	17.3	16.9	17.5
II	III	19.7	18.9	21.2	20.8	18.1	20.3	17.6	22.4	17.7	17.7	19.6	20.4	18.1	18.9	19.8	17.0	18.0	17.8	17.5	17.5	16.3	18.2	19.2	18.7
	IV	19.6	19.0	18.8	22.0	19.6	19.2	19.0	20.7	17.6	18.8	21.7	21.0	17.0	18.6	16.1	17.5	18.4	17.9	17.9	21.2	17.6	16.9	16.0	19.1
	V	18.6	20.4	19.9	19.6	17.8	19.5	20.5	17.9	16.3	19.5	19.9	21.4	19.2	19.2	18.7	20.4	18.4	19.2	18.7	19.8	16.6	19.9	19.1	17.1
	I	33.3	33.0	34.6	35.4	32.2	36.9	36.1	36.2	38.7	35.1	35.1	33.8	30.7	30.0	28.0	33.4	31.5	31.7	31.7	31.9	32.2	33.5	35.0	33.9
	II	33.9	34.0	33.4	33.5	33.6	35.7	35.8	34.8	32.7	34.5	36.4	34.6	31.0	30.3	30.7	32.7	34.2	31.8	31.1	31.9	33.5	33.7	34.5	32.5
III	III	33.9	30.0	36.0	33.7	38.4	35.9	35.1	35.5	34.5	35.7	36.7	34.6	31.9	31.0	31.5	32.4	31.5	32.5	31.9	32.5	33.3	33.4	32.9	31.7
	IV	32.9	33.0	33.5	34.0	35.9	36.9	34.4	35.0	36.9	34.5	36.1	31.1	28.9	32.5	30.1	40.0	32.5	32.6	32.7	33.0	34.7	34.4	35.2	33.2
	V	33.1	32.5	35.2	33.4	34.3	35.3	35.8	36.1	34.1	32.8	35.6	33.5	32.2	31.6	30.6	32.0	32.7	31.7	29.1	32.6	32.5	36.6	35.5	34.2

1955. Greenhouse experiment - (oats)

Appendix XIII c

Shoot: effect of treatments on uptake of total P_2O_5 (% dry matter)

Barbauchlaw Soil — Treatment

Observation	N_0 P_0	N_0 P_1	N_0 P_2	N_0 P_3	N_1 P_0	N_1 P_1	N_1 P_2	N_1 P_3	N_2 P_0	N_2 P_1	N_2 P_2	N_2 P_3
I	0.49	0.43	0.47	0.62	0.49	0.42	0.52	0.58	0.39	0.42	0.44	0.58
II	0.46	0.40	0.39	0.46	0.43	0.38	0.39	0.42	0.46	0.39	0.39	0.39
III	0.23	0.16	0.17	0.19	0.13	0.10	0.12	0.13	0.09	0.10	0.12	0.14

Boghall Soil — Treatment

Observation	N_0 P_0	N_0 P_1	N_0 P_2	N_0 P_3	N_1 P_0	N_1 P_1	N_1 P_2	N_1 P_3	N_2 P_0	N_2 P_1	N_2 P_2	N_2 P_3
I	0.82	0.70	0.74	0.99	0.63	0.65	0.73	0.83	0.66	0.65	0.73	0.86
II	0.66	0.56	0.56	0.75	0.44	0.48	0.52	0.58	0.47	0.44	0.45	0.56
III	0.46	0.36	0.36	0.60	0.15	0.19	0.25	0.31	0.12	0.11	0.13	0.24

Figures refer to composite samples of 5 replications.

Appendix XIII d

Shoot: effect of treatments on uptake of P_2O_5 from fertilizer (% of total)

Barbauchlaw Soil

Observation	N_0 P_0	N_0 P_1	N_0 P_2	N_0 P_3	N_1 P_0	N_1 P_1	N_1 P_2	N_1 P_3	N_2 P_0	N_2 P_1	N_2 P_2	N_2 P_3
I	-	0.15	0.24	0.52	-	0.11	0.32	0.47	-	0.11	0.23	0.48
II	-	0.17	0.31	0.70	-	0.16	0.35	0.64	-	0.16	0.36	0.66
III	-	0.10	0.18	0.38	-	0.07	0.13	0.28	-	0.06	0.14	0.32

