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"A study of the relationships between NPK conversion efficiency, level of self sufficiency and soil type on selected groups of small farms in southern Scotland."

by

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THESIS.

The thesis is basically that there is a definite relationship between the efficiency with which a farm converts raw material in the form of nitrogen, phosphoric acid and potash into saleable produce and the level of self sufficiency at which the particular farm is operated. It is expected that maximum conversion efficiency will occur at different levels of self sufficiency depending upon soil type.

The particular interest is in the Scottish small farm in the area south of the highland fault and the object of the work will be to attempt to measure the relationships between the three parameters, conversion efficiency, level of self sufficiency and soil type.

CONTENTS:

1.0 INTRODUCTION.

As long ago as 1891 the writer of an article on Jethro Tull quoted him as saying 'deduct from agriculture all the practices which have made it flourishing and you have precisely the management of very small farms.'

Whether or not Tull had in mind small farms of the size and type which exist today we do not know but it is certain that the problems confronting the present day small farmer are no less than they appear to have been at that time.

Because of these problems the small farm has been, in recent years, the subject of much discussion by those concerned with agricultural policy and it is therefore appropriate in this introduction to a study of particular aspects of the small farm to say something about the problems and to indicate the trends of present day thought concerning small farms in general.

Obviously the first task is to define the subject and as will become apparent this is no easy matter.

1.1 Definition of the Small Farm.

The main difficulty lies in the fact that farming enterprises represent an almost infinite gradation from the smallest units of one

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or two acres right up to large farms of a thousand acres or more and although the identification of small farms by fixing acreage limits would be convenient, this unfortunately does not lend itself to practical application unless other factors are also considered.

The more important of these factors can of course be stated but it is extremely difficult firstly to measure them with any degree of accuracy and secondly to determine the degree to which each should influence the overall assessment of any one farm; and even if this were done it would almost certainly be found that they exhibited an interdependence which could create immense statistical difficulties and which would require to be measured over a long period of years. Examples of this are numerous. One might be that the personal qualities of the farmer and his family govern their standard of living which in turn affects the amount of income saved for developing the farm thus influencing the standard of management. Then again, the skill and intelligence of the farmer have a direct bearing on the management and this affects the returns he obtains.

Other factors such as soil type, situation, weather, economic conditions and a host of others must all be considered when assessing the status of/

of a farm. Since the word 'small' when used to describe a farm implies not only small acreage but other features such as small turnover for example, the first step in classifying a farm is to assess its status in as much detail as possible and only when this has been done is it safe to classify the farm as small or otherwise.

The fixing of limits is of course necessary in the classification of farms and in the absence of exactitude it is obvious that these limits must be arbitrary. In practice farms are identified in different ways depending on the reason for classification and the best way to illustrate this is to consider examples of ways in which the small farms of Scotland have been classified for partic-:ular purposes.

In the past various attempts have been made to arrive at a method of classification of the small farm which could be successfully used on a national basis and was therefore to a large extent non-specific in its dependence upon any one factor. The latest of these was made in 1958 with a view to providing a basis for a national scheme to give financial assistance to small farmers. The scheme was subsequently introduced by the Department of Agriculture for Scotland* and the money provided is expected to enable small farmers to increase their productivity. In order to be eligible the unit

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*Also by Ministry of Agriculture

under consideration must be classified as a true 'small farm' and this is decided by certain farm characteristics two of which are numerical meas-:urements. The first of these is acreage which must lie within the limits of 20 and 100 and secondly the farm labour requirements expressed in man-days and calculated from a table of standard man-days per acre of each of the common-:ly grown crops must be less than an upper limit of 450 and more than a lower limit which is flexible and might be in the region of 200. Other characteristics of the farm and farmer are requi-:red but reliance is normally placed on the opinions of the officer who reports on the part-:icular case.

This scheme, at present in operation, has many critics most of whom feel that it is not possible to assess the status and subsequently classify a farm in such a simple way. However, it has been mentioned in some detail because it represents one method of identification of small farms at present officially accepted. This method is of course used for the purpose of dist-:ributing grants and while it may be satisfactory for that purpose many agriculturists would find it totally unacceptable for other purposes and in particular they would regard it as being quite inadequate for the identification of small farms in/

in a general survey which might eventually be used to influence agricultural policy. Never:theless, it is interesting to note that in official circles the small farm has certain acreage limits and that presumably to eliminate the possibility of confusion with units of either very high production for example market gardens, or of very low production such as certain types of croft on poor quality land, a figure is obtain:ed which gives an indication of the labour requirements.

Frequent critics of the small farm have been economists whomare able to quote the results of economic surveys to substantiate their arguments and the way in which they define the small farm differs in some respects from the previous example.

An interesting report by Hendry and Bielby appeared in 1957 and this summarises the results of much research on the economic aspects of small farming. In section A of this report the authors, after pointing out the difficulties of arriving at a satisfactory definition of the small farm, show how they achieve a result which is satisfact:ory for their purpose.

Briefly they state that the small farm should be a commercial enterprise which provides a full time occupation or is the primary source of income for the farmer. The lower limit of size is therefore/

therefore fixed at an acreage which depends upon the type of soil, the location and the type of husbandry which is being practised and is of course subject to wide variations. The small farm has also been taken as requiring not less than 1800 hours of work per annum. Any upper limit must inevitably be arbitrary but for their purpose it has been taken as a farm of not more than 100 acres of crops and grass employing not more than one regular full time worker in addition to the farmer. The authors further state that turnover would probably be a better measure of size but is a difficult figure to obtain in the majority of cases.

On this definition of small farms it is interesting to note the relative numbers and percentages in various parts of the country and the authors quote the figures given in TABLE 1.

TABLE 1.

Number of small farms compared with the total number of farms in various districts of Scotland:

District	Small Farms		Total Farms	
North East	5,800	35%	16,700	100%
East Central	1,400	22%	6,400	100%
South East	700	18%	3,900	100%
South West	2,900	24%	12,100	100%
Highlands	2,000	11%	18,900	100%
Scotland	12,800	22%	58,000	100%

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This shows that approximately one fifth of the total number of farms in Scotland are small farms as defined by Hendry and Bielby and that nearly half of these are situated in the North East with a fairly high proportion in the South West.

This last classification has been used as a basis for an economic and statistical survey of small farms with a view to assessing the place of the small farm in Scottish agriculture and for this purpose it has proved to be adequate. It is clear however, that what might be described as a 'general purpose' definition of the small farm is not possible at the present time in view of the large number of factors involved and the most satisfactory approach is at best a compromise.

Although it is proposed to study particular aspects of the small farm as part of the research programme, it will become apparent that accurate classification of small farms is not vital to the success of the project and therefore no great attempt will be made to develop a radically new system. The suitability of farms for special study will be decided in a way which represents a compromise between the two systems outlined and the limits will normally be flexible. The actual method used will be more fully described in a later section.

1.2 The Problems of Small Farming.

Reference has already been made to the problems associated with small farming and the more important of these are worthy of note.

Economists and statisticians who are able to quote actual figures to substantiate their arguments criticise small farms chiefly on the grounds that they are often incapable of providing a living for the farmer and his family. There is no single reason for this which would apply in every case but it is certain that a lack of the resources of the larger type of farm for development purposes often combined with a lack of specialised knowledge on the part of the farmer is responsible for many of the small farm difficulties.

Compared with medium and large farms, statistics quoted by Hendry and Bielby show that production per acre is lower on Scottish small farms as TABLE 2 illustrates.

TABLE 2.

Relative output per acre.

	Hill sheep	Stock rearing	Rearing & feeding	Arable farms	Dairy farms
Small Farms	13.2	20.4	36.4	37.1	45.8
Medium Farms	15.1	24.0	38.9	49.9	46.5
Large Farms	17.8	23.6	35.2	49.8	46.1

The table shows that on average, small farms are/

are producing only 88% of the output per acre of medium and large farms combined. This appears to be largely due to lack of capital but it is interesting to note that in many cases the amount of capital per acre is higher on small farms, particularly the more progressive ones, and the conclusion is inevitable that compared with medium and large type units, small farms must be over capitalised in order to provide a satisfact-:ory living for the farmer and his family. One reason for this is that the small farmer cannot fully utilise the machinery and equipment which he should possess in order to meet his cultivation requirements and in consequence, capital if it is used for that purpose is proportionally greater on the small farm.

A further criticism in the same vein is that in general, the return obtained from farming these units is a small reward for the risk of invested capital and the long hours worked not only by the farmer himself but in many cases by members of his family who receive little or no pay for their labour. It has in fact been shown that small farms frequently show higher labour requirements per acre as compared with larger units and this may be due to under mechanisation caused by lack of capital.

Although the problems associated with small farming/

farming are numerous, most of them appear to arise either from inadequate financial resources or inefficiency caused by lack of skill and while the injection of additional capital into small farms would undoubtedly increase the farmer's income, this practice could hardly be recommended since it seems probable that the extra returns would in most cases represent a comparatively low rate of interest.

Apart from economic considerations a great measure of skill is also required to deal success-:fully with the technical problems associated with the smallness of farms. Partly in an attempt to obtain increased interest on the available capital and partly to reduce outlay on a wide range of equipment it is often found that small farms specialise in one particular enterprise and in doing this there are, of course, technical diffi-:culties. For example, it is more difficult to maintain a balanced type of husbandry which is often most desirable in that it enables some parts of the farm to use the by-products of others. It is also more difficult to use an efficient rotat-:ion and the incidence of pests and diseases increases accordingly.

Farms with a high degree of specialisation are often more akin to factories directly converting/

converting purchased raw material into produce than to true farms which imply a measure of two stage conversion involving both the soil and the livestock.

In conclusion it appears, therefore, that the main problem associated with small farming can be quite simply stated namely to provide an adequate living for the occupiers. Within the limitations of size there are two main reasons for this, lack of capital and lack of skill and it may be noted here that in view of the comparatively narrow profit margins on many of his activities the small farmer must possess considerable skill if he is to show an adequate profit. This is particularly important in 'bad' years when he may find it difficult to keep going on his limited resources, a problem which is seldom so acute on medium and large farms.

1.3 Success factors.

In spite of the fact that small farms in general are experiencing difficulties, examples are by no means lacking of small farms which are entirely successful and which are able to provide a most satisfactory income for the farmer. However, for many this is not the case and a number of suggestions have been put forward with the object of improving the present position. Basically,/

Basically, there are two schools of thought and it is interesting to note that they are in direct opposition. The first believes that there should be more specialisation while the other feels that the small farmer should diversify his interests to a greater degree.

The reasons behind these suggestions are worthy of note. Those who believe in specialis-:ation take the view that since lack of capital is the chief difficulty it would be best to use the greater part of the sum available to finance a highly specialised enterprise such as fattening pigs, rearing broilers or perhaps the intensive use of glass. They feel that the farmer would more readily acquire skill in the operation of one enterprise and this together with close attention to all aspects of the work should enable him to make a study of every detail of his process and thus achieve a high degree of efficiency.

Those who disagree with this suggestion maintain that although in a few cases specialis-:ation may make spectacular profits for the small farmer, it is generally unwise as a long term policy which should be as far as possible immune to changes in the economic climate. They further suggest that the small farmer would be wise to adopt a type of farming which was based upon a sound/

sound rotation for the particular district, modified if necessary in order to provide as much stock feed as possible, and to operate this in conjunction with one or more stock enterprises. In short, they feel that a self sufficient* type of farming not only satisfies a demand for some reduction in working capital but is a much better insurance for the future since it at least provides a continuous background of closely integrated enterprises any one of which could become the main activity in a very short space of time, perhaps within a year and without heavy capital outlay, if the demand for a particular product warranted some emphasis. With such a system it would not matter which product was making the best return whether stock or crop, the farm would have a sound basis upon which to develop it and the facilities to efficiently use any by-products which there might be. This development would of course be restricted to a level which would ensure that the fullest possible use was being made of the other resources of the farm and that the background of self sufficiency was not lost. In this way the future welfare of the farm would be secure in the event of the main product becoming uneconomic.

Apart from the obvious suggestion that small farms/

* Self Sufficiency defined on page 39. Sect. 3.1

farms should be amalgamated into larger units, the above two theories form the basis of all those which have been put forward in recent years in an attempt to alleviate the difficulties of small farming and while many authorities favour extreme specialisation, it is probably true to say that those who advocate a moderate degree of specialisation associated with the flexibility afforded by a background of self sufficiency,* have the greatest support.

1.4 <u>The place of the small farm in the agricultural industry.</u>

In section 1.1 it was shown that small farms represent about 22% of the total number of farms in Scotland but their output expressed as a percentage of the total Scottish output is, naturally, less than this. In fact Hendry and Bielby state that the actual figure is about 16% and W.H.Long of Leeds University states that the average gross income per acre on small farms in England is less than on the larger type of farm and this is taken as an indication that the output per acre was also less. It therefore appears that small farms in many cases produce less per acre than larger farms and that their contribution to the nation in terms of output represents but a small fraction of the total output/

* Self Sufficiency p. 39.

output of the industry as a whole.

In view of these facts it would seem that there might be justification for adopting a policy of amalgamation of small farms into larger units and indeed this has been suggested. However, in order to assess correctly the significance of the economic criticisms it is necessary to examine briefly some of the functions of the small farm.

From a national point of view the family farm has three main functions, firstly it acts as a food producing unit, secondly it provides a home and employment for a family and lastly, in many cases it serves as a rung on the farming ladder enabling a man with initiative and ability but lacking the considerable capital necessary to enter medium scale farming at the present time to make a start on a small farm.

It has already been shown that as a food producing unit the small farm is less efficient than the medium or large farm. This however, refers to output per acre and it is not unanim-:ously agreed that in every case a high output per acre is the most important aspect of farming. The long term view demands that other factors be considered and one of the more important of these is that a healthy agricultural industry is a vital asset to the nation in times of stress. This was of course exemplified to a great extent during the

1939-45/

1939-45 World War and previously during the economic depression of the 1930's. During these periods the ability of the agricultural industry to produce food as efficiently as possible was of prime importance, efficiency in this sense refer:ring more to the maximum yield per unit of raw material than to economic efficiency in terms of low costs of production.

This being the case it would seem that from the national point of view, a sound agriculture which represents an asset to the nation and an insurance for the future is based not only upon economic considerations but also upon biological efficiency. While it is possible to obtain a reasonably accurate economic assessment of the small farm at the present time, many difficulties arise when an attempt is made to measure biolog:ical efficiency and there is therefore a tendency to give prominence to the economics of small farming when this subject is discussed.

Economic considerations also occupy a prominent place when the small farm is assessed on the basis of its ability to provide a home and employment for a family. In this respect the facts unquestionably show that these farms in many cases fail to provide an adequate living. Ideas of an adequate living vary, however, and while/

while this may be true as far as monetary return is concerned one must not lose sight of the numerous perquisites which the small farmer enjoys as compared, for example, with the average industrial worker. It is true that many of these perquisites, in particular farm produce used by the family, can be valued and taken into account by the economists but comparing the small farmer with the average industrial worker, the small farmer's rent is in some cases lower and the money spent on recreation is often less. One of the reasons for the latter is that country life is largely devoid of the money consuming attract:ions of the city and another reason is that amongst small farmers there still persists an attitude of mind which gives them as much if not more pleasure and satisfaction from improving milk yields by judicious breeding and careful feeding or from trimming a hedge or thatching a stack than from taking part in the communal pleasures of town life. From the national point of view it may well be that a body of men whose sole interest is in the land is an asset to the country which cannot be measured in terms of money and which might be worth preserving for this sake alone.

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The fact that the small farm serves as a rung on the farming ladder is frequently illustr-:ated in the average Scottish country district. Examples of small farmers who have become occupiers of medium and even large farms are not difficult to find and in many cases the farms have actually been bought for considerable sums of money by small farmers who originally started with little or no capital. It is noteworthy also that these men are often excellent farmers who not only manage their medium sized farms most successfully but usually leave behind them a well developed unit with a type of husbandry well suited to the farm and one which has been proved to be successful. This, of course, is ideal for the beginner taking up small farming and enables him to make a quick and easy start.

In general the place of the small farm is difficult to assess. Economists find it hard to justify and take the view that if small farms are to remain they must be justified on grounds other than economic. These grounds of course exist and although they may not be entirely conclusive it seems that government policy at least is in favour of maintaining small farms as a part of the agricultural industry and any-:thing which can be done to ease the problems associated/

associated with these units is, naturally of great importance at the present time.

1.5 References and bibliography.

Text Reference P.11

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2.0 OBJECTS OF RESEARCH.

Whether or not the small farm problem will ever be completely solved seems doubtful but obviously a great deal can be done to ease the difficulties by persuading the small farmer to adopt a sound system of farming. Of the suggest-:ions which have been put forward, the system based upon increased self sufficiency seems to hold greatest favour but although self sufficiency is frequently mentioned it appears that little is known about its effects on the overall efficiency of the system.

2.1 General considerations.

Self sufficiency as applied to farming is no new/

new concept but a study of the literature has shown nothing to indicate that any detailed study has been carried out, in fact it is noteworthy that no satisfactory definition of self suffic-:ency in farming has been found. Furthermore it becomes evident when comparing the work of various writers that self sufficiency is being interpreted in different ways. In view of this unsatisfactory position it was decided that it would be both interesting and useful at the present time to investigate in detail some of the technical aspects of self sufficiency in farming, particul-:arly in its application to the small farm in Scotland.

A complete investigation of all the effects of increased self sufficiency, many of which are almost certainly cumulative, would require observation over a long period of years. Never-:theless it is felt that a study of some of the biological consequences of adopting an increased measure of self sufficiency in a farming system, self sufficiency being defined in a particular way, would not only be a contribution to agric-:ultural knowledge by helping to remove some of the confusion which appears to exist at the present time but might also be of value to those who are directly concerned with the welfare of the/

the small farmer. It should in fact enable small farming systems to be planned for particular results with a greater degree of accuracy than was hitherto possible and conversely, the results of operating particular farming systems under stated conditions could be more accurately predicted. Apart from the purely academic interest it is intended that the conclusions of the research should be presented in such a way that they might be of practical use in the field and it is felt that as far as self sufficient farming is concerned the ability to effect comparisons between different systems would be of great value.

Clearly the first requirement is to define self sufficiency in a way which leaves no doubt as to its meaning and the second is to be able to show the results of varying the level of self sufficiency with an accuracy sufficient to permit realistic comparisons to be made and to allow an assessment of the economic consequences of diff-:erent levels to be compared with each other. In this way more effective planning could be carried out.

Although it is necessary to introduce econ-:omics into the planning of farming enterprises, costs and prices vary from time to time and it is felt that a project of this type should not therefore/

therefore conclude with a method of directly assessing the economic consequences of self sufficient farming but should attempt to show instead the biological results in the form of the efficiencies with which raw materials and the resources of the farm are used. From these the quantitative data necessary to maintain fertility and production could be obtained and, if required, these figures could then be related to the costs obtaining at the time. This is basically the object of the research programme and it will now be considered in greater detail.

Having decided that the investigation should exclude economics, consideration was given to the best way to tackle the problem so as to obtain the maximum amount of useful information within the limitations of the available resources. The basic problem is one of efficiency on the small farm and efficiency in this sense is taken to mean the extent to which the farmer uses his farm potential for the production of saleable produce. If economics is to be excluded, it at once becomes apparent that a quantitative assessment does not necessarily reflect profit:ability and this point will require to be taken into careful consideration if the results of the research are not to be misinterpreted. It does not follow however that quantitative data are worthless in practice, indeed there are the

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distinct advantages of permanence and the possibility of relating the data to different products and raw materials with the application of appropriate correction factors if necessary.

2.2 Productivity.

The nature of the quantitative data remains to be decided and this very largely depends on the type of measurements which can readily be made. Since the efficiency with which farm potential is utilised is the criterion, various factors which contribute to farm potential are worthy of note. In general there are three major features of any farm which determine its product-:ivity potential, these are:-

1) Position (geographical, elevation & aspect)

2) Climate.

3) Soil type.

There are naturally many others including proximity to markets which may influence the nature of cropping but in the proposed quantitat-:ive assessment, the type of cropping must be less important than the permanent features of the farm if the results are to be widely applicable in the area studied which covers the low ground parts of the South and East of Scotland.

Since the primary object of farming is to convert raw materials into produce the efficiency with/

with which it does this is of fundamental import-:ance and it is an increase in this type of efficiency which would undoubtedly help the small farmer to overcome many of his present difficul-:ties. This would be an even greater help if at the same time the farmer was able to reduce his capital outlay and his labour expenses. All of these benefits are claimed by those who advocate an increased measure of self sufficiency but the present study will only be concerned with raw material conversion efficiency.

The raw materials of farming are many and varied; they may consist of feedingstuff or fertiliser or both but the majority of small farms in the area to be studied are general arable units which carry a few feeding cattle or a small dairy and occasionally some sheep. On these farms the stock is mainly fed on home grown feed and purchased raw material consists almost entirely of fertiliser. For this reason it is logical to conduct the research on the basis that the raw materials consist of N, P and K and to attempt to assess the conversion efficiency of each of these three elements. It is obvious that there are many complicating factors in work of this type. The raw materials may be supplied by the soil reserves of NPK if not entirely, at least in part, or/

or NPK may be derived from dung produced by livestock fed with either purchased or home grown feedingstuffs. In any event the action of farm:ing mobilises the basic plant nutrients and the ultimate fate of a proportion of these is to form part of the product.

In an active farming system there is there:fore the possibility of measuring the total quantities of NPK purchased whether as fertiliser feedingstuffs or even as livestock and of estimating the quantities sold in the form of produce. The relationship will show the efficie:ncy of conversion into produce of each of the elements. If it is also possible to measure the level of self sufficiency and to cause it to vary, the effect on NPK conversion could be demonstrated. Obviously there are numerous variables whose effects must be eliminated in an experimant of this type and a generalisation would only be possible after conclusive replication.

2.3 Utility of the relationships.

The question arises as to whether or not such a relationship between self sufficiency and NPK conversion would have any real value and whether there is justification for making it the main feature of the research. At this stage it is not proposed to discuss self sufficiency* at length/

* Definition. p. 39.

length or even to define it. It is enough to assume that the level of self sufficiency of a particular farming system on a particular farm can be measured and that the figure so obtained is available for comparison with other features of the system. The advocates of increased self sufficiency consider that it will produce greater efficiency in the utilisation of farm resources and it therefore follows that if the NPK utilisation efficiency is in fact a true measure of the extent to which the resources are used, the type of experiment outlined will not only test the hypothesis but provide additional information which will enable predictions to be made of the effects of any changes in the level of self sufficiency upon the use of raw materials. It is obvious that this information if it carried reasonable accuracy would be of value to farmers faced with a changing economic climate and desir-:ing to make alterations to their system in order to exploit the new conditions and increase profits. This would be especially the case if the proposed new system exhibited a marked change in the level of self sufficiency and the information should show how the various enterprises would best be integrated to achieve maximum raw material efficiency.

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On the basis of this reasoning, it would appear that for any given farm there is a particular level of self sufficiency which under average conditions would give maximum raw material conversion. At this level it can be considered that there exists the optimum balance between stock and crop for that particular farm and this is referred to as the point of biological balance between stock and crop. It seems probable however, that in practice this point may occur at a level of self sufficiency which necessitates a relatively larger number of livestock than is usually economic and in planning a farming system the object should be to operate it as near to this point as possible if the maximum use of raw materials is to be obtained, the actual deviation depending upon economic factors.

An interesting application of this technique would be in the planning of the modern so-called 'agribusiness' where there is often a two stage conversion of raw materials into produce and where the intention is to obtain profits at each stage. With such an enterprise the maximum possible efficiency is essential and if, as in many cases, the system involves growing feed for livestock which is then sold, operation as near to the point of balance as possible would ensure that the/

the best biological return was obtained from the purchased NPK but as already stated, a deviation might be necessary to ensure maximum economic efficiency.

In common with many other processes farming is at best a compromise between conflicting factors but whereas it has been possible in the past to obtain a reasonably accurate evaluation of the economics of farming, the fundamental biological processes have in many cases defied assessment. This has frequently led to economics becoming the sole basis of planning particularly on the small farm and may well be the reason for the instability of the systems which result. There seems little doubt that system planning would be more effective if a compromise was reached between economic and biological considerations. From a national point of view farming potential matters more than current output and not only would this condition be satisfied if such a compromise was made but the farmer would experience the long term benefit of a high status of soil fertility and reserves combined with flexibility of production. For this reason also any research designed to measure the biological efficiency of a farming system is an attractive proposition.

Having decided that work of this type is justified/

justified the primary object of the research will be to show how the level of self sufficiency of a farming system influences the raw material conversion efficiency and using this information a study will be made of the possibility of the existence of a point of biological balance. It has already been mentioned that the intention is to present the results of the research in such a way that they might be of practical use and it is felt that the best way to do this is to provide a family of curves relating self sufficiency to each of N, P and K utilisation efficiencies for each class of farm. In view of the fact that type of stocking and cropping may modify the relationships it will probably be necessary to derive correction factors from the experimental data in order that the results will have a wider field of application. This might be particularly required in the case where the NPK raw materials were purchased in the form of feedingstuffs. Within the limitations of the study it may be possible to discover functional relationships with other factors which influence farming efficiency and with this in mind, consideration will be given to the measurement of any farm characteristic which might conceivably have a bearing on the primary objective.

Summarising/

Summarising the objects of the research the primary task is to test a popular opinion that increased self sufficiency will help the small farmer to make better use of his farm resources and a secondary aim is to show the relationships obtained in such a way that they may be of value in planning or modifying farming systems for particular results. Throughout the work such additional observations and measurements as are possible will be made in the chance that further relationships may appear but since farming is such a complex process it seems doubtful if any will be found which are simple enough to permit conclusive trials to be carried out as an offshoot from the main research.

Although a research programme of the type proposed is often difficult because of the large number of uncontrollable factors found in farming, it is hoped that with suitable replication of experiments and the aid of statistical processes in the interpretation of the data obtained, the objects of the research will be fulfilled.

3.0 SELF SUFFICIENCY IN FARMING.

3.1 General.

Although there is some confusion as to the

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true meaning of self sufficient farming in its practical applications, the basic concept which enjoys almost universal acceptance is nevertheless that it implies a farming system based on stock and crop in such proportions that they are to some extent complementary, the crop being used to feed livestock whose dung is returned to the soil. Difficulties arise however when it is realised that a system based on complete self sufficiency is not possible in practice since it makes no allowance for either saleable produce or losses. On the other hand, a type of farming based entirely on the production of crops using purchas-:ed manures is possible and examples do in fact exist; this represents no degree of self suffici-:ency.

Since the majority of small farms fall somewhere between these two extremes it is poss-:ible to conceive of a scale indicating the degree of self sufficiency and by making some actual measurements of certain characteristics of any particular farm it should be possible to give that farm a position on the scale which would indicate the extent to which it was self sufficient. Assuming self sufficiency could be measured in this way with a useful degree of accuracy/

accuracy, it would then be possible to relate the level of self sufficiency to any other farm characteristic which was capable of measurement and by using the relationships so obtained, to express for example, the efficiency with which the farm used any one or more of its resources as a function of the degree of self sufficiency. In this way not only could it be shown whether or not a self sufficient system was of value on a particular farm but the optimum level of self sufficiency to produce any desired result could be estimated.

Referring again to the self sufficiency scale, complete self sufficiency implies that all livestock and plant foods are retained within the system and operate in loss free cycles, there can therefore be no produce leaving the farm and no purchases of raw materials to balance the loss which would occur in the form of produce. It is thus possible to conceive of two ways in which the raw materials of farming circulate, one entirely within the farming system and one exter-:nal to it in which purchased manures and feeding-:stuffs balance the losses occurring in the form of produce. Obviously these two processes are closely interdependant and to regard them as separate entities represents a gross over-simplification, but the concept is nevertheless useful/

useful when considering self sufficiency. In the case of complete self sufficiency there is therefore internal circulation of raw materials but no external circulation while with no degree of self sufficiency there is external circulation but no internal circulation. It is convenient to refer to these conditions as representing the limits of self sufficiency, in the former case 100% and in the latter, zero %.

On the basis of this reasoning, self suffic-:iency in farming may be defined as an expression which indicates the extent to which crop and livestock are complementary as regards raw material. The measurement of self sufficiency is based on the ratio of the internal circulation of raw material to the total internal and external circulation in the particular system. The level of self sufficiency for raw material may be expressed thus:

$$\%\text{self suffic.} = \frac{\text{Internal circ.}}{(\text{Int. Circ.} + \text{Ext. Circ.})} \times 100$$

This expression obviously represents a generalisation and is only true when the farm is considered as a complete unit. In the example quoted where crops are grown entirely with purch-:ased manures and where there is no livestock, there/

there are plant residues and the effects of soil fauna which could conceivably be regarded as simulating the activity of livestock, but soil fauna is not livestock and by definition does not influence self sufficiency. Nothing is lost by this restriction in fact there is the advantage that a substantially common factor in systems exhibiting widely different levels of self suffic:iency is eliminated and the measured difference is therefore increased.

The question of the raw materials of farming has been dealt with in the previous section and although it will no doubt be possible to derive an overall figure for self sufficiency from the experimental data it is felt that it would be interesting to observe any differences which may exist in the cycles for each of N P and K. For this reason each of the three elements will be considered separately in the first instance.

3.2 Possible effects of self sufficient farming.

The adoption of an increased measure of self sufficiency into a farming system is claimed by many authorities to have great beneficial effects on overall farm efficiency. This is presumably based on the effect that the increased use of dung has on the soil since with a few exceptions increased self sufficiency on small farms usually means/

means that the number of livestock must be increased.

Although there are extremists on both sides, most agriculturists agree that a balance of organic and inorganic manuring is the best policy on the average farm and the present day tendency is to use as much dung and organic manure as it is possible to produce in the belief that by so doing a greater cropping efficiency will result and there will be a greater efficiency in the utilisation of fertilisers. Given proper drainage and a suitable pH there is of course no doubt that organic manuring has desirable physical effects on the soil and the NPK which is in organic combination is generally mobilised more slowly than is the case with inorganic fertilisers. It would appear also that where inorganic fertilisers are used in conjunction with a regular programme of organic manuring there is likely to be a greater retention of the inorganic NPK due to adsorption by humus and also a greater conversion into organic combination as a result of the increased activity of soil micro-organisms.

A probable result of these processes would be that inorganic NPK applied to the seed bed of a crop would experience less leaching and fixation loss in the early stages of crop growth and that this/

this saving would be released as plant food over a comparatively longer period and in quantities which the crop could readily utilise. Yet another possible effect found after the application of dung is that the hormone effects of certain constituents stimulate a greater root development which enables the crop to use available nutrients more readily.

All these processes and many more of less consequence suggest that inorganic NPK is more efficiently utilised in a soil which receives regular organic manuring, particularly with dung, and it therefore seems probable that as the average level of self sufficiency on a farm rises, the efficiency of utilisation of inorganic NPK rises also. However an increase in self sufficiency might well be associated with a decrease in the intensity of cropping and hence the overall level of fertility since it implies a reduction in purchased fertiliser and this means that a way must be found to measure the level of fertility at which the soil is operated. A figure which would undoubtedly bear a close relationship to this could easily be obtained from soil analyses and this will form the basis for the estimation of the level of soil fertility. The potential product-:ivity of different soil types is another variable factor and a similar analysis might represent a relatively/

relatively high state of fertility which would allow a maximum productivity potential on a poor, marginal type of soil and a comparatively low level of fertility on, for example, a good quality market garden type of soil. Soil type is there-:fore important and allowances must be made for it in the research. Probably the easiest way to do this is to repeat a series of experiments on different soil types representing a range of those commonly found in the area studied.

The possible effects of introducing increased self sufficiency into small farming are numerous but for the purposes of this investigation, the most important is undoubtedly that it may affect the efficiency with which the soil converts purchased inorganic fertiliser into saleable produce and the ultimate object of the research programme is to attempt to show whether or not this is the case and if so how it may be measured.

4.0 REVIEW OF LITERATURE.

As the research plan developed it naturally became important to ensure that no work was repeated unnecessarily and this meant an extensive review of agricultural literature and the study of any previous research on self sufficient farm-:ing either in Scotland or under conditions similar/

similar to those prevailing in Scotland. It quickly became evident however that there were a number of difficulties in work of this type chief-:ly caused by the vast amount of literature available and the general nature of the subject at this stage. In order to simplify the search a classified approach was essential and it was decided to investigate each of the main features of the proposed work in sequence.

4.1 Self sufficiency.

Since the research is basically concerned with self sufficiency, it appeared logical that the first task should be to find out if any writer had defined self sufficiency in farming and shown how it could be measured. The concept embraces the whole farming process and the search was therefore started in the standard agricultural texts.

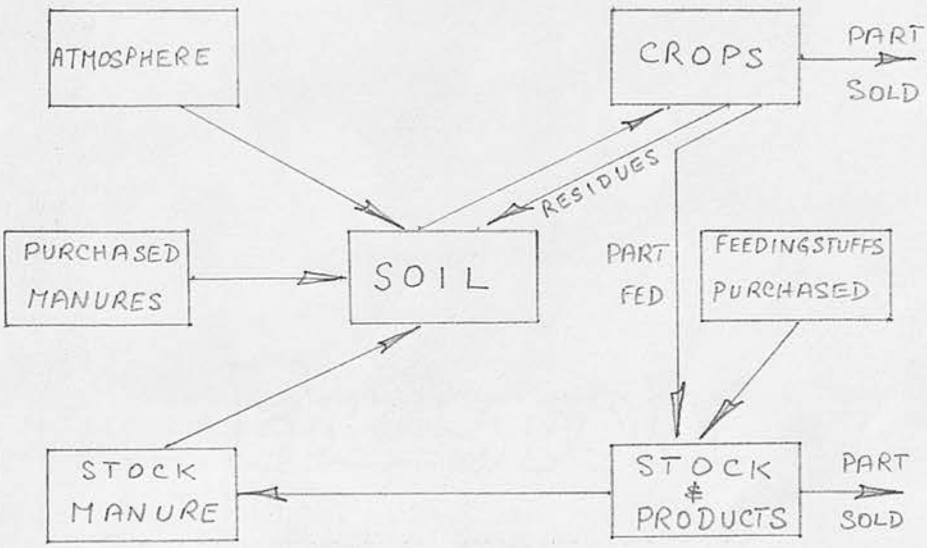
Watson and More (8th. Edit.) although making frequent references to the importance and desirab-:ility of a balance of stock and crop, do not appear to associate this directly with efficiency in the utilisation of purchased NPK. They do point out however, that there is increased retent-:ion of inorganic NPK in well dunged soils but give no evidence to suggest that the degree of recovery has ever been estimated as a function of the/

the level of organic manuring.

