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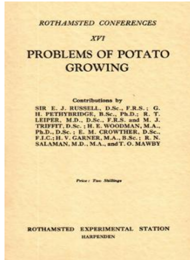
Problems of Potato Growing

Full Table of Content



XVI. Problems of Potato Growing

J. Mollett

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PROBLEMS OF POTATO GROWING

BEING THE REPORT OF A CONFERENCE HELD AT ROTHAMSTED ON FEBRUARY 20TH, 1934, UNDER THE CHAIRMANSHIP OF

Captain J. MOLLETT
(Chairman of the Potato Marketing Board)

With Contributions by

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CONTENTS

FOREWORD

By Sir John Russell, D.Sc., F.R.S.

For many years the potato crop has been one of the most interesting in British agriculture. It has long been associated with high farming, and its growers have survived the stresses and strains of the last few years better than most other intensive farmers. In spite of the fact that our markets were till recently open freely to all the world the potato growers managed to retain practically the whole production for themselves : they have long supplied, or been able to supply, all our requirements, and in addition they have usually exported a certain amount of seed.

This important industry, however, is highly specialised and localised. By far the largest part of the crop is produced in five regions :

(1) Around the Wash, especially the Holland division of Lincolnshire and the Isle of Ely ;
(2) In South Lancashire starting from Ormskirk and crossing into North Cheshire with extensions into Staffordshire ;
(3) In Bedfordshire, especially the region about Sandy and Biggleswade ;
(4) In the East Riding of Yorkshire, with extensions into the West Riding ;
(5) In Durham.

Most of the other counties of course produce some potatoes but usually insufficient for their own needs so that there is a considerable movement of potatoes from the centres above mentioned not only to the large towns and cities but even to small towns and villages to make good the local deficiencies.

One of the greatest troubles of potato growers in the past has been to fit the supply to the demand. In some years a deficit has been threatened and then of course importation began. In other years there has been a great excess, prices have been very low and many thousands of tons of potatoes have rotted in the clamps for want of a market. Against this kind of trouble the individual grower fights in vain and science gives no help : organisation is the only way out and that is being tried now for the first time since the Food Production Department of the war years ceased to function.

Organisation not only gives the individual farmer a more definite idea of his economic position : it gives the scientific worker his best chance for applying sound, trustworthy scientific results to practical problems. And so the setting up of the Potato Marketing Board under the able chairmanship of Captain Mollett, himself a good Yorkshire farmer and potato grower, seemed to offer a unique

https://doi.org/10.23637/ERADOC-1-209

occasion for discussing the problems of potato growing and summarising and publishing the information thus obtained.

Potato growing is necessarily costly. It is quite unsuited to low farming: you must either grow potatoes well or go out of the business. As the Lincolnshire growers say: "Potatoes like company." You cannot simply put them into the ground and leave them in the hope that they will of themselves yield a good crop. Hence, in any scheme of organisation one must envisage a limited area of high yield rather than widely scattered areas of lower yields.

Economical production therefore becomes imperative, and this necessitates:

(1) The use of good seed of the most suitable varieties;
(2) Appropriate schemes of manuring and cultivation;
(3) Control of insect and fungus pests and of other agencies causing disease;
(4) The working out of some method for dealing with excess produce in bountiful years.

All these problems are discussed by leading authorities in the following pages. The control of disease is now known to be effected much more economically by the use of resistant varieties than by any curative treatment. The method has already proved effective for the control of Wart disease; the serious damage this threatened to the industry has been happily averted. The work is not yet complete: it is still necessary to find a good immune First Early and a satisfactory immune substitute for King Edward. This, however, is only a matter of time, and the search has been considerably shortened by Miss Glynne's discovery of a method whereby new seedling varieties can be sorted out rapidly into immunes and non-immunes so avoiding the prolonged field trials previously necessary.

A serious attempt is now being made to find varieties immune to the common Blight. This presents some difficult problems. The Blight fungus, *Phytophthora infestans* appears to exist in several biological strains, and because a variety of potato is immune to one strain it is not necessarily immune to others. However, a beginning has already been made by Dr. Salaman and good results may yet emerge.

Dr. Pethybridge describes the methods for dealing with the more common diseases so far as this is practicable.

The eelworm *Heterodera schachtii* has already caused a great deal of trouble and may yet cause more. Dr. Leiper discusses the present position, and shows that the particular variety infesting the potato is rather different from its closely allied relative that does so much damage to sugar beet on the Continent. In particular it only hatches out from its cysts under the influence of secretions from the root of the potato and of a few other plants, while the sugar beet variety hatches out more easily. Further, the potato eelworm can live for a long while in the soil. For both these reasons rotation is not a com-

https://doi.org/10.23637/ERADOC-1-209

plete cure for eelworm but it mitigates the losses, and the present work suggests that the introduction of a temporary ley into the rotation still further reduces them.

When one remembers that Wart disease became a serious pest only a few years before the War, that the eelworm trouble has been serious only since the War, and the Virus diseases even later, we are bound to recognise that Nature probably has in store a good deal more in the way of troubles and trials for the potato grower. Shall we succeed in keeping out the Colorado beetle, that undesirable alien that persistently tries to land at Tilbury? Is some new and destructive virus disease being compounded that will do heavy damage to crops in the future? We do not know, but we may be quite certain that the problems of plant disease, like those of human disease, are without end, and that adequate research and a pathological service will always be needed.

No less important is the problem of finding suitable manurial and cultivation schemes for obtaining the most economical yields. This problem is always shifting with each change in the economic positions of the grower and of the fertiliser manufacturer, and as the growth of the crop becomes more localised and more intensive so the need for working out the most effective fertiliser recipes becomes more imperative. Dr. Crowther and Mr. Garner show how great is the difference in response to fertilisers on the different soil types: the black soils behave quite differently from the mineral loams. It is impossible to give one formula that suits all soils, and reduction in amount of one constituent may lead to serious losses on one soil, and to a saving of money on another. The new methods of field experiments devised at Rothamsted for use on commercial farms give valuable material for the working out of methods of soil analysis which, we hope, will lighten this problem of choosing the right mixture. At present soil analysis is not a trustworthy guide to manuring though with fuller information such as is now accumulating we hope to make it so.

The reader is entitled to ask why no paper on Quality of Potatoes was included. The reason is that we know so little about the subject. Quality in any crop is difficult to define, but quality in potatoes is particularly elusive. So much turns on the use to which the potato is to be put and on the individual fancy of the buyer that the scientific worker can get hold of very little. Our experiments are summarised in the paper by Dr. Crowther and Mr. Garner: the subject is being closely watched and anything likely to prove useful will be followed up.

Any crop produced in amounts sufficient to satisfy the annual needs of the country is bound in some seasons to yield far more than is wanted. One of the best safeguards against the losses arising from unusual bountifulness of Nature is to provide a satisfactory outlet for this excess production. Farmers who have much livestock can utilise a considerable quantity of potatoes in feeding, subject to the conditions set out in Dr. Woodman's paper. Diseased or sprouted potatoes, for example, are liable to be dangerous. Roughly speaking 1 ton of potatoes is the equivalent of 2 tons of roots or of 5 cwts. of maize and in addition it supplies considerable quantities of the antiscorbutic vitamin so necessary to the animal during the winter period.

One of the difficulties of utilising excess potatoes on the farm is that the farmer who has livestock is very liable to have abundance of other home-grown foods in the year when he obtains excess of potatoes. Moreover, many potato growers have insufficient livestock to consume all their excess production.

In view of these difficulties it has often been suggested that factories should be set up for the manufacture of Power alcohol, farina, or other products from excess potatoes. Considerable enquiry has already been made and the economics of several of the processes have been investigated. One point, however, clearly emerges: factories cannot be put up on the off chance that material may be sent to them if it cannot be sold elsewhere. Factories need regular supplies of their raw materials, and before they could be erected farmers would need to enter into contracts to supply definite amounts of potatoes *each year, whatever the market price*. The potato factory, in short, would need the same kind of safeguard as the sugar beet factories. Once established they could deal with any glut of potatoes, however heavy, and in years of great abundance they would prove a useful economic buttress to the industry.

The following pages show that the problems of potato growing are likely to become more definite but no less serious as time goes on. The present research and advisory system is very effective for dealing with most of them, but it would gain greatly in value by the establishment of a special Potato Research Station in one of the important potato growing districts. The existing testing and demonstration stations serve a useful purpose and a Research Station in touch with these and with the large Research Institutes of the country would complete the scheme and undoubtedly prove of great value.

POTATO DISEASES

By G. H. Pethybridge, B.Sc., Ph.D.

(*Plant Pathological Laboratory, Ministry of Agriculture*)

There are so many specific diseases of the potato plant, due to parasitic fungi and bacteria as well as to viruses—to say nothing of depredations due to insects and other animals and of maladies resulting from non-parasitic agencies—that it is quite impossible to do more than consider a very restricted number of them in the necessarily brief period allotted to the subject to-day. It must not be supposed, however, that those perforce omitted are of no importance, for many of them may cause serious trouble and loss, especially in particular localities or under certain special conditions of soil, weather, or other circumstances that influence the crop.

Just now many farmers will naturally be concerned with the seed potatoes they are going to plant this season, although the best of them will have paid attention to this matter long ago, and will already have their seed boxed and placed under suitable conditions for sprouting. Such boxing and sprouting of seed potatoes is advantageous not alone from the points of view of increased freedom in the choice of actual planting time and ultimate gain in yield, but also because the practice offers a substantial safeguard against the planting of diseased seed. Tubers affected with Blight that still retain any viable eyes will sprout considerably earlier than others, and can thus be recognised and eliminated ; for blighted tubers are the primary sources from which epidemics of Blight arise in the crop. Tubers affected with Dry Rot, a disease particularly common in early varieties, and recognisable by the concentrically wrinkled sunken areas on the skin from which dirty white or bluish pustules, composed of myriads of fungus spores protrude, can also be removed. They should be destroyed by burning, for they constitute " infection centres " from which disease may be transmitted to healthy tubers. It has been proved to be useless to cut out the diseased portions from a tuber affected with Dry Rot and plant the remainder, for it subsequently decays in the soil. It is also dangerous ; for, if the healthy tubers in the same lot are cut into sets, the knife or hands will readily carry infection to them, and the result of planting them will be " misses." The Dry Rot fungus is a wound parasite, and too much care cannot be taken (especially with early varieties) to avoid mechanical damage to the tubers, both whilst lifting the crop and during its subsequent handling and transport. Too often it appears to be forgotten that potato tubers are living things ; as such they deserve, but do not always get, better treat-

https://doi.org/10.23637/ERADOC-1-209 pp 10

ment than is meted out to such commodities as coal, gravel, manures, and so forth. They require air for breathing purposes, and to fill up a closed and unventilated store to the very top with bags of them, as occurred in a case recently investigated, is simply asking for trouble. They must not be exposed to low temperatures or they will be killed, and will subsequently rot without the intervention of any parasitic organism. Nor must they become over-heated, or they will also be killed and afterwards rot ; or, if the temperature is not sufficiently high for that, become affected with Black Heart. Matters of this kind may appear trivial and relatively unimportant ; but, judging from the number of complaints arising from such ill treatment that have been referred to us in recent years, there certainly does seem to be considerable room for improvement in the way seed potatoes are treated. If they could be regarded as being almost as delicate as fruits or eggs, it would not be amiss.