Boghall Soil

Observation	N_0 P_0	N_0 P_1	N_0 P_2	N_0 P_3	N_1 P_0	N_1 P_1	N_1 P_2	N_1 P_3	N_2 P_0	N_2 P_1	N_2 P_2	N_2 P_3
I	-	0.13	0.26	0.38	-	0.12	0.29	0.36	-	0.14	0.29	0.36
II	-	0.26	0.37	0.45	-	0.18	0.36	0.49	-	0.18	0.30	0.48
III	-	0.24	0.42	0.82	-	0.13	0.25	0.44	-	0.08	0.13	0.53

Appendix XIV a

Grain: effect of treatments on fresh weight (g)

Appendix XIV b

Grain: effect of treatments on dry matter (%)

Appendix XIV c

Grain: effect of treatments on uptake of total P_2O_5 (% dry matter)

Appendix XIV d

Grain: effect of treatments on uptake of P_2O_5 from fertilizer (% of total)

Barbauchlaw Soil

Appendix	N_0 P_0	N_0 P_1	N_0 P_2	N_0 P_3	N_1 P_0	N_1 P_1	N_1 P_2	N_1 P_3	N_2 P_0	N_2 P_1	N_2 P_2	N_2 P_3
XIV a	18.5	20.8	18.1	19.4	25.1	24.1	24.3	22.1	25.8	25.5	21.0	22.1
XIV b	89.2	89.2	89.7	89.3	88.6	89.4	89.2	89.3	89.2	88.7	89.8	89.5
XIV c	1.1	1.09	1.17	1.15	1.11	1.00	1.15	1.09	1.08	1.09	1.04	1.14
XIV d	-	7.2	14.7	27.8	-	7.8	14.7	28.3	-	7.1	13.4	28.8

Boghall Soil

Appendix	N_0 P_0	N_0 P_1	N_0 P_2	N_0 P_3	N_1 P_0	N_1 P_1	N_1 P_2	N_1 P_3	N_2 P_0	N_2 P_1	N_2 P_2	N_2 P_3
XIV a	16.0	15.6	18.9	18.0	21.3	20.3	192.	19.8	30.7	28.3	25.8	20.5
XIV b	87.7	87.9	88.3	88.2	87.9	88.3	88.0	88.3	88.0	87.8	88.4	89.3
XIV c	1.23	1.29	1.13	1.21	1.20	1.17	1.10	1.29	1.13	1.09	1.24	1.17
XIV d	-	6.9	13.2	10.9	-	7.4	14.8	16.7	-	6.9	14.0	17.9

1954. "Levels of Phosphorus" experiment

Appendicies Ia, IIa, and IIIa.

Analysis of Variance[1]

Appendix Ia — Population

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
Blocks	3	147	49.0	41	13.6	19	6.3
Treatments	5	216	43.2*	35	7.0 N.S.	19	3.8 N.S.
Error	15	231	15.4	80	5.3	36	2.4

Appendix Ia — Sprouts per hill

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
Blocks	3	3.0	1.0	1.34	0.447	4.3	1.43
Treatments	5	0.4	0.08 N.S.	0.38	0.076 N.S.	0.87	0.17 N.S.
Error	15	2.5	0.17	1.86	0.124	2.19	0.146

Appendix Ia 1 — Shoot Height

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
Blocks	3	67	22.3	95	31.7	512	170.7
Treatments	5	115	23.0 N.S.	431	86.2*	4016	803.2**
Error	15	278	18.5	321	21.4	282	19.27

Appendix Ia 2 — Shoot - fresh weight/plant

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
Blocks	3	19575	6525	123294	41098	83043	2768
Treatments	5	25651	5130 N.S.	35733	7147 N.S.	35552	71104**
Error	15	523223	34882	127093	8473	78400	5227

Appendix Ia 3 — Shoot - % D.M.

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
		(3rd)				(3rd)	
Blocks	3	5.6	1.87	173.7	57.9	31.3	10.4
Treatments	5	9.6	1.92 N.S.	40.4	8.08 N.S.	50.1	10.0**
Error	15	13.8	0.92	74.4	4.96	12.9	0.86

Appendix Ia 4 — Root - fresh weight/plant

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
		(3rd)		(3rd)		(3rd)	
Blocks	3	44.5	14.8	478	159	935.6	311.9
Treatments	5	358.5	71.7 N.S.	515	103 N.S.	1730.4	346.1*
Error	15	949.2	63.3	1551	103	1259.4	83.9

Appendix Ia 5 — Root - % D.M.