In Fream's 'Elements of Agriculture' (13th. Edit.) there appears a section entitled' The fertility balance.' This shows how the biological balance of nature is disturbed when man grows crops which are removed from the site and adds that the losses may not be so appreciable when considered in relation to the total reserves present in any soil. The author points out that such losses fall primarily on the available portion of the total reserves and so the soil becomes unable to provide anything like the amounts of some of the individual constituents necessary to main-:tain a high level of production. If the crops are used solely for feeding the farm stock or for the production of animal products sold off the farm the inroads on fertility are less severe than when the crops themselves leave the farm since some part of the nutrient constituents are retained and returned eventually to the soil in the animal excreta.

The compensating effects of the introduction of material, fertiliser or feedingstuff, from extraneous sources is mentioned and the conclusion is reached that it is possible to balance gains and losses by adjusting the farming system to the inherent fertility of the soil. The necessity of planning/

planning farming systems is emphasised and it is pointed out that the plan may be adapted to grad-:ually elevate or depress the level of fertility at which the soil is operated until a point of substantial equilibrium is reached. The author illustrates the movement of nutrient materials with the following diagram:



Although levels of self sufficiency are not specifically mentioned in this section, it is obvious that the author has a similar concept in mind. It has not, however, been developed in any way which might indicate that attempts have been made to measure the level of self sufficiency.

The search was continued in a number of other works on general agriculture but few references to self sufficiency were found and any writers who mentioned self sufficiency did not define it. At least part of the reason for this is no doubt due to/

to the fact that much of the material was American and because of climatic and other conditions, the tendency there appears to have been towards either extensive farming or specialisation where self sufficiency is not so applicable. Since farming systems in foreign countries are generally based upon different crops and stock, the references to self sufficiency do not generally apply to Scottish conditions and therefore they are not recorded. In British literature the references appear to be few in number and lacking in detail, the reason no doubt being that the concept has never been clearly defined and the obvious impracticability of compl-:ete self sufficiency has led to it being restric-:ted to describe hypothetical farming systems.

4.2 Historical.

The review of modern literature had therefore failed to produce evidence of any serious work on the effects of varying the level of self sufficie-:ncy in a farming system and consideration was given to the possibility of obtaining useful info-:rmation from agricultural history. One of the obvious benefits of self sufficient farming is that its increase leads to greater economy in the use of fertilisers and it therefore follows that before the introduction of inorganic fertiliser, any areas which sustained continuous cropping must have shown a/

a fairly high level of self sufficiency. A study of agricultural history was therefore carried out in order to discover something about the way in which the level of fertility was maintained.

Although much of the available literature was of doubtful accuracy and appeared to have been written by authors with obvious bias (e.g. Handley, Johnston) it was possible to reconstruct a fair picture of conditions in the early days of organ:ised agriculture in Scotland and also of primitive agriculture in certain foreign countries.

In the earliest times when crops were first grown, little thought was given to returning material to the soil to compensate for cropping losses and it seems that the practice in those primitive days was to grow grain on an area of virgin land for probably three or four seasons until the yields became low and then to move to fresh ground. As populations increased and the necessity arose for more intensive use of land this nomadic agriculture gave place to systems of farm:ing which attempted some degree of self sufficie:ncy through the integration of livestock with the cropping programme. Although in Britain the level of self sufficiency was never high, it is interes:ting to note that in parts of China (Systems of Land Tenure in various Countries) local legislation was/

was introduced to control the use of livestock and the disposal of all excreta including human, in order to return all animal, vegetable and human waste materials to the soil for the production of crops. In these areas the rainfall was comparat:ively low and consequently leaching losses were at a minimum, this meant that a high level of self sufficiency was possible and indeed it is reported that these systems were in operation for generat:ions and that food production remained adequate for the communities throughout the period. The area of land required per person is not stated exactly but it appears to have been in the region of three acres.

This system is probably the nearest to compl:etely self sufficient agriculture which has ever been achieved and although the level of cropping would in no way re#semble the intensive cropping of the present day, at least it could not be described as extensive agriculture which depends almost entirely on the virgin soil reserves of plant foods since it is unlikely that even the most extensive systems would remain productive for the long period mentioned and the integration of livestock into extensive systems is not usually so effective. In most of these early farming systems the limiting factor in the maintenance of plant food/

food reserves in the soil would no doubt be phosphate since it is difficult to ensure adequate supplies of this in organic manures. However, the total content of phosphorus element in most soils is comparatively high although only a small proportion is generally available to the plant and it may be that with a semi-intensive system and the increased use of organic matter there is a slow mobilisation of P from the fixed state due to the activity of micro-organisms and the effect of biochemical processes which is sufficient to provide semi-intensive crops with their minimum requirements for a very long period.

Although early British agriculture did not achieve such a high degree of self sufficiency and in fact could not hope to do so because of the climate, attempts were nevertheless made to conserve plant foods by resting the soil and by grazing stock on the grass which grew naturally. When agricultural communities became organised and land was enclosed, legislation was often introduced to ensure that this was carried out. The usual rotation was to grow one or two crops of grain and then allow the fields to be grazed for perhaps three or four years. In parts of Scotland this system developed into the infield and outfield type of farming in which stock were often kept in the/

the small infields during the night and allowed to graze on the larger outfields during the day. By this means the infields became enriched with dung and were capable of being cropped more or less continuously. Since there is an obvious unbalance in the level of fertility of the infields and outfields in this system it cannot however be described as representing true self sufficient farming, it is rather a system which attempts to transfer the plant food reserves of a large area to a small area thus building up a concentration which is sufficient to support continuous cropping.

Although reference is occasionally made to self sufficient farming in agricultural history, in Britain at least it seems that the chief limit-:ing factor in the maintenance of a constant level of self sufficiency was that the overall fertility was nearly always decreasing as no attempt was made, or in fact could be made, to balance cropp-:ing and other losses by the introduction of NPK from sources external to the farm. As the fertil-:ity was reduced it seems that the farms tended to place greater emphasis on livestock and the level of self sufficiency increased. Apart from the extreme cases found mainly in Ireland and the North of Scotland where owing to the great social difficulties land was impoverished beyond measure, the/

the reduced level of fertility was such that it appeared to allow a state of equilibrium with the modified cropping and stocking programme since the systems were in operation for long periods and did not seem to deteriorate. This point of biological balance between soil fertility and the degree of self sufficiency of the cropping and stocking programme was of course altered considerably by the introduction of any plant or animal foods from sources external to the farm. Before the days of inorganic fertilisers, external sources of dung were often available from town stables and on many estates dovecotes were established which provided sources of very rich manure. This introduction of extraneous NPK increased the overall level of fertility of the soil and more intensive cropping could be maintained. The point of balance had therefore been elevated and since it seems probable that sales of produce increased, it follows that the level of self sufficiency would be depressed.

It is interesting to note that in this example an increase in the level of fertility at which biological balance occurs would appear to be associated with a decrease in the level of self sufficiency. As the research proceeds it will be interesting to observe this relationship at other higher levels of overall fertility such as are associated/

associated with modern fertiliser practice.

In general the review of literature has not produced any evidence to suggest that self sufficiency has been investigated in detail and in fact nothing has been found which is of real value in the present work. It is therefore concluded that the proposed research concerning self suffic:iency under Scottish conditions is in fact original work and that there is no significant evidence in the literature that any similar work has been carried out which might assist in the development of experimental technique.

4.3 The Soil.

It has already been mentioned that soil type and the level of fertility are important factors in the research. The study of each of these factors in detail is, however, an enormous task and quite beyond the limitations of the present resources. Fortunately this need not impose any real restrictions on the work provided certain basic aspects of soil type and fertility can be readily measured in the field. The classification of soils is well established and a brief study of literature dealing with this subject showed that soil classification is usually on the basis of geological and ecological characteristics. In 'The Study of the Soil in the Field' (4th. Edit.) Clarke/

Clarke quotes Dokuchaiev's classification as being the basis of all modern soil classification methods. There are five points of this:-

1. Nature of parent material.
2. Mass and character of vegetation.
3. Age of the site.
4. Relief of the site.
5. Climate of the locality.

Expressed another way:

$$\text{Soil} = (G\ E\ B)\,dt$$

where: G = Geological processes.

E = Environmental factors.

B = Biological processes.

This approach to soil classification and the more recent approaches developed from it attempt to ignore the effect of cultivations, which is naturally desirable in a general soil survey but for the purposes of the present work, the influence of soil type upon the efficiency of NPK conversion does depend to some extent upon soil factors which may well be influenced by prolonged cultivation of the virgin soil. The standard methods of soil classification are therefore not entirely suitable for the type of work in hand.

Probably the most important physical feature of the soil is quite simply the degree of 'heaviness' or 'lightness' and it appears from various/

various works including 'Soil' (US Dept. Agric. 1957) that a satisfactory method of measuring 'heaviness' is based on the results of mechanical analysis, in particular the proportion of clay fraction.

Mechanical analysis is commonplace in many laboratories at the present time and it was decided that this should be carried out as routine if farms under investigation appeared to be situated on substantially different soil types. Other physical features of particular farms, notably elevation, aspect and climate will be recorded but it appears from the literature that the differential effects of these factors will be of relatively minor importance in the limited area of study as compared with the effect of soil type.

4.4 Fertility.

Level of fertility is another feature of the soil which it is important to consider but since 'fertility' is a general term dependant upon an almost infinite number of factors, its measurement in the field must necessarily be arbitrary. The question arises as to the best method to use in the present work. The requirements are not stringent and although it is apparent from the literature that there are many ways to reach a figure for overall fertility, the simplest and probably the/

the most reliable for comparative work is based on the standard soil analysis. Biological methods carried out in the field take considerable time and are complicated by weather conditions and other factors, there is also greater difficulty in obtaining figures for each of the elements NPK.

It has been mentioned that the research is concerned with NPK utilisation efficiencies and that it is proposed to deal with each of the three elements separately. In the case of P and K, figures for available amounts of these substances are readily obtained by quantitative analysis but a figure for nitrogen is more difficult to assess. The analysis of the soil for total N can be carried out but the results mean little in terms of the N fertility level as experienced by a growing crop. A search for information concerning the estimation of soil nitrogen, as expected, revealed little of value. Figures have been obtained by many workers showing the content of soil N under different conditions but from the general inconsistence of the results obtained it is obvious that the avail-:able nitrogen content of any soil varies almost from day to day and a figure which exhibits 'repeatability' is virtually impossible to obtain.

The apparent difficulty in estimating the level of soil fertility for nitrogen led to a study of/

of indirect methods of approach. Gisiger (1950) studied the humus content of soils and also measu:red the Carbon/Nitrogen ratio which for cultivated land was found to be about 10:1. Further reading showed that this figure is difficult to change by the application of organic matter and also showed the possibility of obtaining a figure for nitrogen by measuring the loss on ignition. Gisiger quotes the following C/N ratios for various materials:-

Average cultivated soil	10:1
Plant material	15-30:1
Straw and stubble of cereals	80:1
Sawdust and peat	above80:1

He also states that in average soils humus content diminishes according to depth more rapidly than nitrogen content because quantities of immature humus are present in the uppermost soil strata. In an example to estimate the quantity of nitrogen per hectare, the quantity of soil is given as 4×10^6 Kg./hectare to a depth of 30cm.. As shown in the table below, the figures obtained for total nitrogen using this method are comparat:ively high but it must be noted that these figures are for total nitrogen and in any growing season only a fraction of this is mobilised into an available form.

Table showing the relationship between humus content/

content and the weight of total nitrogen per hectare at different levels:-

Humus(L.I.%)	Carbon%	Nitrogen%	Kg./Ha. N.
1	0.58	0.058	2,320
2	1.16	0.12	4,800
5	2.9	0.29	11,600
10	5.8	0.58	23,200

It is obvious from the figures that if in a growing season even 1% of the total nitrogen is mobilised this represents a relatively large quantity for the crop and explains why response to nitrogen is greater on soils with low carbon content.

In experiments to determine the effects of animals on the nitrogen content of soils, Watkin (Wye College, 1954) refers to trials with sheep on pasture with varying Nitro-Chalk treatments and with and without dung and urine. The conclusions reached appear to have been that as far as product-:ivity and therefore, presumably, nitrogen fertil-:ity is concerned, it may be best in certain cases to restrict the use of fertiliser to the minimum and rely on excreta to maintain fertility. The implication is that rather less nitrogen is lost in the grazing process than is at first apparent and presumably the effects of the unsuppressed legumes/

legumes contribute to this comparatively high level of self sufficiency for nitrogen.

Since a high degree of accuracy in this part of the work is not essential, the measurement of soil fertility was not pursued further at this stage and the conclusions reached from the liter-:ature are basically that the figures obtained from soil analyses will be satisfactory in the case of phosphate and potash. The estimation of nitrogen is more of a problem but if satisfactory progress can be made with comparative nitrogen levels as opposed to absolute measurement, then it appears that figures obtained from loss on ignition analysis would serve the purpose.

4.5 Summary.

Although there have been few references to similar work in the literature, enough information has been obtained to proceed with the pilot resea-:rch and it is felt that there is little to be gained by intensifying the review at this stage. The results of the pilot experiment will no doubt indicate the need for further information and since this will be more specific, a second review of literature before the main research would no doubt be more satisfactory.

Since it is probable that more detailed information concerning the protein and ash analyses of /

of livestock will be required, any references to such analyses are being noted. In this connection it appears that specific references of this type are much easier to find than those of a more general nature.

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Dr. Wood, (Mylnefield Horticultural Research Station, Dundee.)

5.0 LINTROSE ESTATE

The review of literature having provided the necessary data for the interpretation of results, the way was thus clear for the planning of field work. Since the first year research is to take the form of a pilot experiment designed not only to provide research data but to assist in the development of satisfactory experimental technique, consideration was given to the best approach to this problem. As already stated there are basically two objects, to measure the degree of self sufficiency/

sufficiency and the NPK recovery on small farms in the Southern half of Scotland and to discover the relationship between these two figures.

Since soil type and other physical features of the farms is considered to be significant, it was decided that in the pilot experiment physical features should be substantially constant for the small farms studied in order to eliminate as far as possible any differential effects. It also seemed logical that the physical features should not exhibit any extremes, in fact that the farms studied should be of average physical type. This suggested at once that an easy way to ensure these conditions would be to study a group of farms situated on average soil with average elevation, aspect and climate. A study of maps of Dept. of Agriculture estates showed that a group existed at Burrelton in Perthshire which appeared to satisfy these requirements and further investigation revealed the following features:

5.1 <u>General</u>.

The estate was purchased by the Dept. of Agriculture in 1927 for the purpose of breaking up into small-holdings and small farms. This resulted in 48 holdings 24 of which were small type with acreages less than about 10 and 24 large type with acreages ranging from about 50 to 100. The large/

large type holdings or small farms are in general occupied by sound tenants who work their farms energetically and who are obviously showing a satisfactory economic return. On most farms the emphasis is on arable cropping associated with a livestock enterprise, usually stock rearing and fattening but occasionally dairying. The livestock consists mainly of cattle but it is common practi:ce on many of the farms to let grazing for sheep at certain times of the year, particularly after taking a crop of hay. There are a few pigs and poultry on the farms but in only one case is there a large enterprise (poultry) constituting the main activity of the holding.

5.2 Physical features.

Situation: Lintrose Estate, Burrelton, Perth:shire. O.S. Sheet 57 : National Grid Reference for approximately centre of estate 210370. Estate lies between the elevation contours of 200 feet and 400 feet above sea level. The 400 foot contour is at the southern extremity and this appears to give the estate a northerly aspect but in fact a large area is substantially flat at an elevation of about 300 feet.

Soil: The soil appears to be of reasonably uniform type throughout the estate and has a medium loamy texture. The land is well drained and/

and is free from wet areas on the part of the estate which is chosen for the research.

This investigation of the physical features of Lintrose Estate indicated eminent suitability for the pilot research. The matter of access to the tenants was easily arranged through the Dept. of Agriculture and it was known that the majority were willing to co-operate in work of this type by providing all the necessary data concerning their activities.

5.3 Selection of Farms for special study.

For the reasons mentioned above it was decid:ed to carry out the pilot work on this estate and each of the 24 small farms was visited in order to check the individual suitability of the farm and farmer. For various reasons it was finally decid:ed to leave out 12 of the total of 24. There were two main reasons for this action, firstly the fact that on 8 farms there was a considerable acreage devoted to the production of soft fruit and veget:ables. The small acreages devoted to each crop and the widely different manurial policies made the enterprise very variable from year to year and even in one year's work it seemed likely that some confusion might arise. The other reason for avoid:ing 4 farms was that the farmers were somewhat unreliable and talks with them showed that it would be/

be difficult to obtain satisfactory figures.

This meant that 12 farms were left for special study. The tenants of these were all keen to co-operate in the work and their farms were well managed and quite suitable for research purposes.

The conclusions reached from the brief survey of Lintrose estate indicated that it was an ideal location for the pilot research and arrangements were therefore made to proceed with the work on the twelve most suitable farms.

6.0 PILOT RESEARCH.

As further consideration was given to the best approach to the field work it quickly became evident that standardisation of technique was essential when dealing with a number of separate farming units and this meant working to a definite research plan. It also appeared logical that the plan should be drawn up with the main research programme in mind, in as far as this was possible, since the main research field work would no doubt be easier and less liable to error if experience had already been gained with the techniques involved.

This led to a detailed study of the past farming programmes on each of the selected farms. These subsequently proved to be basically similar as/

as regards cropping, the chief differences being in the varying emphasis on certain products and in the varying types of livestock enterprise. The variety of crops and livestock means that there is ample opportunity to develop techniques for assessing the biological significance of a wide range of farming activities in the pilot experi:ment and these techniques should require little modification for use in other areas if this should be required as part of the main research programme. It appears that this will be an important feature of the final research plan if it is to have wide application in the areas studied.

It was decided that the pilot research and the main research should each occupy a full farm:ing year and the pilot experiment was scheduled to start in 1959. Since the work involves the measurement and NPK assessment of all the materials which appear in the farming process and the record:ing of the movement of these materials, the best time to start the experiment appears to be when the movement of materials is at a minimum. For this reason it is planned that the work should begin on 1/1/59 and continue until 1/1/60 when the main research will start. This allows no interval for a critical review of the results of the pilot experiment before starting the main research/

research but it is felt that any necessary modif-:ications to the technique should be obvious in the last few weeks of the pilot experiment when the farming activity is approaching the minimum. Also, the advantages to be gained by starting the main experiment at the beginning of the year outweigh those to be gained by delaying the main research in order to review the results of the pilot experiment for a longer period.

6.1 Research Plan.

The first necessity in work of this type is to know exactly what to record and how to obtain the information. NPK transactions which are fundamental to the work are influenced by almost every farming activity which involves the movement of livestock or material and it is clear that a close check on such movements will have to be made. There are naturally great practical diffic-:ulties in estimating quantities of material moved. Within the limitations of available time and resources it is obviously pointless to consider weighing anything like all of the material. This means that reliance must be placed upon estimates and when the matter was given deeper consideration it was realised that this approach need not limit the value of the work providing the technique is standardised and used in every case. Comparisons would/

would still be effective and in certain circumstances there may actually be some advantage in this approach particularly if there was likely to be considerable experimental error.

The problem of dealing effectively with livestock had mention in the review of literature. From preliminary talks with the farmers concerned it was apparent that information about the numbers of livestock purchased and sold together with the dates was readily available as all farmers kept records for their own use. This meant that providing the ages of the animals when bought and sold were known, there was little difficulty in calculating the incremental content of NPK. More of a problem is the amount of the contribution towards internal circulation of NPK by each animal during its stay on the farm but it is hoped that if necessary this problem might eventually be solved by estimating the quantities of feedingstuffs consumed and subtracting the amounts of NPK corresponding to the increment in body weight over the period. Records of the movement of all livestock will therefore be kept and the approximate ages and weights noted. Livestock products in the form of milk, eggs or wool are easily assessed and the quantities of these products will be recorded.

Purchases/

Purchases of fertiliser and its analysis will be noted together with the quantities and types of feedingstuffs purchased during the year. Sales of crop will complete the data and talks with the farmers indicated that visits at two or three week intervals would be sufficient to record all the movement of materials. The records may be checked with the farmers' books at the end of the year.

In addition, soil sampling will be carried out in the early part of the year, the intention being to sample all farms as quickly as possible to avoid the differential effects of cultivations and other farming activities. In view of possible frosty weather, soil sampling has been planned to take place in early March before the spring cultivations and manuring. Analysis of the samples will be carried out for the following:

Loss on Ignition

pH

Lime Requirement

Available P_2O_5

Available K_2O

The figures for lime requirement are not necessary in this work but may be of some use to the farmers.

6.2 <u>Internal movement of materials.</u>

The question of the internal movement of materials/

materials on the farm has been given careful consideration since it appears to be extremely difficult to measure with any degree of accuracy. It is obviously impracticable to weigh total quantities of materials such as turnips carted from the field to feed livestock and sampling techniques are difficult to apply under the circumstances. No less of a problem is the apparent difficulty in estimating the quantities of grass consumed by grazing animals although figures have been seen which claimed to provide a reasonably accurate estimate of protein equivalent and starch equivalent consumed by the animal. However the figures are rather too arbitrary in many respects for work of this type.

Referring to the definition of self sufficiency, the required figure is for the internal circulation of the element and since the true circulation is only as much as the minimum quantity in the cycle, it follows that a measurement of the minimum quantity should suffice. There is little doubt that in the general farming systems found on Lintrose estate the minimum quantity is found in the livestock residues returned to the soil and this therefore provides a comparatively easy way of assessing the internal movement of materials.

The/

The measurement of the quantities of NPK returned to the soil as dung can, it is felt, be carried out with sufficient accuracy by measuring the quantity of dung applied to the land during the year and using published figures for NPK content. These figures appear to vary over a comparatively small range for phosphoric acid and potash but vary rather widely in their nitrogen content. This is presumably due to the different methods of handling the dung before spreading on the land and the higher figures will be taken when it is applied straight from the courts, the lower limit being used when dung is stored in an uncov:ered heap and handled twice.

6.3 External movement of materials.

The external movement of NPK is easier to measure and published data is available giving phosphoric acid, potash and crude protein analysis of all the important crops. The analysis of crops sold is therefore known and the quantity sold is also known with accuracy. The quantity of NPK purchased as fertiliser is easily calculated but some trouble has been experienced in the case of purchased feedingstuffs. The protein analysis of feedingstuff is often known but no figures are available for ash or ash composition. Several approaches/

approaches to the suppliers of feedingstuffs have been made with a view to either obtaining figures for ash and ash analysis or lists of the feeding-:stuff constituents from which the phosphoric acid and potash contents could be calculated. The merchants were reluctant to reveal this informat-:ion for several reasons including trade secrecy and the fact that the composition of a particular feedingstuff can vary considerably depending upon the availability and cost of raw materials in world markets.

A solution to this problem which would appear to provide an acceptable degree of accuracy cons-:ists of calculating the NPK figures for 'standard foods' and using these figures to estimate the NPK content of purchased compound feedingstuffs designed to serve the same purpose. Unfortunately it is obvious from various agricultural textbooks that so-called standard foods can vary not only in percentage composition but in the materials used. These variations are not great however, and calc-:ulations of the NPK contents were carried out for a number of pig rations based upon barley meal and white fish meal with the addition of one or more other substances in various proportions and also for a number of standard production rations for dairy/

dairy cows. It was naturally expected that the figures for nitrogen would agree closely since the rations are usually designed to supply a specific protein equivalent and this was confirmed by the results which also showed close agreement in the case of phosphoric acid and potash.

6.4 Summary of research plan.

The research plan has been discussed in some detail in the preceding three sections and the work may be conveniently divided as follows:

(1) Soil sampling and analysis.

(2) Collection of data concerning the move-:ment of materials on each of the selected farms.

(3) Interpretation of the data in terms of NPK.

The first two operations are fairly straight-:forward but in order to interpret the data in terms of NPK it is necessary to list the analyses of all materials which are likely to be encount-:ered. In case any unforeseen snags should arise in this part of the work it was decided that the list of actual analyses should be made out before the research was started. This precaution would allow changes in technique if, for example, satisfactory figures could not be obtained for a particular material and it proved necessary to take samples for analysis as the work progressed.

In/

In drawing up a detailed research plan there is a great opportunity to anticipate as far as possible any future difficulties and this has been given careful thought from the outset. Minor difficulties are expected but it is hoped that one of the results of detailed planning will be the absence of any major snags which might otherwise impair the value of the work.

7.0 GENERAL.

The necessity for standardisation in the interpretation of materials in terms of NPK has led to the collection of analytical data for a variety of materials which are likely to be found in the farming systems of the area studied. Some thought has been given to the form of expression for Phosphorous and Potassium. It was originally intended that these should be expressed as the element but nearly all analyses are conventionally expressed as P_2O_5 and K_2O and since it is the ratios which are important, there does not appear to be sufficient reason for converting the figures. Further consideration may require to be given to this point if it becomes necessary to eliminate the inactive oxygen to avoid a complex function when/

when relating the combined effects of active elements to some other parameter.

The limited time and resources available mean that it is obviously impossible to carry out NPK analyses of all the materials and the following figures are based upon published results, the references being listed at the end of the section.

7.1 Material grouping.

Materials found in a typical farming system may be classified into five groups as follows:

(1) Crops sold and fed.

Figures for NPK analysis of crops are readily obtained from a number of sources all of which agree closely with each other. The figure for nitrogen is usually quoted as crude protein and this will be converted to percent nitrogen element.

(2) Dung made on the farm.

A number of analyses have been found and the proposal is to use the average and allow a small adjustment especially in the figure for nitrogen depending upon the method of handling the dung.

(3) Purchased fertiliser.

The necessary information is easily obtained from manufacturers lists.

(4) Purchased feedingstuff.

The problems associated with estimating the NPK content of proprietary feedingstuffs has already/

already been mentioned and estimates will be made based upon the analysis of standard foods.

(5) Livestock and livestock products.

The method which it is proposed to use in order to estimate NPK content of livestock has also been outlined and if necessary, graphs will be used to estimate the increase in NPK when stock is kept on the farm for limited periods during the year.

Each of the five groups will now be considered in greater detail.

7.2 Analysis of crops.

The following crops are the most important in the farming systems chosen and the figures show the analyses which will be used. In the conversion of crude protein to nitrogen the factor of 6.25 has been used throughout.

Crop.		Percent of total weight.		
		N	P_2O_5	K_2O
Grain:	Oats	1.65	0.81	0.55
	Barley	1.60	0.84	0.57
	Wheat	1.94	0.86	0.60
Straw:	Oat	0.32	0.18	1.50
	Barley	0.53	0.15	1.30
	Wheat	0.34	0.13	0.80
Hay:	Ryegrass	1.92	0.60	1.80
	Timothy	1.36	0.43	1.40
	Meadow/			

(Hay)		(N)	(P_2O_5)	(K_2O)
	Meadow	1.55	0.43	1.60
Roots:	Potatoes	0.34	0.18	0.60
	Swedes	0.21	0.08	0.30
	Mangolds	0.16	0.09	0.45
	Sugar Beet	0.18	0.10	0.47
	S/Beet Tops	0.32	0.11	0.58
	Kale (marrow)	0.35	0.12	0.55
Fruit:	Raspberries	0.21	0.07	0.25

Advice was given by Dr. Wood, Mylnefield Research Station that NPK figures for raspberries could also be applied to strawberries with little error.

7.3 Dung analysis.

A number of figures for dung analysis have been found; these are as follows:

	Percent of total weight.		
	N	P_2O_5	K_2O
Rothamstead (cow)	0.54	0.32	0.67
Rothamstead (average)	0.64	0.23	0.32
Farm samples average	0.40	0.31	0.40
French figure	0.58	0.30	0.50
Bullock dung	0.62	0.26	0.72
Cow dung	0.43	0.19	0.44
Sanders: Brit. Crop Hus.	0.60	0.35	0.60
Hopkins: Chem. Hum. Sl.	0.60	0.30	0.50

Stable/

	(N)	(P_2O_5)	(K_2O)
Stable manure	0.76	0.56	0.65
Fresh liquid manure	0.04	0.05	0.35
Old liquid manure	0.03	0.01	0.22

Averaging all except the liquid and stable manures gives: 0.55% N, 0.28% P_2O_5 and 0.52% K_2O. These figures appear reasonable when considered in relation to further reading on the subject and will be used in the work. It is also proposed to allow adjustments of about plus 10% or minus 20% maximum in the case of nitrogen and plus or minus 10% in the case of phosphoric acid and potash. It is intended that no adjustment should be made unless there are special circumstances, for example, abnormal feeding of the livestock or unusual methods of handling the dung. The one possible exception to this is in the case of nitrogen where a deduction may be made if the dung is handled twice and stored in the open in an uncovered heap before being applied to the soil. Conversely, an increase might be indicated where fresh dung is applied to the soil as for example, the direct cleaning of dairy byres into a muck spreader which is emptied onto the fields daily. These methods of handling are fairly common in some areas and cannot be considered unusual.

7.4 Purchased fertiliser. /

7.4 Purchased fertiliser.

Each of the merchants supplying fertiliser in the area have been asked for leaflets giving details of the NPK analysis of their products and these figures will serve as the basis for the estimation of purchased fertiliser in terms of NPK.

Consideration has been given to the question of the best way to deal with soluble and insoluble phosphoric acid and it has been decided that in the absence of detailed information on the mobilising effects of micro-organisms and the physiological aspects of root uptake in the various crops, it should be assumed that at least part of the insoluble phosphoric acid can be utilised.

The extent of phosphate fixation is a further complicating factor but since one of the objects of the research is to measure the efficiency with which purchased phosphorus is recovered, it is felt that figures for soluble and insoluble phosphate should be added together and treated as one at this stage. The detailed investigation of the different recoveries of phosphorus in various forms would be an interesting project on its own, it is however somewhat beyond the boundaries of the present work.

7.5 Purchased feedingstuffs.

The method of estimating NPK content of

purchased/

purchased proprietary feedingstuffs has already been explained and the 'standard food' analyses for certain common purchased foods are assumed to be as follows:

	N%	P_2O_5%	K_2O%
<u>Cattle foods</u>:			
Sugar Beet Pulp (dried)	1.42	0.18	0.59
Dairy Prodn. (3½lbs/gal)	3.46	1.30	0.80
Calf Rearing Cmpds.	4.04	2.16	0.96
<u>Pig foods</u>:			
Sow & Weaner Meal	3.03	1.86	0.96
Fattening Meal	2.48	1.44	0.63
<u>Poultry</u>:			
Layers Meal or Pellets	3.00	2.28	1.29

Each set of figures represents the average of a number of rations quoted in standard agricultural textbooks such as Watson and More and Fream's Elements of Agriculture. The actual rations used are shown in the appendix together with a list of the NPK analysis of a number of common feedingstuff constituents.

The foods quoted are thought to be the most important of those purchased by the farms studied and the list should cover most of the work but the intention is that any special foods which either do not fall directly into one of the six compound categories/

categories or which appear to deviate widely in composition will be individually assessed. This should normally be obvious from the manufacturers' figures for crude protein, fibre, etc.. If these differed greatly from the average for the partic:ular application the figure for nitrogen would certainly require to be altered and the different raw material composition of the compound might affect the phosphoric acid and potash content also.

7.6 Livestock.

The assessment of the NPK content of livestock has raised a number of problems chiefly because figures for the ash analysis of complete animals appear to be difficult to find in modern literature. At least one list of figures is available but it was obtained almost a century ago and the use of more recent figures is desirable if they exist.

A thorough search through agricultural and veterinary literature has however revealed little of value and it has therefore been decided to use the figures obtained by Lawes and Gilbert at Rothamsted (1860) for the pilot experiment at least and if possible, revise the figures to conform to more recent findings if these are found before the main part of the research.

Lawes and Gilbert give the figures for nitro:gen as percent crude protein and as in the case of/

of crop and feedingstuff analysis the percent of nitrogen element will be calculated using the factor 6.25.

The information is provided in the following form:

Total Ash.	% of liveweight.
Fat: cattle (calves & oxen)	3.5 - 4.0
lambs and sheep	2.5 - 3.0
pigs	1.5
Store: cattle	4.5 - 5.0
sheep	3.0 - 3.5
pigs	2.7 - 3.0

The general rule is that 35 - 40% of the ash is P_2O_5 and that 5 - 6% is K_2O. Lawes and Gilbert state that these figures are fairly constant with different classes of animal.

Total Crude Protein.	% of liveweight
Fat: cattle (calves & oxen)	14.5 - 15.5
lambs and sheep	11.0 - 12.0
pigs	10.9

Store animals contain 2 - 3% more than fat animals.

In order to calculate the actual quantities of NPK in the various classes of livestock it is necessary to form some idea of the live weights of animals. Watson and More (8th. Edit.), appendix, table 4, give the approximate live weights of commercial/

commercial animals and from this the following list of weights has been derived. The classes of animals chosen represent those commonly found on the farms studied in the pilot experiment and the weights are naturally, very approximate.

Cattle:	small store	700lbs.
	large store	1,000 lbs.
	fat	1,200 lbs.
	calves	150 lbs.
	cast cows	1,200 lbs.
Sheep:	wether lambs	80 lbs.
	mature breeding ewes	150 lbs.
Pigs:	weaners	40 lbs.
	fat bacon	200 lbs.

The actual figures are so variable that it is probably better to calculate the weights of NPK per lb. body weight for each class of stock and multiply this by the estimated weights when the animals are observed on the farms.

It is possible that during the research the situation will be encountered where land is let for short periods for grazing by sheep and in this case it is considered that the best approach is to measure the incremental weight by reference to a curve obtained by plotting liveweight increase against time. This increment could then be converted/

converted to NPK by using the information given and the totals expressed as a net loss to the system.