Potatoes substantially attacked by Common Scab, particularly if the eyes are involved, will not be used for seed by good growers, nor will such as are affected with Powdery Scab. These two diseases are of course also contracted from the soil, and it is well to remember that even healthy seed planted in soil contaminated with either of the two Scab-producing organisms is liable to yield an affected crop of tubers, and particularly so if the soil has recently been limed. Seed potatoes showing the sclerotial incrustations of the Black Scurf fungus should also be looked on with disfavour. True, this ubiquitous fungus is very often present in potato land, but it is advisable not to augment it there. The blemish produced by the fungus on the surface of the new tubers is the least important of its maleficent effects. It is one of the more important causes of " misses " or gaps in the crop. When cold, wet conditions prevail after planting, the Black Scurf fungus readily attacks the tips of the young sprouts, underground, and kills them. The further young growth which follows as a reaction to such attack is in turn destroyed ; and thus nothing in the shape of a shoot may come above ground. On the other hand, even if young shoots do succeed in coming up, they not infrequently become cankered through by the fungus a few inches below soil level, and then wilt and die away. Trouble of this kind is most frequent in land that has carried crops of potatoes in succession for a considerable period and in which, naturally, cumulative disease effects are only to be expected. The remedy is obvious, but too often neglected.

Skin Spot is a disease that needs special attention, for it has caused a great deal of trouble in recent years. It can be recognised on the tuber in the form of small, circular, dark spots on the skin, usually having a slightly raised, minute, pimple in the centre. Often the spots are very numerous and confluent, giving a pock-like appearance to the skin. In ware tubers, Skin Spot, though objectionable, might, perhaps, be regarded more as a blemish than a serious disease, for the fungus that causes it (*Oospora pustulans*) does not penetrate to any considerable depth into the tissue of the tuber, and it is completely removed on ordinary peeling. With seed tubers, however, the matter is very different. The fungus attacks the individual buds in the eyes, and kills them. The severity of attack appears to depend largely on external conditions. Even during winter storage the buds may be killed to some extent, but, fortunately, the potato has the capacity (not unlimited, it is true) of forming new buds in its eyes to replace those lost. The struggle between host and parasite does not cease when the tuber is planted. If the soil is in good condition and the weather and other circumstances are favourable to the potato, then the unattacked buds will soon become large enough and sufficiently robust to resist attack by the fungus. On the other hand, when the soil is ill drained and not well tilled, and particularly when cold, wet weather conditions prevail for any length of time after planting, the fungus gains the upper hand, kills bud after bud as they successively arise, until the tuber may eventually become entirely " blind." It then produces nothing above ground, of course, but it is not actually dead. Unless attacked by some other enemy, the blind tuber produces at its heel end, where it was originally attached to its stolon a rather hard, woody, tumour-like growth. Blind seed tubers, each with a basal tumour of this kind, are not infrequently found at digging time in a gappy drop derived from seed affected with Skin Spot, and the tumours have sometimes been wrongly suspected as having been caused by the Wart Disease organism. They are still alive, so reluctant is the potato to give up the ghost entirely ; and, on replanting them under favourable conditions, adventitious buds are formed on the tumours, which develop into normal foliage-bearing shoots. Seed potatoes showing Skin Spot, therefore, should be regarded with great suspicion. Under unfavourable conditions they are almost certain to give rise to real trouble, and no one can predict with certainty what conditions are likely to prevail after planting. The conditions existing when seed potatoes are properly sprouted in boxes are advantageous to the potato and not to the Skin Spot fungus. If, therefore, sprouting seed potatoes were a universal practice less would be heard of failures of crops due to this disease.

What has been said so far in regard to troubles that may arise from faulty seed potatoes refers to matters that are discernible by careful examination of the tubers. Unfortunately, there are other diseases transmitted with seed potatoes that afford no signs whatever of their presence ; and the chief of these are most of the virus diseases. In practice, judging from reports received, the most important of these from the point of view of general reduction in yield is Leaf Roll. Mosaic and Crinkle probable come next, and the various forms of Streak last. This order, however, does not represent the relative virulence with which these diseases attack potato plants themselves, for Streak and the severe forms of Crinkle may be so intense in their effects that the affected plants may be practically wiped out, and thus few or no tubers that could find their way into commercial seed remain.

The nature of plant viruses is still an unsolved problem, but that those affecting the potato are carried in the seed tuber and that they are transmitted from diseased to healthy plants by insects is unquestionable. Fortunately, however, they do not appear to be carried in the true seed, developed in the so-called potato "plum" or "apple"; and thus the production of virus-free potatoes, for breeding or other purposes, is not an impossibility.

Attempts have been made from time to time to find a ready method of distinguishing between healthy seed potatoes and those derived from virus-attacked plants, but so far without much practical success. In the United States of America a so-called "tuber-index" method of testing seed potatoes for the presence or absence of virus has been developed and practised to some extent. This consists in removing a portion of the tuber containing an eye, planting it in a greenhouse in the winter and noting the state of health of the shoots when they are some eight inches or so high. Those tubers alone are retained for planting, the portions from which have given rise to shoots showing no virus symptoms; and from them relatively healthy stocks can be worked up, provided this is done under isolated conditions, where virus infection from without is not possible or is at a minimum. No doubt, for the raising of special stocks of seed potatoes this method of controlling the health of them is valuable, and particularly so if, as seems to be the case in America, the tuber-indexing can be done for the raiser by a public institution. For the ordinary farmer, however, the method is scarcely practicable.

Attempts have been made recently in Germany to discriminate between healthy and degenerate (*i.e.*, presumably, virus-containing) potato tubers by electrical measurement methods. Arising out of these a so-called copper-strip test has been devised. A bright strip of copper about the size of a pen-knife blade is pushed well into the end of the tuber, which is then kept for about eight hours at a temperature of 37-40 degrees C. After a further sixteen hours at about 20 degrees C., the tuber is cut across. If it is a healthy one there should be a black stain extending for a considerable distance around the slit-like wound made by the copper strip. If it is a degenerate one there should be no such stain, or at most one not extending much beyond the edges of the wound itself. The method seemed so simple as to be worth a trial, hence one was made with tubers known to be derived from plants affected with Leaf Roll and with others that were believed to be healthy. The result, however, was that the tubers affected with Leaf Roll showed the extensive blackening supposed to occur only with healthy tubers; thus, for this particular disease, at any rate, the method appears to be useless. Others have made similar preliminary tests and have also found the method not promising for distinguishing tubers containing virus from healthy tubers.

For the supply of seed potatoes as free as may be from viruses, the farmer therefore has to rely on the good faith of the seed producer, and in recent years much has been done (though much more remains to be accomplished) to raise the standard of health (particularly in regard to virus diseases) of crops of potatoes grown for seed. In Scotland, for example, growing crops showing more than a certain proportion of virus diseases, even if 100 per cent. pure (*i.e.*, true to name), are now no longer awarded official certificates for seed purposes. That really first-class seed potatoes, carrying a bare minimum of virus disease, can be raised, has clearly been shown by the successful work done in the last few years at University College, Bangor, North Wales, an account of which will be found in the Ministry's Journal for July, 1933. In principle, the plan is to start with a small quantity (in some cases, perhaps, a single plant or tuber) of material that is virus-free, or as near to this ideal as can humanly be attained, and to multiply it under rigid conditions that preclude infection (brought by insect vectors) from outside sources. In practice procedure may be slow and difficult at first, but that it can be done is certain.

The temptation to dwell disproportionately on virus diseases of the potato is extremely strong, and must be resisted, and consideration must now be given to one or two other diseases concerned with the growing plant in the field and affecting the crop of tubers raised. Blight (due to *Phytophthora infestans*) is still by far the most important of all potato diseases in this country, for it destroys the tops, reduces the crop yield and rots many of the tubers produced. Time will not permit of any detailed account of the disease now, and most of you will be thoroughly familiar with the subject. Two matters only, therefore, will be touched on to-day, namely the occurrence of primary outbreaks and Blight resistance. It used to be supposed that the first outbreaks of Blight each season always occurred in the extreme south-west of the country ; that in due course infection spread from them eastwards and northwards, in wave-like fashion, the rate of progression of the wave depending largely on weather conditions. For the past ten years or so records have been kept of the dates and localities of the first seasonal outbreaks of potato Blight, and they show that this wave of disease does not in fact exist. Although, of course, mainly owing to climatic conditions, the very earliest outbreaks generally do occur in the south-west and the latest in the north, yet, broadly speaking, outbreaks occur at numerous centres widely distant from one another and at no very widely different dates. A single stone thrown into the water at the edge of a pond will produce a wave (or a succession of parallel waves) that will progress until it reaches the edges and far end of the pond, the whole surface having been traversed from the one original source of disturbance. If a handful of pebbles is broadcast into the pond, however, each will give rise to a circular wave ; and these circles will expand and run into one another until eventually the whole of the surface of the pond will have been wave-traversed. If the whole handful is scattered not at one time, but distributed bit by bit, at comparatively short intervals of time, the whole surface will also eventually be wave-traversed; and this is the kind of picture to bear in mind when considering the seasonal inception and spread of potato Blight here. The practical bearing of this analogy is that when a farmer hears that Blight has once more put in its annual appearance somewhere in the country he should not wait for the advance of any wave of disease from a distance, but realise that it may be practically at his own door already and act accordingly. Each season, as soon as potato Blight has occurred again, in whatever locality, the Ministry of Agriculture makes the fact known as widely as possible through the press and by other methods of publicity. The warning is repeated as further outbreaks are reported, and thus farmers are reminded that the time has arrived when spraying potatoes with Bordeaux or with Burgundy mixture should be undertaken.

One point in connection with the records deserves to be mentioned. It is the comparative frequency with which the first outbreaks occur in proximity to old potato pits or clamps. It is known, of course, that the Blight fungus overwinters in the tubers, and, it is believed, in them alone. Blighted tubers thrown out of a pit and left lying about are naturally dangerous sources of infection to neighbouring potato crops, for the fungus fructifies on them, and the spores produced are readily disseminated. Much could be done to retard and minimize outbreaks of Blight by paying stricter attention to plant sanitation and hygiene and thus suppressing foci from which primary infections arise. Moreover, more could be done than is often attempted to minimise attacks of Blight on the tubers by adequate and careful earthing up of the drills.

A potato variety resistant to or immune from Blight attack has for generations been a desideratum, and many attempts have been made to secure one. Nor have they been entirely unsuccessful, for a few varieties resistant both in haulm and tuber do exist. Unfortunately, however, they do not possess many of the other important characteristics that are bound up with a commercially valuable sort, and they have therefore not come into general favour. Some of them are late ripening varieties, but one of them at least is an early one, and their resistance cannot be explained (as is sometimes supposed) by the assumption that they merely escape infection because they are not in a suitable stage of development for attack when the Blight fungus is active. Their resistance appears to be constitutional or inherent. Renewed attempts have been made during the past ten or twelve years, particularly in Germany, to raise a Blight-resistant variety that will be satisfactory from other points of view, and acceptable to the commercial potato grower. Failure to produce such a variety by breeding from already cultivated varieties alone led to the use by breeders of one or two highly resistant wild species of potatoes, as parents in crosses with cultivated varie-

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ties. A few new varieties were thus raised possessing, apparently, resistance and many or most of the other required characteristics, and the prospects seemed particularly good. Alas, however, when these varieties were sent out, after a few years, for wider trial they broke down, and became attacked by Blight. This happened successively with two sets of specially promising progenies, but there still remains a third set not yet fully tried out. The resistant wild species *Solanum demissum* is concerned in the derivation of this third lot, but there appears to be no obvious reason why the progenies raised from it should ultimately behave differently from those raised with the help of other resistant wild species. Such disasters are of course almost heart-breaking to the breeder, and the question is: how do they come about? The answer is that it is now thought that the Blight fungus exists in the form of more than one "biological species" (just as the Rust fungi do), and that a variety resistant to one biological species may be attacked by a different one. Further and very critical work is required before this belief can be regarded as based on an unshakable foundation; but if it should prove to stand fast, then the breeder's task is made a hundredfold more difficult; for a variety will have to be raised that resists the attack not only of those "biological species" of *Phytophthora infestans* that already exist, but also of others that may possibly come into existence in future.