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
		(3rd)		(3rd)		(3rd)	
Blocks	3	1.8	0.6	364	121.3	362.7	120.9
Treatments	5	63.1	12.6*	74	14.8 N.S.	78.2	15.6 N.S.
Error	15	66.3	4.4	415	27.6	119.8	7.9

Appendix IIa 1 — Tuber - per plant

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
		(3rd)		(3rd)		(4th)	
Blocks	3	21	7	72	24.0	81	27.0
Treatments	5	200	40*	125	25.0 N.S.	184	36.8*
Error	15	131	8.7	318	21.2	113	7.5

Appendix IIa 2 — Tubers - Fresh weight/plant

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
		(3rd)		(3rd)		(4th)	
Blocks	3	30651	10217	145237	48412	304077	101359
Treatments	5	165922	33184 N.S.	480182	96032 N.S.	1125640	225138**
Error	15	2086807	139120	1845743	123049	478409	38561

Appendix IIa 3 — Tubers - % D.M.

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
		(3rd)		(3rd)		(4th)	
Blocks	3	1.6	0.53	1.0	0.33	3.0	1.0
Treatments	5	9.8	1.96 N.S.	5.0	1.0 N.S.	11.0	2.2 N.S.
Error	15	38.1	2.54	33.8	2.3	13.0	8.6

Appendix IIa 4 — Ware

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
Blocks	3	199	66.3	0.90	0.30	0.6906	0.2301
Treatments	5	100	20*	6.42	1.28 N.S.	2.0124	0.4023*
Error	15	86	5.7	6.92	0.46	1.5154	0.1010

Appendix IIa 5 — Seed

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
Blocks	3	3	1	5.14	1.17	5.14	0.86
Treatments	5	116	23.8 N.S.	1.93	0.39 N.S.	111.82	22.36*
Error	15	673	44.9	22.15	1.48	12.98	0.87

Appendix IIa 6 — Chats

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
Blocks	3	1.2	0.4	0.03	0.01	0.1140	0.038
Treatments	5	3.7	0.74 N.S.	0.03	0.006 N.S.	0.0801	0.016 N.S
Error	15	5.8	0.39	0.14	0.09	0.2762	0.018

Appendix IIa 7 — Total Yield

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
Blocks	3	156	52.0	3.4	1.13	4.7	1.6
Treatments	5	182	36.4 N.S.	9.6	1.92 N.S.	141	28.2**
Error	15	942	62.8	26.0	1.13	13.3	0.89

Appendix IIIa 1 — Shoot - % P_2O_5 (D.M. basis)

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
		(3rd)		(3rd)		(3rd)	
Blocks	3	015	0.030	0.05	0.017	0.0174	0.0058
Treatments	5	006	0.012*	0.99	0.198**	0.1585	0.0317**
Error	15	011	0.007	0.22	0.015	0.0577	0.0038

Appendix IIIa 2 — Root - % P_2O_5 (D.M. Basis)

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
Blocks	3	0215	0.072	0.04	0.013	0.0049	0.0016
Treatments	5	0176	0.035 N.S.	0.30	0.060*	0.1123	0.0224**
Error	15	0182	0.019	0.24	0.016	0.0210	0.0014

Appendix IIIa 2 — Tuber - % P_2O_5 (D.M. Basis)

Due to	d.f.	Shawfair S.S.	Shawfair M.S.	Dryden S.S.	Dryden M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.
Blocks	3	03	0.043	-	-	0.032855	0.011
Treatments	5	00	0.020**	0.02	0.004*	0.160328	0.321**
Error	15	07	0.0046	0.02	0.0013	0.019424	0.0013

** denotes significant at the 1% level   * denotes significant at the 5% level   N.S. not significant.

1. Unless otherwise stated analysis refers to 3rd Observation.

1954 and 1955. "Phosphorus from different fertilizer Materials" experiments

Appendicies IV.a, V.a, VI.a and XII.a Xa, XIa.

Analysis of Variance.