Although growth curves are subject to considerable distortion as a result of a variable environment, they are generally of logarithmic form and attempts to produce average growth curves for the classes of livestock dealt with in the research appear in the appendix.* From the results obtained with figures from Watson and More and others it does not seem feasible to derive equations which would give the slope at any point on the curve and differentiation which would standardise the method cannot therefore be applied with any degree of accuracy. Consequently, reference will be made to the actual curves in order to estimate NPK increase over limited periods.

<u>NPK analysis for six livestock classes.</u>

		N%	P_2O_5%	K_2O%
Fat:	cattle, calves, etc.	2.40	1.41	0.21
	lambs and sheep	1.84	1.03	0.15
	pigs	1.74	0.56	0.08
Store:	cattle etc.	2.80	1.78	0.26
	lambs and sheep	2.24	1.22	0.18
	pigs	2.14	1.07	0.16

The above figures are based on the mean of the limits/

* P.P. 180–200

limits set by Lawes and Gilbert for total ash, phosphoric acid content of the ash (taken as 37.5%) and potash content (taken as 5.5%). Store animals are assumed to contain 2.5% more crude protein than fat animals.

On the basis of the above figures the actual weights of nitrogen, phosphoric acid and potash have been calculated for animals representing each of the six classes. The liveweights of the animals are assumed to be as in the list of 'average weights' given earlier in this section.

			lbs. weight of:		
			N	P_2O_5	K_2O
Fat:	cattle	1,200 lbs.	28.8	16.9	2.52
	sheep	110 lbs.	2.02	1.16	0.17
	pigs	220 lbs.	3.83	1.23	0.18
Store:	cattle	800 lbs.	22.4	14.2	2.08
	lambs	80 lbs.	1.79	0.98	0.14
	pigs	40 lbs.	0.86	0.49	0.06

Although the weights of the animals will differ slightly from farm to farm, the above figures are fairly typical of animals found on the farms studied and they serve to illustrate the consider- :able quantities of NPK contained in livestock, a fat bullock containing the equivalent nitrogen of over one hundredweight of Nitro-Chalk and a phos- :phoric acid/

Phosphoric acid equivalent of about three quarters of a hundredweight of superphosphate.

7.7 Livestock products.

On the type of farms studied there are two main livestock products, milk and eggs, with a possible third, wool. Figures are readily avail:able for the composition of milk and the average of those studied is as follows:

Fat	3.87%	
Solids-not-fat	8.92%	
including: Milk proteins		3.39%
Lactose		4.81%
Mineral matter		0.72%
Water	87.21%	

The average composition of milk ash appears to be as follows:

Phosphoric acid (P_2O_5)	30.4%
Potash (K_2O)	26.8%

From the above figures the NPK composition of whole fresh milk has been calculated as follows:

Nitrogen (N)	0.54%
Phosphoric acid(P_2O_5)	0.22%
Potash (K_2O)	0.19%

It appears from various works that the max:imum variation in these figures for milk from healthy cows should not exceed 15% in isolated cases and will normally lie within 5 or 10%.

It/

It is felt that for the purposes of the present work this tolerance is acceptable and the intention is to use the figures as they stand without allowing any adjustment.

Figures for the composition of eggs are also readily obtained but these seldom give the analysis of the ash. McCance and Widdowson give the P and K composition of fresh, whole eggs as phosphorus element 208 mg. per 100 g. and potassium element 138 mg. per 100 g. but there is some doubt about whether this includes the shell. For the purposes of the present work it is necessary to include the shell and figures obtained from W. Bolton (egg shell protein, unpublished) and 'The Avian Egg' Romanoff and Romanoff, 1949 show that the average composition of fresh hens egg is as follows:

	Weight	Crude prot.	P	K
Egg shells	5 g.	4.4%	0.4%	trace
Egg contents	52 g.	12.4%	0.22%	0.14%

In order to standardise the method it is necessary to convert the figures to percentages of N, P_2O_5, and K_2O. When this is done the following figures result:

	N%	P_2O_5%	K_2O%
Egg shells	0.71	0.92	negligible
Egg contents	1.99	0.50	0.17

Since/

Since entire eggs are sold from the farms the correct analysis has been calculated based on a content to shell ratio of 10 to 1.

Analysis of entire eggs:

1.91% N   0.54% P_2O_5 0.16% K_2O

These figures will be used to assess the NPK composition of eggs produced on the farms and the weight of an average egg will be taken as 55 g. or 1.94 oz. which itself is the average of a number of published 'mean weights' of all commercial grades of hens eggs.

It was stated at the start of the section that wool is a possible third livestock product. A brief survey of the literature has not revealed an analysis for wool and before carrying out a further search for information it has been decided to leave the wool analysis until it is actually required. In view of the type of husbandry on the group of farms at Lintrose it seems unlikely that sales of wool will be encountered.

7.8 <u>Summary</u>.

The foregoing sections from 7.1 have attempted to set out the NPK analyses of all the materials commonly found in the farming systems of the area. In most cases it has been possible to average out a number of analytical results for a particular material and it is hoped that by so doing a fair approximation/

approximation has been made to the analyses of the actual materials found in the field. Graphs for the NPK analysis of livestock appear in the appendix* and when using these it appears to be desirable to use the weights of animals rather than the ages whenever this is possible.

A few examples of the method used in the calculation of standard ration analysis also appear in the appendix† together with a summary of all the analytical data for ease of reference.

8.0 STUDY OF THE SOIL.

The necessity for studying the soil on the twelve farms chosen for the pilot experiment has already been explained and it will be recalled that the primary object of this is to measure the overall fertility of each of the farms. This information will be related to the level of self sufficiency and other parameters such as the efficiency of recovery of NPK.

8.1 Fertility measurement.

'Soil fertility' is a broad concept embracing an extremely large number of factors, many of which are not fully understood and many of which defy exact measurement. Fortunately, crop growth depends to a large extent on the soil content of NPK/

* pp 180-190 † pp 170-179

NPK and since assessment of these elements is possible, they will be used to provide an indicat-:ion of soil fertility. It is felt that this approach is acceptable since the object is to carry out comparative studies of farms and provid-:ing similar sampling and analytical techniques are used in every case, the comparisons should be effective.

In the normal soil analysis figures are obtai-:ned for pH and lime requirement. If the 'fert-:ility' of the soil means its ability to grow crops then pH should be considered when assessing fert-:ility. However, if this is done, it becomes necessary to impose limits for critical high and low pH values and within the working range yields do not vary greatly.

Loss on ignition analysis is assumed to be proportional to nitrogen content of the soil. This is justified since the carbon/nitrogen ratio is substantially constant for any one soil type and at Lintrose the soil is similar over all the farms.

Consideration has been given to the best method of combining the individual N, P and K fig-:ures for each farm and this has led to several possibilities each with its own advantages and disadvantages. The most attractive method appears/

appears to be a simple multiplication of the figures for each of Loss on Ignition %, potash and phosphoric acid. The actual units used need not be the same for each of L.I.%, P_2O_5 and K_2O but should naturally be the same for a particular element on all farms. This approach allows any one element to become a limiting factor and the effect of each element on the final figure is linear.

This linearity is probably incorrect and other methods of integrating the factors could be used which would observe the correct functions and also provide limits. Integration is not possible, however, since the functional interrelationships between N, P and K are not known with any degree of accuracy and the prospect of deriving such functions from experimental results is not attractive since they are almost certain to depend upon a wide range of soil characteristics.

Simple multiplication will therefore be used and the resulting figure will be taken as an indication of farm fertility for comparison with other farms in the group. The figure cannot be used with certainty as a measure of absolute fertility in view of the many modifying factors associated with soil type, location, climate, etc. but/

but it is thought to be quite suitable for comparative work over a limited area such as Lintrose Estate.

8.2 Soil sampling.

Sampling of all farms was carried out during the winter of 1958 - 59 and was quite straightforward, no special problems arising in this part of the work. Separate samples were taken for each field or area of ground which had been cropped separately and each sample consisted of 15 to 20 corings taken to a depth of about 8 inches. These were taken at random over each sample area giving a total of 113 samples averaging 9.42 per farm.

The usual precautions were taken to ensure that no applications of lime, slag or fertiliser were made since the land was cropped, this meant that some odd fields had to be sampled rather earlier than intended to avoid delaying the work on the farms. This slight time difference is not expected to affect the analysis and these samples are therefore averaged with the others on the farms concerned.

In raspberry growing it is common practice to apply fertiliser to the base of the canes and the land between drills often receives comparatively little fertiliser. When raspberry breaks were being/

being sampled the corings were therefore distributed not only over the entire area but also over different positions in the drills in an attempt to obtain an average sample.

The soil sampling for the pilot experiment was completed early in 1959 and the results were obtained a few weeks later from the Edinburgh and East of Scotland College of Agriculture, Soil Chemistry Department.

8.3 Soil analysis results.

The detailed results for each sample are given in Appendix 3* and the means of the samples for each farm are shown below. Figures for lime requirement were also given in the soil reports but are not reproduced since they are of no value in this work, they were nevertheless of great interest to the farmers.

		- - - - - Mean - - - - -			
Farm	No. of samples	L.I.%	pH	K_2O	P_2O_5
L/1	12	7.50	6.08	112	10.25
L/5	8	7.70	6.10	135	8.63
L/7	8	8.55	6.44	162	8.50
L/8	12	7.75	6.24	184	17.90
L/9	8	8.25	6.20	95	18.10
L/15	11	8.65	6.42	149	9.00
L/16	9	8.30	6.59	136	8.12
L/20	8	7.10	6.30	156	9.25
L/21	9	7.38	6.15	147	8.45

L/23/

* pp. 201-225

Farm	No.of samples	Mean L.I.%	Mean pH	Mean K_2O	Mean P_2O_5
L/23	10	8.60	5.90	137	5.70
L/24	7	8.00	5.80	121	7.85
L/25	11	8.40	6.20	167	8.17

The above figures have been averaged and the following overall means obtained:

L.I.%	pH	K_2O	P_2O_5
8.02	6.20	142	10.00

The farmers concerned were given these overall mean figures together with their own individual field results and, surprisingly, they appear to regard the overall means as the lowest desirable limits for their particular farms. It was explained to them that if all farmers adopted this attitude, the means would soon rise to levels which were entirely uneconomic but their latent desire to grow better crops than their neighbours seemed to arouse their competitive spirit and there seems little doubt that many will attempt to increase their fertility. As an example, farmer L/9 is above the average in all except potash and he earnestly intends to use more potash on his low reading fields until this also is above the average.

This/

This experience of giving farmers figures representing an average for the district along with their own soil reports has been mentioned in some detail since it might be of use in advisory work. It would appear to be a way of encouraging farmers to increase their fertility, where this is desir-:able, by providing them with a definite target and the knowledge that by exceeding this, their average fertility would be above that for the district.

8.4 Discussion of soil results.

It has been stated that the main object of studying the soil was to obtain an indication of the relative fertility levels of the farms. Although this is true, it is also important to know something of the effect of past rotational policy and it is felt that soil analysis can help in this part of the work.

The measurement of the self sufficiency of a farming system and consequently the relationships between self sufficiency and other parameters will only be effective if the farm is operating on a substantially level plane of self sufficiency and fertility. In planning the research great care was taken to ensure that the farms chosen for the experiment had not changed their farming systems for/

for a number of years and had no intention of doing so during the period of the research. It will be recalled that some farms were rejected because of the instability of their systems.

Since an inefficient rotation or sudden changes in manurial policy will no doubt affect the soil analysis in such a way that there will be a greater variation between fields, it was decided to investigate this aspect of the soil analyses. Several approaches were considered and it was decided that the best method was to display the deviations from the farm means for each of L.I.% pH, K_2O and P_2O_5. This has been done and the resulting graphs appear in Appendix 3.* It will be noted that the analytical results are expressed as percentages of the mean and that the deviations are calculated by subtracting 100 giving deviat-:ions of either sign. These are arranged in progressive order from the lowest to the highest along the horizontal axis. The broken green and brown lines indicate the actual percent deviation for L.I.% and pH respectively but since this was generally small, the deviations have been multi-:plied by a factor of 5 in order to exaggerate the deviations and provide a clearer indication for comparison with other farms. These are shown as continuous/

* p.p. 201 - 225

continuous green and brown lines for L.I.% and pH respectively. Potash and phosphoric acid curves are plotted without exaggeration and are shown as red and blue respectively.

The curves clearly indicate which farms have the greater overall consistency and which show wide variations in their field to field analysis. Farm L/20* shows the most even fertility over all fields and farm L/21† shows what is probably the greatest variation. It is interesting to note that L/20 is an arable farm with a small area of fruit where the farmer attempts to work to a definite rotation and farm L/21 carries a dairy herd and the land is either grazed or used mainly for growing stock feed. On L/21 the rotation is much more flexible than on L/20 and this is indeed reflected in the curves.

Tt seems from these graphs that the more livestock there is on a farm the greater the variation in fertility between fields. This, however, should not be regarded as a general rule and is no doubt due to the rotations which happen to suit these particular farms. A dairy or stock farm operated on a definite and strict rotation would probably show a consistent fertility level over all fields.

8.5 <u>Conclusion</u>.

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* p.p. 216-217 † p.p. 218-219

In section 8.1 the question of fertility measurement was discussed in some detail. It was decided that the best approach was to multiply the mean figures for L.I.%, K_2O and P_2O_5 for each farm and use the resulting numbers as fertility indices for comparative work. One possible snag with this approach was that no allowance is made for the effects of abnormal pH and the pH figures cannot be introduced into the multiplication since the effect of pH on crop growth is obviously non-linear in fact, a high pH may depress yields and produce trace element deficiencies. It was mentioned however, that yields do not vary to any great extent over a working range the limits of which might be within the range 5.5 to 6.8 approximately. These figures are chosen from some experience in advisory work and although trouble may arise at these pH figures, the low or high pH generally appears to be associated with other factors such as low phosphoric acid, low pH on a marginal type of soil or high organic matter, high pH which may cause trace element troubles such as manganese deficiency in oats.

The lowest farm of the twelve is L/24* with a mean of pH 5.8 and the highest L/16† with pH 6.59. These figures are well within the arbitrary limits and/

* p.p. 222 - 223 † p.p. 214 - 215

and it is therefore assumed that no cropping diff-:erences will arise as a result of pH variations. It is true that odd fields such as L/25/E with pH 7.0 and L/24/A with pH 5.2 exceed the limits but these are few in number and do not justify the introduction of pH into all fertility calculations.

It has therefore been decided that the pH variations are not severe enough to warrant con-:sideration and fertility measurement is based upon the product of L.I.%, K_2O and P_2O_5 analysis figures. When this is done the results appear as follows:

Farm	Fertility Index
L/1	8,620
L/5	8,960
L/7	11,790
L/8	25,500
L/9	14,180
L/15	11,600
L/16	9,160
L/20	10,250
L/21	9,180
L/23	6,720
L/24	7,600
L/25	11,450

Although these figures are based upon actual soil/

soil characteristics it is interesting to note that in general they reflect the opinions of casual observers, mainly Department of Agriculture staff, who know the farms and the farmers and who were asked to place the farms in what they consid:ered to be an order of merit. The disagreements were usually the dairy and livestock farms which the casual observers placed higher on the scale but this can probably be explained by the fact that a large proportion of their raw material is purchased in the form of feedingstuffs instead of fertiliser and a high level of fertility is not so essential in order to provide a satisfactory economic return. The observers were in fact bas:ing their opinions more on economics than on fertility.

The figures are intended to provide a basis for fertility comparison between farms and it is considered that in this respect they are satis:factory. They will therefore be used in the pilot research.

9.0 COLLECTION OF DATA.

The pilot experiment was scheduled to run from 1st. January 1959 until 1st. January 1960 and/

and during this time close contact was maintained with the twelve farms to enable accurate records to be kept of all purchases and sales. Each farm was visited on an average of once every fortnight or three weeks and at the end of the year the purchases of raw material and the sales of produce were summarised to simplify conversion into N, P and K.

In the case of livestock the numbers purch-:ased or sold were noted together with the age and estimated weights. The time of purchase or sale was also recorded since this is important in assessing the NPK increments during the animals' stay on the farm.

When noting purchases of fertiliser or feed-:ingstuff it was necessary to obtain as much information as possible about the product. In the case of fertiliser, the manufacturer's name and type code for the particular consignment such as S.A.I., CCF No. 1, was generally adequate as the NPK analysis could easily be obtained from the manufacturer's lists but greater care was required in the case of feedingstuffs since no NPK figures are normally published.

Although the majority of farmers appear to use proprietary foods of the large, well known manu-:facturers quite a number use foods which are compounded/

compounded locally by small firms and care had to be taken to ensure that the figures quoted for 'albuminoids' closely matched the figures for nitrogen in the standard rations used in the present work. This, of course, is no guarantee that the figures for P_2O_5 and K_2O will also match but it at least confirms that the food was compounded to serve the same purpose and any errors in P_2O_5 or K_2O are not likely to be serious enough to materially affect the overall results.

In order to calculate the level of self sufficiency it is necessary to know the quantity of dung used on the farm. The technique used was based on the measurement of the area of cattle courts multiplied by the normal depth of dung and the number of times the court was emptied. This gave the total volume of dung and the density was assumed to be within the range 12 - 16 cwt. per cubic yard depending upon the degree of compaction (Watson and More). If the dung was stored out of doors in an uncovered heap for any length of time the figure for nitrogen analysis was reduced within the predetermined negative tolerance, the extent depending upon the time of storage. If it had been applied to the fields directly from a dairy byre for example, the nitrogen figure might have been increased within the/

the positive tolerance.

9.1 Individual farm results.

The detailed schedules of materials and live-:stock for each farm are somewhat lengthy and it is felt that there is little point in reproducing the full schedules in the main text. As an example of the method used, the full schedule for one of the farms is given below. ~~and the schedules for the remaining eleven farms studied in the pilot exper-:iment appear in the appendix.~~

Schedule of materials and livestock for a typical farm (L/25).

Input:

38 cwt. Nitro-shell (23-0-0) 4260 lbs.

125 cwt. CCF No. 2 (13.5-13.5-13.5) 14000 lbs.

12 cwt. Nitro-chalk (15-0-0) 1345 lbs.

16 cwt. Fison turnip (7.5-15.0-7.5) 1792 lbs.

29 cwt. Poultry mash (3.00-2.28-1.29) 3250 lbs.

40 cwt. Beet pulp (1.42-0.18-0.59) 4480 lbs.

2 cwt. Barley (1.60-0.84-0.57) 224 lbs.

22 cwt. Wheat (1.94-0.86-0.60) 2465 lbs.

Output:

340 cwt. Barley (1.60-0.84-0.57) 38100 lbs.

1400 cwt. Potatoes (0.34-0.18-0.60) 157100 lbs.

30 cwt. Oat straw (0.32-0.18-1.50) 3360 lbs.

100 cwt. Oats (1.65-0.81-0.55) 11200 lbs.

20 cwt./

20 cwt. Barley Straw (0.53-0.15-1.30) 2240 lbs.

60 tons S/Beet (0.18-0.10-0.47) 134500 lbs.

12480 eggs (1.91-0.54-0.16) 1783 lbs.

Livestock:

4 cattle sold fat (2 mos.)

4 cattle sold fat (3 mos.)

5 cattle sold fat (6 mos.)

4 cattle sold fat (6 mos.)

10 cattle stores from 6 cwt. (9 mos.)

5 cattle stores from 6 cwt. (6 mos.)

50 sheep grazed for 4 months.

Dung:

196 tons normal (0.55-0.28-0.52) 439000 lbs.

In the above schedule the numbers in brackets following the weights of fertiliser, feedingstuff and crop refer to the percentage of N, P and K respectively. P and K are expressed as percent P_2O_5 and K_2O. The time expressed in months after livestock entries denotes the number of months in the year of study during which the animals were on the farm. The size of the animals either immedi-:ately before or immediately after the period is indicated and it has been found that this is normally adequate for NPK assessment.

9.2 Conversion to weights of NPK.

Calculation of the weights of NPK in the materials is straightforward and since there are nearly 2,000 multiplications involved, a slide rule was/

was used. This not only accelerated the work but the use of the rule is normally held to ensure a high degree of accuracy. The results appear below:

NPK content of materials for typical farm L/25.

Material (input)	N	P_2O_5	K_2O
Nitro-shell	980	-	-
CCF No.2	1890	1890	1890
Nitro-chalk	216	-	-
Fison Turnip	135	269	135
Poultry Mash	98	74	42
S/Beet Pulp	64	8	26
Barley	4	2	1
Wheat	48	21	15
	3435	2264	c 2109
Material (output)			
Barley	609	320	217
Potatoes	534	283	943
Oat straw	11	6	50
Oats	185	91	62
Barley straw	12	3	29
Sugar beet	242	135	632
Eggs	34	10	3
	1627	848	1936
Livestock			
4 cattle 2 mos. fat	6	4	1
4 cattle 3 mos. fat	10	6	1
5 cattle 6 mos. fat	26	14	2
4 cattle/			

4 cattle 6 mos. fat	21	11	2
10 cattle 9 mos. str.	91	52	8
5 cattle 6 mos. str.	32	18	3
50 sheep 4 mos.	29	16	2
	215	121	19
Dung			
196 tons normal	2415	1230	2281

The figures show the pounds weight of the substances N, P_2O_5 and K_2O contained in the materials. In the case of livestock the weights represent the increment during the period of stay on the farm.

9.3 Calculation of Conversion Efficiency and Self Sufficiency.

The totals obtained above were used for the calculation of conversion efficiency and level of self sufficiency for each of N, P and K.

Calculation of conversion efficiency was based upon the relationship:

$$C.E.\% = \frac{\text{Total output of material}}{\text{Total input of material}} \times 100$$

and calculation of level of self sufficiency was carried out using the relationship:

$$S.S.\% = \frac{\text{Int. circ. of material}}{(\text{Int. + Ext. circ.})} \times 100$$

The/

The results are as follows:-

	N	P_2O_5	K_2O
Total input	3435	2264	2109
Total output	1842	969	1955
C.E.	53.7%	42.8%	92.7%
Dung analysis	2415	1230	2281
S.S.	43.3%	44.1%	46.2%

This gives an overall average self sufficiency of 44.5% and an overall average conversion efficiency of 63%. The fertility index for this farm is 11,450.

10.0 RESULTS OF PILOT EXPERIMENT.

It will be recalled that the object of the experiment is to investigate the relationship between level of self sufficiency, conversion efficiency and fertility on farms of the type selected for study. Figures have been obtained for each farm in the group using the method outlined above for the calculation of S.S.% and C.E.% and to obtain one overall figure for S.S.% and one for C.E.% for each farm, the separate results for N, P and K have been averaged.

When this is done the results appear as follows:

Farm/

Farm	Fert. Ind.	Av. S.S.	Av. C.E.
L/1	8620	40.5	38.4
L/5	8960	41.2	45.0
L/7	11790	47.5	49.0
L/8	25500	42.8	50.0
L/9	14180	39.4	59.2
L/15	11600	57.2	32.1
L/16	9160	55.5	53.5
L/20	10250	40.4	55.0
L/21	9180	58.8	23.5
L/23	6720	78.5	32.5
L/24	7600	65.0	46.3
L/25	11450	44.5	63.0

10.1 C.E./S.S. relationship.

The graph obtained when the above figures for self sufficiency and conversion efficiency are plotted with self sufficiency on the horizontal axis appears in the appendix.* This shows an over-:all decline in C.E.% with rising S.S.% and there appears to be a peak C.E. in the region of 45%. It is however, somewhat ill-defined and is not quite as expected.

Consideration was given to this point and it became obvious that in order to achieve a fair comparison between these parameters on different farms, as many other factors as possible would require/

* p.p. 244 - 245

require to be equal.

All farms in the group are situated on similar soil type, experience similar climatic conditions and are capable of growing, and in fact do grow, similar crops. A number of basic factors are thus common to all farms and indeed it will be recalled that the farms were chosen with this in mind.

It has been shown that there is a considerable variation in soil fertility from farm to farm and in order to discover the relationship between self sufficiency and fertility, a graph* was drawn with fertility index on the horizontal axis. This clearly shows a tendency towards a logarithmic fall in self sufficiency with rising fertility and is in fact much as expected.

Since the level of self sufficiency on any farm is largely governed by the stocking policy which is in turn based upon one or more of a number of factors such as economics, the type of farming common in the district or the farmer's personal preference, soil fertility is probably more the result than the cause of a certain level of self sufficiency. Nevertheless, the logarithmic rel-:ationship does in fact exist and if the effects of different fertility levels are to be eliminated it will be necessary to adjust the figures for self sufficiency.

Some/

* Appendix: 7. p.p. 248 – 249

Some thought has been given to various methods of dealing with the problem and it has been decided that the most satisfactory approach is to draw a horizontal line on the S.S. v F.I. graph* at the point on the vertical axis corresponding to the over-all average self sufficiency and measure the percent difference on the vertical scale between this line and the logarithmic curve at each fertility level. Thus at low levels of fertility the self sufficiency is higher than average by an amount corresponding to the difference between the curve and the mean self sufficiency and at high levels of fertility the reverse is the case. It follows that the correction factor would be subtracted from the figure for self sufficiency if the farm had a low fertility index and vice versa.

It is obvious that soil fertility must have an effect upon the efficiency with which the farm converts purchased NPK into saleable produce and in order to compare conversion efficiency with self sufficiency, the conversion efficiency figures must be compensated for the effect of fertility. This has been achieved using a similar method to that used for self sufficiency correction and the curve showing C.E.% v Fert. Index appears in the appendix.†

This graph is not clearly defined as a linear rise in C.E.% with rising fertility as it stands

but/

* p.p. 248 - 249 † Appendix. 6. p.p. 246-247

but by integrating with a mechanical planimeter type integrator, the nearly linear rise became apparent. Correction factors for C.E.% were obtained from this graph using the same method as described for S.S.% correction factors and results for both S.S.% and C.E.% are tabulated below.

Farm	S.S. corrn.	True S.S.	C.E. corrn.	True CE
L/1	- 8.0	32.5	+ 3.0	41.4
L/5	- 6.0	35.2	+ 2.5	47.5
L/7	+ 5.0	52.5	- 1.0	48.0
L/8	+15.0	57.8	-17.0	33.0
L/9	+ 9.0	48.4	- 3.5	55.7
L/15	+ 4.0	61.2	- 1.0	31.1
L/16	- 5.0	50.5	+ 2.0	55.5
L/20	0	40.4	+ 1.0	56.0
L/21	- 5.0	53.8	+ 2.0	25.5
L/23	-22.0	56.5	+ 5.0	37.5
L/24	-14.0	51.0	+ 3.5	49.8
L/25	+ 3.5	48.0	0	63.0

Overall average S.S. = 50.9 (uncorrected)

Overall average C.E. = 45.6 (uncorrected)

10.2 <u>Corrected C.E./corrected S.S. relationship.</u>

The graph of corrected C.E. v corrected S.S. appears in the appendix* and is roughly bell-shaped with a slight positive skew. In the early stages of the/

*Appendix 8 p.p. 250 - 251

the work it was expected that this type of graph might result and that the conversion efficiency would peak at a certain level of self sufficiency. This peak appears to occur between about 45 and 50% self sufficiency and it is approximately at this point in the self sufficiency scale that the overall average figure of 50.9 lies.

It is unfortunate that no farms had corrected self sufficiency measurements within the range 42 to 48% as there is insufficient information in this section of the graph to clearly define the peak. The broken section was drawn to link the point having co-ordinates C.E. 26% and S.S.23%. These figures were obtained from a farm which was earlier consid-:ered to have unreliable records and was therefore abandoned from the experiment. It appeared that the farmer had been selling dung and produce which were not disclosed. In calculating the C.E. and S.S. the farmer's figures were slightly altered to provide what was considered to be a more probable picture of the actual farming activities over the year and the resulting point on the graph is therefore unreliable. Nevertheless, it is apparent that even if the point is allowed considerable latitude on either axis it still indicates that the C.E. falls in the region of 30% S.S. and it is therefore felt that the result from this farm may have some significance, this is the/

the reason for its inclusion.

10.3 Summary of Pilot Research.

There were several reasons for carrying out a pilot experiment before starting the main work and it is felt that the main objects have been achieved. The techniques used to collect information appear to have worked well and no real difficulties have been experienced in persuading the farmers to provide comprehensive details of their activities. The det-:ailed records which were obtained at regular inter-:vals during the year were compared with the entries in the farmers'books and at the end of the period and this served as a useful check on the movement of livestock and materials.

The analytical information concerning the state of the soil fertility was adequate and has enabled useful figures for overall farm fertility to be obtained. The graphs* which appear in the appendix showing the range of analyses from field to field on each farm are of doubtful value and it is not thought necessary to repeat these in the main experiment. On the other hand, some additional information concern-:ing the mechanical analysis of the soil would be interesting and arrangements are being made to obtain further details from the Macaulay Institute, Soil Survey Department, (Dr. Glentworth).

The method used to convert the weights of mater-:ials to/

* p.p. 201-225

to the N,P and K equivalents is considered to be satisfactory and it is proposed to use virtually the same list of standard analyses for subsequent work.

Livestock has been assessed as an output to the system as regards NPK since NPK contained in purchased animals does not find its way through the soil with the possible exception of the NPK in the contents of the alimentary canal which is negligible. The original reasons for adopting this method have already been explained and there is no new reason for making any changes; this method will therefore be repeated.

A further object of the pilot research was to test the thesis that the conversion efficiency would peak at a certain level of self sufficiency and this has in fact been demonstrated on Lintrose Estate. The point at which this peak occurs is expected to vary with certain factors such as location, climate and soil type and although this has not yet been tested, the indications are that a variation will occur.

The pilot research has been extremely valuable and as a result the way is now clear for carrying out the main work using techniques which have been successfully tested and are therefore established as being suitable for the type of work in hand.

11.0 MAIN RESEARCH./

11.0 MAIN RESEARCH.

It has been shown in 10.3 that suitable techniques for recording and interpreting farming activities have been established and it is proposed to use these in the main part of the research. It is intended, however, to examine certain details, particularly of the analytical data, to discover if more recent figures are available for the analysis of certain items. It will be recalled that the figures for livestock composition were based on analyses carried out by Lawes and Gilbert at Rothamsted about 100 years ago and although there is no reason to doubt the accuracy of these results or to suppose that the analysis of the present day type of carcase, which has changed slightly in conformation, differs in any significant measure, it is thought desirable to intensify the search for a more recent analysis of farm animals.

The main research will also require to demonstrate, if possible, the effect of location and soil type upon the C.E./S.S. relationship and it will be interesting to examine the data obtained from the farms with a view to identifying any other measurable factors which influence conversion efficiency in a predictable manner. This may, for example, be found in the ratio of NPK purchased as feedingstuff to NPK purchased as fertiliser or in the different proportions/

proportions of clay fraction in the soils of differ:ent farms.

11.1 Main Research Plan.

In order to demonstrate the differential effects of soils upon the C.E./S.S. relationship it is obvious that a number of farms must be studied which show a considerable variation in soil type and a convenient way of doing this is to choose several groups of farms on soil types ranging from heavy clay to the lightest soil found in the area of study. It must be borne in mind, however, that time and res:ources are limited and whereas there are advantages in studying large numbers of farms, the work must be restricted to such proportions as will allow detailed study of each unit. This restriction is inevitable but it need not impair the value of the work to any great extent if the farms are chosen with care and accurate recording is possible.

In the pilot experiment twelve farms were studied in one area and from experience of time and work involved in the collection of data, repetition of the experiment using the same number of farms on each of a number of different areas would involve an excess:ive amount of work; such an excess in fact, that accuracy would undoubtedly suffer. This is to be avoided at all costs and it appears that the total number of farms should not exceed 15 or 16.

If/

If four soil types are studied there will there:fore be four farms in each group and if three soil types are studied there will be five or possibly six farms in each group. The object of the work is to demonstrate the effect of soil type on the C.E./S.S. relationship and the implication is that the level of self sufficiency at which the peak conversion efficiency occurs will vary in accordance with the soil type. This means that it is desirable to have as large a number of farms as possible in each group in order to define the curve.

11.2 Choice of Groups.

The actual number of groups depends upon the range of soil types which is studied and since it is desirable to keep the number of farms in each group as high as possible, a compromise must obviously be reached.

A study of the soil types in the Southern part of Scotland shows a very large number of variations. However, these are based upon different combinations of a considerable number of soil characteristics many of which are relatively unimportant in this work. For various reasons which will be discussed in great:er detail in a later section dealing specifically with soils, it has been decided that a useful indicat:ion of the effect of soil type will be obtained by studying groups of farms on three soil types. There will/

will therefore be three groups each composed of five farms making a total of fifteen farms studied in the main experiment. The selection of the actual sites is discussed in the section dealing with soils.

11.3 Preliminary Work.

In general, the plan for the main experiment is well defined being a virtual repitition of the work carried out in the pilot experiment. There are, however, certain minor alterations required in tech-:nique such as those already outlined for dealing with different soil types and it is also desirable to revise the analytical data if this is possible.

It has therefore been decided to repeat not only the basic experimental method of the pilot research but also to extend the review of literature and the study of the soil to ensure that only the most recent and reliable information is used in the main part of the work.

12.0 SECOND REVIEW OF LITERATURE.

Before proceeding with the details of the main experiment it is desirable to extend the original review of literature to discover if there should be any revisions, particularly in the analytical data which was used for the pilot experiment. The review should/

should also reveal recent research in this particular field, if any, and it should therefore be of some value at this stage in the work.

12.1 NPK analysis of Livestock.

The figures used in the pilot experiment were obtained from work carried out by Lawes and Gilbert and while there is no reason to doubt their accuracy some form of check is naturally desirable. During the first review of literature no other figures were found and it was necessary to use the Lawes and Gilbert figures as they stood. Reading has since been carried out with the object of revising these figures, if necessary, in the light of more recent analyses.

Some references were obtained from 'Nutrition Abstracts and Reviews' No. 28 1958 (R.D.V.C.), in particular, Duncan pp. 695-716 quotes figures for Ca and P in cattle of different ages and type. Examples are:

	Ca	P
Dairy calves 9 - 10 weeks	1350g.	740g.
Beef calves 3 mos.	1108g.	850g.
Dairy calves 6 mos.	782-1503g.	440-837g.
Beef calves 5½ mos.	1509-1899g.	883-1118g.
Dairy hfrs. 2½-3½ yrs.	4513-7350g.	2252-3821g.
Steers 40-48 mos.	6302-8073g.	3376-4327g.

etc. etc..