There is another important aspect of the Blight resistance problem that may be alluded to in passing; there is unfortunately no time to deal with it adequately now. It is the question as to whether resistance, even if it appears to be inherent or constitutional, is necessarily really permanent in the variety. Can external factors so influence the potato plant that Blight resistance becomes weakened or even entirely lost in the course of years when the variety comes into general cultivation? The scientific breeder will probably answer no, if resistance is really bound up with the gene (the supposed material unit of the cell that carries the heritable characteristics of the plant), and seeing that propagation is entirely vegetative; but it will be up to him to demonstrate beyond doubt that Blight resistance is or can be so linked up and remain absolutely permanent.

It may now be well to turn from this perhaps somewhat depressing picture of Blight-resistance and its practical possibilities to that of resistance to a totally different disease, a picture of a much more cheerful and satisfactory aspect, namely, resistance to Wart Disease. Here it can be said that the existence of some old and the raising of certain new resistant varieties has been of immense practical importance to the farmer. Thanks to them and to the administrative measures governing their employment the losses due to this disease in this country are now entirely negligible, although discovered foci of soil infection have not ceased to accumulate slowly. This satisfactory state of affairs, however, must not lead to diminished care or to neglect of the precautions that have led to this happy result, for the menace still remains. The careful work of recent years has shown that potato varieties can be arranged in a series, starting with those that are extremely susceptible to Wart attack, passing through those that are less susceptible, to some that are somewhat resistant ; then to others definitely resistant, highly resistant, almost immune and apparently actually immune, in turn. By the use of these immune and very highly resistant varieties for planting in infected land normal crops can be grown, in spite of the fact that the parasite is still there and may remain in viable condition there for a great number of years. When breeders succeed, as no doubt eventually they will do, in producing highly resistant or immune first early varieties to replace the susceptible ones still necessarily grown in their absence, and when highly resistant or immune substitutes for such valuable main crop varieties as King Edward become available, then Wart Disease will become a matter of secondary importance. Immunity and resistance here do seem to be a permanent feature of the variety ; at any rate, no authentic case of breakdown has yet been known to occur. Time and further experience alone can determine whether such a thing is possible.

To those who may have studied the historical aspects of this disease it will be of interest to mention that further light has been shed on its early history in this country by investigations recently made in Finland. There is circumstantial evidence that the disease had existed in England for some few years prior to 1900, when its presence and nature were first recognised by Professor Potter (*Jour. Board Agric.* 9, 1902-3, p. 320). It was evidently seen here (and illustrated, though not correctly identified) in 1898 by G. Abbey (*Jour. Hortic. Cott. Gard. and Home Farmer*, 3 Ser., 37, 1898, p. 463) and by A. Sutton (*Jour. Roy. Agric. Soc.*, 3 Ser., 9, 1898, p. 598). It was also probably seen, but not specifically recognised, in the same year by Wm. G. Smith (*Jour. Roy. Hortic. Soc.*, 22, 1898-99, clxxvi. and clxxviii.). These are our earliest definite records.* It was first described and recognised as a new disease, in 1896, in Hungary, by K. Schilberszky (*Ber. Deut. Bot. Ges.* 14, 1896, p. 36). Now, A. Hilli, writing in 1932 (*Perunasyövän* (*Synchytrium endobioticum* [*Schilb.*], *Perc.*) *leviämisen syistä suomessa ja ulkomailla*, Helsinki, 1932, p. 64) brings forward substantial evidence to show that Wart Disease was introduced into Finland with a consignment of Magnum Bonum potatoes from England in the year 1893. That would be five years before the disease was recognised in this country and three years before it had been discovered and described in any country. How long it may have been here prior to 1893 no one can say, but

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* Since the above was written, a slightly earlier record has come to light. It is clear from the description given in an answer to a correspondent, published in Vol. 30 of the *Gardeners' Chronicle*, Aug. 22nd, 1896, p. 227, that certain potatoes showfng warty growths submitted to the Editor, must have been affected with Wart Disease. Both M. C. Cooke and Worthington Smith, well-known mycologists, examined the specimens and agreed that this manifestation of disease was a novelty.

had we possessed a phytopathological service in this country forty years ago, how much trouble might have been avoided!

Finally, although strictly speaking insect pests do not come within my special province, but are dealt with by my entomological colleagues, something must be said about the existing Colorado beetle menace to this country. It is scarcely necessary to emphasise the enormous damage that this insect and its grubs can do to potato crops by devouring the tops; this is well known. In general shape and appearance the beetle reminds one of a lady-bird beetle, but it is from two to three times larger than our commoner lady-birds, and instead of having black spots on its back, it has ten black stripes running lengthwise. In colour it is a light yellowish brown, and the soft grubs are reddish. During the last decade this pest, previously confined to North America, has become well established in France, and each year it has migrated further north in that country until now it is not far from the Channel coast. All possible practical precautions are being taken to keep the pest out of England, but an isolated case involving a few beetles was discovered last August at Tilbury. Full particulars concerning this will be found in an article by Mr. J. C. F. Fryer, Director of the Ministry's Plant Pathological Laboratory, Harpenden, who is in chief command of operations against the pest. This was published in the Ministry's Journal for January last, and in addition, an Advisory Leaflet (No. 71) on the subject, with a coloured plate, was published in the same month. A copy of this should be in the hands of every potato grower. Once before, over thirty years ago, this pest was found here; curiously enough, also at Tilbury. It was then successfully eradicated and it is hoped and believed that the same succcss will crown the present efforts at extermination. However, the beetle has now become established so very much nearer to our shores than it was formerly that it is necessary to be more than ever on the alert in order to detect immediately any fresh case of invasion. Promptness of detection is essential for swift suppression. Operations against this pest can successfully be conducted only with the active assistance and co-operation of farmers and other occupiers of land. This has so far been most willingly given and will no doubt be as readily continued. Suspected specimens should be sent, packed as carefully as possible to avoid damage in the post, to The Secretary, Ministry of Agriculture, 10 Whitehall Place, London, S.W.1. On packets sent by letter post thus addressed postage need not be prepaid.

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THE EELWORM PROBLEM

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That the potato-root eelworm, *Heterodera schachtii*, is widely distributed in Britain is now unhappily a well recognised fact, but it is of significance that although the parasite was diagnosed in England as long ago as 1917, the serious nature of the infection has only recently been realised by the majority of growers.

Now, there is every reason to suppose that previous to 1917 the parasite was well established in several district, for, only two years after Taylor's diagnosis of the pest in Yorkshire, it was recognised both in Cumberland and Cambridgeshire. In the latter instance the attack was so severe that in a field where 7 cwt. of seed was planted, the yield was 5½ cwt. only. This clearly indicates that this infection at least was of several years standing. Subsequent records show that in the early post-war years practically all the potato-growing districts in Britain contained foci of infection. Since no steps were taken to limit the spread of the disease, and in many districts potatoes were grown almost annually on infected land, it is not surprising that the eelworm problem has assumed its present very serious aspect.

In this connection it may be worthy of mention that a similar state of affairs had previously been brought about in Germany by the same eelworm, only in that case sugar-beet was the plant attacked. The sugar-beet industry, begun in Germany about 1800, was for many years so successful, and beet growing proved so profitable, that sugar-beet was repeatedly grown on the same land. The system of rotation and fallowing formerly practised was abandoned. As a result of this, eelworm became very prevalent, and in 1876 no less than 24 factories were closed down and thousands of acres of previously fertile land had to be returned to pasture. Scientific investigation of the eelworm problem was begun in Germany as early as 1870, and is still being carried out, but so far no practicable measure of ridding infested land of eelworm, other than by prolonged rotation with non-susceptible crops, has been devised. That the pest can be controlled by this means is amply demonstrated by the present day success of beet-growing in Germany.

Of recent years attention has been paid in Europe generally, as well as in Britain, rather more to the depredations of the eelworm on potatoes than on beet, for although the nematode responsible for the damage is the same, the problems it presents differ in certain important respects. This is due to the remarkably high specialisation

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which occurs when this particular eelworm lives for many generations parasitic upon a single species of host. It has been found that not only does such a specialised population of eelworm tend to lose the power of attacking plants other than the usual host or closely related species, but other physiological differences occur which influence the response of the eelworm to certain stimuli. One very important difference is that, whereas the larvae of the strains specialised for beet require only the stimulus afforded by suitable conditions of temperature and moisture to cause them to emerge freely from the cysts, the larvae of the potato strain require a further chemical stimulus before hatching will take place with any great freedom. This is provided by the root excretions of the potato plant. When non-susceptible crops are grown, the beet strain tends to die out from infected land much more rapidly than the potato strain, for greater numbers of larvae are freed each year. The advantage of this to the grower is, however, counteracted by the higher probability in the case of the beet strain that some weed may become infected and serve as a reservoir of infection, for in general the beet strain is less highly specialised than the potato strain.

Although it is usual to refer to these specialised populations of eelworm under such general titles as " beet strain," " potato strain " and " pea strain," for example, yet another important factor, which is perhaps insufficiently realised even by scientific workers whose experience is confined to a limited district, is that a strain specialised for a single host in one district may differ in minute respects from an apparently similar strain specialised for the same host in another area. Yet these slight differences may assume very great importance, more particularly in relation to the question of devising methods of control.

That such differences in the potato strain do exist in Britain has been repeatedly pointed out in publications of the Institute of Agricultural Parasitology. Research workers of this Institute, while carrying out laboratory studies and small scale experiments at the field station at St. Albans, pursue their main observational work, and conduct field experiments, in those districts where the parasite constitutes the most serious menace to agriculture. In this way knowledge has been gained of the different strains of eelworm which occur in north and south Lincolnshire, Yorkshire, Lancashire, Bedfordshire and Wiltshire, as well as Hertfordshire, and thereby contradictory results appearing in the literature have been understood and assigned to differences in soil type and agricultural practice.

To appreciate fully the significance of these minute differences in physiological reaction, a detailed knowledge of the work which has been carried out, both in this country and abroad over a period of years, is, of course, necessary. A summary of some of the more striking points can only be attempted here.

The most obvious point which arises in connection with the control of the eelworm and the treatment of the disease known as " potato-sickness " with which it is associated, is its association with certain types of soil, and bound up with this are questions of land values and agricultural practice. It is obvious that where very fertile, highly-valued land becomes infected, it is economically possible to apply manurial or chemical treatment involving considerable outlay, while any other method of control which might include, for example, fallowing for a considerable period, would be quite impracticable. In other cases exactly opposite conditions prevail. Very frequently highly fertile land is found to be infected as a result of potato cultivation carried on year after year despite eelworm and " potato-sickness " making their appearance, until a stage is reached where it becomes impossible for the land to bear a successful potato crop.

In these cases it is common to find the grower of the opinion that potatoes are the only possible crop from which he can make a profit. Where this is actually the case, as sometimes happens with small holdings, there seems no alternative to the land becoming derelict ; but where alternative crops can be grown there is some evidence that one reasonable crop of potatoes can be produced every four or six years, which is preferable to annual losses from the constant failure of the potatoes.

There is little doubt that the establishment of the sugar-beet industry in Lincolnshire and South Yorkshire has saved thousands of acres of fertile but " potato-sick " land from going out of cultivation. But there is now great danger that beet may be grown so frequently on this infected land that a host transference may be effected by the eelworm. As an illustration of the depreciation in land values which follows as a result of eelworm infection the case of a farm in Yorkshire may be quoted. In 1930 this farm was let at a rental of £2 an acre : in 1933 it failed to let at a rental of 10s. an acre although it is situated in a beet growing area. Land depreciation is therefore one of the serious consequences which must be kept in mind in estimating the damage following upon the spread of this eelworm.