			1954		1955		1954		1955		1954		1955	
	d.f. for	d.f. for	Dryden		Barbauchlaw		Dryden		Barbauchlaw		Dryden		Barbauchlaw	
Due to	Dryden	Barbauchlaw	S.S.	M.S.	S.S.	M.S.	S.S.	M.S.	S.S.	M.S.	S.S.	M.S.	S.S.	M.S.
			Population				Root % D.M.				Chats			
			Appendix IVa		Appendix Xa.1		Appendix IVa.5 (3rd)		Appendix Xa.7 (2nd)		Appendix Va.6		Appendix XIa.7	
Blocks	3	4	28	9.3	122	30.5	21	7	21	5.3	0.1	0.03	0.0030	0.0008
Treatments	5	5	34	6.8 N.S.	42	8.4 N.S.	88	17 N.S.	25	5.0 N.S.	0.1	0.02 N.S.	0.0167	0.0033 N.S.
Error	15	20	133	8.9	325	16.3	118	7.9	122	6.1	0.2	0.013	0.0388	0.0019
			No. of sprouts/hill				Tubers - number/plant				Total Yield			
			Appendix IVa		Appendix Xa.2		Appendix Va.1 (4th)		Appendix XIa.1 (4th)		Appendix Va.7		Appendix XIa.4	
Blocks	3	4	2	0.67	3	0.75	33	11	6	1.5	14	4.7	1	0.25
Treatments	5	5	-	- N.S.	-	- N.S.	169	33.8**	48	9.6 N.S.	16	3.2*	117	23.4**
Error	15	20	1	0.067	1	0.05	93	6.2	193	9.7	17	1.13	33	1.65
			Shoot - Height				Tubers - Fresh weight/plant				Shoot - % P_2O_5 (D.M. basis)			
			Appendix IVa.1 (3rd)		Appendix Xa.3 (3rd)		Appendix Va. 2 (4th)		Appendix XIa.2 (2nd)		Appendix VIa.1 (3rd)		Appendix XIIa.1 (3rd)	
3locks	3	4	25	8.3	36	9	73611	24537	34333	8583	0.08	0.03	0.0015	0.0004
'reatments	5	5	319	61.5 N.S.	1148	229.6**	179610	35922 N.S.	755261	151052*	0.09	0.018 N.S.	0.0400	0.0080**
Error	15	20	820	54.6	314	15.7	1212118	80807	1140305	57015	0.17	0.011	0.0334	0.0017
			Shoot- Fresh weight/plant				Tubers - % D.M.				Root - % P_2O_5 (D.M. basis)			
			Appendix IVa.2 (3rd)		Appendix Xa.4 (2nd)		Appendix Va.3 (3rd)		Appendix XIa.3 (2nd)		Appendix VIa.2 (3rd)		Appendix XIIa.2 (3rd)	
locks	3	4	155560	51833	10254	2563	2	0.67	19	4.8	0.08	0.027	0.0044	0.0011
reatments	5	5	155942	31188 N.S.	118136	26627**	18	3.4 N.S.	10	2.0 N.S.	0.10	0.020*	0.0129	0.0026**
rror	15	20	602632	40175	18191	910	179	11.9	53	2.7	0.12	0.008	0.0158	0.0008
			Shoot - % D.M.				Ware				Tuber - % P_2O_5 (D.M. basis)			
			Appendix IVa.3 (3rd)		Appendix Xa.5 (2nd)		Appendix Va.4		Appendix XIa.5		Appendix VIa.3 (3rd)		Appendix XIIa.3 (3rd)	
locks	3	4	27	9	4	1	2	0.6	5	1.3	0.01	0.003	0.0263	0.0066
reatments	5	5	16	3.2 N.S.	24	4.8*	3	0.6 N.S.	138	27.6**	0.14	0.028 N.S.	0.0250	0.0050**
rror	15	20	134	8.9	31	1.5	4	0.27	24	1.2	0.23	0.015	0.0159	0.0008
			Root - Fresh weight/plant				Seed							
			Appendix IVa.4 (3rd)		Appendix Xa.6 (2nd)		Appendix Va.5		Appendix XIa.6					
locks	3	4	965	321.6	79	19.8	16	5.3	6	1.5				
reatments	5	5	955	191.0 N.S.	333	66.6*	11	2.2*	3	0.6 N.S.				
rror	15	20	1236	82.4	391	19.5	14	0.93	8	0.4				