Other/

Other references were:

Hogan and Nierman 1927 Miss. Ag. Exp. Sta. Bull. No. 107.

Moulton et al. 1922 Miss. Ag. Exp. Sta. Bull. No. 55.

Ellenberger et al. 1936 J. Dairy Sci. 19. 444 Proc. and 1950 Vt. Ag. Exp. Sta. Bull. No. 558.

The figures quoted for P show a considerable range in the older animals and calculation has revealed that, in most cases, this range includes the Lawes and Gilbert figures for P. Thus it is concluded that the Rothamsted figures appear to be approximat-:ely correct for the P content of cattle in the light of fairly recent work (1958).

Figures have been seen for the P and K content of pigs and sheep (Meat Technology: The science of meat and meat products) but the figures were not given for the entire body, only parts such as bone, muscle tissue, viscera, skin,hair, etc.. An attempt was made to arrive at figures for the entire body based on the proportions of the different parts but although the results were of the same order as those of Lawes and Gilbert, it was considered that the method of obtaining them was somewhat indirect and therefore the figures were unreliable.

No direct references to the N content of live-:stock have/

have been seen although figures for the protein content of tissues and organs are readily available from a number of sources. It appears, in fact, that recent reseasch is almost always concerned with more detailed work and tthat an overall analysis of the animal, being of a general nature, is seldom if ever required.

A considerable number of references were studied during this review and no NPK analyses of entire animals were found. References to the composition of organs and parts of the body are quite common in the literature but are of little or no value in this work. The conclusion is therefore that the figures quoted by Lawes and Gilbert are probably the only analyses of entire animals which are suitable for use in this work and it is felt that they should be used in the following experiments.

12.2 Analysis of Soils.

The review of literature was extended to cover soils and the particular interest was in the mechan-:ical analysis of soils in the area of study. Reference was made to the soil survey being carried out by the Macaulay Institute for Soil Research and great help has been received from Dr. Glentworth and his staff.

It appears from work carried out by the Institute and by other bodies such as the West of Scotland College/

College of Agriculture that a sufficiently wide range of soil types exists in the South of Scotland to provide opportunity for research on soil varying from a heavy clay to a light sand. It also appears that the ratio of clay to sand is likely to influence the C.E./S.S. curve more than any other single soil characteristic and the results should be interesting and possibly useful to those whose job it is to plan the future of the small farm.

The method of soil sampling and analysis for pH L.I.%, P_2O_5 and K_2O is quite standard and there is no reason for any changes to be made. No special study of this part of the work has therefore been carried out.

12.3 Analysis of materials.

It will be remembered that the analytical data for materials such as feedingstuffs and crops was obtained largely from Watson and More and from Freams 'Elements of Agriculture'. Although these are both standard works and the figures will no doubt be thoroughly reliable, it was decided to check them against analyses from other sources if these could be found.

The 'Scottish Surveyor's Year Book and Diary' 1961 gives a table (p. 283) showing the compensation for the residual value of feedingstuffs and this table quotes average N, P_2O_5 and K_2O analyses for 37 different/

different materials. The figures have been checked against those derived from Fream and Watson and More and although practically every analysis is different the variation is generally small. An attempt was made to discover the source of the figures but without success and their reliability is therefore in some doubt since surveyors are generally more concerned with the compensation value per ton of food consumed. The NPK analyses are in fact incidental and it may well be that no great effort has been made to ensure a high degree of accuracy.

Some thought was given to the possibility of averaging the two sets of figures but it is felt that owing to the degree of uncertainty about the surveyor's figures it would be more satisfactory to leave the existing figures unaltered.

Further reading revealed nothing with a higher degree of authenticity than the source of the existing analyses and it has therefore been decided to use these as they stand for the calculation of the NPK content of feedingstuffs and crops. The NPK content of fertilisers is less of a problem and is easily calculated using the manufacturer's statement of percentages, no revision is therefore required in this part of the work.

12.4 <u>Summary of Second Review of Literature.</u>

The/

The object of the second review of literature was to ensure that nothing had been overlooked in the original review which might be of benefit to the research and it was a further object that the data obtained from the first review should be revised in the light of recent work which would not be published at that time.

It is felt that both these objectives have been fulfilled and the way is now clear to proceed with the main experimental programme.

13.0 CHOICE OF SITES.

The general requirements will already be apparent from previous sections but summarising briefly, they are that groups of farms on a range of soil types should be studied in order to discover the effect of soil type on the C.E./S.S. relationship. The soils should range from a light sandy type to a heavy clay.

The research is concerned with small farms as defined in section 1.1 and it appears from the pilot experiment that there should be about five farms in a group. It is further apparent from the pilot experiment that there is a maximum number of farms which it is desirable to study from the point of view of/

of the available time and resources, this number appears to be in the region of 15. From these facts three groups of five farms each is the obvious choice and with this in mind a search was started for suit:able sites.

There are a number of advantages in studying small farms on Department of Agriculture estates the most important being that the tenants are more accustomed to official activity in the form of stat:istical surveys, visits from government officers and so on. For this reason they are more receptive, or less antagonistic, to the type of co-operation required in this work. A search was therefore carried out amongst the Department of Agriculture estates to discover firstly, if any estates were situated on substantially different soil types. Correct soil type is probably the most important requirement at this stage but it is also necessary to ensure that the farms are suitable for study and in this respect the general requirements are similar to those outlined while planning the pilot experiment (5.3).

Since three groups seems to be the most conven:ient number, it is logical to arrange the experiment so that one is situated on a sandy soil, one on a medium loam and one on a heavy clay, this should provide the required range. A fairly large proportion of the estates were situated on the 'medium loam' type of soil and several were situated near the coast on light/

light, sandy soils but it proved virtually impossible to find a Department estate of small farms on heavy clay although there are a few smallholdings of 5 - 10 acres on this type of soil. The following three sections will deal with the actual selection on sandy soil, clay soil and medium loam respectively.

13.1 Sandy Soil.

D.A.F.S. estates on light sandy soil are to be found in the counties of Kincardineshire, Fife and Wigtownshire and further investigation showed thatq the Kincardineshire and Fife estates are composed mainly of smallholdings with acreages ranging up to about 15 or 20. This left Wigtownshire as a possible site since the estate appeared to be very largely made up of small farms. A visit to the estate confirmed the soil type and size of farms as being suitable for the work in hand but the time and expense involved in making frequent visits to the area appeared to be a drawback. Nevertheless, a few farmers were approached about the possibility of carrying out the work and not only did they show great interest but the impression was formed that in most cases they were quite capable of carrying out the greater part of the recording themselves. This meant that visits could be made at less frequent intervals and it was decided that subject to a more detailed investigation of the soil being satisfactory a/

a group of five farms on this estate (Dunragit) should be chosen for the experiment on light land.

A few farms were selected almost at random from those which were thought to be suitable in other respects and the landcon each farm was examined by taking samples down tp plough depth and noting the physical appearance of the soil particles. This preliminary test was done in almost every field and it was apparent that in fact the soil had a sandy texture over the entire area. One exception was noted where the field was situated on land which had obviously been a peat bog and the soil was dark coloured and peaty with little evidence of sand content. This, however, was an exception and in general, the soil over the estate appeared to be suitable for the experiment.

The Macaulay Institute was again consulted and was able to give the following information on the soil in that particular area.

Depth "	%sand	%silt	%clay	L.I.%	O.M.%	C/N.
2 - 6	86.5	3.60	7.10	2.77	2.00	16.81
12 - 16	97.0	2.40	nil	0.62	0.10	3.80
20 - 23	92.9	5.60	nil	1.47	-	-

and from another pit in the area:-

2 - 8	68.3	10.1	17.2	9.10	(3.57% carbon)	
12 - 20	73.5	8.00	15.3	6.70	(1.96% carbon)	
25 - 30	88.2	2.90	6.10	2.83	-	-

Advice was given that the first set of results is/

is more typical of the area and it will be seen that there is approximately 90% sand down to normal plough depth. It is therefore concluded that the soil on this estate is suitable for the experiment and the choice of individual farms is discussed in section 14.

13.2 Clay Soil.

It has already been stated that a search through the list of D.A.F.S. estates has shown that no suit:able groups of farms can be found on clay soil. This meant that it was necessary to consider studying other farms which were privately owned and in order to simplify the search to some extent it was decided to look through the D.A.F.S. records of Small Farmer's Schemes in areas where clay land occurs. The obvious choice was the Carse of Stirling and a visit to the Department office in Stirling resulted in the discov:ery of a considerable number of Small Farmer's Schemes in progress on carse land. The fact that the units were eligible for the Scheme was an indicat:ion that they were true small farms and that the occupiers were actively farming the land. In this regard it is worth recording that a fair number of occupiers of small farms find outside work and attem:pt to run their farms on a part time basis.

The method of assessing the siutability of the soil already described in the previous section (13.1) was repeated and visual inspection left no doubt that the/

the land had a high percentage of clay and silt. It is important to note, however, that certain farms had patches of mossy soil and although these were usually of limited extent, it was considered important to avoid mossy or peaty areas. These areas were partic-:ularly obvious near the edge of the carse and presumably the method used to clear the peat from the land when it was reclaimed affected the extent of the peat removal. It seems that the peat was cut and carted or carried to the river (Forth) where it was dumped and allowed to float down to the sea. Thus the efficiency of peat removal would probably be greatest near the river where transport of the large quantities of material was somewhat easier. The river of the present day is not particularly wide at this part but it may well have been much larger at the time of reclamation. At one time there must have been a considerable depth of water over the carse and the 25" O.S. map shows a spot where the skeleton of a whale was found.

The survey staff of the Macaulay Institute had recently covered this area and a typical mechanical analysis appears below.

Depth"	%sand	%silt	%clay	L.I.%	O.M.%	C/N
2 - 5	8.00	43.2	48.8	13.0	9.49	15.6
10 - 15	3.80	34.3	61.9	5.28	1.33	10.9
22 - 27	6.20	35.7	58.1	5.18	-	-

This/

This shows a very high clay and silt content down to cultivation depth and very little sand. The land is well drained mainly by an organised system of ditches with tile or stone laterals and the carse appears to be the ideal site for an experiment on a clay soil.

13.3 Medium Loam type of Soil.

The research is being conducted on three soil types and so far, a light sandy type of soil and a heavy clay have been chosen. It is logical that the third soil type should be approximately intermediate between these two extremes and the requirement is thus for a high quality medium loam. It will be recalled that the pilot experiment was carried out on just such a soil and consideration has therefore been given to using the same site. There are no apparent objections to this unless it is considered that the same farms should not be studied for a second year. It would be almost essential to do this since the twelve farms chosen for the pilot experiment are about the only suitable farms on the estate.

Some thought has been given to this point and there does not appear to be any reason for choosing different farms. The farms were all quite suitable for the work and experience has already been gained with the recording of data on these units. This would be some advantage and it should be possible to persuade/

persuade the farmers to give considerable assistance in this part of the work by keeping the detailed, day to day records themselves. It would also be interesting to observe the variation in characteris:tics such as level of self sufficiency and conversion efficiency for the different materials N, P_2O_5 and K_2 O from year to year on the same farm.

The Macaulay Institute was approached with regard to figures for the mechanical analysis of soil on Lintrose estate. This area has also been soil-surve:yed and a typical analysis appears below.

Depth"	%sand	%silt	%clay	L.I.%	O.M.%	C/N
1 - 4	68.1	11.9	17.5	4.94	3.15	12.5
13 - 16	69.8	11.3	15.2	3.70	1.75	11.2
16 - 17½	62.1	12.4	22.6	2.93	0.66	6.9

This analysis was carried out on samples taken from a pit on one of the farms studied in the pilot experiment and it shows a mechanical analysis approx:imately intermediate between the analyses for the sand and clay soils. Lintrose is therefore a satisfactory site for the experiment from the point of view of soil type.

13.4 Final Selection of Sites.

Having chosen three sites which are suitable for the work on the basis of their soil characteristics, it is necessary to explore other factors before making the final selection.

The /

The most doubtful site is at Lintrose where there may be objection to using the same farms for a second year but the reasons are not obvious and apart from this the site is quite satisfactory. It is therefore intended to proceed with the experiment in the mean-:time. When planning the pilot experiment some care was taken to ensure that the farms studied were typical small farms with a balanced system of farming. For example, it was necessary to avoid highly special-:ised units with large numbers of pigs or poultry or with intensive market gardens although no objections were raised with regard to a limited acreage of rasp-:berries since the growing of this crop is common practice in the district around Coupar Angus.

The farms on Dunragit estate are mostly operated with a dairy or stock rearing enterprise as the main feature and on the Carse of Stirling the emphasis is on stock rearing and fattening together with the production of timothy hay. The type of husbandry on Lintrose estate has already been described and it will be recalled that it varies from dairying, through mixed arable and livestock rearing to intensive market garden production.

At first sight it seems logical that the fifteen farms should all have a similar type of farming but since the soil type is so different it is virtually impossible to find similar farms in all three areas. However/

However, the type of development on Dunragit and the Carse of Stirling is broadly similar in the sense that there is emphasis on livestock in both cases and it should be possible to choose farms on Lintrose estate with considerable emphasis on livestock. This would ensure that self sufficiency measurements were all within the same approximate range but it must be remembered that the object is to discover the level of self sufficiency at which maximum conversion efficiency occurs and it would seem more important to choose farms which appear to have a high convers-:ion efficiency for the particular area. By choosing farms on this basis, the peak in the C.E./S.S. curve should be reasonably well defined with the five measurements. In other words, the farms chosen for study should be well managed and should have properly integrated livestock and cropping programmes.

13.5 <u>Choice of Farms.</u>

Having decided upon the sites the next task was to choose five farms on each. Bearing in mind the considerations outlined in the previous section, a number of farms was visited on each site and the final choice was based upon such factors as apparent efficiency, correct type of development, personal qualities of the farmer, etc.. The approach was similar to that used for the pilot experiment and described in section 5.3.

The/

Dunragit Estate, Wigtownshire.

Carse of Stirling.

The photographs (35 m.m. Kodacolor) represent an attempt to illustrate the different qualities of the three sites and the approximate geographical locations of the sites are shown on the attached sketch map. The picture of Dunragit, Wigtownshire was taken from the north-east corner of Luce Bay looking west-north-west across the top of the bay towards the estate of Dunragit which can be seen in the distance. The topography consists mainly of sand dunes and three of the farms chosen for study have fields which run down to the dunes. The soil is thus very sandy and the elevation of all farms except one is under 50 feet a.s.l.. Since this estate is on the north shore of Luce Bay, the average aspect is slightly towards the south but on three of the farms the land is substant-sially level.

The photograph taken on the Carse of Stirling is intended to show the typical clay and the very flat nature of the carse. The colour of the soil is, in fact, very similar to that shown in the picture when viewed in daylight and the flat land can be seen extending to the edge of the carse where the land starts to rise to the hills around Doune and Aberfoyle. In the distance there are a few typical stacks or 'leets' of timothy hay, one of the main products of this area. The photograph was taken on one of the farms/

Lintrose Estate, Coupar Angus, Perthshire.

farms studied and the farm in the distance is another.

A view looking north across Lintrose estate is shown in the third picture and the intention was to depict a district of high quality soil, capable of growing all the usual arable crops and where livestock consists mainly of fattening cattle. The white house in the distance is the dwellinghouse of farm L/8 and the other farms studied in the pilot experiment lie to the left and right and beyond this point.

14.0 SOIL SAMPLING.

Soil sampling was carried out during the winter of 1959 - 1960 and as in the pilot experiment separate samples were taken for each field or area of ground which had been cropped separately and each sample consisted of 15 to 20 corings taken to a depth of 8 or 9 inches. The usual precautions were taken to avoid contamination of the samples with recently applied lime or fertiliser and apart from this there were no special problems.

Sampling was completed early in 1960 and the results were obtained in due course from the soil chemistry department of the Edinburgh School of Agriculture. Consideration was given to carrying out the analysis as part of the research programme but there/

there are considerable advantages in using the advisory facilities provided by the Colleges and analysis was therefore carried out by the soil chemistry department of the Edinburgh School of Agriculture. This approach ensures standard technique and consequently a higher degree of accuracy.

14.1 Dunragit soil results.

The results of analysis of samples taken at the Dunragit farms are as follows:

Farm	No. of samples	- - - - Mean - - - - -			
		L.I.%	pH	K_2O	P_2O_5
D/1	9	7.2	5.7	129	13
D/2	11	8.2	5.4	225	7
D/3	9	8.1	5.8	212	8
B/1	9	7.9	5.7	253	7
P/6	9	8.4	5.8	195	9

It has been decided that there is little to be gained from graphical display of the field to field variation in individual parameters and consequently the type of graph used in the pilot experiment to study the effectiveness of past rotational policy in maintaining uniform fertility has not been drawn. However, the individual field analyses appear in the appendix* and from these it will be seen that farm D/1 has what is probably the most consistent analysis. It is interesting to note that it also has the lowest level/

* p.p. 226 - 231

level of fertility in the group.

The L.I.% is somewhat higher than expected for this type of sandy soil but is probably explained by the fact that there is a considerable emphasis on rotational grass and practically every grain crop is undersown. The pH is much as expected and is remarkably constant over the five farms. Potash and phosphoric acid results show that there is an adequate manuring policy and the phosphoric acid content although not high is sufficient for the type of cropping in the area.

14.2 Carse of Stirling soil results.*

The results of soil analysis of samples from the Carse farms are as follows:

		- - - - Mean	- - - - - -		
Farm	No. of samples	L.I.%	pH	K_2O	P_2O_5
C/1	10	9.8	5.9	226	4
C/2	12	8.0	6.6	211	9
C/3	8	7.6	6.2	189	5
C/4	9	7.7	6.2	168	7
C/5	8	7.8	6.0	194	6

Comparing the figures with those for Dunragit the L.I.% and K_2O are roughly similar but the Carse farms have a slightly lower P_2O_5 content and a higher pH. The lower phosphoric acid is to be expected but one usually associates soil which has been underlying peat with acid conditions. A possible explanation/

*Appendix: 4(b). p.p. 232-237.

explanation is that there has been a regular liming policy since the land was reclaimed and another might be that the particular colloidal content exerts a buffering action in the region of pH 6.

14.3 Lintrose soil results. *

The results of analyses of samples taken from the five farms on Lintrose estate which were selected for the main research are as follows:

Farm	No. of samples	- - - - Mean - - - - - L.I.%	pH	K_2O	P_2O_5
L/9	8	8.2	6.2	104	18
L/16	9	8.3	6.5	137	8
L/20	8	7.1	6.3	163	10
L/24	7	8.1	5.9	132	9
L/25	11	8.4	6.2	177	8

Comparing these figures with those obtained from the same farms one year earlier there has been, on balance, a slight rise but this is so small as to be relatively insignificant. It was expected that similar figures would be obtained and in fact consideration was given to using the original results but since sampling was being carried out at Dunragit and the Carse of Stirling it was thought desirable to sample Lintrose at the same time.

The figures for Loss on Ignition and pH are similar to those obtained from the other two sites but/

*Appendix: 4(c). p.p. 238-243.

but the figures for potash are generally below the figures for the other two groups. This was not expected in view of the differences in soil type and the fact that Lintrose soil is considered to be more fertile but it can probably be explained, at least to some extent, by the fact that the Dunragit farmers favour more frequent applications of fertiliser in small quantities to reduce leaching losses and thus maintain a relatively higher level of available NPK. Although this does not apply on the Carse, the clay has a naturally higher potash reserve.

14.4 Fertility Indices.

The method described and used in the pilot research has been repeated to calculate the fertility indices of the fifteen farms now studied. It will be recalled that this entails simple multiplication of the mean figures for loss on ignition, potash and phosphoric acid for each farm. When this is done the results are as follows:

Dunragit:

Farm	Fertility Index
D/1	12,074
D/2	12,900
D/3	13,736
B/1	13,990
P/6	14,740

Carse/

Carse of Stirling:

Farm	Fertility Index	
C/1	8,850	
C/2	15,190	
C/3	7,180	
C/4	9,050	
C/5	9,080	
Lintrose:		(Last year)
L/9	15,340	14,180
L/16	9,090	9,160
L/20	11,570	10,250
L/24	9,620	7,600
L/25	11,890	11,450

The figures for Dunragit are remarkably constant as compared with those for the other two groups and this may be due to the fact that all five farms at Dunragit have similar rotations and similar manuring policies, probably more so than is the case with the other groups. The figures for the Carse of Stirling and Lintrose are of the same order and it is inter:esting to note the relatively small changes in the Lintrose figures since last year.

In general it appears from the fertility indices that the choice of farms has been satisfactory. There are no extremes and indeed on Dunragit the figures are/

are sufficiently close almost to permit plotting the C.E./S.S. curve without the application of correction factors.

15.0 <u>COLLECTION OF DATA, MAIN RESEARCH</u>.

The main research was scheduled to run from 1st. January 1960 until 1st. January 1961 and during this time all farms were regularly visited to ensure that accurate records were kept. Experience gained in carrying out the pilot experiment proved to be extremely valuable and as a result the farmers themselves were briefed to enable them to keep most of the records and routine visits were concerned mainly with checking. This approach is almost essential when dealing with sites in different parts of the country in view of the amount of travelling involved and it was particularly useful in the case of Dunragit which is comparatively inaccessible, it meant, in fact, that visits could be made at less frequent intervals without sacrificing accuracy.

The schedules of materials and livestock were compiled as described in section 9 and no serious problems arose. One difficulty which appeared in the early stages of the work was to find a method of accurately measuring the quantity of dung produced on certain/

certain farms where it was customary to clean the dairy byres into a muck spreader which was emptied onto grassland at frequent intervals. This method appeared on two farms and applied to about half the dung produced on each farm, the remainder being stored in an uncovered heap for later application to arable land. It was comparatively easy to record the number of loads and this figure was multiplied by the average weight of four or five of these. To obtain this weight, a number of loads were flattened down into the spreader and the volumes measured, these were converted to weight in the usual way and averaged.

It will be recalled that the figure for nitrogen content of dung was given tolerance limits to allow for adjustments to compensate for different methods of handling. An increase would normally be made in the above case where fresh dung was applied to the land but since about half the production was stored in uncovered heaps which would indicate comparatively heavy nitrogen loss, the figure has been left without adjustment at 0.55%.

The detailed schedules are not reproduced in the main text since it is considered that they are rather lengthy. A similar approach to that used in the pilot experiment has been adopted with slightly more detail. Figures quoted for each farm are as follows:

Total/

Total Input (fertiliser, feed, etc..)

Total Output

Conversion Efficiency

Dung Analysis

Level of Self Sufficiency

(The above for each of N, P_2O_5 and K_2O)

Average Conversion Efficiency.

Average Self Sufficiency.

Fertility Index.

15.1 Dunragit Results.

Farm	N C.E.	N S.S.	P_2O_5 C.E.	P_2O_5 S.S.	K_2O C.E.	K_2O S.S.
D/1	38.0	43.2	10.0	47.6	11.0	68.0
D/2	33.0	53.3	15.0	51.4	16.0	71.0
D/3	72.0	60.5	18.0	64.0	25.0	76.2
B/1	62.0	61.8	13.0	66.9	17.0	83.7
P/6	58.0	53.7	19.0	59.0	31.0	76.7

(all above are %)

The above table shows conversion efficiency and level of self sufficiency for each of N, P_2O_5 and K_2O on each of the five farms. The table below shows input and output for each of N, P_2O_5 and K_2O on the same five farms.

Farm	N I.P.	N O.P.	P_2O_5 I?P.	P_2O_5 O.P.	K_2O I.P.	K_2O O.P.
D/1	5190	1987	8628	849	6245	674
D/2	6453	2151	6002	914	4587	731

D/3/

D/3	4146	3009	7720	1318	5485	1361
B/1	2591	1605	5164	656	2821	474
P/6	3058	1785	3905	731	1891	594

(above figures in lbs. weight)

The following table shows dung analysis, average conversion efficiency, average self sufficiency and fertility index for the five Dunragit farms.

	Dung			Average		
Farm	N	P_2O_5	K_2O	C.E.	S.S.	F.I.
D/1	1515	771	1432	19.7	52.9	12074
D/2	1895	965	1791	21.3	58.6	12900
D/3	4610	2345	4360	38.3	66.9	13736
B/1	2590	1320	2450	30.7	70.8	13990
P/6	2070	1053	1956	36.0	63.1	14740

(figures for dung in lbs. weight, figures for C.E. and S.S. are %, F.I. in units)

15.2 <u>Carse of Stirling Results.</u>

	N		P_2O_5		K_2O	
Farm	C.E.	S.S.	C.E.	S.S.	C.E.	S.S.
C/1	90.5	29.0	40.0	38.2	1262	28.6
C/2	268	24.2	52.5	32.4	514	24.3
C/3	94.0	20.2	42.0	26.7	500	20.6
C/4	120	31.8	26.2	40.0	330	32.9
C/5	84.0	30.2	35.0	39.2	414	29.6

(all above are %)

Farm/

Farm	N		P_2O_5		K_2O	
	I.P.	O.P.	I.P.	O.P.	I.P.	O.P.
C/1	4089	3693	3117	1248	284	3583
C/2	1922	5155	3351	1754	945	4864
C/3	6344	5960	4959	2098	1093	5470
C/4	3288	3945	5367	1404	1075	3545
C/5	4775	3995	3929	1359	935	3871

(above figures in lbs. weight)

Farm	Dung			Average		
	N	P_2O_5	K_2O	C.E.	S.S.	F.I.
C/1	1512	770	1430	464	31.9	8850
C/2	1650	840	1560	278	26.9	15190
C/3	1502	764	1420	212	22.5	7180
C/4	1834	934	1735	159	34.9	9050
C/5	1723	876	1628	178	33.0	9080

(figures for dung in lbs. weight, figures for C.E. and S.S. are %, F.I. in units)

15.3 Lintrose Results.

Farm	N		P_2O_5		K_2O	
	C.E.	S.S.	C.E.	S.S.	C.E.	S.S.
L/9	81.0	39.2	43.0	38.9	51.7	43.3
L/16	68.5	53.0	37.9	52.8	53.4	57.2
L/20	69.3	41.0	31.2	41.5	66.8	37.2
L/24	46.7	62.5	29.5	62.6	56.9	64.5
L/25	71.3	53.7	39.0	52.8	74.5	51.4

(all above are %)

Farm/

Farm	N I.P.	N O.P.	P_2O_5 I.P.	P_2O_5 O.P.	K_2O I.P.	K_2O O.P.
L/9	1952	1581	1886	811	2427	1253
L/16	3009	2062	2815	1067	3084	1645
L/20	2641	1830	2926	911	3038	2026
L/24	2870	1338	2296	678	2038	1159
L/25	2562	1828	2463	961	2546	1896

(above figures in lbs. weight)

Farm	Dung N	Dung P_2O_5	Dung K_2O	Average C.E.	Average S.S.	F.I.
L/9	1015	515	955	58.6	40.5	15340
L/16	2325	1190	2200	53.3	54.3	9090
L/20	1270	646	1200	55.8	39.9	11570
L/24	2215	1130	2095	44.4	63.2	9620
L/25	2120	1080	2000	61.6	52.6	11890

(figures for dung in lbs. weight, figures for C.E. and S.S. are %, F.I. in units)

15.4 Method of Display.

The results obtained above were examined with the object of discovering the best method of displaying the C.E./S.S. relationship. Some consideration was necessary in view of the relatively high figures obtained for conversion efficiency on the Carse of Stirling farms which meant that a different scale at least would require to be used for this group.

As in the case of the pilot experiment the object is to show if possible, the level of self sufficiency which/

which gives maximum conversion of N, P_2O_5 and K_2O within each group. It was therefore decided that the same general method of plotting C.E. on the 'y' axis against S.S. on the 'x' axis should be used with suitable adjustments in the scaling factors to prod:uce a convenient display. It will be appreciated that the ratio of the 'x' and 'y' scaling factors is less important than the shape of the graph which is expected to show a peak.

In the pilot research, correction factors were used to eliminate the differential effects of fert:ility. In the cases of Dunragit and the Carse of Stirling, however, the fertility indices do not show marked variation within each group and it has there:fore been decided to plot the C.E. and S.S. figures without the application of correction factors which are considered to be unnecessary. In fact, if correction factors were used, they would be small and would have little effect upon the graph shape.

The fertility indices for Lintrose are broadly similar to those obtained in the pilot experiment and they do exhibit some variation. Therefore, correction requires to be applied and this will be based upon the graphs of C.E. v F.I. and S.S. v F.I. used in the interpretation of last year's (1959) figures from Lintrose.

15.5 <u>Lintrose correction factors</u>.

Correction factors have been obtained using the C.E. v F.I. and S.S. v F.I. graphs which were drawn using/

using the results obtained during the pilot experim-:ent. Undoubtedly a better method would be to draw a fresh set of graphs based upon analyses carried out in the year of the main experiment but since only five sets of figures are available, it was considered that the error would be less in using the previous year's graphs which were based upon twelve sets of figures.

The method of using these graphs is to draw lines on the 'y' axes corresponding to the overall average C.E. and S.S. found from the results of the main experiment and to note the positive or negative diff-:erences between this line and the integrated curve at the particular fertility indices. These figures are then used to correct the individual farm C.E. and S.S. results. It will be noted that the overall average S.S. is virtually the same for both pilot and main experiments.

	Uncorrected		Correction		Corrected	
Farm	C.E.	S.S.	C.E.	S.S.	C.E.	S.S.
L/9	58.6	40.5	+4.0	+11.0	62.6	51.5
L/16	53.3	54.3	+12.0	-5.0	65.3	49.3
L/20	55.8	39.9	+9.0	+4.0	64.8	43.4
L/24	44.4	63.2	+11.0	-2.5	55.4	60.7
L/25	61.6	52.6	+8.0	+5.0	69.6	57.6

16.0/

16.0 SUMMARY OF MAIN EXPERIMENT.

The results obtained from the three groups of farms are shown in the appendix* as graphs relating C.E.% on the 'y' axis to S.S.% on the 'X' axis. Each of the three graphs shows a peak conversion efficiency at a certain level of self sufficiency and it will be recalled that the farms were chosen in the hope that this would occur. The farms in each group were, in fact, selected largely on the basis of their 'apparent' conversion efficiency and self sufficiency as judged by observation of the farms and discussions with the farmers about their rotations and systems of management (13.4). The method was to choose a number of farms showing a high conversion efficiency and from these select five representing a range of self sufficiencies. At the time there was considerable doubt as to whether casual observation would be accurate enough to provide a suitable range of farms but the graphs indicate that the selection has been reasonably successful.

16.1 Discussion of Dunragit results.

Referring to the Dunragit graph,† the peak conversion efficiency occurs at about 67% self sufficiency and the C.E. has fallen to about half its peak value at 52% S.S. and 75% S.S. where the C.E. appears to flatten out to give the curve a bell shape. The points for each of the farms are fairly well distributed to show the shape of the curve but it would have been/

* p.p. 252-257 † p.p. 252-258.

been desirable to have rather more information at the peak and at high levels of self sufficiency. However, at levels of self sufficiency above about 70% the choice of farms becomes severly limited and it would have been difficult to find subjects which were suitable in other respects. The explanation is no doubt that the higher levels of self suffic-:iency require an intensive stocking policy assoc-:iated with comparatively little arable ground or intensive grass production. This type of farm would not be economic at Dunragit, in fact, high self sufficiency with low NPK conversion efficiency is typical of marginal or hill farming. In this connection it is interesting to note that the high-:est self sufficiency point on the curve refers to farm B/1 which, although still on sandy soil, had outcrops of rock and was situated at a higher elev-:ation than the other four farms.

The levels of self sufficiency for nitrogen and phosphoric acid are substantially similar on any farm and all S.S. figures are within the limits 43% to 84%. On the other hand, figures for C.E.% for each of NPK show considerable variation. In general, the figure for nitrogen C.E.% is at least twice the figure for phosphoric acid C.E.% or potash C.E.% and there is not a great variation between the C.E. figures for phosphoric acid and potash. C.E. and S.S. are generally below those for Lintrose (pilot experiment)/

experiment) in the case of phosphoric acid and potash and the figures for nitrogen are roughly comparable.

The experiment at Dunragit appears to have been successful within the limits of available time and resources and although the graph cannot be regarded as providing conclusive evidence of the C.E./S.S. relationship, it does provide a fair indication of the way in which C.E. varies with self sufficiency and this was the object of the experiment.

16.2 Discussion of Carse of Stirling results.

The results of the experiment on the Carse of Stirling have not been as expected and because of this they are extremely interesting. It is a well known fact that clay soils are sometimes rich in potash particularly if they have been derived from orthoclase felspar but the availability of the potassium to plants appears to have been held in doubt and it seems likely that the K_2O availability of clay varies considerably from one site to another. The results of the experiments on the five Carse of Stirling farms demonstrate quite clearly that the soil not only contains available K_2O but is capable of supplying comparatively large quantities to growing crops over long periods. The outputs of K_2O (representing losses to the farming system) are always greatly in excess of the inputs (representing gains to the farming system), the differences are as/

as follows:-

Farm	K_2O			
	Input	Output	Loss	C.E.%
C/1	284	3583	3299	1262.0%
C/2	945	4864	3919	514.0%
C/3	1093	5470	4377	500.0%
C/4	1075	3545	2470	330.0%
C/5	935	3871	2936	414.0%

(Input, output and loss in lbs. weight K_2O)

The average farm is therefore losing about 3,000 lbs. of K_2O per year (or about 60 lbs. per acre per year) and presumably this loss has occur:red annually for at least a century since it is mainly due to the large production of Timothy hay which is the traditional crop of this area and was a popular feed for city horses. In spite of the high output of K_2O, the manurial policy on most farms is such that no great emphasis is placed on potash applications presumably because it has proved to be unnecessary. Fertiliser applications consist mainly of nitrogen which is applied in fairly large quantity and phosphate applied often as basic slag.

The figures for nitrogen are also interesting and in two cases the C.E.% has exceeded 100 (C/2 268% ; C/4 : 120%).