There is another point which must not be omitted in considering the relative importance of eelworm in different districts and different types of land. The physical condition of soil greatly influences the eelworm's rate of reproduction and consequently affects the rate of spread from isolated foci of infection. Recent work has also shown that the rapidity of eelworm elimination which follows a suspension of potato planting is likewise influenced by soil composition, so that the good results obtained by this means in a light, sandy, well aerated soil must not be too confidently anticipated in districts where the soil has a closer texture.

With regard to the more inherent physiological variations which are found to occur in strains of eelworm in different parts of the country, comparatively little is as yet known. Such information as is available, however, serves to emphasise the importance of this aspect of the eelworm problem. Variations in size of the larvae would scarcely seem to have a bearing on the economic side of the problem. Yet it has been shown in Germany that a proportion of larvae contained in the cysts of the highly specialised oat strain are capable of penetrating the roots of beet, and that these larvae can be distinguished from the ordinary forms, which attack oats only, by their shorter length. It is a probable and generally accepted supposition that the specialised strains or races of *Heterodera schachtii* have arisen from a common unspecialised stock, and have acquired their specialisation as a direct adaptation to environment. That is to say, that following each successive generation produced upon any host plant, the worm tends to attack that particular host plant more readily, and other possible hosts less readily. Hence the greater frequency with which any crop is grown, the higher becomes the specialisation of the parasite for that particular host. In the potato strain this specialisation has become so intense that in some districts no other plant species can serve as host. Hence when potatoes are withheld from infected land the parasite gradually and very slowly dies out. It remains, however, always a matter for conjecture how far the specialisation has been carried in any one district. Some other plant, either cultivated or a weed, is quite liable to serve as a host under exceptional circumstances and slight infections of this sort are generally overlooked although they are sufficient to carry on the infection during a rotation period.

In certain districts of Ireland docks are attacked; in Lancashire, couch grass; in South Lincolnshire, *Chenopodium album*; and in Wiltshire, carrots have on one occasion been found to serve as a host. In other districts cysts which do not conform to the type produced on the potato plant have been isolated from the soil of potato fields although it has not been possible to discover on what plant they have been developed.

Whether in these cases the infection can be re-transferred to the potato, or passed on to some other cultivated host, is not known as the conditions governing host selection have not yet been fully investigated. It has been found, however, that in some districts, under special conditions, the potato strain of the eelworm will attack beet, hence it is of the utmost importance that sugar-beet should not be grown too frequently, and under no circumstances for two consecutive seasons upon land infected with the potato strain of *Heterodera schachtii*. A strain of the eelworm which very readily attacks beet, mangolds, cabbages and a large variety of weeds is known to exist already in western England. It is of interest that this strain does not attack potatoes. As yet it is not known whether, following reproduction upon an unusual host the parasite shows a loss of previously acquired specialisation, but if this proved to be the case occasional infections on weeds would assume an even greater importance.

In the main the researches carried out in Britain have been directed towards the discovery of some means of controlling the parasite. Towards this end three main lines of investigation have been followed. Firstly, methods have been sought for eliminating the eelworm from infected land. Secondly, variations in farming practice have been tried with the object of ensuring an occasional good crop of potatoes from land known to be infected. And thirdly, reasons for the alarming rate of spread of the parasite have been investigated.

The application of chemical substances to infected soil has given no evidence of control by elimination of the eelworm. In such instances better crops have been obtained following the use of chemicals, but this improvement has been due probably to a temporary effect, not on the parasite but on a second factor, which is probably nutritional. Some such treatment may yet be discovered which can be used on small areas of very valuable land, but for general purposes most substances which might be employed are prohibitively costly.

Good results have been obtained in eliminating eelworm by the use of grass excretions, but this method is still in the experimental stage. On infected "warp" land the eelworm is known to survive for more than ten years when potatoes are withheld and cereal and other immune crops are grown. In a field of this type the eelworms have been reduced by 48 per cent. in eighteen months by the use of a grass ley. By this method the eelworms are stimulated to hatch from the cysts, after which, in the absence of the potato plant, they die out. What effect this method will have upon the second factor concerned in the production of disease, remains unknown. It may well be that in some districts the eelworm may attack the grass, although this has not yet occurred in the experimental area. In any event it seems probable that at least four years will be necessary for anything like a complete elimination of the parasite, though the time will be strongly influenced by the type of soil.

With regard to the second method of approaching the control of the eelworm, it has been shown that after a four-year rest from potatoes certain types of land, such as that occurring in South Lincolnshire, will produce a satisfactory crop despite a high degree of eelworm infestation if adequately supplied with organic manure. Although the eelworm content of the soil is increased by the cultivation of potatoes, the change of cropping, coupled with the manuring, seems to eliminate the second disease-producing factor, in the absence of which eelworm has a comparatively slight effect in reducing the yield.

It has been estimated, from figures supplied by growers, that on rich land with a moderate eelworm content, but where a four-course rotation has prevented the symptoms of "potato-sickness" from appearing, a profitable yield of potatoes may be expected, although this may be from one to three tons per acre less than the yield from similar but uninfected fields. It is not known whether this four-course system can be repeated indefinitely with satisfactory results where very heavy infections exist, but it should prove successful in cases of moderate infection. Here again secondary factors such as type of soil and available organic manure are of considerable importance.

Heavy applications of farm-yard manure applied in the rows at the time of planting has given improved yields as compared with other methods of manuring, more particularly where artificial fertilisers are used alone. This method ensures that the first roots can make some growth before being attacked by the eelworms, which gives the plants a better chance of tolerating eelworm damage. It has been suggested that heavy manuring combined with early lifting would decrease the eelworm population of soil, provided the roots were collected and burnt, but in practice it has been shown that after such treatment the eelworm content of slightly infected soil is actually increased by at least 100 per cent. owing to the impossibility of removing all the roots.

As we see it, the present position with regard to the control of eelworm trouble on potatoes is that, pending the discovery of some method whereby the eelworm can be eliminated from infected land, the only measure which can be adopted by growers, to avoid financial loss upon the actual crops and grave damage to the land, is the consistent use of four, or preferably six-course rotation. If the use of the special grass ley now under trial proves satisfactory, it will be possible, at least in some districts, to use it in the rotation for one or two years to reduce the eelworm content of the soil more rapidly. The effect of enforced rotation in infected areas would not only lessen the financial loss sustained by the individual grower, but would check the depreciation of land values and would limit production.

With regard to the spread of eelworm throughout the country, investigations have shown that the most fertile source of distribution to new districts has been by the use of seed potatoes grown in infected land. Cysts have been found in the fragments of loose soil in potato bags and adhering to the tubers, in sufficient quantities to produce an appreciable infection in previously clean land within a single season. An average of seven cysts per tuber has been found in such a sample of seed, and as each cyst may contain several hundred eggs, the rapidity with which the eelworm has spread is amply accounted for.

If it is quite impossible to place restrictions on the sale of seed from infected land, it would surely be practicable to grant certificates to clean seed where these were applied for by growers. The recognition of *Heterodera schachtii* on the growing plant is an easy matter, and might well be undertaken by the horticultural inspectors of the Ministry. If supplies of certified clean seed were available from even a few firms of reputable growers, and greater publicity were given to the dangers of eelworm infection either in the daily press or weekly papers devoted to horticulture, sufficient interest would probably be aroused to check the spread of the disease. There can be little doubt that farmers and small-holders who have once suffered from infected land would welcome the possibility of guarding against the introduction of infection to clean land. It is hoped that a method of cleaning seed potatoes will shortly be available so that the demand for clean seed should not exceed the supply. The adoption of similar measures is being strongly advocated in Germany, although only a comparatively small area of that country is infected. In Sweden legislation has been carried out to prevent the importation of seed potatoes from countries known to be infected with the eelworm. Small areas of Schleswig-Holstein which were known to be infected with the potato strain of the eelworm were returned to pasture after the war through the action of the Danish Government, with the result that to-day there is no eelworm problem in Denmark. Are we to admit that the Danish agriculturist has the monopoly of foresight and of courage ?

UTILISATION OF EXCESS POTATOES ON THE FARM

By H. E. Woodman, M.A., Ph.D., D.Sc.
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When low prices rule for potatoes, and when even at such prices the markets are dull, it is advisable to consider how part, at least, of this crop may best be utilised for making good any shortage of feeding stuffs in other directions, as, for example, when the root crop has proved disappointing. Before any conclusions can be made, it is necessary to be quite clear about the composition of potatoes. In this way only can we decide what type of food is capable of being replaced by potatoes in the rations of live-stock.

Comparison of Potatoes with Swedes and Mangolds

The composition and feeding value of potatoes as compared with average swedes and mangolds are shown in the accompanying table :

	Potatoes per cent.	*Mangolds per cent.*	*Swedes per cent.*
Moisture	76.2	88.0	88.5
Albuminoids	2.1	1.0	1.3
Oil	0.1	0.1	0.2
Carbohydrate	19.7	9.4	8.1
Fibre	0.9	0.7	1.2
Ash	1.0	0.8	0.7
Dry matter	23.8	12.0	11.5
Starch equivalent	17.8	6.8	7.3
Protein equivalent	0.8	0.4	0.7

We note that potatoes contain about 76 per cent. of water and 24 per cent. of dry substance. By far the greater part of the food material consists of carbohydrate, the percentage of this constituent amounting to almost 20 per cent. It is noteworthy that potatoes contain only a small amount of protein and almost negligible amounts of fibre, oil and mineral matter. From these facts we learn that almost the sole function of potatoes in the ration is to furnish digestible carbohydrate. We must not rely on them to supply digestible protein and minerals. When feeding potatoes to live-stock, we must be careful to ensure that the ration also contains foods capable of providing the protein and mineral matter lacking in the potatoes.

If we examine the data in the table, we find that the food material of mangolds and swedes is very similar in character to that of potatoes. All these foods are rich in carbohydrate and poor in protein,

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oil, fibre and minerals. Potatoes, however, contain rather more than twice the amount of carbohydrate found in swedes and mangolds. Weight for weight, therefore, potatoes have rather more than twice the feeding value of swedes or mangolds, a comparison which is further borne out by a consideration of the percentages of dry matter and starch equivalent in these foods. The stockfeeder will not be far wrong if he regards 1 lb. of potatoes as the equivalent of 2 lb. of swedes or mangolds when he wishes to feed potatoes in the place of roots. This is, however, a deliberately cautious estimate, for the evidence of the starch equivalents really signifies that 1 lb. of potatoes should be equal to about 2½ lb. of roots.

I have said that the food constituents in potatoes and roots are very similar in nature. There is one important distinction, however. The carbohydrate in potatoes is almost wholly in the form of starch, whereas in swedes and mangolds it takes the form of sugar. From the feeding standpoint, I regard this difference as a point in favour of potatoes, since sugar has only three-quarters the fattening value of starch. The reason for this is that sugar, owing to its soluble character, suffers a greater degree of destructive fermentation by bacteria in the paunch of sheep and cattle than does starch.

Nature of Albuminoids in Potatoes

I ought at this stage to call your attention to certain peculiar features of the albuminoid constituent of potatoes, peculiarities which are shared also by the nitrogenous components of roots. We have seen that potatoes contain 2.1 per cent. of crude protein or albuminoid, of which, as can be demonstrated by animal experiment, 1.1 per cent. can be digested and utilised by farm animals. But of this small amount of digestible albuminoid, only 0.6 per cent. consists of the kind of true protein we find in milk, meat or egg-white. The remaining 0.5 per cent., that is to say, almost half of the digestible albuminoid in potatoes, consists of nitrogenous substances of much simpler nature than protein. The chemist knows them under such names as asparagine, amino acids, ammonium compounds, etc., and mistakenly groups them together under the name of " amides."