** denotes significant at the 1% level. * denotes significant at the 5% level. N.S. not significant.

1955. "Levels of phosphorus" experiment

Appendicies VIIa, VIIIa and IXa

Analysis of Variance

	d.f.	d.f. for appendix IXa 4,5,6.	Barbauchlaw S.S.	Barbauchlaw M.S.	Boghall S.S.	Boghall M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.	Boghall S.S.	Boghall M.S.	Barbauchlaw S.S.	Barbauchlaw M.S.	Boghall S.S.	Boghall M.S.
			Population	Appendix VIIa 1			Shoot - % D.M.	Appendix VIIa 5			Tubers - fresh weight/plant	Appendix VIIIa 2		
							(2nd)		(2nd)		(3rd)		(3rd)	
Blocks	4		143	35.8	43	10.8	5	1.25	5	1.25	73472	18368	125556	31389
Treatments														
P	4		167	41.8 N.S.	315	78.7**	20	5 N.S.	5	1.25 N.S.	729318	182330**	228056	57014 N.S.
N	1		4	4 N.S.	15	15.0 N.S.	2	2 N.S.	1	1.0 N.S.	2794	2794 N.S.	8712	8712 N.S.
Interaction PxN	4		135	33.8 N.S.	198	49.5**	3	0.72 N.S.	5	1.25 N.S.	9473	2368 N.S.	25188	6297 N.S.
Error	36		1311	36.4	355	9.3	73	2.02	17	0.47	491421	13651	1903204	52886
			Sprouts per hill	Appendix VIIa 2			Root - fresh weight/plant	Appendix VIIa 6			Tubers - % D.M.	Appendix VIIIa 3		
							(2nd)		(2nd)		(3rd)		(3rd)	
Blocks	4	4	1	0.25	-	-	254	63.5	194	48.5	2	0.5	10	2.5
Treatments														
P	4	2	1	0.25 N.S.	2	0.5**	825	206**	71.0	17.8 N.S.	18	4.5**	8	2.0 N.S.
N	1	1	-	- N.S.	-	- N.S.	1	1 N.S.	6.0	6.0 N.S.	4	4.0**	-	- N.S.
Interaction PxN	4	2	-	- N.S.	-	- N.S.	248	62 N.S.	12.0	3.0 N.S.	8	2.0 N.S.	4	1.0 N.S.
Error	36	20	5	0.14	4	0.111	1300	36.1	1601	44.5	34	0.94	26	0.72
			Shoot - height	Appendix VIIa 3			Root - % D.M.	Appendix VIIa 7			Total Yield	Appendix VIIIa 4		
			(3rd)		(3rd)		(2nd)		(2nd)					
Blocks	4	4	96	24	62	15.5	10.0	2.5	10	2.5	1	1.5	42	10.5
Treatments														
P	4	2	2724	681**	279	69.8**	10	2.5 N.S.	28	7.0 N.S.	217	54.1**	52	13.0*
N	1	1	110	110**	82	82.0**	11	11.0 N.S.	35	35.0**	1	1 N.S.	12	12.0 N.S.
Interaction PxN	4	2	24	6 N.S.	42	10.5 N.S.	15	3.75 N.S.	2	0.5 N.S.	14	3.5*	12	3.0 N.S.
Error	36	20	478	13.3	573	15.9	127	3.5	165	4.6	40	1.1	136	3.8
			Shoot - fresh weight/plant	Appendix VIIa 4			Tubers - number/plant	Appendix VIIIa 1			Ware	Appendix VIIIa 5		
			(2nd)		(2nd)		(3rd)		(3rd)					
Blocks	4	4	19230	4807	12665	3166	160	40	60	15	5	1.25	22	5.5
Treatments														
P	4	2	295565	73891**	35686	8922 N.S.	227	66.8*	62	15.2 N.S.	92	23.0**	20	5.0*
N	1	1	376	376 N.S.	10628	10628 N.S.	7	7 N.S.	3	3.0 N.S.	12	12.0**	14	14.0**
Interaction PxN	4	2	3760	940 N.S.	12291	3073 N.S.	50	12.5 N.S.	9	2.3 N.S.	13	3.3 N.S.	5	1.25 N.
Error	36	20	203772	5660	196475	5457	923	25.6	370	10.3	69	1.92	58	1.6

x** significant at the 1% level   * significant at the 5% level   N.S. not significant