Nitrogen results are shown in the following table:

Farm/

Farm	Nitrogen Input	Output	Loss	C.E.%
C/1	4089	3693	-	90.5
C/2	1922	5155	3233	268.0
C/3	6344	5960	-	94.0
C/4	3288	3945	657	120.0
C/5	4775	3995	-	84.0

(Input, output and loss in lbs. weight N)

The maintenance of soil nitrogen content in the case of farms C/2 and C/4 is undoubtedly largely due to fixation by legumes such as clovers and beans although in the case of farm C/2 the loss amounts to about 50 lbs./acre which appears to be rather large for balance by the action of legumes. However, since other farms in the group show no loss the year of experiment was perhaps exceptional in the case of farm C/2.

Phosphoric acid results are more in line with figures obtained in the Lintrose experiments and show no outstanding features which might suggest either greater or less phosphoric acid loss in a clay soil.

16.3 Discussion of Lintrose results.

The five farms at Lintrose were selected from those studied in the pilot experiment and consequently figures are available for two consequtive years. This has allowed comparisons to be made and in general there is little difference. When planning the/

the pilot experiment, an important factor in choosing the farms was the stability of the systems from year to year and this may be the reason for the substantially similar results obtained over the two years.

Conversion efficiency peaks* at about 56% self sufficiency and this compares with 48% in the pilot experiment showing a difference of about 8%. The curve for the pilot experiment drops steeply betw-:een 50% and 60% and this is reflected in the main experiment. It therefore appears that for the particular soil type at Lintrose the peak occurs between about 45% and 55% and falls off rapidly at higher levels of self sufficiency. At levels of self sufficiency below about 45% the gradient is not so steep and this gives the curve a positive skew.

In the main experiment, the low conversion efficiency for farm L/9 has influenced the shape of the graph* probably more than it would have done if there had been a larger number of points and it may well be that the peak occurs somewhere in the region of 52 - 55% self sufficiency. In any event, the peak conversion efficiency of the pilot exper-:iment (62%) is of the same order as the peak conversion efficiency of the main experiment at Lintrose (69.6%) a difference of 7.6% which can be considered small in this type of work.

It/

* Graph p. 257

It has already been shown that the self suff-:iciency has increased in the second year by about 8% and although the reason for this is not known with certainty and could be due to random variation, it is interesting to speculate that it may have been because the farmers were already aware of the experimental work and of the factors which influen-:ced self sufficiency. Naturally this is undesir-:able and in any repetition of the experiment, care would require to be taken to ensure that this did not recur because of human error, intentional or otherwise. Exaggerated claims for the sake of effect are not unknown, therefore it would be important to check the farmer's figures wherever possible.

In general, the shape of the curve* is satis-:factory in the sense that it shows a peak and as has already been stated, this is more important in the present work than the actual numerical values for conversion efficiency.

17.0 <u>CONCLUSION</u>.

In a research project of this nature the numerical results require interpretation since they do not in themselves provide an immediate and obvious proof of the thesis. In the previous sect-:ion the/

* p. 257

the results from each of the three main experimental sites were discussed separately, it is now proposedd to discuss the experimental work as a whole with the object of forming conclusions and in order to dis-:cover if the thesis has been proved.

17.1 C.E./S.S. relationship.

It will be recalled that first attempts to demonstrate the C.E./S.S. relationship were not rewarding (pilot experiment) until it was discover-:ed that correction factors designed to eliminate the differential effects of fertility produced the desired effect and gave a curve which showed a definite C.E./S.S. relationship. The curve was approximately bell shaped with a slight positive skew.

At the time, there were some doubts about the repeatability of this method using correction factors on different soil types but later experime-:nts have shown that providing correction factors are used in cases where there are a number of measurements on farms situated on the same soil type but which show a wide variation in levels of fert-:ility, there appears to be a fairly close agreement in the shape of the C.E./S.S. curves obtained.

The fact that groups of farms were obtained which did not show a sufficiently wide variation in fertility to warrant the application of correction factors and which gave a bell-shaped curve is taken to/

to be an indication that the correction factors operate successfully when they are required.

It is to some extent unfortunate that it was out of the question to consider studying a greater number of farms in the main research. Experimental work of this nature where the object is to produce a curve is much more conclusive with a large number of co-ordinates to give greater detail throughout the length of the graph and in the case of the three main experiments, five farms each was fewer than is really desirable. Nevertheless, the curves have been drawn and by careful selection of the farms it has been possible to achieve a satis-:factory distribution of the five co-ordinate points.

The points in the S.S. scale at which the C.E. appears to peak are as follows:-

	peak C.E.%	at	S.S.%
Dunragit (sand)	38.3		66.8
Lintrose (loam)	69.6		57.6
Carse (clay)	460.0		34.0

The actual value of the peak conversion efficiency is relatively insignificant and in fact the variation is extremely wide. More important are the figures for S.S. which show the levels at which the maximum use is made of the raw materials N, P_2O_5 and K_2O. It will be observed that on sandy soil/

soil a comparatively high level of self sufficiency is necessary in order to achieve the greatest possible NPK conversion efficiency whereas with a clay soil, the level of self sufficiency for the same condition is about half the previous figure.

There is, of course, nothing significantly new in this general statement but one of the chief objects of the work has been to show how the parameters could be measured and the above figures represent, as far as is known, the first attempt to do this. The conclusions to be drawn from the C.E./S.S. curves are straightforward; it can be stated with safety that in any particular district which has substantially even soil type and uniform farming systems, it is possible to plot a curve which shows the level of self sufficiency at which maximum biological use is obtained from purchased raw material.

The conditions which qualify the above statement are that raw material is reckoned as N, P_2O_5 and K_2O, that 'substantially even soil type' refers more to the ratio of clay to sand than to any other feature and that 'maximum biological use' does not necessarily bear any relationship to economic profitability.

It may also be concluded that the C.E./S.S. curve is roughly bell-shaped with a slight positive skew/

skew and it is therefore clear that a farmer with a low level of self sufficiency who wishes to incr:ease his conversion efficiency must excercise great care to ensure that he does not overshoot the peak. If this should occur, there is the danger that the conversion efficiency will fall off rapidly with relatively small increments of self sufficiency. At levels of self sufficiency below the optimum, the variation in conversion efficiency is more gradual and unless very accurate measurements can be made, it is better to err on the low side.

It appears that on a clay soil the aim should be to operate in the region of 30% self sufficiency, on a medium loam about 50% and on a light, sandy soil about 60% but obviously the most satisfactory method of discovering the optimum level of self sufficiency is to make actual measurements on farms in the particular district and to draw a graph.

The particular C.E./S.S. graphs shown have greatest application to arable units where purch:ased raw material is chiefly NPK. On livestock rearing or dairy farms where the emphasis is on home grown feedingstuffs such as roots, grain and intensive grass production, the graphs should also apply/

apply since the greater part of the raw material will also be NPK. Dairy farms which use large quantities of purchased feed or extensive hill farms relying upon the natural resources of large areas of rough ground which are neither cultivated nor manured may be regarded as unsuitable for use with these graphs.

17.2 Conclusions from Casse of Stirling experiment.

In many ways the experiment on the Carse of Stirling was the most interesting of the three main experiments. The results have already been discussed at some length in section 16.2 but no conclusions were drawn in that section. The chief object of the experiment was to obtain a bell-shaped C.E./S.S. graph in order to discover the optimum level of self sufficiency and this object has been fulfilled. There are, however, other features of the work which are worthy of note.

The exceptionally high conversion efficiency for potash has been recorded together with conversion efficiencies for nitrogen which exceed 100% and possible explanations have been put forward. The conclusions which can be drawn from these results are, firstly, that the Carse of Stirling has very large reserves of potentially available K_2O ('potentially available' because soil analysis does not show unduly high available potash) and secondly/

secondly, that nitrogen fixation either by B. radicicola or by free living organisms such as azotobacter appears to occur at a comparatively higher rate than is the case on lighter soils. This second conclusion concerning nitrogen fixation is based upon the assumption that all nitrogen entering the particular farms which showed over 100% C.E. for nitrogen, was recorded during the collection of data. If this is so, the atmosphere is the only other source from which the excess nitrogen could have been obtained.

It is true that legumes are prominent in the cropping programmes but it is considered that the efficiency of fixation must be rather higher than on lighter soils to account for the quantities of nitrogen involved (16.2). Both conclusions, the first concerning potash and the second, nitrogen are interesting in as far as they go and it is felt that they may well provide justification for further work concerning the behaviour of clay soils. It would, for example, be interesting to know how long the potash supply is likely to last and whether the nitrogen fixation process which appears to be more efficient than usual could be stimulated on other soils where it might be used to consider-:able advantage.

17.3 Additional Information.

In section 2.3 it was stated that observations would/

would be made in the chance that further relationships might appear. This is normal practice in most experimental work and consequently the data obtained from the experiments has been carefully examined in an attempt to discover any such relationships. For example it was decided when planning the work that each of N, P_2O_5 and K_2O should be treated separately and this has been done throughout the work. The chief reason was that it was thought possible that there might be a pattern in the C.E./S.S. relationships for each nutrient. This was, however, a secondary objective and the limitations of time and resources unfortunately dictated that this part of the work could not be carried through in a satisfactory and complete manner.

When considering such detail it is more or less essential to have a large number of results and the present day technique would be to programme these into a computer which would then seek out any trends. This approach has not been possible and rather than make a poor attempt with the available information it was decided that the work should not be carried out. It appears, however, from the figures which have been obtainedd that such relationships may, in fact, exist particularly in the case of nitrogen. A study of phosphate results may also be rewarding and may lead to the discovery of more efficient ways of using phosphate to avoid the heavy losses which often occur./

occur. In any event a repetition of the method used in the present work would appear to offer a satisfactory starting point for more detailed study into the relationships between efficiency in the use of raw material and the day to day management and livestock programmes of small farms.

17.4 Practical application of the Relationships.

The research has been carried out in an attempt to throw some light on particular aspects of small farming in southern Scotland and in view of the fact that information concerning the efficiency of small farms as converters of raw material into produce is so scanty it has been necessary to keep the study comparatively broad. This approach has had certain advantages in the sense that it has permitted the observation of factors which might otherwise have been missed and it is hoped that it may also be regarded as providing sufficient information to assist in agricultural planning. Further, it opens what would appear to be an alternative to economics as a method of studying the farming process for the purposes of determining future agricultural policy.

Several ways in which the relationships may be used in planning farming systems have already been indicated and it is clear that projected changes in a farming system may be evaluated in terms/

terms of conversion efficiency. This means that by a reverse process, an indication can be obtained of the economic consequences of changing a farming system and it should therefore be possible to plan for particular results. At the present time such planning is usually based upon judgement and although this may be thoroughly reliable, there would appear to be some advantages in using a system based upon actual measurements which could be repeated by different workers with similar results. There would therefore be some degree of standardisation in hitherto arbitrary methods.

As an example of the type of planning which would be more effective using a standard technique it seems probable that the peak conversion efficiencies for each of N, P_2O_5 and K_2O may in certain instances, occur at different levels of self sufficiency and it might therefore be more satisfactory to choose a level of self sufficiency which gave maximum use of one particular nutrient. On the Carse of Stirling, efficiency in the use of K_2O or possibly N may not be so important as efficiency in the use of P_2O_5 and on this type of soil it might be of greater value to operate the farms at the level of self sufficiency which gave maximum conversion efficiency for phosphate rather than the level of self sufficiency which gave greatest average/

average conversion efficiency for all three nutrients.

It will be observed that no attempt has been made to investigate the conversion efficiencies of medium and large farms to serve as a basis for comp:arison. This is, of course, intentional since the object has been to study particular aspects of small farms exclusively, in an attempt to learn more about the efficiencies of different types of farm and different methods of management. If this method of comparing existing and projected systems has thrown any light on the small farm problem or has suggested new ways of tackling certain of the technical difficulties associated with present day small farms, it will have been well worth-while.

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APPENDIX. - - - Index.

APPENDIX 1. - - - Analytical data.

The following tables show the nitrogen, phosphoric acid and potash contents of twenty basic feedingstuff constituents together with details of the method used to calculate the nitrogen, phosphoric acid and potash contents of a number of 'standard' compound foods commonly used on the farms studied.

Nitrogen, phosphoric acid and potash are expressed and calculated in the usual way that is, as N, P_2O_5 and K_2O.

ANALYSIS OF PURCHASED FEEDINGSTUFF CONSTITUENTS.

	N%	P_2O_5%	K_2O%
Maize meal	1.47	0.39	0.33
Flaked maize	1.57	0.60	0.25
Maize gluten feed	3.80	0.70	0.20
Wheat bran	2.42	2.80	1.50
Wheat middlings	2.72	2.60	1.40
Wheat meal	1.94	0.86	0.60
Crushed oats	1.65	0.81	0.55
Barley meal	1.60	0.84	0.57
Soya bean meal	7.15	2.10	1.90
Cracked beans	4.06	0.88	1.28
Bean meal	4.10	0.88	1.28
Rice meal	1.33	2.50	0.70
Linseed cake	4.80	1.70	1.30
Palm kernel cake	2.80	1.10	0.50
Coconut cake	3.40	1.50	2.00
Decorticated earth-nut cake	7.50	1.30	1.50
Decorticated cotton cake	6.60	2.70	1.60
Fish meal	9.75	9.00	1.20
Dried grass	2.90	0.64	2.20
Sugar beet pulp	1.42	0.18	0.59

PURCHASED COMPOUND FEEDINGSTUFF ANALYSIS.

Cattle foods:

(1) Dairy cake: (a total of eight rations have been averaged, two are quoted by way of example)

Ration (a):-

2	parts	Maize meal
1	"	Crushed oats
1	"	Bean meal
2	"	Palm kernel cake
1	"	Decorticated earth-nut cake

The total of seven parts (taken as 700) gives:

21.79 N   5.97 P_2O_5 4.99 K_2O

which reduces to:

3.10% N   0.85% P_2O_5 and 0.71% K_2O

Ration (b):-

2	parts	Maize gluten feed
1	"	Rice meal
1	"	Barley meal
1	"	Linseed cake
1	"	Decorticated cotton cake

The total of six parts (taken as 600) gives:

21.93 N   9.14 P_2O_5 4.57 K_2O

which reduces to:

3.65% N   1.52% P_2O_5 and 0.76% K_2O

Cattle foods: (contd.)

(2) Calf rearing compounds: (two rations quoted by way of example)

Ration (a):-

2 parts Linseed cake
2 " Flaked maize
1 " Oats
1 " Fish meal

The total of six parts (taken as 600) gives:

24.14 N   14.41 P_2O_5 4.85 K_2O

which reduces to:

4.02% N   2.40% P_2O_5 and 0.81% K_2O

Ration (b):-

3 parts Flaked maize
2 " Linseed cake
1 " Fish meal

The total of six parts (taken as 600) gives:

24.06 N   14.20 P_2O_5 4.55 K_2O

which reduces to:

4.01% N   2.37% P_2O_5 and 0.76% K_2O

Pig foods:/

Pig foods:

(1) Sow and weaner meal: (two rations quoted)

Ration (a):-

2 parts White fish meal
1 " Soya bean meal
8 " Middlings
5 " Barley meal
4 " Flaked maize

The total of twenty parts gives:

62.68 N 47.50 P_2O_5 19.35 K_2O

which reduces to:

3.13% N 2.37% P_2O_5 and 0.97% K_2O

Ration (b):-

1 part Soya bean meal
1 " Linseed cake meal
2 " Middlings
1 " Bean meal
2 " Flaked maize
3 " Barley meal

This reduces to:

2.94% N 1.36% P_2O_5 and 0.95% K_2O

(2) Pig fattening meal: (two rations quoted)

Ration (a):-/

Pig foods: (contd.)

(2) Ration (a):-

2 parts White fish meal
5 " Middlings
7 " Barley meal
6 " Maize meal

This reduces to:

2.65% N 1.96% P_2O_5 and 0.26% K_2O

Ration (b):-

1 parts Decorticated earth-nut cake
2 " Wheat meal
2 " Crushed oats
3 " Flaked maize
2 " Middlings

This reduces to:

2.48% N 1.16% P_2O_5 and 0.74% K_2O

Poultry foods:

Layer's meal or pellets:

40 parts Weatings
18 " Bran
10 " Dried grass
15 " Maize meal
7 " Ground oats
5 " Fish meal
5 " Soya bean meal

The/

Poultry foods: (contd.)

The above ration shows the following analysis:

3.00% N 2.28% P_2O_5 and 1.29% K_2O

SUMMARY OF ANALYTICAL DATA.

(1) Crop analysis:

		N%	P_2O_5%	K_2O%
Grain:	Oats	1.65	0.81	0.55
	Barley	1.60	0.84	0.57
	Wheat	1.94	0.86	0.60
Straw:	Oat	0.32	0.18	1.50
	Barley	0.53	0.15	1.30
	Wheat	0.34	0.13	0.80
Hay:	Ryegrass	1.92	0.60	1.80
	Timothy	1.36	0.45	1.40
	Meadow	1.53	0.45	1.60
Roots:	Potatoes	0.34	0.18	0.60
	Swedes	0.21	0.08	0.30
	Mangolds	0.16	0.09	0.45
	Sugar beet	0.18	0.10	0.47
	Sugar beet tops	0.32	0.11	0.58
	Kale, marrow-stem	0.35	0.12	0.55
Fruit:	Raspberries	0.21	0.07	0.25

(2) Dung analysis:

Normal figures:

0.55% N   0.28% P_2O_5 and   0.52% K_2O

Adjustments: Nitrogen - plus 10% to minus 20%
Phosphoric acid - plus or minus 10%
Potash - plus or minus 10%

---

(3) Purchased compound feedingstuffs:

Cattle foods:	N%	P_2O_5%	K_2O%
Dairy production ration	3.46	1.30	0.80
Calf rearing compounds	4.04	2.16	0.96
Pig foods:			
Sow and weaner meal	3.03	1.66	0.96
Fattening meal	2.48	1.44	0.63
Poultry foods:			
Layer's meal or pellets	3.00	2.28	1.29

---

(4) Livestock analysis:

Fat cattle, calves, etc./

(4) Livestock analysis: (contd.)

	N%	P_2O_5%	K_2O%
Fat cattle, calves, etc.	2.40	1.41	0.21
Lambs and sheep	1.84	1.03	0.15
Fat pigs	1.74	0.56	0.08
Store cattle etc.	2.80	1.78	0.26
Store lambs etc.	2.24	1.22	0.18
Store pigs	2.14	1.07	0.16

	lbs. weight of:		
	N	P_2O_5	K_2O
Fat cattle 1,200 lbs.	28.8	16.9	2.52
Fat sheep 110 lbs.	2.02	1.16	0.17
Fat pigs 220 lbs.	3.83	1.23	0.18
Store cattle 800 lbs.	22.4	12.2	2.08
Store lambs 80 lbs.	1.79	0.98	0.14
Store pigs 40 lbs.	0.86	0.49	0.06

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(5) Analysis of livestock products:

Whole fresh milk	0.54	0.22	0.19
Whole eggs (including shell)	1.91	0.54	0.16

APPENDICES 2.(a), (b) and (c)

The following graphs are drawn using the colours green, violet and red. The green curves indicate the weight of material in animals of particular age (brown, horizontal axis) and are read in conjunction with the green, vertical scale. Violet indicates approximate body weight on the violet, vertical scale for any age on the horizontal scale and in similar manner the red graph relates to the red scale and shows the %age material for any age. In the case of cattle, two sets of curves have been drawn, one for fat and one for non-fat animals.

APPENDIX 2.(a) - - - Livestock. (cattle)

The following tables and graphs show the nitro:gen, phosphoric acid and potash content of beef cattle. For the purposes of the graphs, cattle are divided into two categories:

(a) Full growth with fattening.

(b) Full growth without fattening.

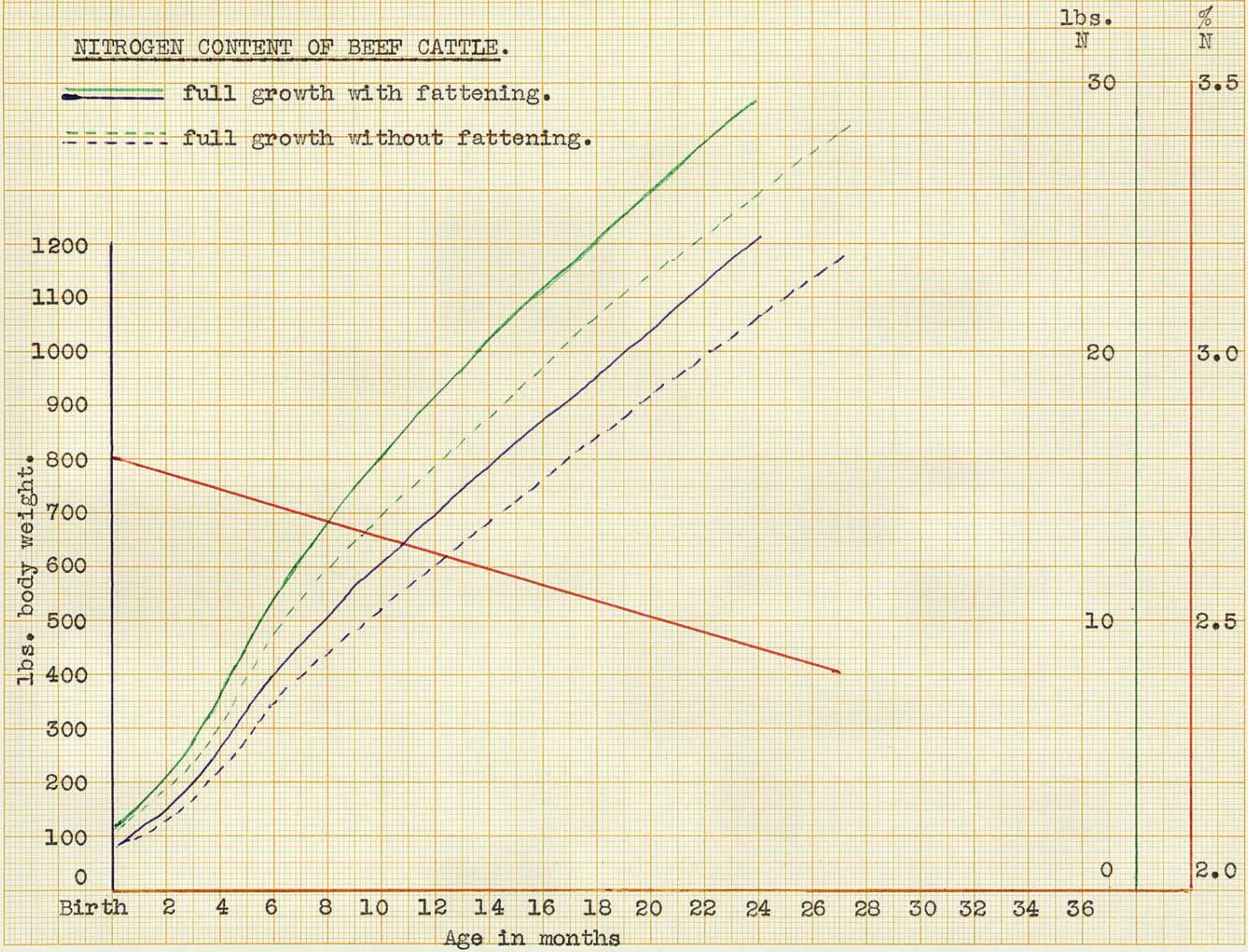
Figures are quoted showing the percent nitrogen, phosphoric acid and potash for a range of ages up to 27 months and an indication is given of the weight of material contained in the animal. The relationship between age and body weight is, naturally, arbitrary.

NITROGEN CONTENT OF BEEF CATTLE.

Age mos.	N%	Weight (a)	lbs. N (a)	Weight (b)	lbs. N (b)
0	2.80	80	2.24	80	2.24
3	2.75	200	5.50	170	4.67
6	2.70	400	10.80	350	9.45
9	2.66	560	14.90	480	12.80
12	2.62	700	18.30	600	15.70
15	2.57	830	21.30	720	18.50
18	2.52	950	24.00	840	21.20
21	2.48	1080	26.80	950	23.50
24	2.43	1200	29.20	1060	25.80
27	2.40	-	-	1170	28.00

(a) Full growth with fattening.

(b) Full growth without fattening.



NITROGEN CONTENT OF BEEF CATTLE.
full growth with fattening.
full growth without fattening.
lbs. N
% N
30
20
10
0
3.5
3.0
2.5
2.0
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
lbs. body weight.
Birth 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
Age in months

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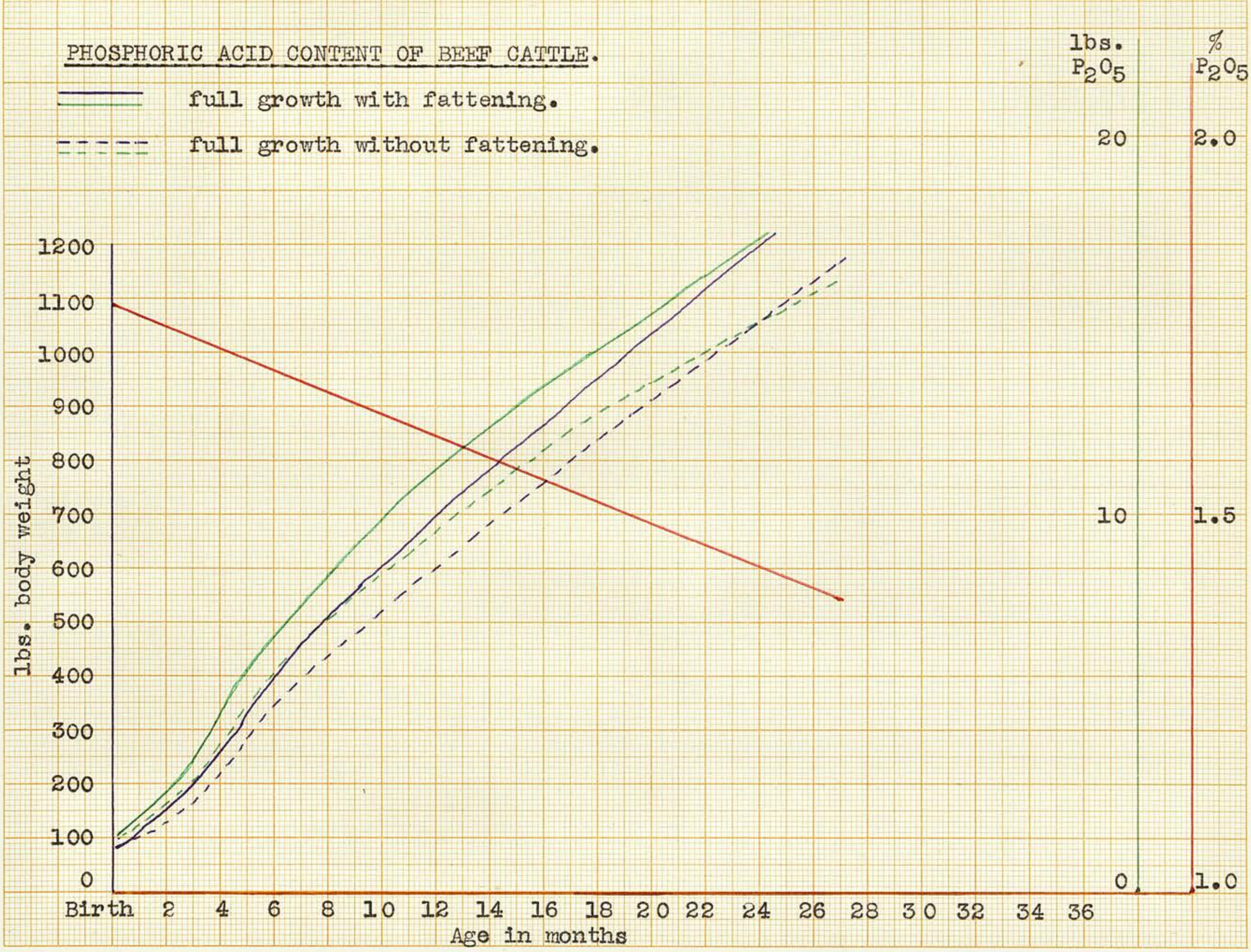
PHOSPHORIC ACID CONTENT OF BEEF CATTLE.

Age mos.	P_2O_5%	Weight(a)	lbs.P_2O_5(a)	Weight(b)	lbs.P_2O_5(b)
0	1.78	80	1.42	80	1.42
3	1.74	200	3.48	170	2.96
6	1.70	400	6.80	350	5.95
9	1.65	560	9.23	480	7.92
12	1.60	700	11.20	600	9.60
15	1.56	830	12.90	720	11.20
18	1.52	950	14.40	840	12.80
21	1.46	1080	15.80	950	13.90
24	1.43	1200	17.20	1060	15.20
27	1.39	-	-	1170	16.25

(a) Full growth with fattening.

(b) Full growth without fattening.

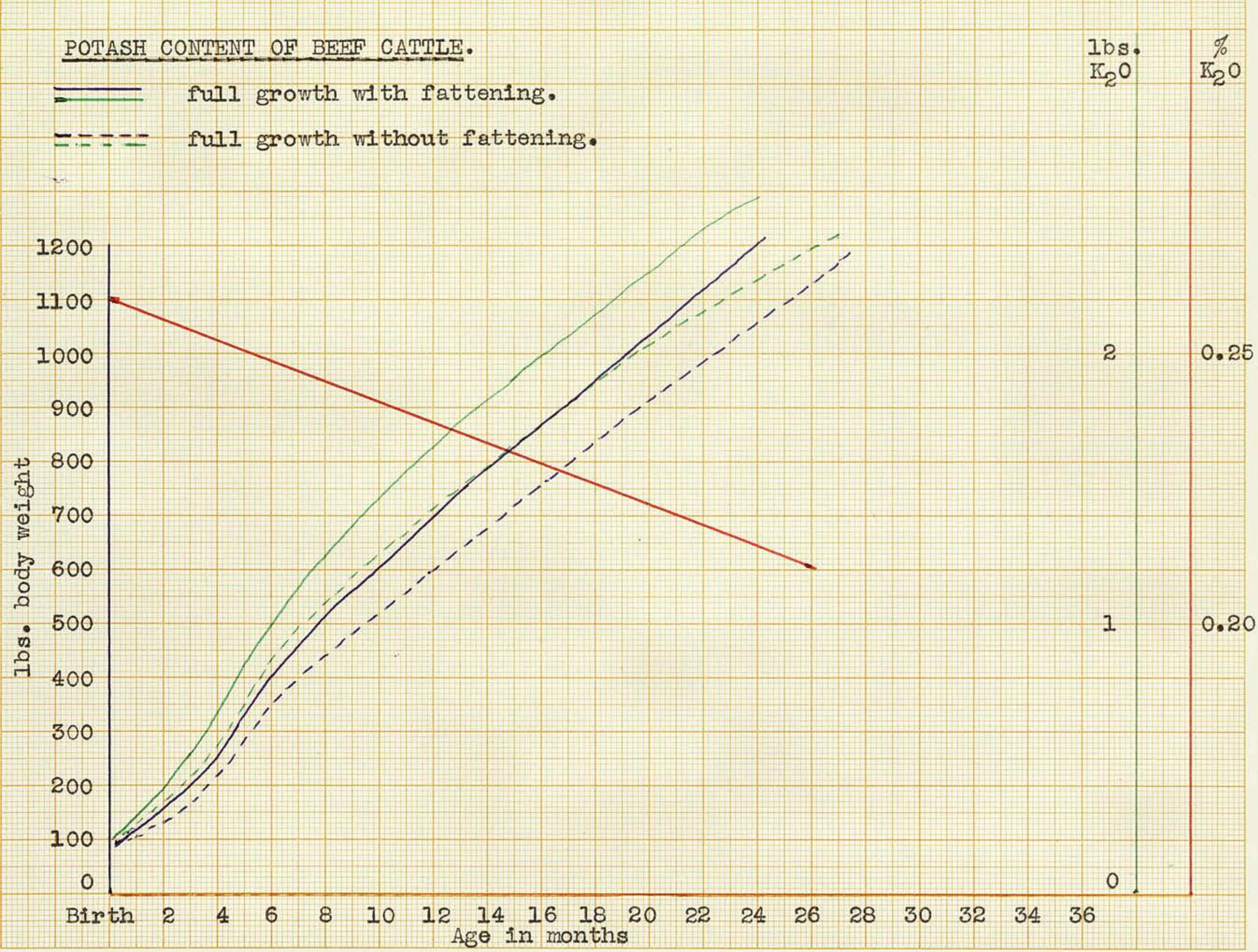

PHOSPHORIC ACID CONTENT OF BEEF CATTLE.
full growth with fattening.
full growth without fattening.
lbs. P_2O_5
20
10
0
% P_2O_5
2.0
1.5
1.0
lbs. body weight
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Birth 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
Age in months

POTASH CONTENT OF BEEF CATTLE.

Age mos.	K_2O%	Weight(a)	lbs.K_2O(a)	Weight(b)	lbs.K_2O(b)
0	0.260	80	0.208	80	0.208
3	0.254	200	0.508	170	0.432
6	0.248	400	0.992	350	0.868
9	0.243	560	1.360	480	1.170
12	0.237	700	1.660	600	1.420
15	0.231	830	1.920	720	1.660
18	0.225	950	2.140	840	1.890
21	0.220	1080	2.380	950	2.090
24	0.214	1200	2.570	1060	2.270
27	0.208	-	-	1170	2.440

(a) Full growth with fattening.

(b) Full growth without fattening.


POTASH CONTENT OF BEEF CATTLE.
full growth with fattening.
full growth without fattening.
lbs. body weight
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Birth 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
Age in months
lbs. K_2O
2
1
0
% K_2O
0.25
0.20

APPENDIX 2.(b) - - - Livestock. (sheep)

The following tables and graphs show the nitro-:gen, phosphoric acid and potash content of sheep. The types selected are medium breeds and crosses for mutton and as in the case of cattle, the relationship between body weight and age is approximate.