In order to understand completely the nutritive properties of the potato, we must inquire into the feeding value of these so-called " amides." The case of the potato has been satisfactorily settled by the Scandinavian chemist, Hindhede, who, by feeding experiments over long periods, has demonstrated that the assimilable albuminoid of potatoes is an extremely valuable type of protein for repairing and building up body tissue. Experiments in Denmark have led to the conclusion that when dairy cows are fed on rations containing the correct requirements of starch equivalent and digestible protein, almost 90 per cent. of the " amides " in the food are built up in the animal into milk protein. In Germany, Morgen has proved that if asparagine, a typical food amide, be added to a ration containing sufficient energy or starch equivalent, but deficient in digestible protein, then it can serve not only for maintenance of the dairy cow, but also for milk production. At a later date, his fellow-countryman, Honcamp, obtained the surprising result that it is possible to replace part of the true protein in the rations of dairy cows by an amide like urea without seriously affecting milk yield. This savours of the magical when we remember that urea arises normally in the body as a waste product from protein breakdown and has to be eliminated through the kidneys into the urine.

In this country we have solved the question by means of what I may term "committee research" (as distinct from experimental inquiry). We have agreed to assume that the "amides" have a nutritive value equal to half that of digestible true protein. The so-called protein equivalent is the digestible true protein plus half the "amides." For potatoes this amounts to 0.8 per cent., and this, therefore, is the figure that should be used when assessing the contribution of potatoes to the digestible protein content of the ration.

The manner of utilisation of these "amides" is of interest. The bacteria which flourish in the paunch of the ruminant, and which incidentally are responsible for the digestion of fibre, develop and multiply at the expense of the nitrogen in these "amide" substances. By this means, "amide" nitrogen is built up into the protein of the bacteria, and on the decease of the latter, the so-called "bacterial protein" undergoes digestion like ordinary food protein, thus administering to the maintenance and production requirements of the animal.

I trust I have not dwelt too long on this peculiar feature of potato composition. In actual feeding practice, I do not think it has any great significance, because, as I have already pointed out, potatoes should be fed for the carbohydrate that they contain, and the stock-feeder should look to the other ingredients of the ration to supply the necessary digestible protein.

Comparison of Potatoes with Cereals

And now to come back to more practical issues. We have seen that potatoes belong to the class of carbohydrate-rich foods and as such may be fed in replacement of roots. But how do they compare with that other important class of carbohydrate foods, namely, the cereals, such as wheat, barley and maize? If we examine the composition of the dry substance of potatoes, we find that the main distinction between potatoes and cereals is largely a matter of moisture content. On the basis of dry matter, maize for example contains about 80 per cent. of carbohydrate, mainly as starch, and about 11.4 per cent. of protein, whereas potatoes contain about 83 per cent. of carbohydrate, also mainly as starch, and about 9 per cent. of protein. Both maize and potatoes are poor in fibre and minerals. Obviously we may regard the dry food substance in potatoes as being similar to the food material in the cereal grains.

Potatoes are, in fact, " watered " carbohydrate concentrates. They may be used, therefore, as a substitute for barley and maize, as in the rations of pigs, in which case it is important to remember that 1 lb. of cereal meal is equal to 4 lb. of potatoes. Incidentally, the more general use of potatoes in pig rations should enable our huge imports of maize to be cut down very considerably.

Vitamins in Potatoes

I may mention here that a very satisfactory feature of the composition of potatoes is their richness in the anti-scorbutic vitamin C. This renders potatoes peculiarly suitable for inclusion in the rations of farm animals during the non-grazing winter season. They also contain small amounts of vitamins A and B. The cooking of potatoes reduces slightly their vitamin potency, but even in this condition they are quite a good source of these accessory factors, particularly of vitamin C.

Precautions in the Use of Potatoes for Live-stock

Before passing on to illustrate in detail how, and in what amounts, potatoes may be included in the rations of the different classes of live-stock, it will be as well if I call attention to certain precautions which should be observed when potatoes are being utilised in this way.

(1) Only clean, sound potatoes should be used for feeding. Dirty or rotting potatoes should be rigidly excluded, since they may cause internal irritation and give rise to inflammation of the linings of the digestive tract. This danger is particularly to be feared with young animals, especially in pig-feeding.

(2) Raw potatoes, even when clean and in sound condition, are slightly acrid and bitter in taste, and have a laxative action on the bowels of the animal. If large allowances of raw potatoes are included in the rations of live-stock, therefore, digestive troubles such as " blowing " and " scouring " may result, and for this reason, especially in pig-feeding, many feeders prefer to cook or steam potatoes if more than small amounts are to be fed. This improves palatability and renders them a safer food by reducing their laxative character. Indeed, cooked potatoes have, if anything, a slightly constipating action. The water draining away from the potatoes after cooking should preferably not be used, because its inclusion increases the liability to digestive troubles.

(3) Raw potatoes are frequently fed whole, but many feeders prefer to put them through the root slicer before use, thereby eliminating risk of choking. The important point to remember is that the daily allowances should at first be small, the amount being increased gradually to a maximum which should never err on the side of excess. They should on no account be fed *ad libitum*

(4) In my opinion, although this might not be admitted generally, it is inadvisable to use raw potatoes at all for very young stock. Neither should I use raw potatoes in more than moderate amount for animals in the later stages of pregnancy, although again I am prepared for a division of opinion on this point.

(5) When potatoes have sprouted during storage, the sprouts should in no circumstances be fed to live-stock, as they contain a poisonous substance known as solanine, a compound which appears to form a connecting link between the saponins and the alkaloids. This poison seems to be a regular constituent of all parts of the potato plant, the tubers containing about 0.01 per cent. Although the amount does not increase when the potatoes are stored, or when they decompose, the substance passes in large quantities into the young shoots when the tubers germinate, so that the sprouts may contain as much as 5 per cent. This means that the young shoots should not on any account be used in feeding. The same risk attaches in smaller degree to tubers that have turned green under the action of sunlight. If such tubers are to be fed to stock, they should be boiled before use to extract the solanine and the water allowed to drain away. It is safer, however, to avoid the use of such greened potatoes as far as practicable.

We may now go on to consider in more detail how potatoes may best be used in the feeding of live-stock, and because cattle are the least sensitive to the laxative action of raw potatoes, we will first deal with their use in the fattening of mature bullocks.

Potatoes in the Fattening Rations of Store Beasts

If the precautions I have enumerated are given due consideration, there is no reason why the allowance of raw potatoes in the fattening rations of store beasts should not be increased up to about 40 lb. per head. This is equivalent to a swedes allowance of about 80 lb. The potatoes should preferably be sliced, and care should be taken to ensure that only small quantities, say 5 to 7 lb. per head, should be given at first, the amount being increased gradually to the maximum. I do not advise going beyond the 40 lb. limit, although if the potatoes are steamed before use, rather bigger amounts can be fed with safety. The rest of the ration should consist, as when using roots, of the usual allowances of oil cake and hay or straw, with possibly some cereal to make up the full requirement of starch equivalent. The animals should also be provided with a salt lick, both for the sake of the mineral and for increasing palatability. German authorities recommend oil cakes with a sedative action, such as linseed cake or coconut cake, but many Lincolnshire feeders prefer to take advantage of the astringent qualities of cotton cake to counterbalance the laxative action of the potatoes.

Potatoes in " Baby Beef " Rations

That potatoes can be used with advantage in the rations of " baby beeves " seems clear from the following experience. A few years ago I was given the " finishing " ration of a farmer who was described as the best feeder of " baby beef " in Lincolnshire. I was not informed of the gentleman's name, so that I cannot " hold him up to honour " on this occasion. Being a Lincolnshire farmer, however, he may be with us to-day. We shall learn this perhaps when the time for discussion arrives. Indeed, I feel sure he will be found to be present, probably several times over !

The ration consisted of 7 lb. rye grass and clover hay, oat straw chaff *ad lib.*, 3 lb. sugar beet pulp, 1 lb. each of bean meal, ground oats, crushed wheat and linseed cake, together with 56 lb. of raw potatoes. I must confess I was surprised to note the heavy allowance of raw potatoes in the ration, but we must bear in mind that this was Lincolnshire feeding. Since an ounce of experience is said to be worth several tons of theory, I think we may safely conclude that raw potatoes may be used in the production of " baby beef." I should be inclined to counsel moderation, however, in their use for this purpose.

Potatoes in the Rations of Dairy Cows

In the feeding of dairy cows, raw potatoes may also be used, but in greater moderation than with fattening cattle. We recall in this connection the recent controversy about the feeding of roots to dairy cattle. The " breeze " of this controversy has at least served to clear the air, and it can now be stated that roots are a very serviceable ingredient of a cow's ration if restricted to about 40 lb. per head per day. Now 40 lb. of roots are equal to about 20 lb. of potatoes, and I regard 20 lb. of raw potatoes as a suitable maximum for dairy cows. Starting with 5 to 7 lb. of sliced potatoes, the amount may be gradually increased to about 20 lb. Excessive feeding of raw potatoes, however, must inevitably lead to " blowing " and other digestive disturbances, with consequent lowering of milk yield. For this reason, it is important to control the feeding of potatoes indoors rather than to cart them to the field and spread them on the pasture.

Owing to the absence of the yellow pigment, carotene, potatoes are inclined to give milk and butter of pale colour, but the milk will not suffer in other respects provided the rations are properly balanced. I should not be inclined to recommend the too liberal use of potatoes on cream and butter farms, unless it is possible also to feed pigmented food such as kale, cabbage or carrots to counteract the effect of the potatoes.

Before leaving this phase of the subject, I feel sure you will be interested in the following dairy rations recommended by Mr. J. Mackintosh, of the National Institute for Research in Dairying. They illustrate very clearly how potatoes may be used in the feeding of this class of live-stock.

Rations including Potatoes for Dairy Cows

(1) For maintenance only:

(a) Hay	12-14 lb.	(b) Hay	7-10 lb.
Roots	20 lb.	Oat straw	5 lb.
Potatoes	12 lb.	Roots	28 lb.
		Potatoes	14 lb.

(2) For maintenance plus first gallon:

(a) Hay	14 lb.	(b) Hay	10 lb.	(c) Hay	7 lb.
Roots	35 lb.	Oat straw	5 lb.	Oat straw	5 lb.
Potatoes	15 lb.	Kale or cabbage	30 lb.	Beet pulp	6 lb.
Dec. ground nut cake	1 lb.	Potatoes	12 lb.	Potatoes	15 lb.
		Soya bean meal	1 lb.	Dec. ground nut cake	1½ lb

Potatoes in the Feeding of Sheep and Horses

I cannot speak from personal experience of the feeding of potatoes to sheep, but Kellner, the German authority, states that sheep can take raw potatoes almost as well as cattle. He recommends the feeding to fattening sheep at the rate of 4 lb. of raw potatoes per 100 lb. live-weight. Since 4 lb. of potatoes are equal to 8 lb. of roots, you will note that with such an allowance, there is still room in the ration for some roots or kale in addition to the customary small allowances of hay and concentrated supplement. Potatoes are also sometimes carted to the flock on pasture and fed in the raw, whole condition. If any of my listeners are in the habit of using potatoes for sheep-feeding, I should be very interested to hear of their experiences at discussion time.