Barbauchlaw		Boghall		Barbauchlaw		Boghall	
S.S.	M.S.	S.S.	M.S.	S.S.	M.S.	S.S.	M.S.
	Seed				**Tuber - % P_2O_5 (Total)**		
	Appendix VIIIa 6				Appendix IXa 3		
					(3rd)		(3rd)
1	0.25	3	.75	0.01	0.0025	0.0092	0.0023
36	9.0***	10	.25$^{\text{N.S.}}$	0.04	0.01***	0.0506	0.0127***
5	5.0***	-	-$^{\text{N.S.}}$	0.01	0.01***	0.0002	0.0002$^{\text{N.S.}}$
2	0.5$^{\text{N.S.}}$	3	0.7$^{\text{N.S.}}$	0.01	0.0025$^{\text{N.S.}}$	0.0048	0.0029$^{\text{N.S.}}$
21	0.58	50	1.4	0.04	0.0011	0.0815	0.0023
	Shats				**Shoot - % P_2O_5 (from fertilizer)**		
	Appendix VIIIa 7				Appendix IXa 4		
					(3rd)		(3rd)
0.0167	0.0042	0.0696	0.0174	144	36.0	54	13.5
0.1748	0.0437***	0.0340	0.0085$^{\text{N.S.}}$	2606	1303***	1225	612.5***
0.0044	0.0044$^{\text{N.S.}}$	0.0033	0.0033$^{\text{N.S.}}$	22	22$^{\text{N.S.}}$	128	128.0$^{\text{N.S.}}$
0.0228	0.0057$^{\text{N.S.}}$	0.0094	0.0024$^{\text{N.S.}}$	155	77.5$^{\text{N.S.}}$	63	31.5$^{\text{N.S.}}$
0.2318	0.0064	0.1642	0.0046	956	47.8	656	32.8
	Shoot - % P_2O_5 (Total)				**Root - % P_2O_5 (from fertilizer)**		
	Appendix IXa 1				Appendix IXa 5		
(3rd)		(3rd)			(1st)		(3rd)
0.0153	0.0038	0.0194	0.0048	112	28	47	11.8
0.0840	0.0210***	0.0043	0.0011$^{\text{N.S.}}$	3501	1750***	1057	528.5***
0.0192	0.0192*	-	-$^{\text{N.S.}}$	105	105*	18	18.0$^{\text{N.S.}}$
0.0009	0.0002$^{\text{N.S.}}$	0.0127	0.0032$^{\text{N.S.}}$	440	22.0$^{\text{N.S.}}$	12	6.0$^{\text{N.S.}}$
0.1054	0.0029	0.0636	0.0018	475	20	1350	6.8
	Root - % P_2O_5 (Total)				**Tuber - % P_2O_5 (from fertilizer)**		
	Appendix IXa 2				Appendix IXa 6		
(3rd)		(3rd)		(3rd)		(3rd)	
0.0045	0.0011	0.0126	0.0032	552	138	61.0	15.3
0.0467	0.0117***	0.0078	0.0019$^{\text{N.S.}}$	5266	2633***	2409	1204***
0.0017	0.0017$^{\text{N.S.}}$	0.0292***	0.0292***	93	93$^{\text{N.S.}}$	26	26$^{\text{N.S.}}$
0.0100	0.0025$^{\text{N.S.}}$	0.0018	0.0005$^{\text{N.S.}}$	2	1$^{\text{N.S.}}$	32	16$^{\text{N.S.}}$
0.0972	0.0027	0.0698	0.0019	666	33.3	273	13.7

