# COMMON SCAB OF POTATOES[1]

## PART II.

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(With Plates III and IV.)

### INTRODUCTION.

An account of some experiments on Remedial Measures for Common Scab has been given by the writer in a recent Report (8). It was there shown that the disease may be inhibited by green-manuring and that, where it is possible to apply a sufficient quantity of green organic matter and to work this into a very intimate mixture with the soil, scab may be entirely prevented. One photograph illustrating this result (Pl. III, Fig. 1) is reproduced from the report. In the experiments described, the green manuring was carried out, for the most part, by the addition of grass cuttings, but this treatment, though simple to apply in the case of a garden or allotment, is obviously impracticable for potato cultivation on a farm. Here, the process must necessarily consist of ploughing in a green crop. The first section of this paper describes some trials of the green-manuring treatment carried out in this way, and gives an account of some further experiments in which hay and spent hops were tried as substitutes for green crops.

The second section deals with the action of liming on scab and the counteraction of its effect by green-manuring. Much attention has been given of late years to the relation of the soil reaction with the incidence of scab and the action of lime on scab must obviously yield valuable evidence in any discussion of this subject. In the third section, an attempt is made to show that the deductions previously drawn from such evidence are fallacious and the various theories put forward to account for the occurrence of scab and its cure by green-manuring are considered.

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## SECTION I. FURTHER EXPERIMENTS ON GREEN-MANURING AND ON THE USE OF SUBSTITUTES FOR GREEN CROPS.

These were carried out with the object of ascertaining whether the practice of green-manuring, as it obtains in ordinary farm practice, would suffice of itself to inhibit scab, and also whether such substitutes as old hay and spent hops would exert a similar effect.

### *Green-manuring.*

*Exp.* 1. A plot 22 ft. × 6 ft. was divided into two parts. On one half, three successive crops of mustard were grown and dug in during the summer of 1919 and these were followed by a crop of rye which was dug in in the following spring. Potatoes were then planted on the whole plot, artificial manures only being applied.

The amount of scab on the fallowed half of the plot was unfortunately rather little but the green-manured half yielded a clean crop.

*Exp.* 2. This was carried out in a garden near Bradford which had been devoted to the growing of a number of potato varieties in 1919. The whole crop was then so badly scabbed that the potatoes were scarcely recognisable. In December 1919, rye was sown thickly over a large strip 57 ft. × 9 ft. across the garden, and the winter being mild, a good crop 10 ins. high was produced by the following May. This was cut with a scythe. The stubble was then dug in, trenches made for planting the potatoes and the green crop strewn in the trenches, little by little, as they were being filled in. For the sake of comparison, another strip was treated with grass at the rate of 15 tons per acre strewn in the trenches as in the case of the rye. This amount of grass had been shown by previous experiments to be an effective dressing for scab. A third strip was planted as a control. No farmyard manure was applied to any of the plots but all were given artificials at the same rate.

The results showed a fair amount of scab on the untreated plot, though this was considerably less than in the previous year. Both the rye and grass plots however gave crops with 90 per cent. clean tubers and no difference between the two plots in this respect could be observed.

*Exp.* 3. This consisted of a trial of green-manuring on a farm scale. A green crop of rye and vetches 8 to 9 ins. high was ploughed in in the spring of 1920. Within a week of ploughing the land was harrowed and ridged up, most of the green stuff falling into the furrows. Dung was added in the usual way, and the potatoes were then planted. The result of the experiment was, however, negative since both the green manured-part and the control strip which had been left gave clean crops. It is of interest in showing that it is possible on a farming scale to plant potatoes at a very short interval after a green crop has been ploughed in. In this way the decay of the vegetable matter proceeds at the same time as the formation of the new crop, a condition which appears to be essential to the success of the treatment.

The three experiments, all of which were carried out in 1920, suffer from the fact that the amount of scab produced in that year was considerably less than usual, but the results are sufficient to indicate that green-manuring, as carried out by the ploughing in of a growing crop, may be very effective in reducing scab. The writer has since received confirmation of this statement from a well-known firm of seedsmen in this country, who have carried out the treatment with great success, and

also from Mr E. Gram of the Experimental Plant Pathology Station, Lyngsby, Denmark, where Lupins were used as the green crop.

*Hay and Spent Hops as substitutes for Green-manure.*

*Exps.* 4, 5. The experiments in which these materials were tested were carried out in 1921, which was probably the worst year for common scab on record.