I do not consider raw potatoes a suitable food for horses, since their digestive system is likely to be upset very easily by such a food. It is interesting to note, however, that certain authorities assert that small quantities of potatoes, say 3 to 5 lb. per head per day, have a beneficial effect on condition. I think I am right in stating, however, that the best feeders look askance on the feeding of raw potatoes to horses.

Potatoes in Pig Rations

I need not say much about the feeding of potatoes to pigs, since this is an old-established custom. The function of potatoes in this connection is to replace part of the carbohydrate food such as barley meal or maize meal, the replacement being based on the finding that 4 lb. of potatoes are equivalent to 1 lb. of meal. It is always advisable to cook or steam potatoes before feeding them to pigs. These animals have a relatively small and simple digestive tract and are readily liable to digestive disturbances from the use of more than small amounts of potatoes in the raw condition. I am aware that numbers of feeders use raw potatoes in the case of in-pig sows, but even with sows, my own preference is for cooked potatoes. I may point out that the almost negligible oil content of potatoes renders them a suitable food for baconers. In these days of bacon schemes, it is perhaps advisable to avoid the use of foods containing more than a small percentage of oil. As examples of how cooked potatoes may with advantage be employed in pig-feeding, I need only quote the following rations suggested by Principal W. A. Stewart, of the Northampton Farm Institute.

Rations including Potatoes for Pigs

(1) Weaners:		(2) Early Stage of Fattening:		(3) Later Stage of Fattening:	
Barley meal ..	¼ lb.	Barley meal	1½ lb.	Barley meal	2½lb.
Potatoes ..	4 lb.	Potatoes	6 lb.	Potatoes	10-12 lb.
Weatings ..	1 lb.	Weatings	1½ lb.	Weatings ..	1½ lb.
Fish meal ..	¼ lb.	Fish meal	½ lb.	Soya bean meal	¾ lb.

(4) In-pig Sows:		(5) Sows in Milk:	
Potatoes	8-12 lb.	Barley meal	2 lb.
Weatings	1½ lb.	Potatoes	8 lb.
Fish meal	¼-½ lb.	Weatings	4 lb.
		Fish meal	1 lb.
		Soya bean meal ..	1 lb.

Conservation of Potatoes

In this final section I should like to deal very briefly with certain methods whereby surplus potatoes might be conserved for feeding at a later date. This may be done on a farm scale by the method of ensilage and on an industrial scale by artificial drying.

Ensilage of Potatoes

Ensilage of potatoes is conveniently carried out in the stack in conjunction with grass or other green crop, alternating a 3 ton layer of grass or green clover with a 1 ton layer of whole potatoes, preferably the small, unsaleable tubers. Owing to the heat engendered in the storage, the potatoes come out in a floury, semi-cooked condition. I was very agreeably impressed with the results of a trial of this kind which I saw carried out a few years ago, and I am confident that the process offers great possibilities. The protein-rich character of the grass, if mown at the correct stage, is balanced against the carbohydrate-rich nature of the potatoes.

Artificial Drying of Potatoes

The practice of artificially drying the surplus potatoes is now practised widely on the Continent. Two methods are in use, the first for the production of potato slices and the second for potato flakes. I am not aware that these processes have been taken up on any scale in this country. If they have not, it is to be regretted for the following reasons: (1) Artificial drying enables the small tubers to be disposed of profitably, and is a means of carrying over a surplus of potatoes from one season to another. (2) It would forge another link between agriculture and industry and give employment to many workers. The dried potatoes so produced would lead to a reduction of our imports of maize. (3) The dried product is in a convenient form for transport and storage. It is more palatable than raw potatoes and constitutes a safer food. It can therefore be fed more liberally to livestock. Fattening cattle can be given up to 10 or 12 lb. per head per day, and even horses, which are very sensitive to raw potatoes, can have up to one-third of their corn ration replaced by dried potatoes.

The product may replace other carbohydrate foods according to the following scheme ; 1 lb. dried potatoes = 1 lb. wheat = 1lb. barley $= \frac{9}{10}$ lb. maize $= 1\frac{1}{5}$ lb. oats $= 1\frac{1}{5}$ lb. dried beet pulp $= 1\frac{1}{5}$ lb. molassed beet pulp.

Alcohol from Surplus Potatoes

By the terms of reference, I have been limited to considerations of a nutritional nature in dealing with the disposal of surplus potatoes. For that reason I have not referred to the many industrial processes in which the humble potato might play an honourable rôle. Amongst the brightest of these possibilities is the use to which potatoes might be put in the production of alcohol. I do not necessarily mean alcohol for consumption purposes, but power alcohol. I am told that there is already a strong movement in this direction, and as members of the great agricultural community of this country, we give this movement our blessing. We look with favourable eye on all proposals which have as their object the betterment of the farmer's lot in these stirring, though still difficult times.

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RECENT FERTILISER EXPERIMENTS ON POTATOES

By E. M. Crowther, D.Sc., F.I.C.
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The art of field experimentation has now reached the stage of development at which it may be applied with confidence and with advantage to examine the behaviour of fertilisers on crops grown commercially on ordinary farms. It is no longer necessary to treat the results of properly conducted field trials with the cautious reserve with which one examines the photographs in the seedsman's catalogues or on the trade stands at agricultural shows. Only the more striking of the older trials and demonstrations received publicity. In many of the trials at experiment stations the conditions were made abnormal, as *e.g.* in the continuous crop experiments at Rothamsted, in order to make the results clear enough to swamp accidental irregularities of soil, season and pests. Farmers were naturally suspicious of applying the results of such experiments and demonstrations to their own land and they tended to rely on compound fertilisers which had proved their value for many years over a variety of soils. One or other of the constituents in these mixtures could generally be relied on to push up the yield and the belief grew up that there was some special virtue in a "properly balanced fertiliser" over and above the obvious one that it covered the risk of making mistakes by one-sided manuring. It must, however, be realised that experience and rough trials with compound fertilisers fail to show which ingredient is in fact effective. They therefore fail to give information which can be used to relate manuring practice to the results of soil survey or analysis.

The modern field experiments, which were first used on several commercial farms in 1927, have the supreme advantage that they show their own accuracy and reliability. Failure to get a significant response does not in any way mean that the experiment has failed, for it is always possible to say how large the effect would need to be before it could be detected. Insignificant responses in accurate experiments suggest that economies could be effected by reducing the amount of the ineffective fertiliser.

The present paper reviews the results of some fifty experiments conducted in the years 1927 to 1933 on ordinary commercial main-crop potatoes on a wide variety of soils—sands, silts, loams, clay loams, light and heavy fenland peats, acid peats, etc. The detailed results of all of the experiments are in the Rothamsted Reports for these years. In rather less than half of the experiments dung was used as a basal dressing, but it is not possible from this series of experiments to assess the value and effects of the dung in these

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basal dressings. Dung was used where it was available and where experience showed that it was needed. It was not used on many of the richer fenland soils.

Frequency of the Responses in Yield

The experiments varied greatly in size, complexity and accuracy. Many were simple 16- or 25-plots experiments testing different amounts of superphosphate. More complex ones had 36 or 81 plots to test different amounts and combinations of nitrogen and potash and a few had 27, 36 or even 162 plots to test all three nutrients. It is not possible therefore to give any satisfactory general average of the responses. The most concise summary is obtained by setting out (a) the numbers which gave signficant responses (or depressions) for each fertiliser and (b) the numbers in which the effect was not larger than could easily have occurred purely by chance variations.

The results are shown for the experiments as a whole and also for a special group of highly organic fenland soils. Every experiment undertaken is included ; there has been no selection or elimination

Significant responses to fertilisers

Nutrient	*Soil*	*Negative*	*Insignificant*	*Positive*
Nitrogen	Fen ..	—	2	11
	Others	—	3	16
	Total (32)	—	5	27
Phosphoric Acid ..	Fen ..	—	—	8
	Others	2	17	13
	Total (40)	2	17	21
Potash	Fen ..	—	5	9
	Others	—	14	8
	Total (36)	—	19	17
INTERACTIONS :	N and P_2O_5	1	9	6
	N and K_2O	—	19	4
	P_2O_5 and K_2O	—	16	1

In 90 per cent. or more of the trials there was a definite response to sulphate of ammonia. Fenland soils, which are rich both in total and in available nitrogen, responded to sulphate of ammonia just as frequently as the mineral soils.

Each of eight fenland soils responded to superphosphate, but only in 13 out of 32 trials did the mineral soils give significant responses to superphosphate. In two experiments superphosphate definitely reduced the yield. In three experiments on acid peat—" moss " soils in Lancashire—there was no phosphate response. It is clear then

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that fenland soils stand out quite distinctly from other soils in their need for phosphate, as is, of course, well recognised in practice.

In 36 potash trials one half gave definite responses, with some indication that fenland soils were more responsive to potash than mineral soils. In so far as the soils tested in these experiments were typical, they show that sulphate of ammonia is almost always effective and that superphosphate is effective on fenland soils. Superphosphate on mineral soils and potash on all soils are much less consistently successful in increasing yield.

Some evidence on " balance " in fertilisers may be obtained from experiments where two fertilisers were tested both alone and together. If one fertiliser increases the effectiveness of a second fertiliser, then the response to the mixture should be greater than the sum of the responses to the separate fertilisers. It is unlikely that any such interaction will be detected unless one or other has a marked effect when used alone. If a soil is acutely deficient in potash it may not show a nitrogen response until the potash deficiency is corrected ; nitrogen and potash might then show a positive interaction. If, however, both fertilisers have marked effects then it is unlikely that the two together will have a much greater effect than the sum of the two separate effects, for yields cannot be pushed up indefinitely. The experiments show that sulphate of ammonia and superphosphate quite often " interact positively," i.e., they frequently reinforce each other's effect. Thus in 6 out of 16 trials the response to sulphate of ammonia in the presence of superphosphate was significantly greater than that in the absence of superphosphate, or, alternatively, the response to superphosphate was greater in the presence of sulphate of ammonia than in its absence. This harmonises with the striking effects of superphosphate on fenland soils, for these are known to be rich in available nitrogen. The interactions of nitrogen and potash and of potash and phosphate were much less frequent. Positive significant effects were obtained 4 times out of 23 for nitrogen and potash and only once in 17 trials for potash and phosphate.

Size of the Responses in Yield

So far no notice has been taken of the sizes of the response. Field experiments are rarely accurate enough to detect as significant responses which would be too small to be profitable but, on the other hand, apparently large and profitable increases in small experiments may be essentially accidental results. In most of these experiments the standard error per plot was about 15 cwt. per acre and a response of 1 ton per acre would be detected as significant in an experiment with 16 or 25 plots. The size of the responses in the present series of experiments may be illustrated by setting out the responses to certain standard dressings which occurred in most of the experiments:
N=0.4 cwt. N per acre or 2 cwts. of sulphate of ammonia per acre.
P=0.6 cwt. P_2O_5 per acre or 4-5 cwts. of superphosphate per acre.
K=1.0 cwt. K_2O per acre or 2 cwts. of sulphate of potash per acre.

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		Decrease		*Increase*						
Response in cwt. per acre ..		20-10	10-0	0-10	10-20	20-30	30-40	40-50	50-60	*Over* 60
Nitrogen ..	Fen Soils	—	1	1	1	1	6	2	—	1
	All Soils	—	3	3	5	7	9	3	1	1
Phosphoric Acid	Fen Soils	—	—	—	1	2	2	1	2	—
	All soils	3	9	8	7	4	5	2	2	—
Potash	Fen soils	1	3	1	3	2	—	—	2	2
	All soils	1	7	11	7	4	—	—	3	3

The comparisons are restricted to plots which received the other two nutrients with and without the one under test. The results are set out by showing the number of experiments in which the response in cwts. of potatoes per acre was from 0 to 10, 10 to 20, and so on. The actual responses are subject to large and unequal errors but the results as a whole are clear enough to illustrate the main features.