Appendix XVI

Uptake of P_2O_5 - Total and Fertilizer derived

		Boghall									Barbauchlaw							
		P_2O_5 lb. per acre									P_2O_5 lb. per acre							
Obser-vation	Treat-ment	Shoot		Root		Tuber				Treat-ment	Shoot		Root		Tuber			
		Total	from fert-ilizer	Total	from fert-ilizer	Total	from fert-ilizer	Total uptake (S+R+T)	Total from fertilizer (S+R+T)		Total	from fert-ilizer	Total	from fert-ilizer	Total	from fert-ilizer	Total uptake (S+R+T)	Total from fertilizer (S+R+T)
I	P_0	4.1		0.58		0.98		5.66		P_0	1.4		0.26		1.8		3.5	
	P_1	7.0	1.75	1.00	0.19	1.86	0.39	9.86	2.33	P_1	3.2	1.4	0.39	0.14	3.6	1.5	7.2	3.0
	P_2	7.3	3.28	1.00	0.30	2.38	0.86	10.68	4.44	P_2	4.6	1.9	0.48	0.24	5.2	3.0	10.3	5.1
	P_3	7.4	3.50	1.20	0.47	3.38	1.39	12.0	5.36	P_3	6.0	4.0	0.70	0.43	6.1	4.1	12.9	8.5
	P_4	8.6		1.30		2.42		12.3		P_4	8.8		1.00		5.2		15.3	
	N_1	7.2	2.95	1.10	0.34	2.22	0.75	10.5	4.04	N_1	4.7	2.5	0.55	0.26	4.3	2.3	9.5	5.1
	N_2	7.5	2.55	0.90	0.24	1.94	0.62	10.3	3.41	N_2	5.0	2.9	0.56	0.28	4.5	2.6	10.0	5.8
II	P_0	7.2		0.90		18.00		26.1		P_0	2.8		0.32		7.0		10.1	
	P_1	8.6	1.20	1.00	0.10	14.24	2.28	28.8	3.58	P_1	2.7	0.7	0.32	0.06	11.0	3.3	13.7	4.1
	P_2	9.3	2.20	0.94	0.19	20.13	5.84	30.4	8.23	P_2	3.6	1.4	0.31	0.11	13.2	6.5	17.1	8.0
	P_3	8.9	3.56	0.84	0.28	20.42	7.96	30.2	11.80	P_3	4.0	2.3	0.38	0.24	16.8	10.8	21.2	13.3
	P_4	9.3		1.19		23.95		34.4		P_4	5.7		0.55		16.9		23.1	
	N_1	7.6	1.98	0.87	0.18	21.63	6.49	30.10	8.65	N_1	3.7	1.5	0.39	0.17	12.5	5.6	16.4	7.3
	N_2	10.0	2.60	1.00	0.22	19.47	5.25	30.50	8.07	N_2	4.1	1.7	0.35	0.18	12.0	6.4	16.5	8.3
III	P_0	3.7		0.80		25.4		26.6		P_0	2.0		0.34		12.4		14.7	
	P_1	3.4	0.37	0.89	0.08	25.1	3.78	29.4	4.23	P_1	1.7	0.3	0.28	0.04	17.4	5.1	19.3	5.5
	P_2	3.8	0.64	1.10	0.15	33.7	7.75	38.6	8.54	P_2	2.0	0.7	0.30	0.07	18.7	9.3	21.1	10.0
	P_3	3.9	1.00	0.92	0.21	32.2	11.9	37.0	13.11	P_3	1.9	0.8	0.33	0.11	22.0	13.6	24.3	14.5
	P_4	3.7		1.10		29.5		34.3		P_4	2.9		0.36		24.2		27.6	
	N_1	3.5	0.56	0.87	0.13	31.48	8.18	35.9	8.87	N_1	2.0	0.6	0.32	0.07	19.0	8.7	21.4	9.4
	N_2	3.9	0.78	1.30	0.21	30.32	7.28	35.5	8.27	N_2	2.2	0.7	0.34	0.09	18.5	9.1	21.1	9.9

P_0, Control; P_1, 0.25; P_2, 0.55; P_3, 1.0 and P_4, 2.0 cwt. P_2O_5 per acre. N_1, 0.5 and N_2, 1.0 cwt. N per acre.

Method of calculation of the data of the uptake of P_2O_5 derived from the ra

Treatments and Sample No.	Counter and Scaler	Date	Time of Counting From T o	Time Counted (Mins)	Scaler Reading From To	Total Counts	Counts per Minute	Correction for dead time	Back-ground counts	Net counts per Minute	Amount corrected to J.N.1272
	1	2	3	4	5	6	7	8	9	10	11
1st Sampling											
BT_13^* (N_1P_3)	L.D.479 and 1009	30.7.55	20.00 20.06	6	472900 476966	406	678	+ 2	16	664	+ 27
2nd Sampling											
BT_224 (N_1P_3)	J.N.1272 and 1221	8.9.55	14.21 14.29	8	1833	1833	229	Nil	11	218	Nil
3rd Sampling											
BT_33 (N_1P_3)	L.D.479 and 1009	24.9.55	12.49 14.29	100	279400 291257	11857	118.6	Nil	15.6	103	+ 4.1

* B = Sample from Barbauchlaw (B) field experiment, T_1 = tuber, 1st sampling, 3 = sample number, N_1P_3 = Nitrogen at 40 lb./ac. and phos

Col. 1. Two counters and scalers were used. Either counter L.D.479 and Scaler 1009 or counter J.N. 1272 and Scaler 1221.

Col. 4. With scaler 1009 two readings had to be made of register at the beginning and end of a measurement. Scaler 1221 was always re

Col. 8. Because of the finite dead time some counts are not recorded by the scaler. L.D.479 and scaler 1009 had dead time of 300 micr
The counts to be added were read from tables which were constructed on the basis of a simple formula relating lost counts to th-
D. Taylor. Metheven monograph on Physical Subjects. 1951 page 87).