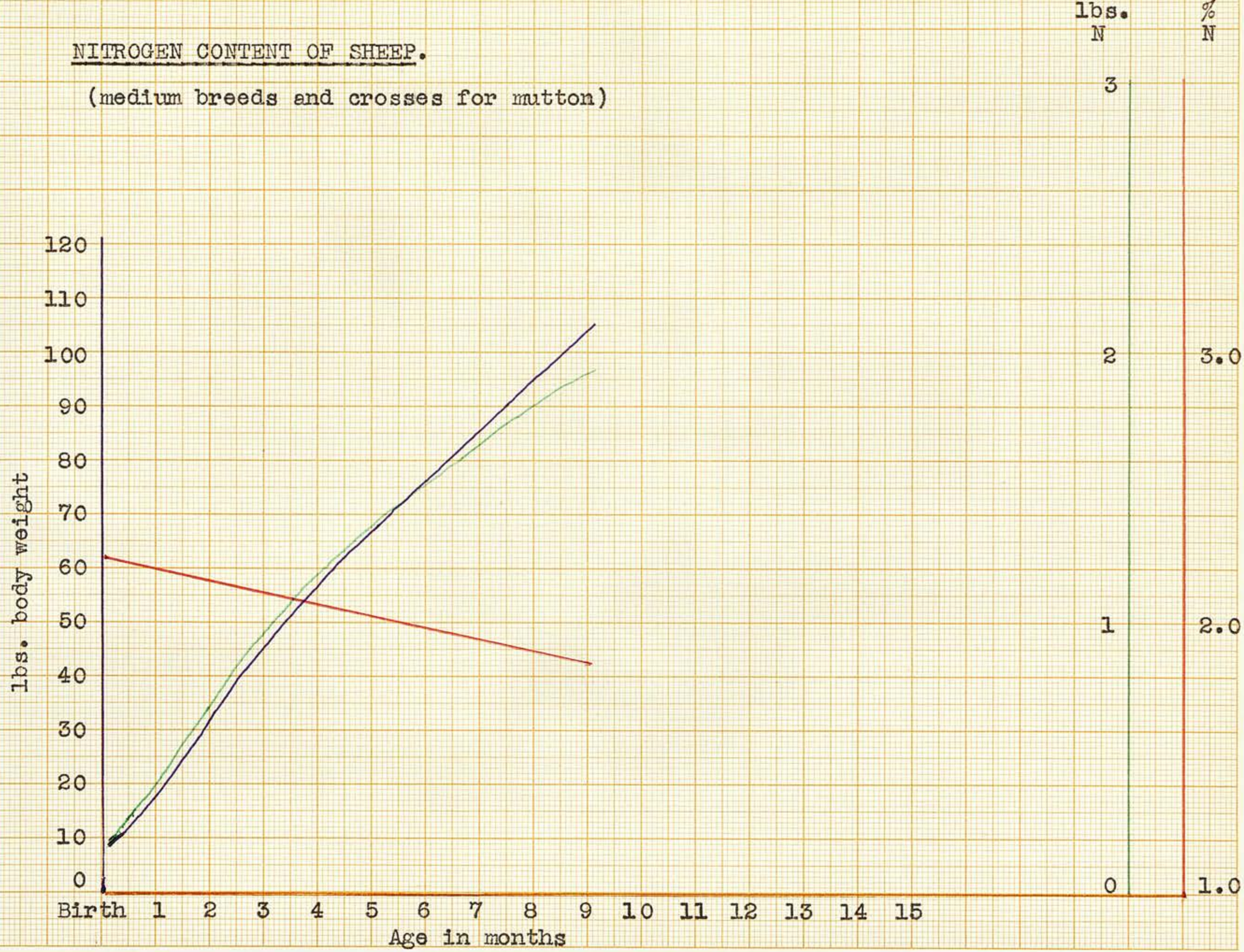
NITROGEN CONTENT OF SHEEP.

(medium breeds and crosses for mutton)

Age mos.	Weight lbs.	N%	Weight N lbs.
0	8	2.24	0.179
1	18	2.20	0.396
2	32	2.15	0.688
3	45	2.10	0.945
4	57	2.06	1.170
5	67	2.02	1.350
6	76	1.97	1.500
7	86	1.93	1.660
8	95	1.89	1.800
9	104	1.84	1.920

NITROGEN CONTENT OF SHEEP.

(medium breeds and crosses for mutton)



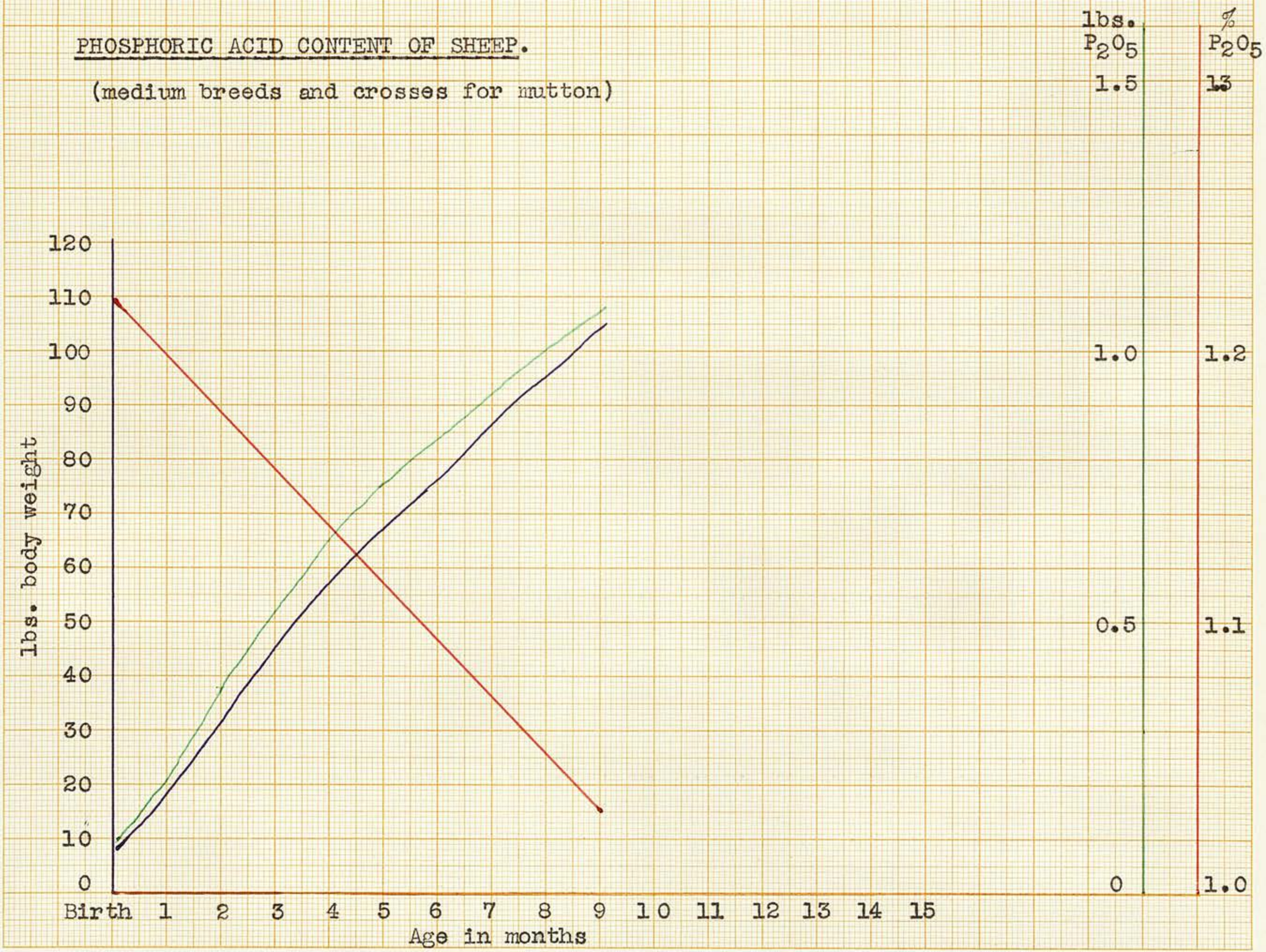
PHOSPHORIC ACID CONTENT OF SHEEP.

(medium breeds and crosses for mutton)

Age mos.	Weight lbs.	P_2O_5%	Weight P_2O_5 lbs.
0	8	1.22	0.098
1	18	1.20	0.216
2	32	1.18	0.378
3	45	1.16	0.522
4	57	1.14	0.650
5	67	1.12	0.750
6	76	1.09	0.830
7	86	1.07	0.920
8	95	1.05	1.000
9	104	1.03	1.070

PHOSPHORIC ACID CONTENT OF SHEEP.

(medium breeds and crosses for mutton)



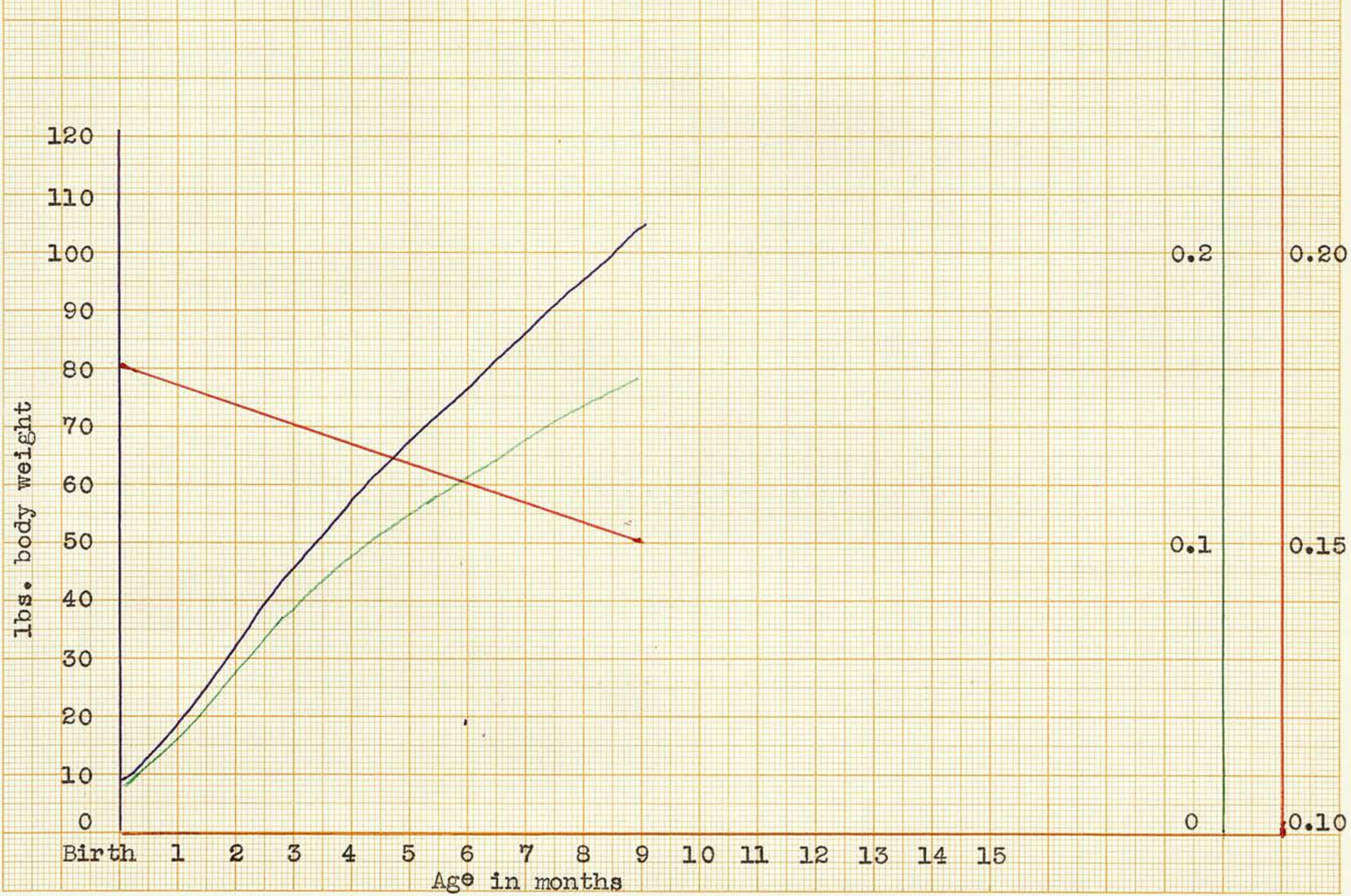
POTASH CONTENT OF SHEEP.

(medium breeds and crosses for mutton)

Age mos.	Weight lbs.	K_2O%	Weight K_2O lbs.
0	8	0.180	0.0144
1	18	0.177	0.0319
2	32	0.173	0.0554
3	45	0.170	0.0765
4	57	0.167	0.0952
5	67	0.163	0.1092
6	76	0.160	0.1217
7	86	0.157	0.1350
8	95	0.153	0.1454
9	104	0.150	0.1560

POTASH CONTENT OF SHEEP.

(medium breeds and crosses for mutton)



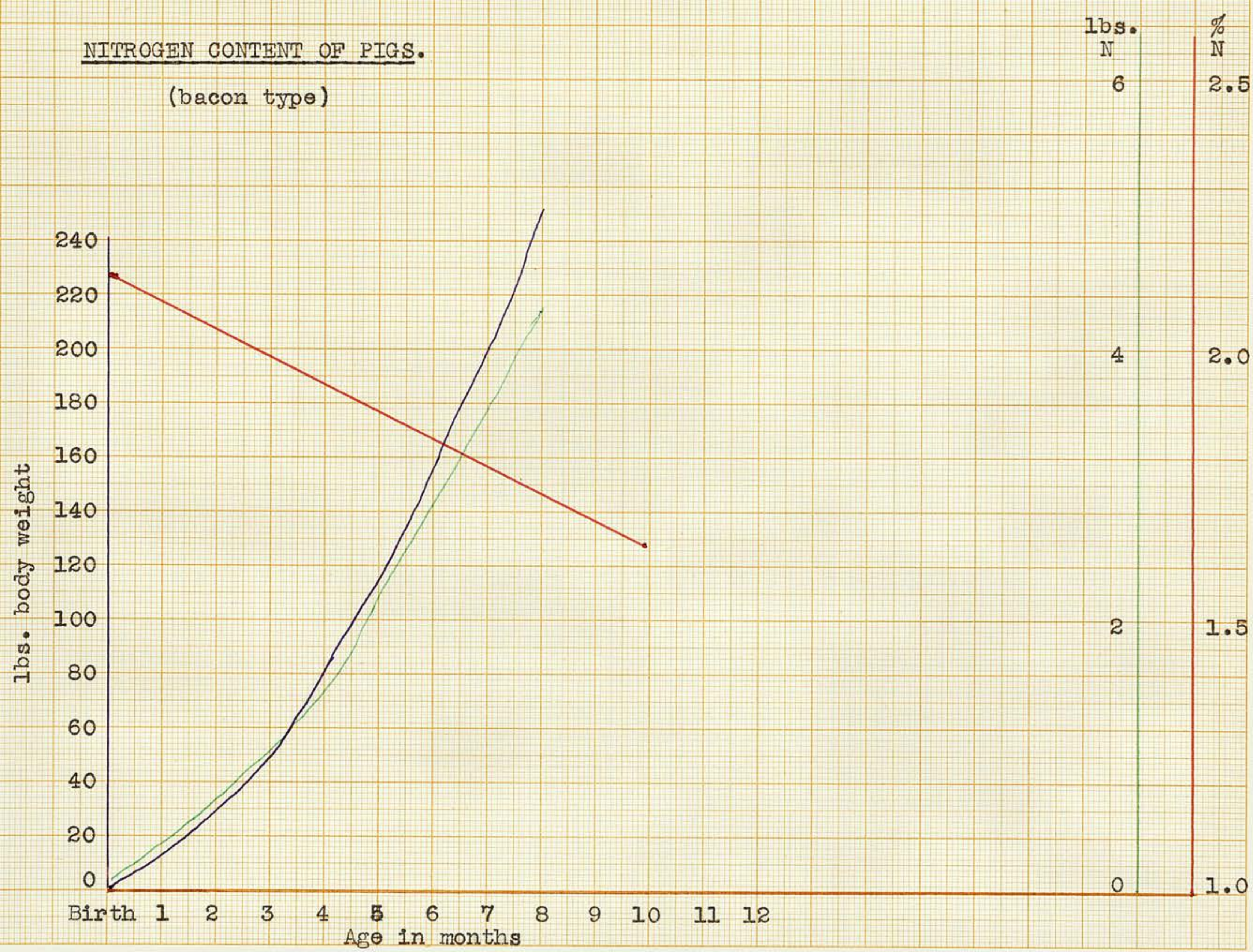
APPENDIX 2.(c) - - - Livestock. (pigs)

The following tables and graphs show the nitrogen, phosphoric acid and potash content of pigs. The data refers to pigs of bacon type and the relationship bet-:ween body weight and age is approximate.

NITROGEN CONTENT OF PIGS.

(bacon type)

Age mos.	Weight lbs.	N%	Weight N lbs.
0	3	2.14	0.064
1	14	2.09	0.239
2	32	2.04	0.650
3	50	1.99	0.995
4	80	1.94	1.550
5	115	1.89	2.180
6	155	1.84	2.850
7	200	1.79	3.580
8	245	1.74	4.250


NITROGEN CONTENT OF PIGS.
(bacon type)
lbs. body weight
240
220
200
180
160
140
120
100
80
60
40
20
0
Birth 1 2 3 4 5 6 7 8 9 10 11 12
Age in months
lbs. N
6
4
2
0
% N
2.5
2.0
1.5
1.0

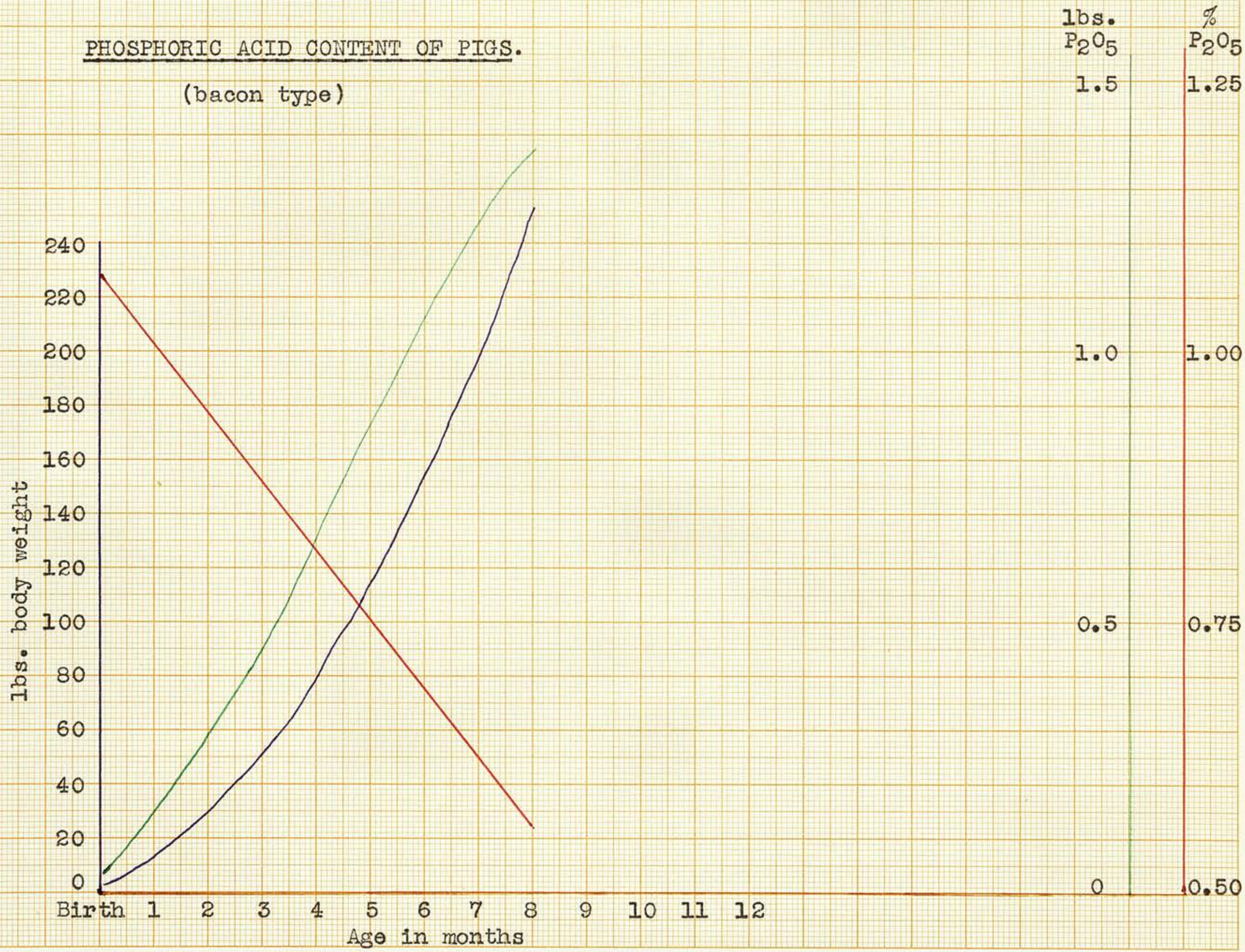
PHOSPHORIC ACID CONTENT OF PIGS.

(bacon type)

Age mos.	Weight lbs.	P_2O_5%	Weight P_2O_5 lbs.
0	3	1.07	0.032
1	14	1.01	0.141
2	32	0.94	0.300
3	50	0.88	0.440
4	80	0.82	0.655
5	115	0.75	0.860
6	155	0.69	1.070
7	200	0.62	1.240
8	245	0.56	1.370

PHOSPHORIC ACID CONTENT OF PIGS.

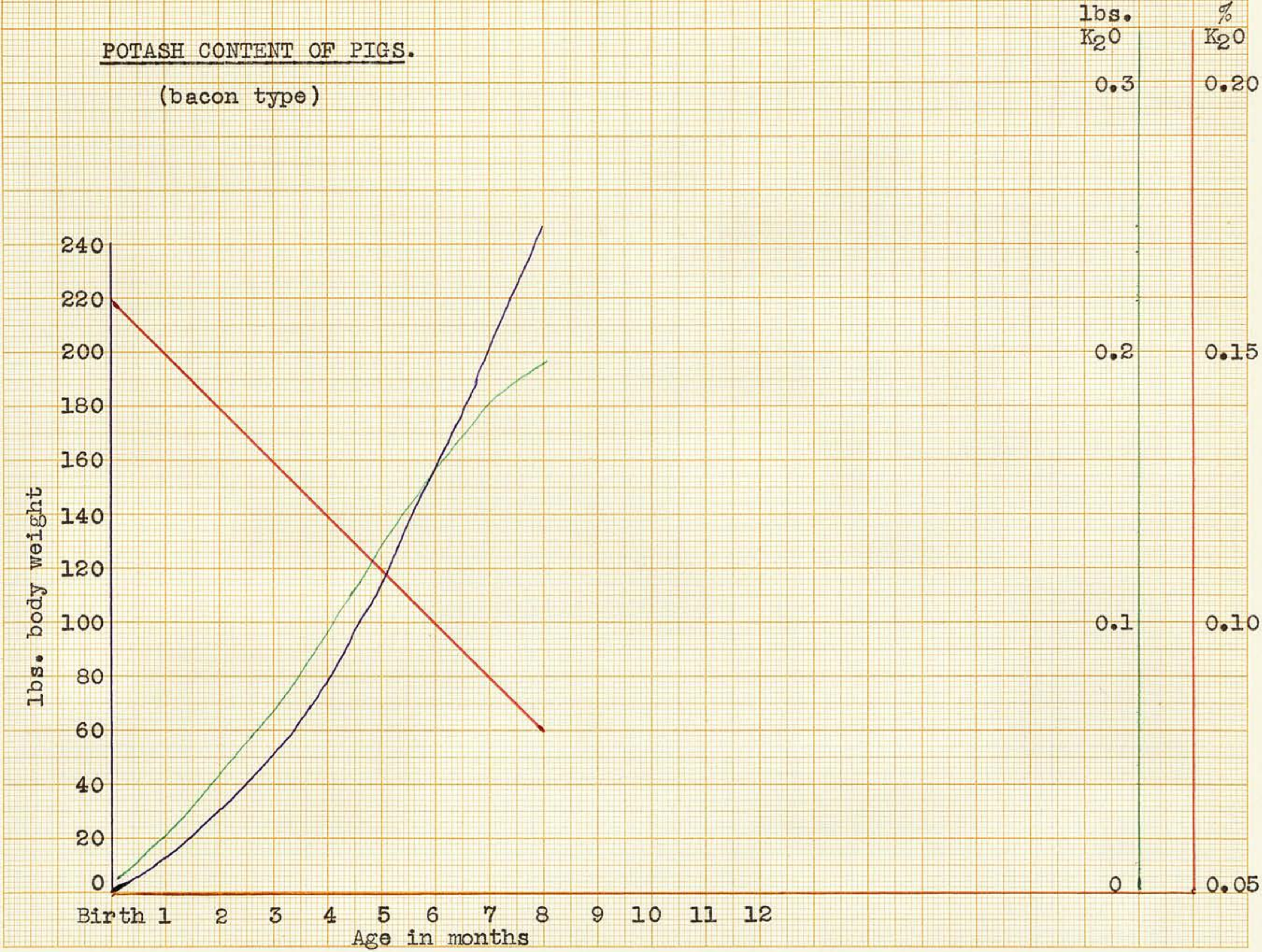
(bacon type)



POTASH CONTENT OF PIGS.

(bacon type)

Age in mos.	Weight lbs.	K_2O%	Weight K_2O lbs.
0	3	0.16	0.0048
1	14	0.15	0.0210
2	32	0.14	0.0450
3	50	0.13	0.0650
4	80	0.12	0.0960
5	115	0.11	0.1270
6	155	0.10	0.1550
7	200	0.09	0.1800
8	245	0.08	0.1960



POTASH CONTENT OF PIGS.
(bacon type)
lbs. K_2O
% K_2O
0.3
0.20
0.2
0.15
0.1
0.10
0
0.05
240
220
200
180
160
140
120
100
80
60
40
20
0
lbs. body weight
Birth 1 2 3 4 5 6 7 8 9 10 11 12
Age in months

200

APPENDIX 3. - - - Soils.

In the following twelve tables of soil analyses, the columns headed 'D%' show the corrected deviation from the arithmetic mean expressed as a percentage of the mean. Each 'D%' column gives the deviations for the results which appear in the preceding column. It is important to note however, that the deviations for L.I.% and pH have been multiplied by five.

In the following twelve graphs, colours are used to identify the curves:-

— — —	L.I.% deviation
———	L.I.% deviation x 5
— — —	pH deviation
———	pH deviation x 5
———	K_2O deviation
———	P_2O_5 deviation

FARM: L/1 (12 samples)

Field	L.I.%	D%	pH	D%	K_2O	D%	P_2O_5	D%
A	7.7	15	6.0	5	108	4	11	7
B	6.9	40	6.2	10	66	41	8	22
C	7.5	0	6.2	10	113	1	10	3
D	8.0	35	6.3	15	108	4	3	71
E	7.5	0	6.3	15	128	14	13	27
F	7.4	5	6.2	10	83	26	10	3
G	6.8	45	5.7	30	128	14	12	17
H	7.3	15	6.0	5	200	78	11	7
I	7.8	20	6.2	10	88	21	9	12
J	7.9	25	6.2	10	108	4	11	7
K	7.5	0	5.8	25	93	17	12	17
L	7.7	15	5.7	30	118	5	13	27

Mean L.I.% - - - 7.50

Mean pH - - - - 6.08

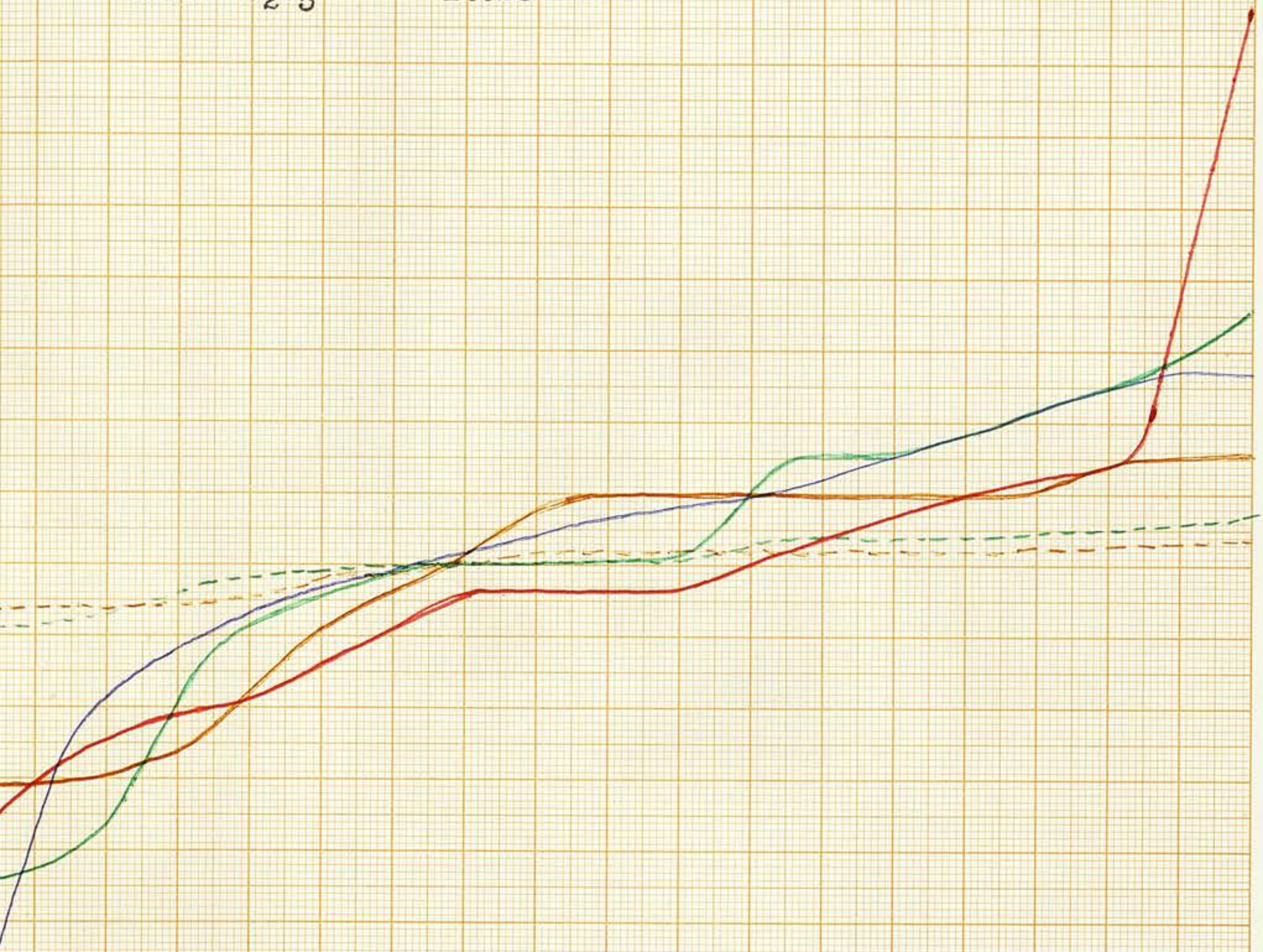
Mean K_2O - - - 112.00

Mean P_2O_5 - - - 10.25

Fertility Index - - 8,620

FARM: L/1

No. of samples - -	12
Mean L.I.%	7.50
Mean pH	6.08
Mean K_2O	112.00
Mean P_2O_5	10.25



Fertility Index: 8,620

FARM: L/5 (8 samples)

Field	L.I.%	D%	pH	D%	K_2O	D%	P_2O_5	D%
A	7.5	15	5.6	40	233	116	12	39
B	8.2	30	6.3	15	140	4	8	7
C	7.7	0	6.1	0	140	4	8	7
D	7.3	25	6.3	15	108	20	5	42
E	8.0	20	5.6	40	108	20	7	19
F	8.0	20	6.8	60	128	5	11	28
G	7.6	5	6.2	10	103	24	8	7
H	7.2	30	5.8	25	118	13	10	16

Mean L.I.% - - - 7.70

Mean pH - - - 6.10

Mean K_2O - - - 135.00

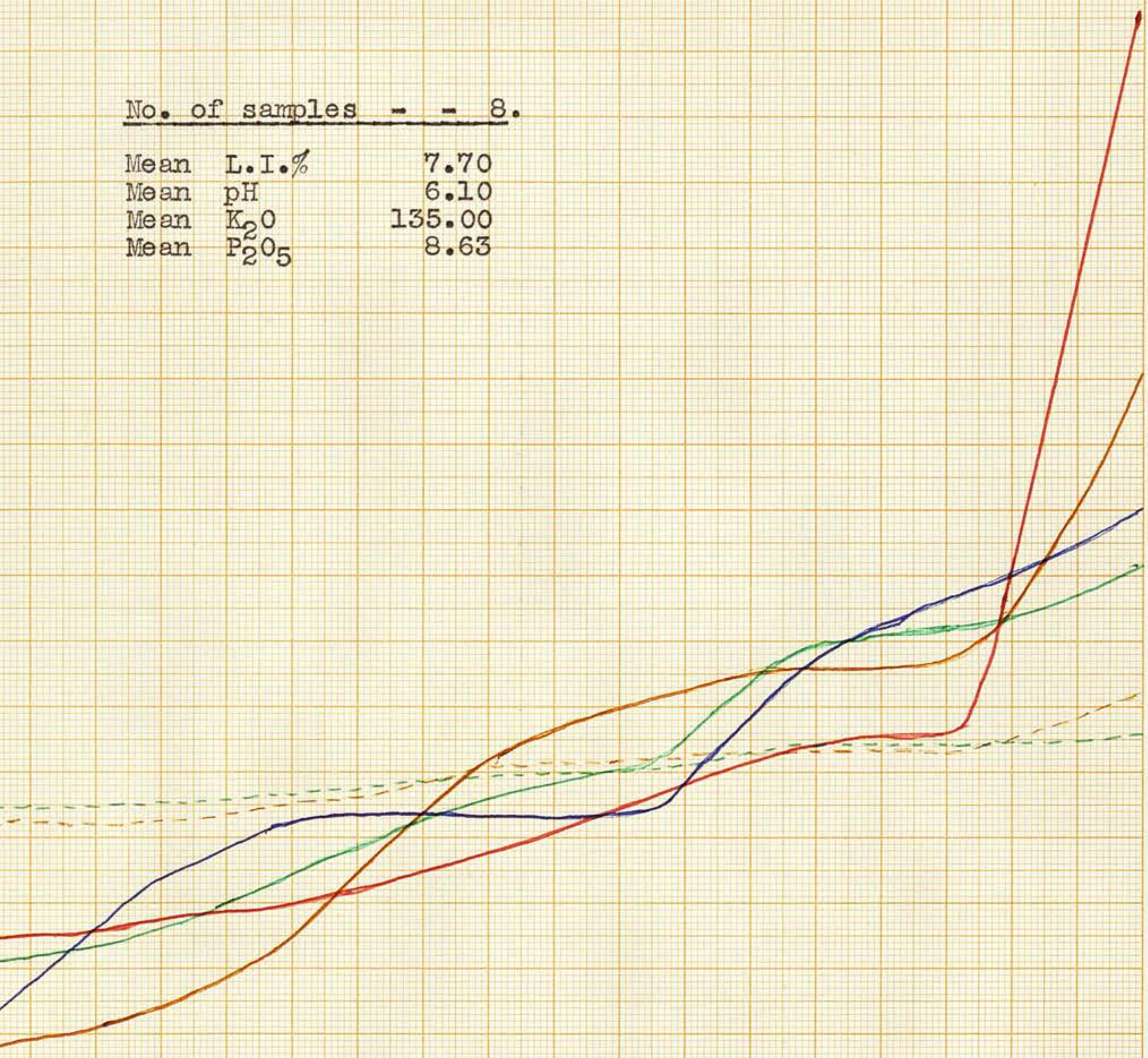
Mean P_2O_5 - - - 8.63

Fertility Index - - 8,960

FARM: L/5

No. of samples - - 8.