The responses to 2 cwts. of sulphate of ammonia per acre were between 1 and 2 tons of potatoes per acre in just one half of the experiments, and the other results are grouped round these values, some above and some below, in such a way as to make it possible to speak of a general nitrogen response at the rate of about 15 cwts. of potatoes per cwt. of sulphate of ammonia.

The responses to superphosphate were much less consistent. In over one-quarter of the trials the superphosphate plots yielded less than those without superphosphate. Only in one-third of the trials did the response exceed 1 ton per acre ; these more responsive centres included 7 of the 8 fenland trials and only 6 of the 32 trials on other soils. Phosphate response obviously depends on the soil.

The responses to potash were even less consistent than those to superphosphate. At half of the centres the responses were less than 10 cwts. of potatoes per acre. 30 of the 36 trials fall into a consistent group with small responses but the other six centres (4 on light fenland soils and 2 on light sands) show enormous responses of about 3 tons per acre. In isolated soils potash fertiliser doubled the crop. Some soils have an acute potash shortage whilst the majority of potato soils show only slight effects in yield. The common recommendation of potash for potatoes would appear to be mainly an insurance against the chance of acute shortage of potash, but the general use of compound fertilisers provides no opportunity for detecting the soils which are acutely deficient in potash.

Although responses to sulphate of ammonia are general, responses to superphosphate and potash obviously vary greatly from soil to soil. Efficient manuring must take account of these soil differences.

It may be noted that the Rothamsted experiments of 1927 to 1932 which are included in the above summary gave much smaller responses to potash fertilisers than had been obtained on the same farm from 1921 to 1926. The explanation may be that in the earlier years little stock was kept and little dung was used on the farm. Further, in several years of the earlier period the experiments on potatoes had no dung but received large dressings of fertilisers. In the later years the potatoes always had a basal dressing of dung and the experimental dressings of fertiliser were smaller. The results of the earlier experiments are given in Sir John Russell's Bulletin 28 of the Ministry of Agriculture, Second Edition, 1933, page 154.

Potato Quality and Composition

In this country there have been few systematic studies of the effect of fertilisers on potato quality. On the Continent, where potatoes are used as industrial raw materials for starch or alcohol production, it is customary to quote "starch percentages" in fertiliser trials or to express the yields as starch per acre instead of as tons of fresh tubers per acre. Actually the data express only densities or dry matter contents ; they are determined not by chemical analysis but by weighing the samples in air and then in water and using standard tables. The results have little bearing on "cooking quality" and in any case "cooking quality" is a matter of taste which varies from country to country. There is some evidence that good boiling or steaming quality depends on a high ratio of starch to protein or alternatively on a low nitrogen percentage on the dry matter.

In 1929 Rothamsted had an opportunity of collaborating with Dr. Lampitt of Messrs. Lyons who undertook careful cooking trials and chemical analyses on the produce of all of our experimental plots. Rothamsted continued the analytical work in the subsequent years.

Marks for Quality of Steamed Potatoes (1929)

Cwts. K_2O per acre	*Woburn*	*Rothamsted*	*Cwts. N per acre*	*Woburn*	*Rothamsted*
0	32.6	28.5	0	34.4	29.2
0.5	33.6	29.5	0.3	33.3	29.3
1.0	34.5	29.6	0.6	32.9	29.1

Effect of Potash Fertilisers on Dry Matter Contents of Tubers

	No Potash	*Sulphate*	*Muriate*	*30 per cent Potash Salt*	*Rate of Dressing cwts. K_2O per Acre*
Woburn 1929	27.5	26.7	26.2	24.8	1.0
Rothamsted 1929	26.1	25.9	24.9	24.2	1.0
,, 1930	23.1	23.3	22.7	22.1	0.8
,, 1931	20.9	20.5	20.2	20.2	0.8
,, 1932	22.6	22.1	—	—	0.8

Effect of Sulphate of Ammonia on Nitrogen Content of Dry Matter of Tubers

Rate of Application, cwts. per acre	0	1	1.5	2	3	4
Woburn 1929	1.44	—	1.49	—	1.54	—
Rothamsted 1929	1.52	—	1.58	—	1.65	—
,, 1930	1.34	1.40	—	1.47	—	—
,, 1931	1.40	1.41	—	1.46	—	—
,, 1932	1.28	—	—	1.35	—	1.43

Unfortunately 1929 was a drought year and our yields were low and irregular. The cooking quality tests were probably more irregular than would be obtained in more normal years. They showed that fertilisers had no effect on quality for frying and that sulphate of ammonia slightly decreased and potassic manures slightly increased quality for steaming. The effects of fertilisers were, however, small by comparison with the effects of different soils. It was impossible by manures to raise the quality of our Rothamsted potatoes to the level of our Woburn potatoes. There were no clear results on the relative values of sulphate and chloride of potash.

The analytical data for experiments in four years at Rothamsted and one year at Woburn show that potash fertilisers reduce the dry matter contents of the fresh tubers, especially in dry seasons. Sulphate of potash had little effect, muriate of potash had more and 30 per cent. potash salt much more.

Sulphate of ammonia consistently increased the nitrogen content of the dry tuber. Superphosphate reduced the nitrogen content of the dry tuber in those years in which it greatly increased the yield. Potash had no effect on the nitrogen content of the dry tuber.

Although the potato is essentially a carbohydrate food it is interesting to observe that it is an efficient crop for converting inorganic nitrogen—sulphate of ammonia—into vegetable protein. The recoveries in the potato tuber of the nitrogen added as sulphate of ammonia in the Rothamsted experiments of 1929 to 1932 were 21, 43, 29, and 36 per cent. respectively ; in addition 20 per cent. may be recovered in the haulm.

The results already available suggest that the effects of fertilisers on potato composition are relatively small and unimportant unless there is a wide price range for quality or unless fertilisers are used in very heavy dressings.

Future Experiments

The experimental data presented are admittedly incomplete and need to be supplemented by very many more field experiments, both by simple experiments on the direct effect of fertilisers on commercial farms and by more complex experiments at research stations and colleges. Farmers with heavy fertiliser bills might find that an adequate fertiliser trial would point the way to considerable economy and to greater efficiency. Other farmers might find that comparatively small outlay on the proper fertilisers would greatly

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increase their returns. It is possible that our tests were made on land of more than normal fertility and that in practice good responses would be obtained more frequently. Now that there is to be a national body to effect economies in marketing it would be well to consider whether there is not room for more systematic enquiry on economies in production. Each good field experiment has general as apart from purely local value, for up to the present little headway has been made on the old and fundamental problem of relating fertiliser practice to the results of soil examination. The problem can only be studied seriously where there is a mass of reliable field information to provide standards for testing the value of methods before they are used for advisory work. If the results are to have value in practice they must be standardised in practical terms on typical commercial land.

Analytical results for readily soluble potash in soils from some of the 1932 and 1933 potato experiments already discussed may be quoted to illustrate the possibility of detecting acute deficiences by analysis.

Amount of Potash Soluble in one per cent. Citric Acid
(parts per 100,000 of soil)

	Mineral Soils	*Fenland Soils*
Soils with large potash responses (2 tons per acre or more)	4	8, 10, 12, 15
Soils with small or no potash response ..	12, 17, 19	21, 28, 34, 38

Although there is a certain amount of overlapping there can be no doubt that this or some other improved method of soil analysis could be used with advantage to detect cases of acute potash shortage.

The experiment stations need to concentrate on more complicated experiments which are at present beyond the resources of the commercial farm. Thus, they must study not merely the effects of fertilisers and organic manures in a single year but also the residual effects over several years. Again, they should provide standard experiments which should run year after year to ascertain how far the responses to fertilisers on a single soil vary from season to season. We have already experiments of both of these types at Rothamsted with one of the latter type running parallel at Woburn. The results of the first four seasons are already interesting. Thus, potatoes responded to potash on heavy land at Rothamsted in three of these four seasons but not in any one on light land at Woburn. On the other hand both barley and sugar beet responded in two seasons at Woburn but not in any one at Rothamsted.

A number of such standard experiments would provide a basis for interpreting the results of isolated experiments on ordinary farms and, in addition, they would throw light on the still more important problem of discovering the conditions under which fertilisers act and the way in which the plant feeds.

SOME FERTILISER EXPERIMENTS WITH POTATOES ON FENLAND SOILS

By H. V. Garner, M.A.

(*Rothamsted Experimental Station*)

Thanks to the active co-operation of certain fenland farmers it has been possible in recent years to conduct a series of replicated trials with fertilisers on the potato crop on a number of black soils. The cultivation of the crop has been entirely in the farmers' hands, while the scheme of manuring and the experimental details have been carried out by members of the Rothamsted Staff. The design of the experiments have been such as to enable a valid estimate of the experimental error to be made, and in most cases several levels of the nutrient in question have been tested in the same experiment both alone and in combination with other manures. The trials have been carried out on fifteen fields comprising the following types of soil (1) Deep black land artificially clayed. (2) Black soil almost touching the clay at deep plough depth. (3) Light blowy fen. (4) Black soil grading into silt. A small beginning has thus been made to explore by the new experimental technique the vast and very varied district in which the potato forms the chief crop. The one fertiliser that is in universal esteem in this district is superphosphate. Many farmers consider this to be enough in itself, but an increasing amount of compound fertilisers containing a proportion of the other nutrients, nitrogen and potash, are coming into use. The quantitative effects of these manures, including superphosphate itself does not appear to have been accurately ascertained on a range of soils in the past ; so that the results of these preliminary trials may be of interest. It will be convenient in the first place to discuss the results obtained with the three nutrients in turn.

The Effect of Superphosphate

Eight experiments bear on this point, 6 of them testing superphosphate in an ascending scale of dressings. In every case the increase in crop following the use of superphosphate has been significant (i.e., the observed increase would not occur by chance more than once in 20 trials). The effect is therefore very general and even including the highest dressings the average performance of superphosphate is an increase of nearly 8 cwt. of potatoes for each

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1 cwt. of fertiliser used. The most responsive centres were at Little Downham on a clayed land of excellent quality ; and land of somewhat similar type at Stow Bridge where handsome increases were obtained by increasing the dressing from 5 cwt. to 10 cwt. per acre. On the lighter and poorer soils there is evidence that some falling off in effectiveness of the phosphate occurs after the level of 5 cwt. has been reached.

The Effect of Nitrogen

Nitrogen was tested in 13 experiments and in three of these increasing levels of sulphate of ammonia were included. The yield of potatoes was increased significantly by sulphate of ammonia in 11 of these experiments. The average effect in all trials expressed on a basis of 1 cwt. of sulphate of ammonia was an increase of nearly 15 cwt. of potatoes per acre. At the three centres at which the effect of increasing applications of sulphate of ammonia were examined there was distinct signs of falling off in effectiveness on increasing the sulphate of ammonia from the 2 cwt. to the 4 cwt. level. The increments due to sulphate of ammonia were most marked on the soils of rather heavy character ; those either clayed artificially, or having clay or silt near the surface. The lighter soils gave slightly smaller but very profitable increases.

It appears therefore that both nitrogen and also phosphate give their biggest effects on the heavier soils.

The Effect of Potash

There were 14 experiments involving potash, four of them testing increasing levels of sulphate of potash. Although nitrogen and phosphate showed some signs of different behaviour on the different soils, their action could nevertheless be fairly considered as a whole taken over all soils.