Col. 11. 4% was added to counts in L.D.479 because ratio of efficiencies of counter J.N.1272 to counter L.D.479 to P^{32} radiations was de

Col. 12. Each count is here corrected to 12.00 hr. on day of counting by using formula:- counts at 12.00 hr. = counts at t hours x [1
This was done to simplify the later calculations of the amount of $P_2^*O_5$ in the sample.

Col. 13. 10 + 11 + 13.

Col. 14. The standard N.SS was made up from the original superphosphate and contained 50 mg. $P_2^*O_5$ per 10 ml. This standard was counted
mically as a function of time of counting. The best straight line (by least squares) was drawn to fit the experimental points-
half life. The figure quoted in Col. 14, is that read off from this graph (and is divided by 50) at 12.00 hrs. on the day of

Col. 15. 13/14

Col. 17. 15/16

dioactive superphosphate.

Amount corrected to 12.00 hrs. on day of counting	Counts/Min. 12.00 hrs. and to counte r J.N.1272	Counts/Min. /mg. $P^*_2O_5$ of standard N.S.S.	Mgs. $P^*_2O_5$ in Sample	Total P_2O_5 in 10 ml. of sample	% $P^*_2O_5$ derived from fertilizer
12	13	14	15	16	17
+ 10	701	917	0.76_5	1.03	74.2
+ 1	219	129.1	1.69_5	2.66	63.5
+ 0.3	107.4	59.0	1.82_0	2.64	68.9

phorus at 112 lbs. P_2O_5 per acre rate.

set to zero counts at the beginning of a measurement.

o seconds, J.N.1272 and scaler 1221 had dead time of 500 micro seconds.

e observed counting rate (see "The measurements of Radioisotopes by

termined to be 1.04/1.00

$+\lambda\ (t-12)],\ \lambda = 0.002\ hr^{-1}$ corresponds to half life of 14.3 days.

over about 4 months and the corrected counts/min. plotted semi-logarith-

; it gave a half life of 14.2 days in good agreement with the published

counting and hence gives the counts/mg. $P^*_2O_5$ at the appropriate time.

"Greenhouse" experiment - oats

Appendices XIIIa 1 and XIIIa 2

Analysis of Variance.

	d.f.	Barbauchlaw		Boghall		Barbauchlaw		Boghall	
		S.S.	M.S.	S.S.	M.S.	S.S.	M.S.	S.S.	M.S.
		Appendix XIIIa 1				Appendix XIIIa 2			
		Shoot - fresh weight (1st Sample)				Shoot - % D.M. (1st Sample)			
Blocks	4	4	1.0	30	7.5	6	1.5	5	1.3
Treatments									
P	3	42	14.0^{**}	12	4.0^{*}	9	$3.0^{N.S.}$	7	$2.3^{N.S.}$
N	2	1	$0.5^{N.S.}$	10	5.0^{**}	37	18.5^{**}	-	$-^{N.S.}$
Interaction P x N	6	4	$0.66^{N.S.}$	7	$1.2^{N.S.}$	23	$3.8^{N.S.}$	7	$1.2^{N.S.}$
Error	44	37	0.84	56	1.3	77	1.7	49	1.1
		Shoot - fresh weight (2nd Sample)				Shoot - % D.M. (2nd Sample)			
Blocks	4	67	16.8	29	7.2	14	3.5	10	2.5
Treatments									
P	3	23	$7.6^{N.S.}$	36	$12.0^{N.S.}$	56	18.6^{**}	8	$2.7^{N.S.}$
N	2	84	42.0^{**}	167	83.5^{**}	5	2.5	11	5.5^{**}
Interaction	6	33	$5.5^{N.S.}$	34	$5.7^{N.S.}$	8	1.3	6	$1.0^{N.S.}$
Error	44	216	4.9	181	4.1	56	1.3	55	1.3
		Shoot - fresh weight (3rd Sample)				Shoot - % D.M. (3rd Sample)			
Blocks	4	9	2.3	36	9	2	0.5	13	3.3
Treatment									
P	3	30	10.0^{**}	72	$24^{N.S.}$	6	$2.0^{N.S.}$	12	$4.0^{N.S.}$
N	2	40	20.0^{**}	418	209^{**}	2	$1.0^{N.S.}$	55	27.5^{**}
Interaction	6	20	$3.3^{N.S.}$	83	$13.8^{N.S.}$	8	$1.3^{N.S.}$	46	7.6^{*}
Error	44	85	1.9	515	11.7	40	0.9	83	1.9

** denotes significant at the 1% level. * denotes significant at the 5% level. N.S. not significant.