Mean L.I.%	7.70
Mean pH	6.10
Mean K_2O	135.00
Mean P_2O_5	8.63



Fertility Index: 8,960

FARM: L/7 (8 samples)

Field	L.I.%	D%	pH	D%	K_2O	D%	P_2O_5	D%
A	9.2	40	6.4	5	173	7	8	6
B	8.4	10	6.6	15	213	32	5	41
C	7.9	35	6.7	20	140	14	10	18
D	7.7	50	6.5	5	113	31	9	6
E	8.8	15	6.4	5	98	40	7	18
F	9.0	25	6.2	20	263	62	11	29
G	8.6	5	6.3	10	165	2	8	6
H	8.9	20	6.4	5	128	21	10	18

Mean L.I.% - - - 8.55

Mean pH - - - - 6.44

Mean K_2O - - - 162.00

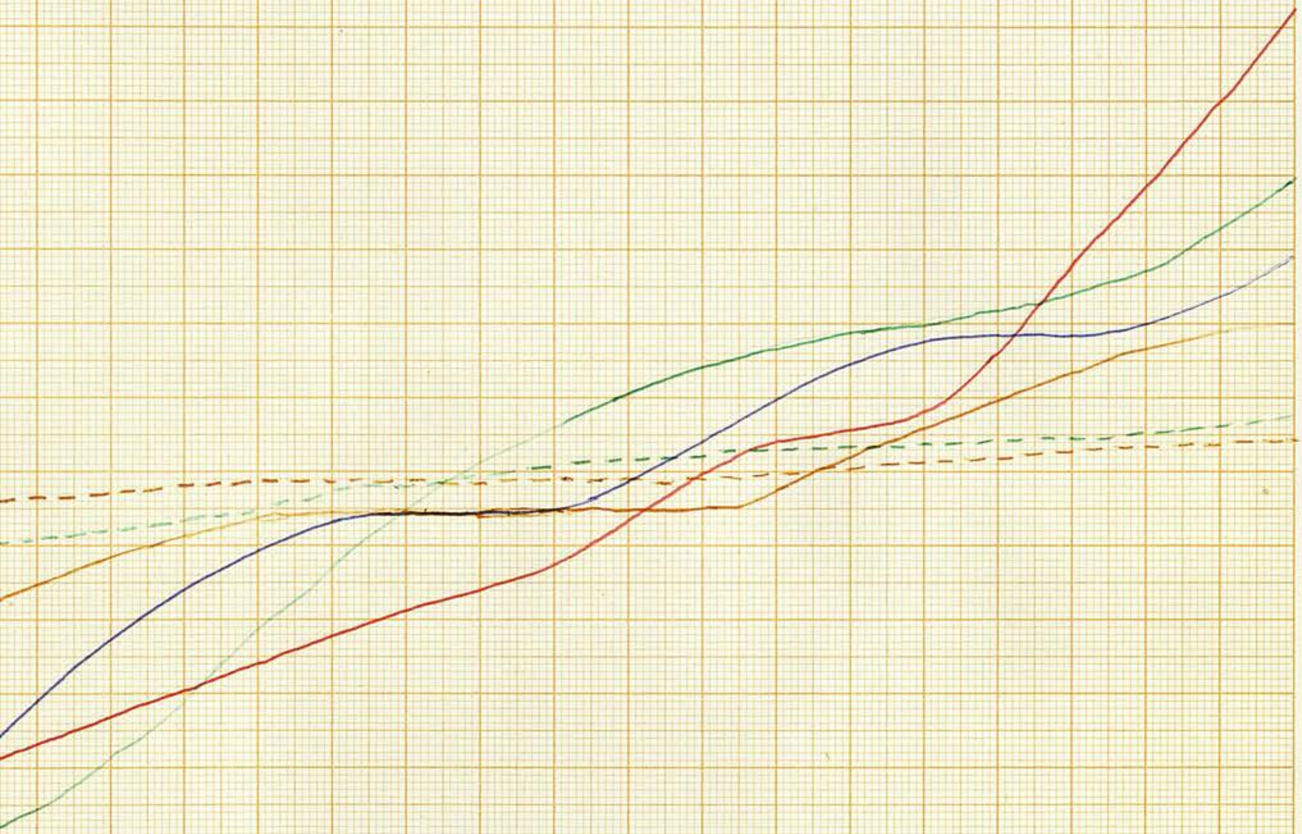
Mean P_2O_5 - - - 8.50

Fertility Index - - 11,790

FARM: L/7

No. of samples - - 8.

Mean	L.I.%	8.55
Mean	pH	6.44
Mean	K_2O	162.00
Mean	P_2O_5	8.50



Fertility Index: 11,790

FARM: L/8 (12 samples)

Field	L.I.%	D%	pH	D%	K_2O	D%	P_2O_5	D%
A	7.2	40	6.0	15	375	104	19	5
B	7.9	5	5.7	40	335	82	21	17
C	8.8	65	5.8	30	150	18	17	6
D	7.2	40	6.1	10	165	10	15	17
E	8.1	20	6.6	30	180	2	20	11
F	8.3	30	5.7	40	193	5	14	22
G	7.7	5	6.5	25	168	9	22	22
H	7.3	30	6.7	40	88	52	17	6
I	8.9	70	6.1	10	78	58	12	33
J	7.5	20	6.6	30	140	24	22	22
K	6.9	60	6.3	5	150	18	14	22
L	7.2	40	6.8	50	193	5	22	22

Mean L.I.% - - - 7.75

Mean pH - - - 6.24

Mean K_2O - - - 184.00

Mean P_2O_5 - - - 17.90

Fertility Index - - 25,500

FARM: L/8

No. of samples - - 12.

Mean L.I.%	7.75
Mean pH	6.24
Mean K_2O	184.00
Mean P_2O_5	17.90

Fertility Index: 25,500

FARM: L/9 (8 samples)

Field	L.I.%	D%	pH	D%	K_2O	D%	P_2O_5	D%
A	8.0	15	6.3	10	78	18	16	12
B	8.6	20	6.7	40	60	37	18	1
C	8.2	5	6.1	10	50	47	9	50
D	7.9	20	6.1	10	66	30	22	22
E	8.3	5	6.2	0	93	2	22	22
F	8.7	25	6.2	0	108	14	17	6
G	8.2	5	6.4	15	103	8	25	38
H	7.9	20	5.7	40	200	110	16	12

Mean L.I.% - - - 8.25

Mean pH - - - 6.20

Mean K_2O - - - 95.00

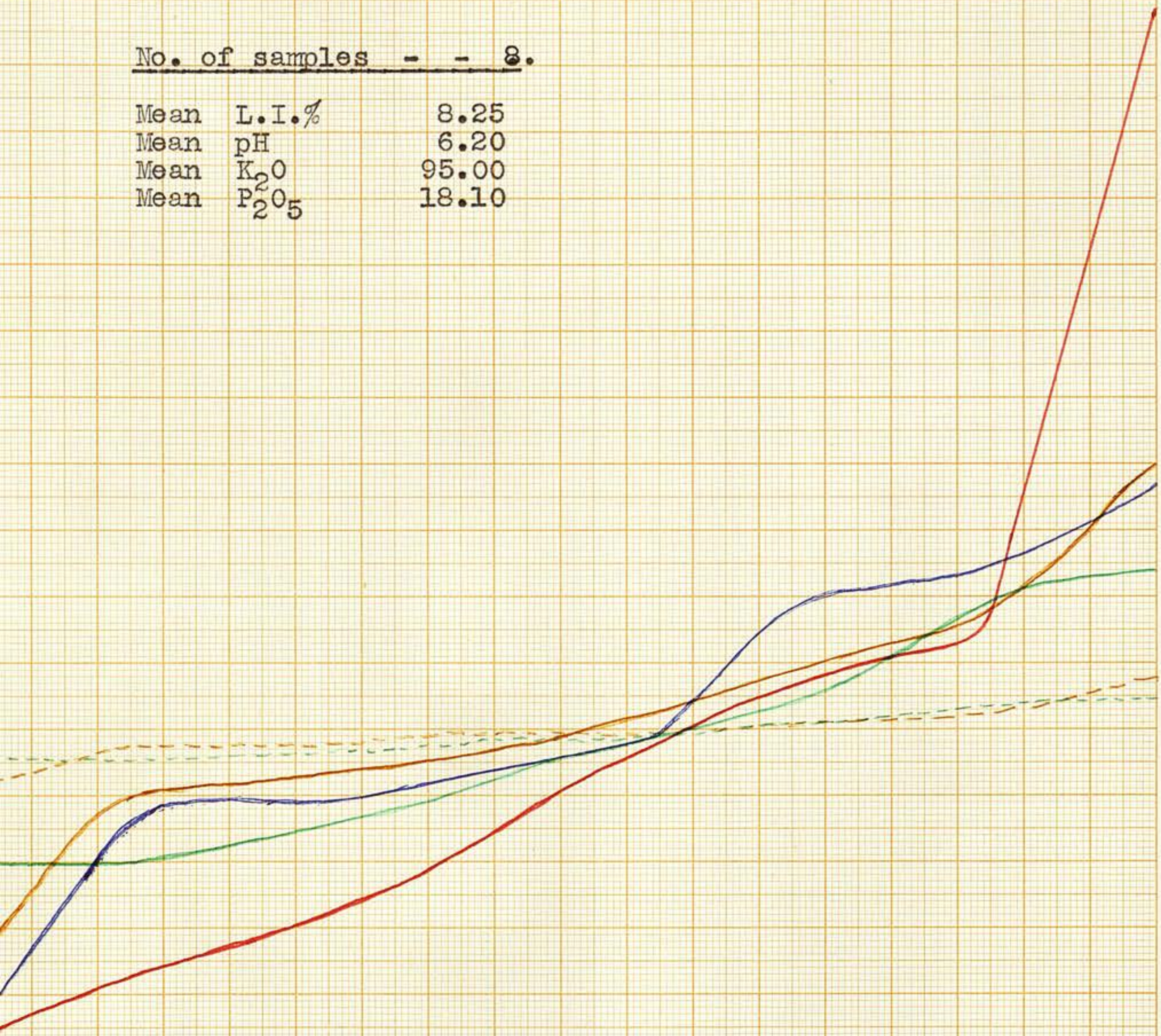
Mean P_2O_5 - - - 18.10

Fertility Index - - 14,180

FARM: L/9

No. of samples - - 8.

Mean	L.I.%	8.25
Mean	pH	6.20
Mean	K_2O	95.00
Mean	P_2O_5	18.10



Fertility Index: 14,180

FARM: L/15 (11 samples)

Field	L.I.%	D%	pH	D%	K_2O	D%	P_2O_5	D%
A	9.5	50	6.5	5	98	34	5	44
B	8.9	15	6.4	0	365	145	8	11
C	9.3	40	6.1	25	165	11	9	0
D	8.4	15	6.4	0	93	38	9	0
E	7.9	45	6.4	0	98	34	8	11
F	8.5	10	6.8	30	108	28	12	33
G	9.0	20	6.6	15	128	14	9	0
H	8.7	5	6.6	15	103	31	9	0
I	7.7	55	6.5	5	128	14	11	22
J	8.5	10	6.4	0	140	6	7	22
K	8.8	10	5.9	40	213	43	12	33

Mean L.I.% - - - 8.65

Mean pH - - - - 6.42

Mean K_2O - - - 149.00

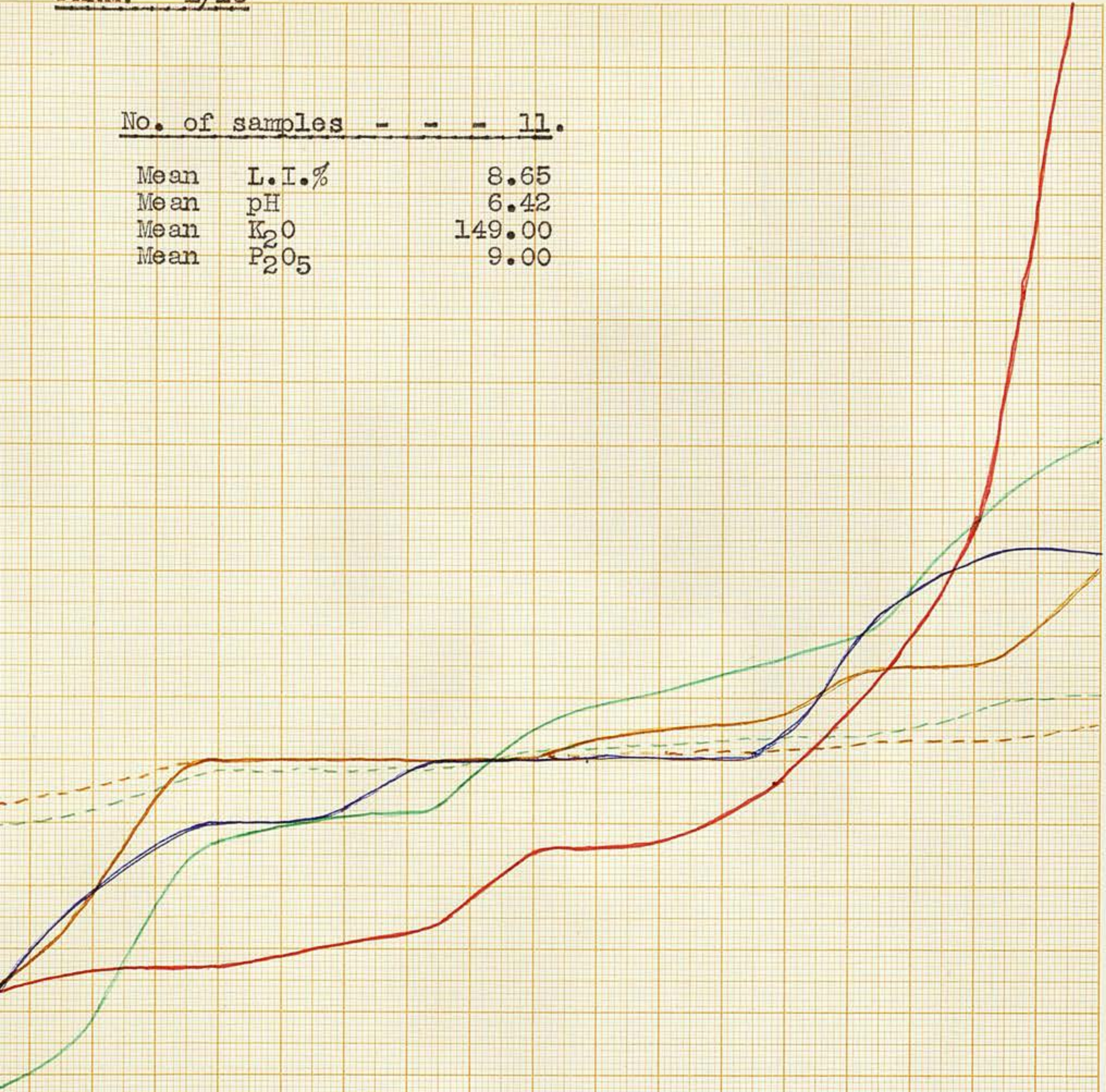
Mean P_2O_5 - - - 9.00

Fertility Index - - 11,600

FARM: L/15

No. of samples - - - 11.

Mean	L.I.%	8.65
Mean	pH	6.42
Mean	K_2O	149.00
Mean	P_2O_5	9.00



Fertility Index: 11,600

FARM: L/16 (9 samples)

Field	L.I.%	D%	pH	D%	K_2O	D%	P_2O_5	D%
A	7.5	50	6.5	10	128	6	10	23
B	8.2	5	6.4	15	113	17	7	14
C	7.9	25	6.4	15	263	93	8	1
D	8.6	20	6.8	15	165	21	12	48
E	8.3	0	6.7	10	173	27	8	1
F	9.2	55	6.7	10	83	39	5	38
G	8.7	25	6.7	10	103	24	5	38
H	7.9	25	6.6	0	118	13	8	1
I	8.4	5	6.5	5	78	42	10	23

Mean L.I.% - - - 8.30

Mean pH - - - - 6.59

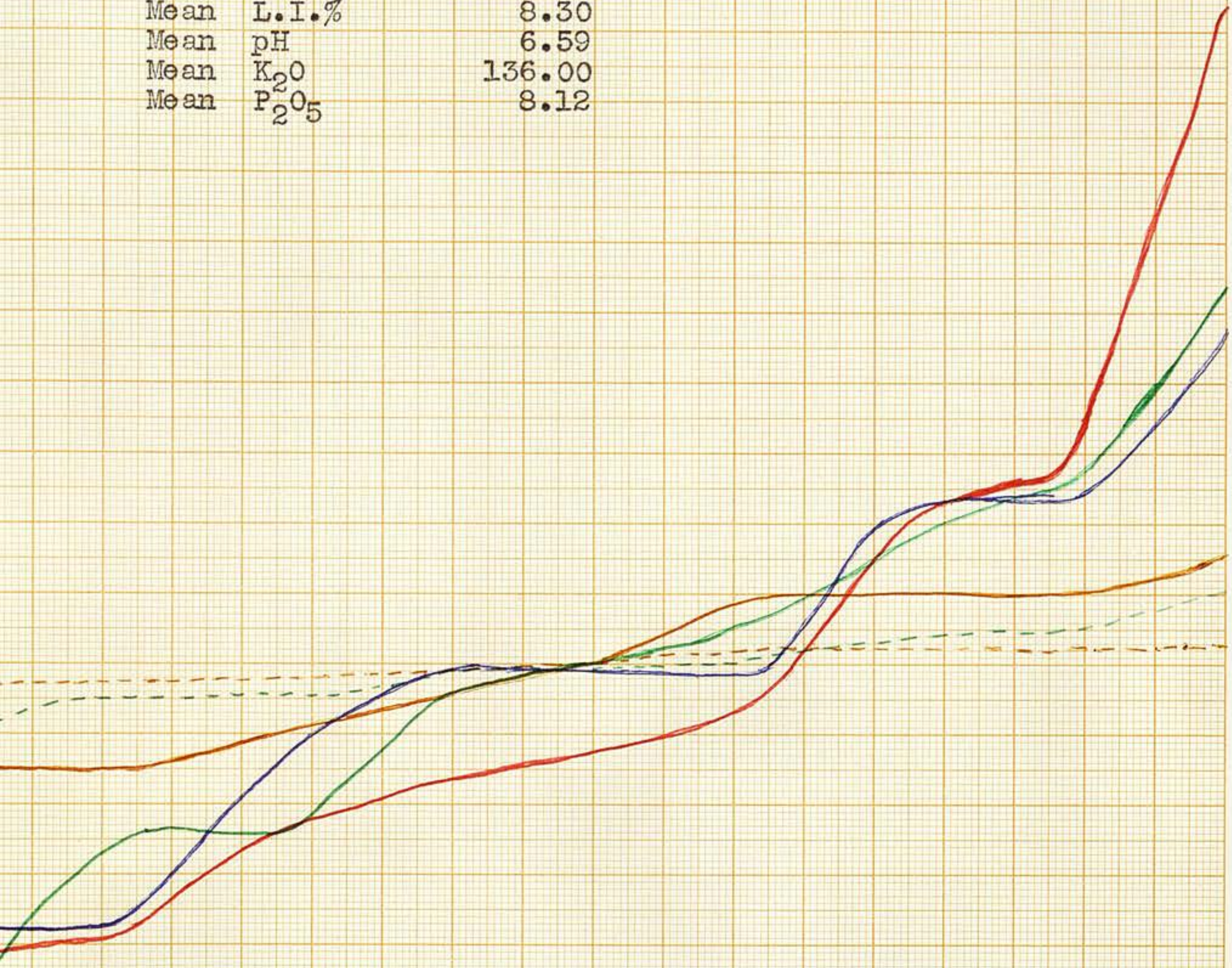
Mean K_2O - - - 136.00

Mean P_2O_5 - - - 8.12

Fertility Index - - 9,160

FARM: L/16

No. of samples - -	9.
Mean L.I.%	8.30
Mean pH	6.59
Mean K_2O	136.00
Mean P_2O_5	8.12



Fertility Index: 9,160

FARM: L/20 (8 samples)

Field	L.I.%	D%	pH	D%	K_2O	D%	P_2O_5	D%
A	6.9	15	6.5	15	168	8	7	24
B	7.4	20	6.5	15	98	37	6	35
C	6.8	20	6.3	0	185	19	9	3
D	7.1	0	6.1	15	145	7	13	41
E	7.5	30	6.4	10	140	10	9	3
F	7.0	5	6.2	10	165	6	9	3
G	7.3	15	6.3	0	165	6	9	3
H	6.8	20	6.0	25	185	19	12	30

Mean L.I.% - - - 7.10

Mean pH - - - - 6.30

Mean K_2O - - - 156.00

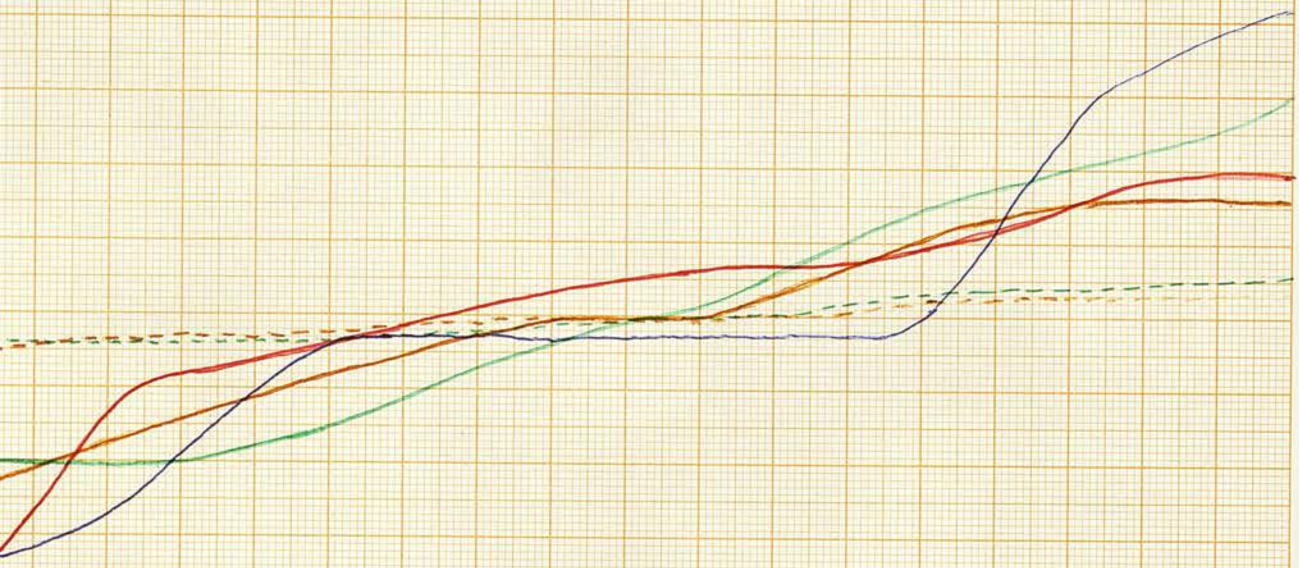
Mean P_2O_5 - - - 9.25

Fertility Index - - 10,250

FARM: L/20

No. of samples - - 8.

Mean	L.I.%	7.10
Mean	pH	6.30
Mean	K_2O	156.00
Mean	P_2O_5	9.25



Fertility Index: 10,250

FARM: L/21 (9 samples)

Field	L.I.%	D%	pH	D%	K_2O	D%	P_2O_5	D%
A	7.1	20	6.5	30	63	57	5	41
B	7.7	20	5.8	30	140	5	6	29
C	6.6	55	5.5	55	260	77	14	66
D	8.3	60	6.0	10	240	63	7	17
E	6.9	35	6.3	10	60	59	11	30
F	6.9	35	6.2	5	175	19	5	41
G	7.4	0	6.1	5	88	40	6	29
H	7.3	5	6.7	45	78	47	5	41
I	8.3	60	6.3	10	225	53	17	100

Mean L.I.% - - - 7.38

Mean pH - - - - 6.15

Mean K_2O - - - 147.00

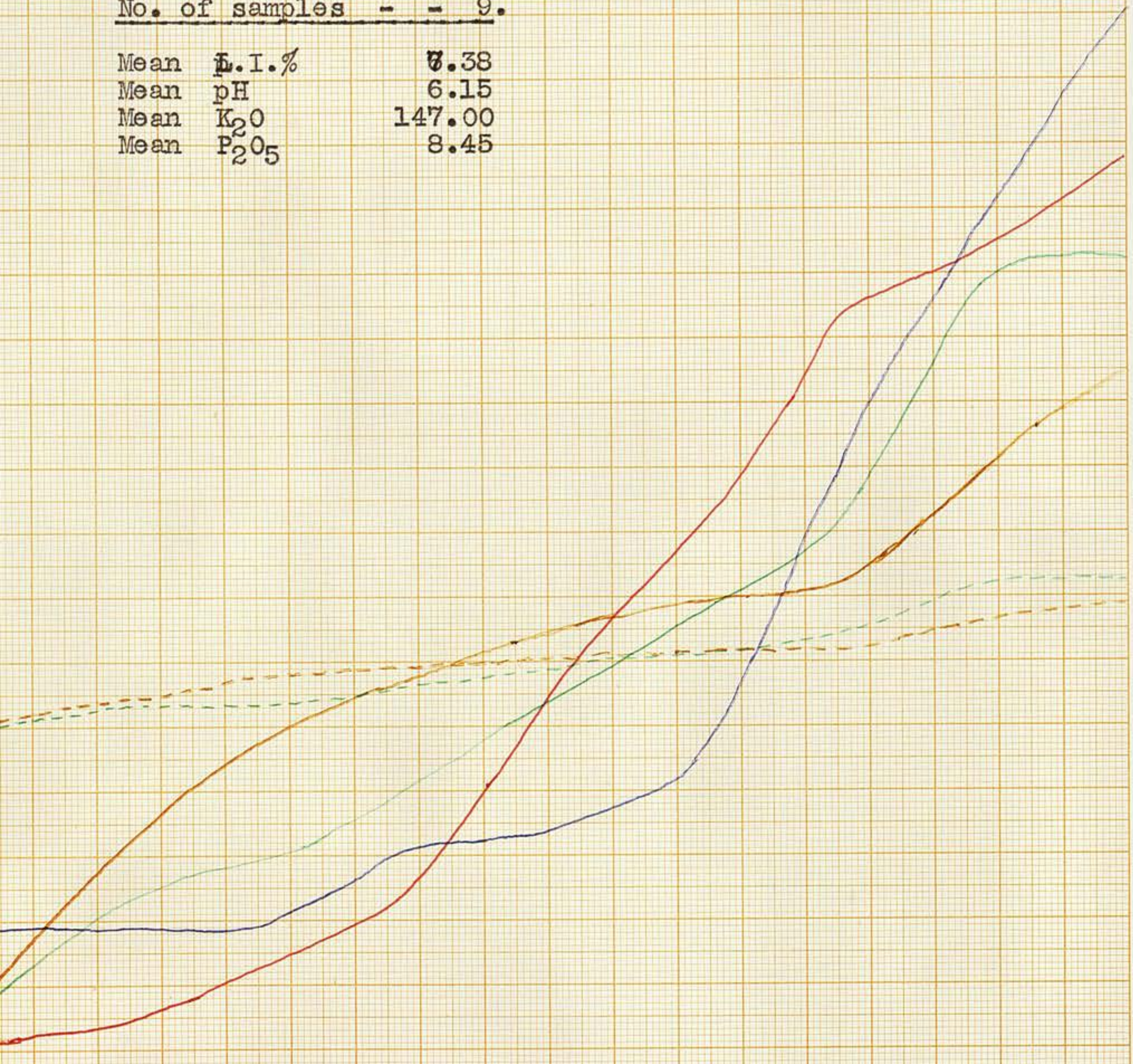
Mean P_2O_5 - - - 8.45

Fertility Index - - 9,180

FARM: L/21

No. of samples - - 9.

Mean L.I.%	7.38
Mean pH	6.15
Mean K_2O	147.00
Mean P_2O_5	8.45



Fertility Index: 9,180

FARM: L/23 (10 samples)

Field	L.I.%	D%	pH	D%	K_2O	D%	P_2O_5	D%
A	8.0	35	6.0	10	193	41	6	5
B	8.7	5	6.0	10	383	180	8	40
C	9.1	30	6.1	20	140	2	3	47
D	8.3	20	6.3	35	140	2	6	5
E	8.9	20	6.2	25	113	17	9	58
F	9.2	15	5.7	15	73	47	5	12
G	8.4	10	5.8	10	98	28	7	23
H	8.7	5	5.6	25	60	56	4	30
I	7.9	40	5.7	15	66	52	5	12
J	8.5	5	5.9	0	108	21	4	30

Mean L.I.% - - - 8.60

Mean pH - - - - 5.90

Mean K_2O - - - - 137.00

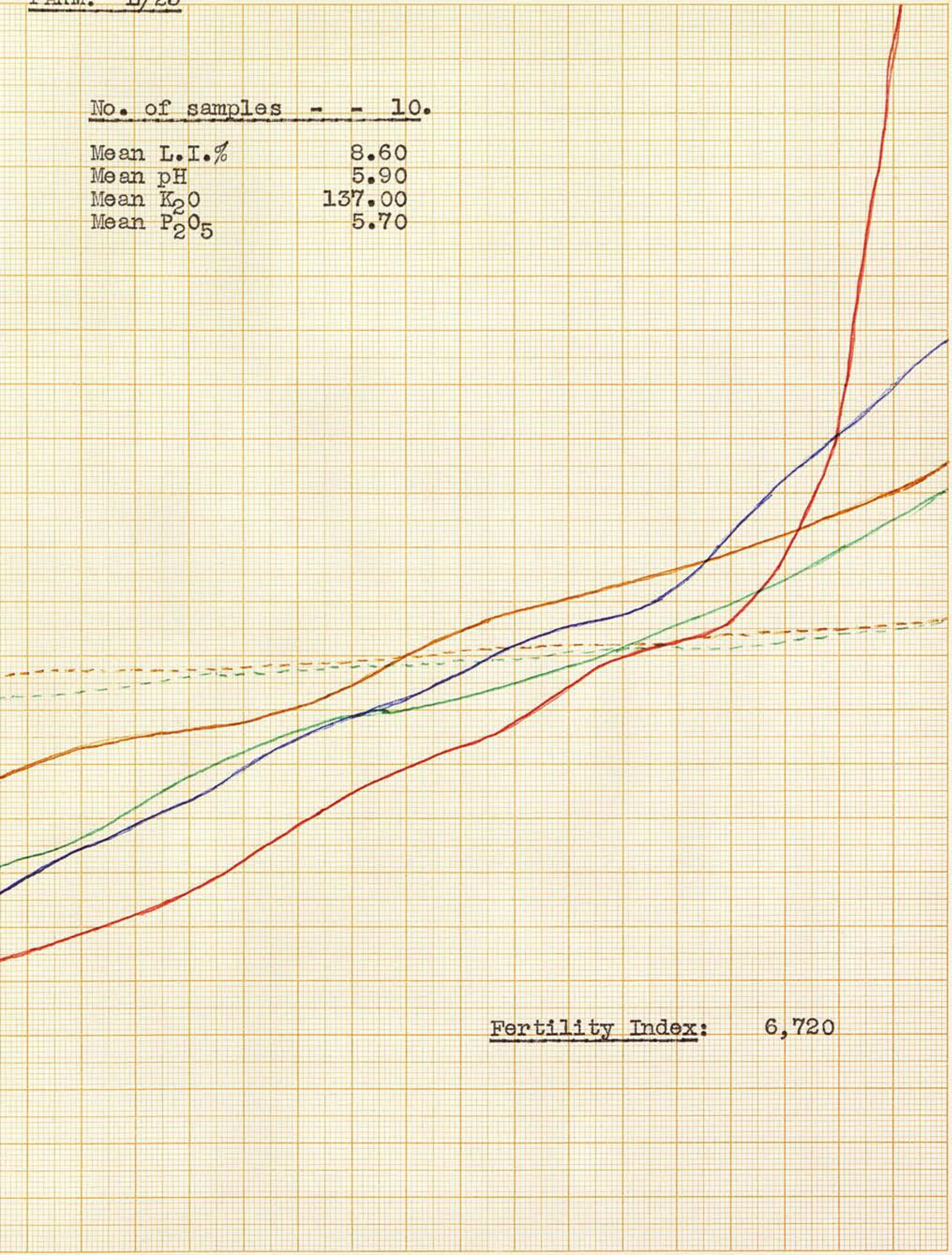
Mean P_2O_5 - - - 5.70

Fertility Index - - 6,720

FARM: L/23

No. of samples - - 10.