This is not the case with potash so far as these experiments are concerned. On the five heavier soils only one significant response was obtained and this was on the silty fen. At the nine other centres of distinctly lighter or more peaty character eight gave strong and significant responses to potash. At these responsive centres the average increase per 1 cwt. of sulphate or muriate of potash amounted to 18 cwt. of potatoes. At the other five centres it was practically nil.

Interactions

Hitherto we have measured the effect of a manure by its average performance taken over all combinations actually tested. More detailed examination shows that the effectiveness of a manure usually depends on the presence or absence of other fertilisers. Fortunately so far as our results with potatoes are concerned, the fertilisers usually tend to reinforce each others' effects. The effect of (say) nitrogen and phosphate used together is usually greater than the sum of the effects of each fertiliser used alone. In some of these experiments these interactions have been definitely significant.

	Tons per acre		
	Used alone	*Used with Sulphate of Ammonia*	*Difference (interaction)*
Increase due to Superphosphate.			
Little Downham 1932	2.96	4.40	1.44 ± 0.71
March 1932	1.03	1.92	0.89 ± 0.24
Increase due to Sulphate of Potash			
Thorney 1932 (no dung)	3.49	4.78	1.29 ± 0.52
Thorney 1933 (dung)	0.74	2.19	1.45 ± 0.52

This type of result is observed in greater or less degree in most of the experiments and constitutes an argument in favour of complete fertilisers.

The above series of experiments indicate that the Fenland soils so far examined give handsome responses not only to superphosphate but in most cases to sulphate of ammonia, while the soils containing little clay respond excellently to potash also. These fertiliser effects tend to reinforce each other when mixed manures are used.

THE RAISING OF BLIGHT-RESISTANT VARIETIES AND VIRUS-FREE STOCKS

By Redcliffe N. Salaman, M.D., M.A.

(*Director of the Potato Virus Research Station, Cambridge*)

Blight-Resistant Varieties

The possibility of raising potato varieties which shall be resistant to *Phytophthora infestans* has interested me for a great many years. In 1910 I showed that such resistance was to be found in the hybrid species *S. edinense*, and that it behaved as a Mendelian recessive factor. One of these seedlings retained its immunity to blight for 21 years, during which time it was allowed to grow without disturbance in a kitchen garden. In 1914 I introduced the species *S. demissum* into the breeding experiments, and found that it exhibited a complete resistance to blight. Crosses were made with domestic varieties, but the war put an end to the work. In 1922 crosses were again made between *S. demissum* and domestic varieties, and the generations derived from those original crosses are being bred to-day in the Potato Virus Research Station, Cambridge, under the care of Miss C. O'Connor who has taken over the greater part of the practical side of the work. As a result of prolonged breeding and selection from these original crosses, we have obtained seedlings which exhibit a very high resistance to the common blight of the field and at the same time possess good economic qualities. In this connection it should be remembered that *S. demissum* is everything that a potato should not be: in our climate it bears no tubers, it has stolons 6-10 feet long, and it is so late that it flowers right on into the winter, hence selection and back-crossing to suitable domestic varieties with continuous testing for susceptibility has been essential in order to combine resistance and economic worth.

In 1931 we found, as did Müller and others in Germany, that the blight fungus *Phytophthora infestans* can itself develop strains whose power of infectivity may be different from that of the parent fungus. We have, in fact, encountered a strain which so far is not prevalent in the potato fields, but which will attack certain of our resistant seedling varieties. This of course is disappointing, but Miss O'Connor has countered it by finding a Peruvian variety which is immune both to the new and the original strains of *Phytophthora infestans*. We are now interbreeding the two resistant stocks and have obtained a fresh set of seedlings some of which are resistant to both strains of *Phytophthora infestans*. Whether they will be resistant to others which may yet be evolved, waits to be seen. The difficulty which

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may arise from the possible existence of manifold strains of the invading fungus should not be exaggerated, for it by no means follows that in this climate all these new forms will be able to thrive and spread as has the common form against which our stocks are already resistant.

We have found that the ordinary domestic varieties and their seedlings exhibit no resistance to artificially produced attacks of blight, and very little if any to attack in the field, so that it is essentially amongst wild varieties that we must seek for the gift of resistance. That potato varieties resistant to the common strain of blight can be produced is an indisputable fact ; that we shall produce in the near future a variety resistant to such other strains of *Phytophthora infestans* as are likely to become widespread in nature is, I think, highly probable.

The work necessary for the achievement of this goal is arduous and has already involved considerable private expenditure. The Potato Trade, which one would imagine might be interested in the problem, has neither assisted nor encouraged those who are striving to counter its attacks, and the Government is unprepared to risk even a couple of hundred pounds a year to insure against a scourge which not only costs the country on the average something like £5,000,000 a year, but to whose action most of our political troubles in Ireland may be directly traced.

Virus-Free Stocks

The production of stocks of potato varieties which should be free of virus disease was one of the original tasks of the Potato Virus Research Station, and one which has been successful to a greater degree than was anticipated when the work started.

It should be noted that not all varieties respond in the same manner to the attacks of the various virus diseases we know of. Thus an attack of the " X " virus kills an Epicure straightway, seriously affects a King Edward, but has little—often no—effect on most other varieties. Paracrinkle, which is present in a latent condition in every King Edward, produces in such varieties as Arran Victory and Arran Chief an almost fatal disease. The " Y " virus, which is the most widely destructive and easily communicated of all the viruses, will ruin more or less completely nearly every variety grown in this country ; yet there is a variety called Kathadin which can to a great extent retain its vigour, notwithstanding its infection. Thus we see that the potato is a plant which on the one hand is peculiarly liable to virus infection, and on the other exhibits in a remarkable degree the capacity to act as a " carrier," i.e., plants of certain varieties which, though impregnated throughout their tissues with a potentially virulent disease germ, display no clinical symptoms suggestive of its presence.

The aim of the Potato Virus Research Station has been to secure stocks of varieties which are entirely free from virus infection ; in this it has succeeded in great measure.

Thus we have stocks of the following varieties in which no critical tests, so far known, have demonstrated the presence of any virus :

Abundance	Arran Victory	Great Scot
Arran Banner	British Queen	International Kidney
Arran Cairn	Catriona	Kerr's Pink
Arran Chief	Champion	King George
Arran Comrade	Di Vernon	Majestic
Arran Consul	Duke of York	May Queen
Arran Crest	Eclipse	Ninetyfold
Arran Pilot	Epicure	Sharpe's Express
Arran Scout		

In some varieties, after testing a very large number of sources, we are obliged to content ourselves with stocks which, though vigorous and healthy in their appearance, nevertheless, do " carry " a virus ; such are :

King Edward ..	which carries the Paracrinkle virus
Irish Chieftain ..	,, ,, ,, " A " virus
Golden Wonder ..	,, ,, ,, " A " ,,
The Baron	,, ,, ,, " X " ,,
Uptodate	,, ,, ,, " X " ,,

In order to secure a clean stock of any variety, immature tubers are taken from the healthiest-looking plants on which no sign of disease can be observed, grown in the best seed-producing areas of Scotland and Ireland, during the month of June. The tubers are kept till the next season and cut in halves, one half is grown outside in an observation plot, the other in a pot in an insect-proof house. If the former displays definite disease before the end of June, then the whole unit is discarded ; if it does not, then the glasshouse plant is tested for the presence of virus infection by grafting scions to a number of healthy test varieties, and also by inoculating its sap into tobacco and *Datura* seedlings. If the tuber unit reacts negatively to all these tests, then the glasshouse pot is harvested and the seed tubers preserved throughout the winter in an insect-free store, and in the following season sufficient pots are planted to establish an adequate glasshouse stock and the remainder is planted in isolation in the field.

Testing of each proved variety is repeated each season, nuclear stocks of which never leave the shelter of the insect-proof glasshouse and store ; in this manner the virus-free stocks, once won, are maintained indefinitely.

The outside plots are grown in complete isolation in cornfields ; they are never planted nearer than half a mile to any other potatoes, and the individual plots are separated by 120 yards one from another. These plots are visited several times in the season and rigorously rogued if necessary, but as the seed is virus-free, no infection is eve:

seen till late in the season and such plants are removed at the earliest possible moment.

Seed from the outside plots is available for farmers and seed-producers and should be used for raising further seed under similar conditions of isolation. In this way we have raised in the neighbourhood of Cambridge and Barley, stocks of potatoes which have left the protection of the glasshouse two, three and four years. The stocks acquire some virus disease in the second and subsequent years, but very little, if any, in the first year. A large number of statistically planned yield tests of the material grown outside have been made as against best Scotch seed, and in nearly èvery case the Cambridge stocks, even in their third year from the glasshouse, have proved themselves superior.

There is no doubt that seed which is virus-free gives a healthier stand and a far higher yield than ordinary commercial seed. If seed raisers were to avail themselves of the material that the Potato Virus Research Station can offer them, and use it in the manner advised, they would most certainly raise larger and better crops. The ideal which is being aimed at is that the best seed-growing area, whether in Scotland or elsewhere, should be planted with the best available seed, and such seed we possess in Cambridge. It should not be difficult to effect a co-operative arrangement of this nature but, in fact, few if any raisers appear ready to take the trouble to renew their stock seed and work it up to the necessary bulk in the manner advocated.

POTATO GROWING IN LINCOLNSHIRE

By T. O. Mawby
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The first thing to consider in planning an acreage of potatoes is the crop after which the potatoes are to be grown. There are various rotations of cropping, here are some of them :

Wheat—Sugar Beet—*Potatoes*. Wheat—Peas—*Potatoes*. Oats —Wheat—Sugar Beet—*Potatoes*. Wheat—Mustard—Winter Tares—*Potatoes*. Wheat—Winter Beans—*Potatoes*.

The land has now to be cultivated. As soon as the corn crop is in the stack it is usual to work the stubble in order to destroy any weeds. The land is left in this state until the middle of November. (In some cases where the field needs it a dressing of about 12 loads of farmyard manure is applied per acre.) The field is now deep ploughed to a depth of between 10 in. and 12 in. and sub-soiled a further 6 in. to 8 in.

The land is then left in this form until the spring. If the winter has been mild or wet, it is probably necessary to drag the land before levelling with the harrows, but usually and particularly after a severe winter, it is only necessary to use heavy harrows before ridging. The field is now ridged or drawn out for the potatoes. The distance between the ridges varies between 26 in. and 30 in. It is usual in most cases, however, to have the ridges 29 in. apart.

Next comes the sowing of the artificial manures. These are mixed according to the type of land and a certain quantity is applied ranging between 5 cwt. and 15 cwt. per acre. This is sown by machinery down 3 rows at a time. The seed is then planted out of chitting boxes. First earlies are usually planted from 10 in. to 12 in. apart and late varieties from 12 in. to 15 in. apart. The rows are then split or covered.

Cultivation now begins almost immediately. The drags are fitted with spuds and drawn through the field between the rows taking 3 rows at once. It is necessary to get as close to the potatoes as possible the first time for, as soon as the tuber takes root, considerable damage can be done by cutting off the small fibres.

After various cultivations the shoots begin to show above the ridges and when far enough out the ridges are half-hilled. Later these are pulled down again and the process of hilling the potatoes is carried out.

Lifting is done by various methods. For early varieties the spinner is used and in some cases the Hoover digger. For late varieties the single plough is used. The potatoes are then clamped or graved, covered with straw and a thin coat of earth put on the straw leaving about 6 in. of straw on each side at the top of the clamp for air. Later in the winter the whole clamp is covered with about 12 in. of earth and left until dressing commences.

The figure of the cost of producing the crop up to the time of clamping varies according to the type of land, the cost of seed, the season and labour. On silt land the cost is high and varies between £26 and £32 per acre. Usual varieties grown are Eclipse, Majestic and King Edward.

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