Mean L.I.%	8.60
Mean pH	5.90
Mean K_2O	137.00
Mean P_2O_5	5.70



Fertility Index: 6,720

FARM: L/24 (7 samples)

Field	L.I.%	D%	pH	D%	K_2O	D%	P_2O_5	D%
A	8.2	10	5.2	50	175	44	6	24
B	7.7	20	5.8	0	140	16	6	24
C	8.1	5	6.2	35	118	2	11	40
D	8.0	0	5.8	0	98	19	8	2
E	7.4	40	6.0	15	128	6	8	2
F	8.5	30	5.9	10	108	11	8	2
G	7.9	45	5.8	0	78	35	8	2

Mean L.I.% - - - 8.00

Mean pH - - - - 5.80

Mean K_2O - - - 121.00

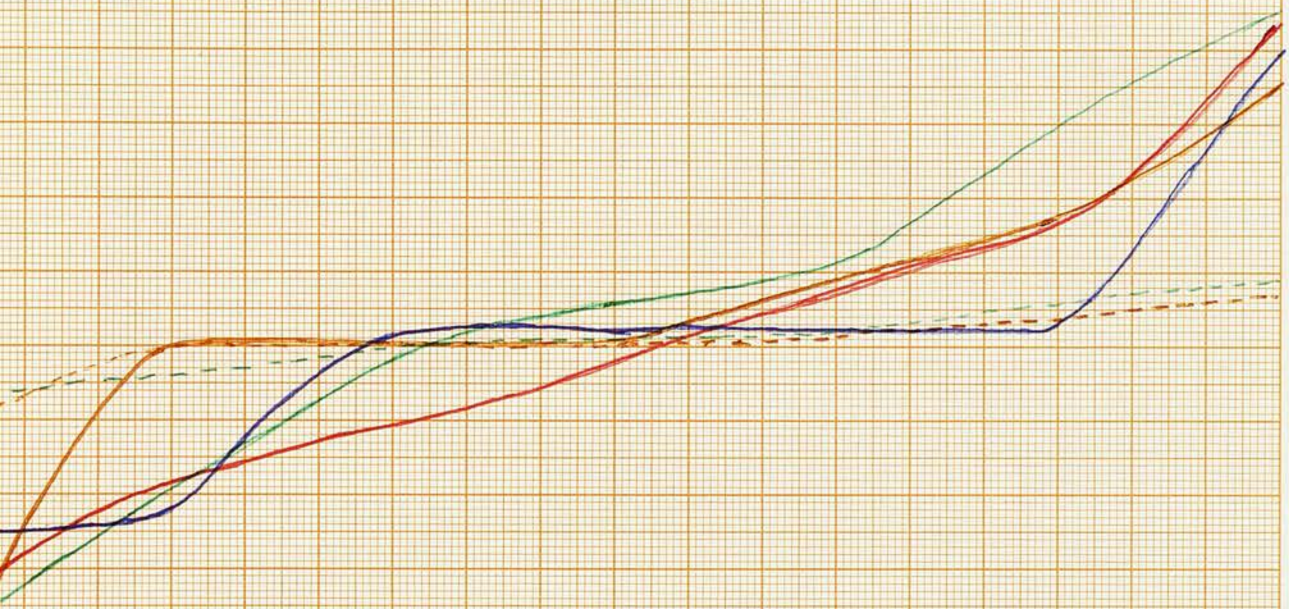
Mean P_2O_5 - - - 7.85

Fertility Index - - 7,600

FARM: L/24

No. of samples - - 7.

Mean	L.I.%	8.00
Mean	pH	5.80
Mean	K_2O	121.00
Mean	P_2O_5	7.85



Fertility Index: 7,600

FARM: L/25 (11 samples)

Field	L.I.%	D%	pH	D%	K_2O	D%	P_2O_5	D%
A	9.1	40	5.6	50	140	16	9	10
B	8.6	10	5.8	35	140	16	6	25
C	8.3	5	6.0	15	260	56	8	0
D	8.9	30	6.2	0	193	15	8	0
E	7.8	35	7.0	65	145	13	12	50
F	8.4	0	6.5	25	260	56	10	25
G	9.3	55	6.3	5	88	47	8	0
H	8.5	5	6.4	15	260	56	7	13
I	7.9	30	6.2	0	73	56	5	38
J	7.7	40	6.0	15	150	10	10	25
K	8.2	10	6.2	0	128	23	7	13

Mean L.I.% - - - 8.40

Mean pH - - - 6.20

Mean K_2O - - - 167.00

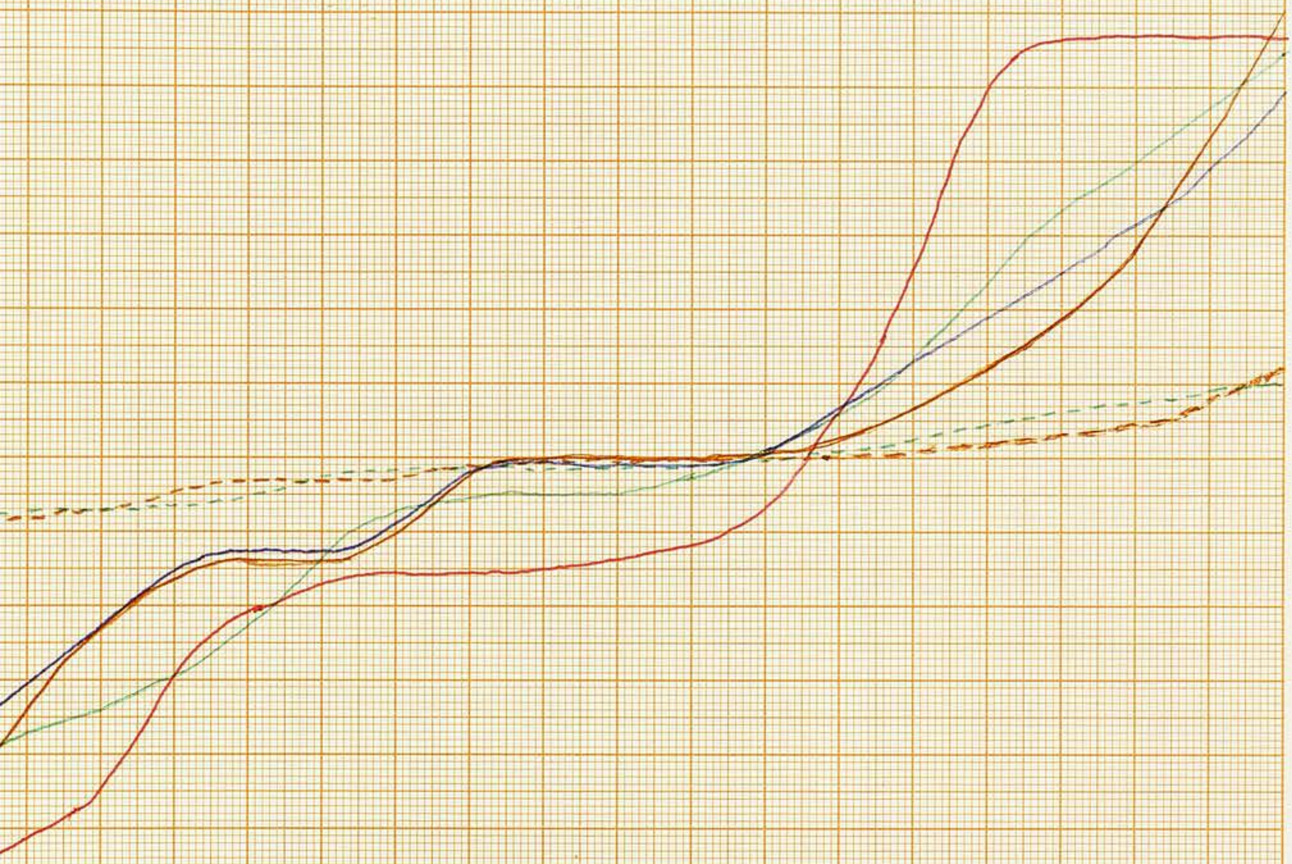
Mean P_2O_5 - - - 8.17

Fertility Index - - 11,450

FARM: L/25

No.of samples - - 11.

Mean L.I.%	8.40
Mean pH	6.20
Mean K_2O	167.00
Mean P_2O_5	8.17



Fertility Index: 11,450

APPENDIX 4(a) - - - Soils.(main)

The following tables show the results of analysis of samples from the main experiment at Dunragit.

FARM: D/1 (9 samples)

Field	L.I.%	pH	K_2O	P_2O_5
A	7.2	5.6	108	4
B	7.6	5.7	128	2
C	7.0	5.6	150	11
D	7.5	5.3	168	18
E	6.8	5.6	173	20
F	7.3	6.0	88	17
G	7.3	5.9	108	15
H	7.7	5.9	98	13
I	6.9	5.9	140	14

Mean L.I.% - - 7.2

Mean pH - - 5.7

Mean K_2O - - 129

Mean P_2O_5 - - 13

Fertility Index - 12,074

FARM: D/2 (11 samples)

Field	L.I.%	pH	K_2O	P_2O_5
A	9.3	5.2	173	3
B	8.6	5.3	240	9
C	8.8	5.5	365	10
D	8.1	5.5	260	10
E	7.5	4.9	343	8
F	7.7	5.0	445	10
G	8.1	5.6	165	4
H	7.4	5.5	150	7
I	7.9	5.4	98	7
J	8.3	5.4	118	6
K	8.1	5.6	118	5

Mean L.I.% - - 8.2

Mean pH - - 5.4

Mean K_2O - - 225

Mean P_2O_5 - - 7

Fertility Index - 12,900

FARM: D/3 (9 samples)

Field	L.I.%	pH	K_2O	P_2O_5
A	8.2	6.0	185	5
B	9.4	5.8	165	6
C	8.7	5.5	145	5
D	7.5	5.7	173	9
E	7.1	5.7	260	4
F	8.0	5.8	518	6
G	7.3	5.8	213	13
H	8.2	5.9	108	12
I	8.4	6.0	140	9

Mean L.I.%	- -	8.1
Mean pH	- -	5.8
Mean K_2O	- -	212
Mean P_2O_5	- -	8
Fertility Index	-	13,736

FARM: P/6 (9 samples)

Field	L.I.%	pH	K_2O	P_2O_5
A	8.4	6.0	343	11
B	9.2	5.1	185	6
C	8.3	5.5	108	8
D	7.9	6.0	218	9
E	7.7	6.2	225	8
F	8.6	6.2	173	13
G	7.8	6.2	78	11
H	8.5	5.7	165	10

Mean L.I.% - - 8.4

Mean pH - - 5.8

Mean K_2O - - 195

Mean P_2O_5 - - 9

Fertility Index - 14,740

FARM: B/1 (9 samples)

Field	L.I.%	pH	K_2O	P_2O_5
A	8.2	6.2	408	13
B	7.4	6.0	300	11
C	7.8	5.9	283	10
D	6.9	5.3	185	3
E	7.5	5.4	328	9
F	8.1	5.6	263	6
G	9.0	6.2	173	4
H	8.6	5.8	165	3
I	7.9	5.3	173	7

Mean L.I.% - -	7.9
Mean pH - -	5.7
Mean K_2O - -	253
Mean P_2O_5 - -	7
Fertility Index -	13,990

APPENDIX 4(b). - - - Soils(main).

The following tables show the result of analysis of soil samples from the main experiment at Carse of Stirling.

FARM: C/1 (10 samples)

Field	L.I.%	pH	K_2O	P_2O_5
A	9.2	6.0	260	4
B	9.6	5.8	218	3
C	11.0	6.0	240	3
D	10.3	5.7	253	3
E	9.4	5.9	185	5
F	9.7	6.1	275	4
G	9.3	5.8	200	3
vH	10.1	6.2	240	6
I	9.6	6.0	173	7
J	9.7	5.9	213	3

Mean L.I.% - -	9.8
Mean pH - -	5.9
Mean K_2O - -	226
Mean P_2O_5 - -	4
Fertility Index -	8,850

FARM: C/2 (12 samples)

Field	L.I.%	pH	K_2O	P_2O_5
A	8.7	6.6	218	7
B	7.6	5.9	173	3
C	8.0	6.5	320	5
D	6.9	6.3	200	3
E	7.4	6.5	185	6
F	7.9	7.4	263	34
G	8.3	6.5	165	4
H	7.6	6.9	185	8
I	9.0	6.9	200	14
J	8.6	6.8	173	5
K	7.8	6.9	213	7
L	8.4	6.3	240	6

Mean L.I.% - - 8.0

Mean pH - - 6.6

Mean K_2O - - 211

Mean P_2O_5 - - 9

Fertility Index - 15,190

FARM: C/3 (8 samples)

Field	L.I.%	pH	K_2O	P_2O_5
A	7.6	6.3	260	4
B	8.0	6.5	253	2
C	7.8	5.9	120	3
D	7.4	5.8	168	6
E	6.9	7.0	150	4
F	9.2	6.0	200	14
G	7.0	5.9	213	5
H	6.9	6.1	150	3

Mean L.I.%	- -	7.6
Mean pH	- -	6.2
Mean K_2O	- -	189
Mean P_2O_5	- -	5
Fertility Index	-	7,180

FARM: C/4 (9 samples)

Field	L.I.%	pH	K_2O	P_2O_5
A	8.0	6.5	185	7
B	7.6	6.9	128	6
C	8.3	5.8	260	8
D	7.4	6.6	150	3
E	7.0	6.3	118	5
F	7.7	5.7	140	6
G	6.9	5.8	98	4
H	8.7	6.2	173	9
I	7.8	6.0	263	11

Mean L.I.%	- -	7.7
Mean pH	- -	6.2
Mean K_2O	- -	168
Mean P_2O_5	- -	7
Fertility Index	-	9,050

FARM: C/5 (8 samples)

Field	L.I.%	pH	K_2O	P_2O_5
A	8.0	5.9	173	5
B	7.5	5.8	240	11
C	6.8	6.3	320	6
D	9.7	5.9	200	4
E	6.8	6.4	213	8
F	7.4	6.0	165	14
G	7.6	5.8	118	5
H	8.6	6.1	128	7

Mean L.I.% - -	7.8
Mean pH - -	6.0
Mean K_2O - -	194
Mean P_2O_5 - -	6
Fertility Index -	9,080

APPENDIX 4(c). - - - Soils(main).

The following tables show the results of analysis of samples from the main experiment at Lintrose.

FARM: L/9 (8 samples)

Field	L.I.%	pH	K_2O	P_2O_5
A	8.2	6.3	93	16
B	8.3	6.5	83	17
C	8.2	6.2	50	10
D	8.0	6.1	60	22
E	8.3	6.2	103	17
F	8.6	6.1	165	16
G	8.2	6.4	108	25
H	8.0	5.8	173	18

Mean L.I.%	- -	8.2
Mean pH	- -	6.2
Mean K_2O	- -	104
Mean P_2O_5	- -	18
Fertility Index	-	15,340

FARM: L/16 (9 samples)

Field	L.I.%	pH	K_2O	P_2O_5
A	7.5	6.4	140	12
B	8.3	6.4	108	8
C	7.5	6.3	165	5
D	8.6	6.7	165	8
E	8.4	6.5	140	10
F	8.9	6.7	88	8
G	8.4	6.6	240	5
H	8.2	6.7	128	5
I	9.1	6.4	63	7

Mean L.I.%	- -	8.3
Mean pH	- -	6.5
Mean K_2O	- -	137
Mean P_2O_5	- -	8
Fertility Index	-	9,090

FARM: L/20 (8 samples)

Field	L.I.%	pH	K_2O	P_2O_5
A	6.9	6.4	140	7
B	7.3	6.5	113	7
C	6.9	6.4	165	8
D	7.0	6.3	145	12
E	7.3	6.1	175	9
F	7.4	6.2	165	8
G	7.5	6.3	175	11
H	6.6	6.1	225	14

Mean L.I.% - -	7.1
Mean pH - -	6.3
Mean K_2O - -	163
Mean P_2O_5 - -	10
Fertility Index -	11,570

FARM: L/24 (7 samples)

Field	L.I.%	pH	K_2O	P_2O_5
A	8.5	5.4	165	7
B	7.7	6.0	165	6
C	8.0	6.1	145	10
D	8.2	5.8	113	8
E	8.0	5.9	128	9
F	7.9	6.0	113	12
G	8.1	5.8	98	9

Mean L.I.% - - 8.1

Mean pH - - 5.9

Mean K_2O - - 132

Mean P_2O_5 - - 9

Fertility Index - 9,620

FARM: L/25 (11 samples)

Field	L.I.%	pH	K_2O	P_2O_5
A	9.3	5.6	165	8
B	8.5	5.7	140	8
C	8.3	5.9	225	7
D	8.9	6.1	260	8
E	8.1	6.7	140	10
F	8.2	6.5	185	11
G	8.6	6.5	118	9
H	9.7	6.5	260	8
I	8.2	6.3	113	5
J	7.4	6.5	200	7
K	7.4	6.3	145	6

Mean L.I.% - -	8.4
Mean pH - -	6.2
Mean K_2O - -	177
Mean P_2O_5 - -	8
Fertility Index -	11,890

APPENDIX 5.

Graph showing conversion efficiency plotted against level of self sufficiency. Pilot experiment.

PILOT EXPERIMENT.

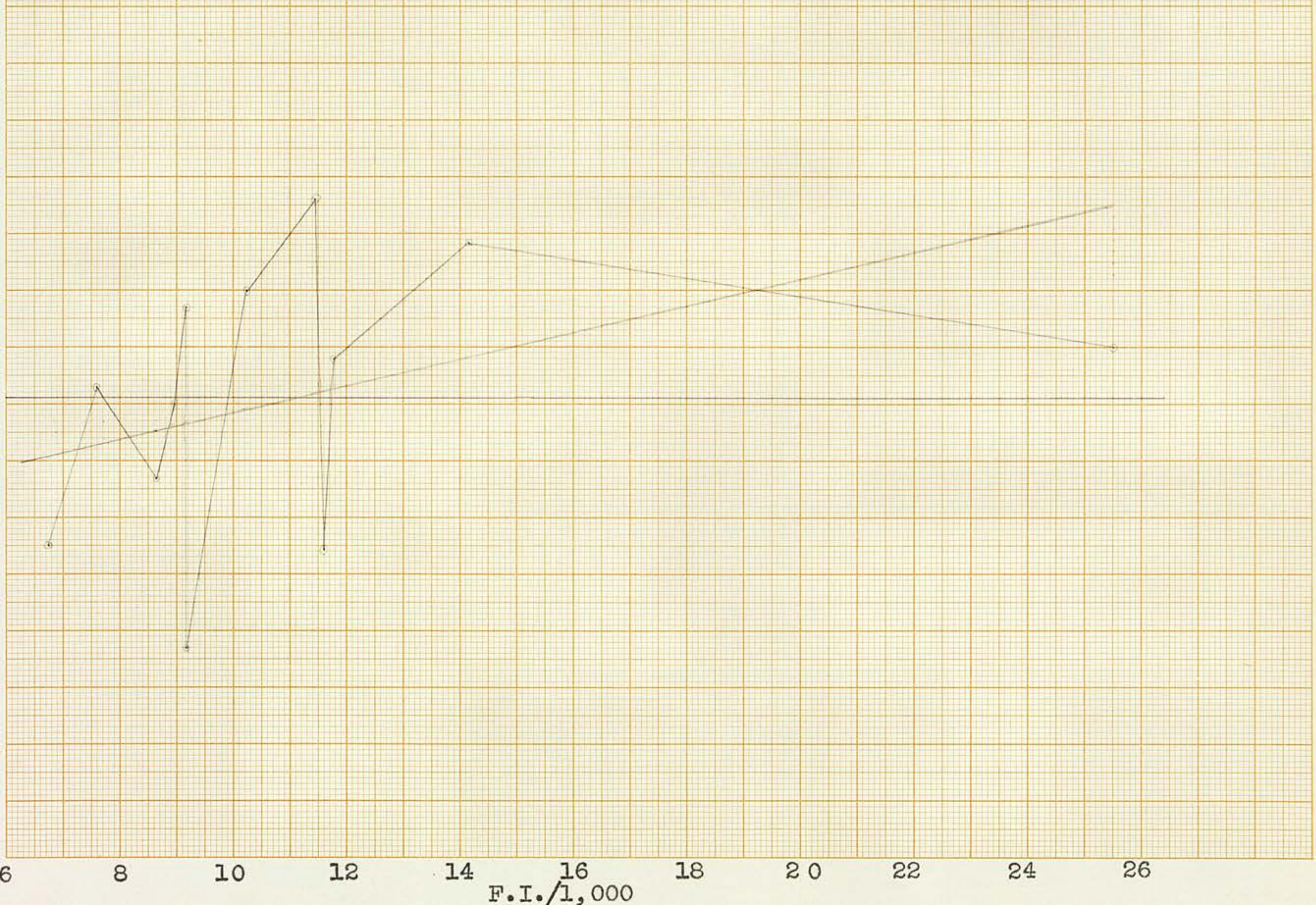
C.E.% v S.S.% (both uncorrected)

APPENDIX 6.

Graph showing conversion efficiency plotted against fertility index/1,000. Pilot experiment.

PILOT EXPERIMENT.

Conversion Efficiency % v Fertility Index/1,000

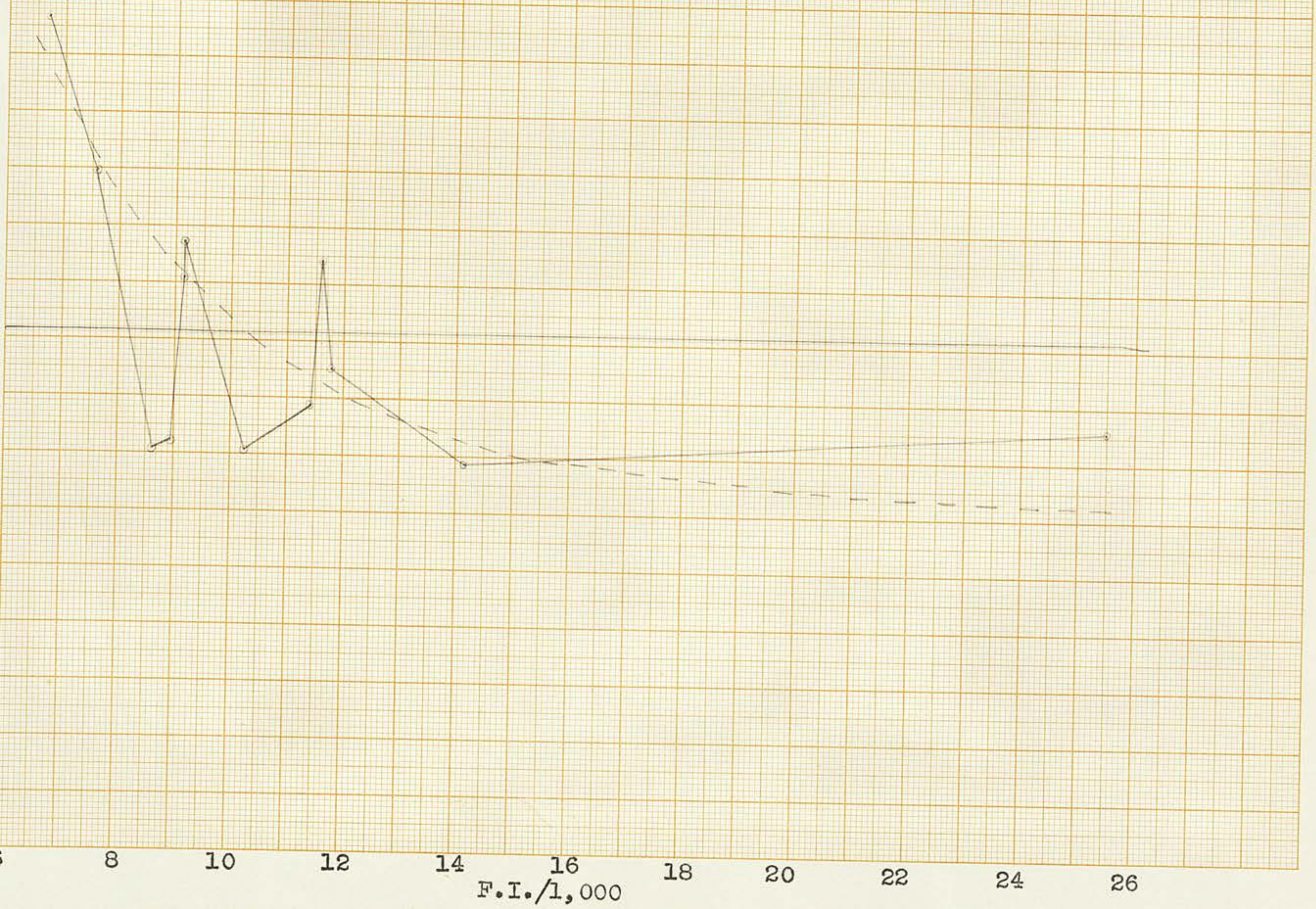


APPENDIX 7.

Graph showing self sufficiency plotted against fertility index/1,000. Pilot experiment.

PILOT EXPERIMENT.

Self Sufficiency % v Fertility Index/1,000



APPENDIX 8.

Graph showing corrected conversion efficiency plotted against corrected self sufficiency.

Pilot experiment.

PILOT EXPERIMENT.

Corrected C.E.% v Corrected S.S.%

APPENDIX 9.

Graph showing conversion efficiency plotted against self sufficiency for five farms at Dunragit.

Main experiment.


MAIN EXPERIMENT.....DUNRAGIT.
C.E.% v S.S.%
D/3
D/2
D/1
0
50
60
70
80
Average S.S.%

253

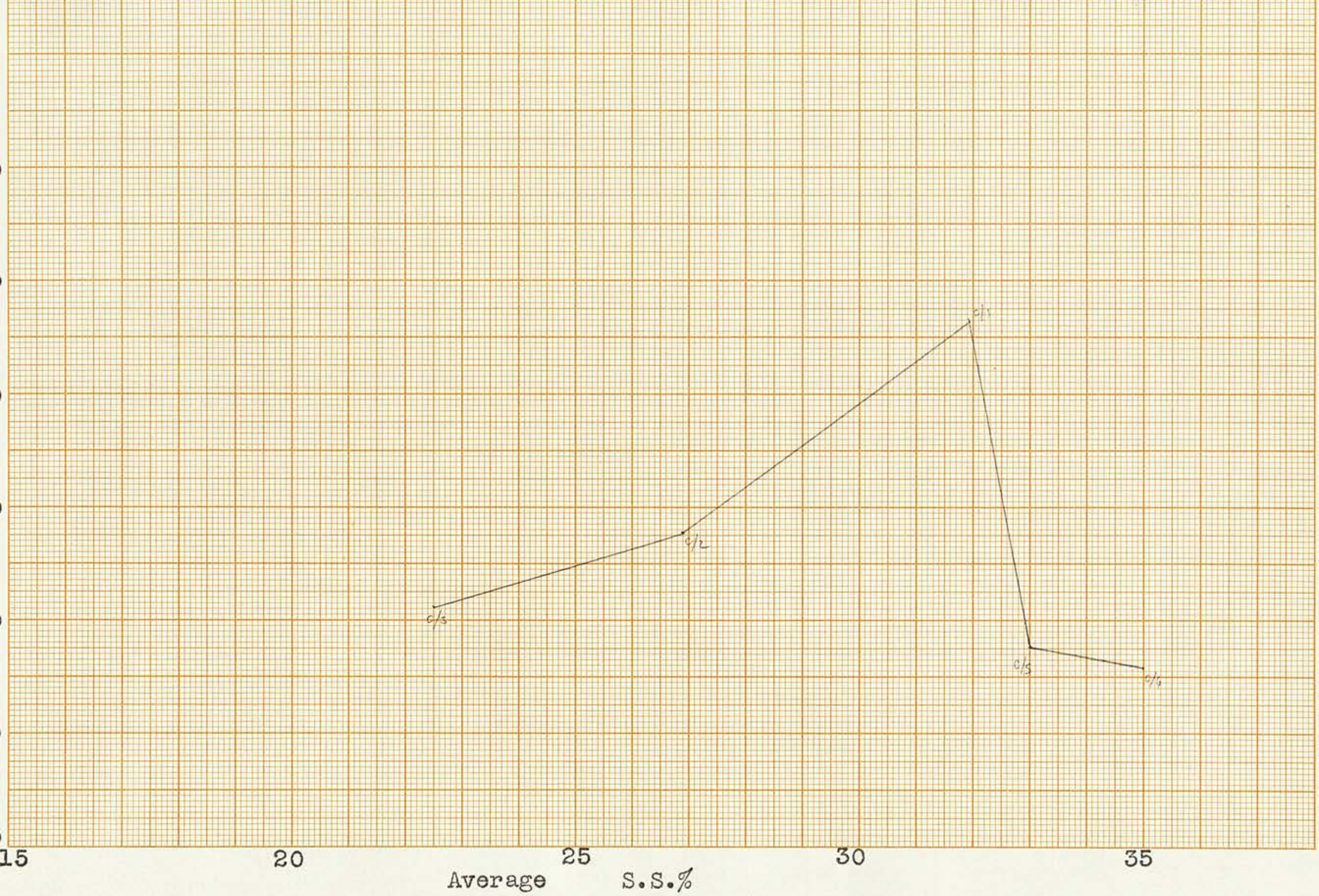
APPENDIX 10.

Graph showing conversion efficiency plotted against self sufficiency for five farms on the Carse of Stirling.

Main experiment.

MAIN EXPERIMENT.....CARSE OF STIRLING.

C.E.% v S.S.%



APPENDIX 11.

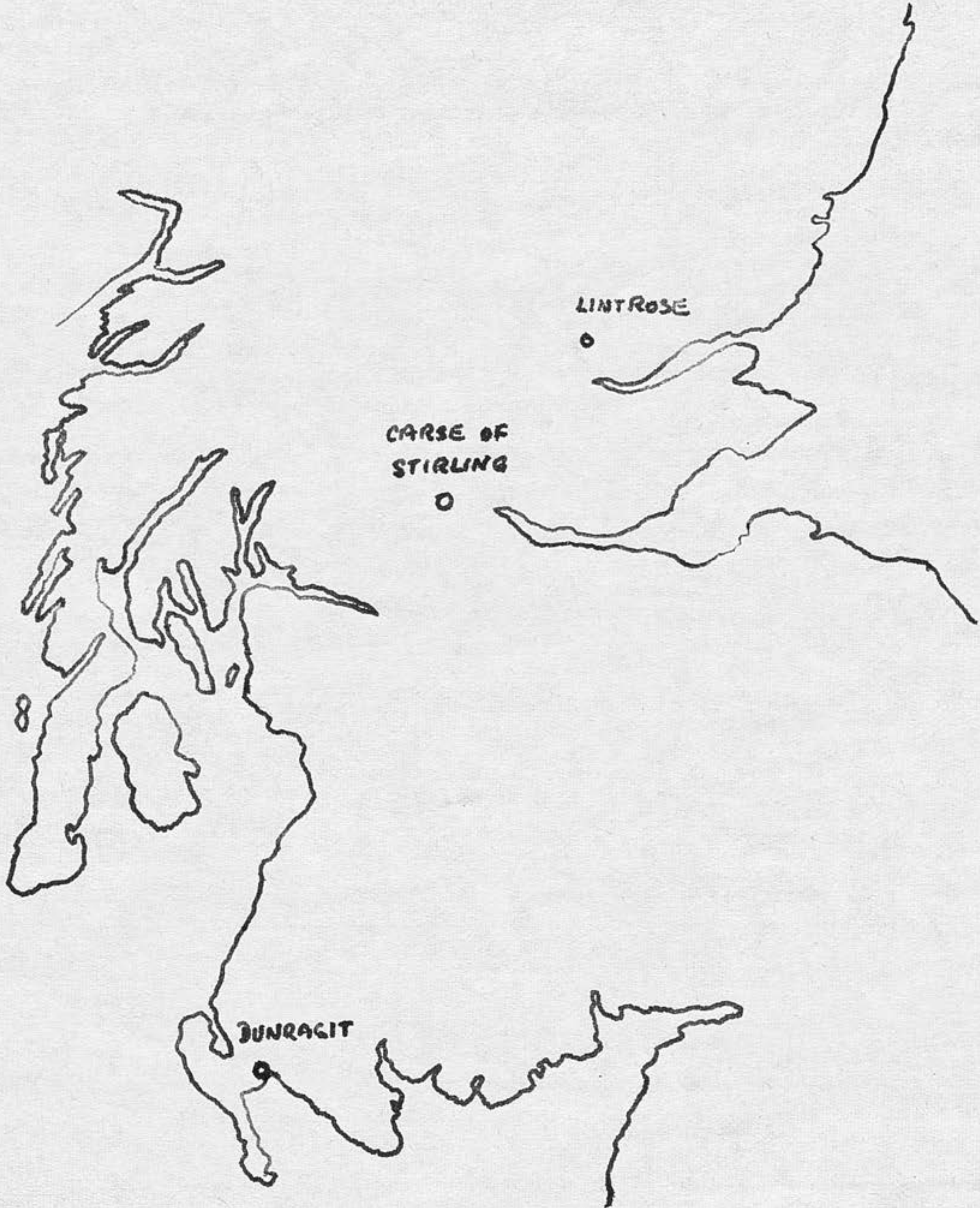
Graph showing conversion efficiency plotted against self sufficiency for five farms at Lintrose.

Main experiment.

MAIN EXPERIMENT..... LINTROSE.

Corrected C.E.% v Corrected S.S.%

257


LINTROSE
CARSE OF
STIRLING
DUNRAGIT