No old hay was available and seeds hay from the previous year's crop was used. This was applied to two small plots at the rates of 2½ tons and 5 tons per acre respectively. Spent hops, in the wet state in which it comes from the brewery, was applied to two other plots at the rates of 5 tons and 10 tons per acre respectively. In each case a control plot was planted. All the plots received artificials but no farmyard manure. The results were as follows:

| Treatment (rate per acre) | Description of crop |
|---|---|
| Seeds hay (2½ tons) | Badly scabbed |
| ,, ,, (5 tons) | Moderately scabbed |
| Untreated plot (1) | Badly ,, |
| Spent hops (5 tons) | Moderately ,, |
| ,, ,, (10 tons) | Very slightly ,, |
| Untreated plot (2) | Very badly ,, |

It thus appears that seeds hay is of little use as a substitute for green manure and this is possibly due to its stiff coarse nature, on account of which the attack of soil organisms on it is necessarily slow. It is possible that meadow hay being softer in texture would have given better results.

In the case of spent hops, the heavier dressing gave very good results which would certainly justify further trials being made with this otherwise apparently worthless product.

## Section II. The effect of lime on scab.

The literature on common scab abounds with experiments on liming but the results of these are so conflicting that little can be learnt from them. Similarly, potato growers, in some districts, assert that lime has no effect on scab, whilst others, in different districts, or on soils of a different type, regard liming as the surest way of producing a scabby crop.

There is now little doubt that this apparently inconsistent action of lime is closely connected with the reaction and type of soil to which it is applied. In the experiments which follow, either the initial hydrogen-ion exponent or the lime requirement of the soil or measurements of both data were taken in all cases. The type of soil in Exp. 6 was a very light sandy loam; in Exps. 7, 8, 10, and 11 it was a fairly light silty loam, and in Exp. 9 a similar but somewhat heavier loam.

*Exp.* 6. This was carried out on a farm near Selby. The principal crop was potatoes and these yielded as much as 16 tons per acre of fine clean tubers on which scab had never been seen. In 1916, however, the farmer complained of the poorness

of his rotation crops, in particular of barley and seeds hay, and this was no matter for surprise, when it was observed that the acid indicating weed, spurrey, grew in abundance on the land. A liming experiment was planned and carried out on the field in question by Dr J. A. Hanley, Lecturer in Agricultural Chemistry at this University, to whom I am indebted for the following details. The lime-requirement[1] of the soil was found to be 21 cwts. per acre. Five plots, each one acre in area, were marked out and treated as follows:

| No. of plot | Dressing of lime or chalk per acre[2] | |
|---|---|---|
| 1 | Ground chalk (undried) | 2 tons |
| 2 | „ „ „ | 5¾ tons |
| 3 | Control | |
| 4 | Ground quicklime | 1 ton |
| 5 | „ chalk (dried) | 2 tons |

In addition, and as a result of the good effect of these dressings on the crops grown from 1916 to 1920, the farmer applied ground chalk at the rate of 5 tons per acre to a further considerable area of the same field. In 1921, the crop was again potatoes and two varieties "Majestic" and "Ally" were grown. At lifting time these were examined by Dr Hanley and the writer, who arrived independently at the same conclusions regarding the amount of scab on the respective plots. These observations, together with the hydrogen-ion exponents of the soils of plots 2, 3 and 4 which were determined on May 19th, 1921, are given in the table below.

| No. of plot | *p*H | Degree of scab |
|---|---|---|
| 1 | — | Moderate |
| 2 | 6·6 | Very bad |
| 3 | 5·0 | Practically none. Tubers showing one or two scabs could be found but were not noticeable to a casual observer |
| 4 | 5·2 | Slight |
| 5 | — | Rather bad |

The "Majestic" crop was perhaps slightly less scabbed than the "Ally," but the relative amount of scab on the different plots was the same in both cases.

On the portion of the field which had been chalked by the farmer the crop was as badly scabbed as on plot 2.

Photographs of the produce of the "Majestic" crop on plots 2 and 3 are shown on Pl. III, Fig. 2.

*Exp.* 7. This was laid down in the first place as a manurial experiment (which included some liming trials) on pasture land at the University Experimental Farm, Garforth. In 1917, the field was ploughed up and has since carried arable crops, that of 1921 being potatoes. Particulars of the experiment are given in the Guide to the Farm experiments (14), and it is only proposed to state here the details as they concerned the liming of the plots and its effect on the potato crop.

[1] For the sake of clearness, the lime-requirements given in this paper have been expressed throughout in terms of weight of lime per acre. The figures so given, however, are merely calculated from the percentage of calcium carbonate as determined by the Hutchinson and MacLennan method, and must not be regarded as any exact measure of the amount of lime necessary to bring the soil to a neutral reaction. In practice a quantity of lime considerably in excess of that indicated would probably be required for this purpose.

[2] This chalk contained about 15 % moisture.

Each plot was divided into two parts, a north and a south half.

In 1898, the north half of plot 14 was dressed with quicklime at the rate of 3 tons per acre and the south half at the rate of 6 tons per acre. In addition, in 1911, the north end of all the plots was given ground chalk at the rate of 5 tons per acre. The action of this liming was clearly visible on the soil in 1921, four years after the grass had been ploughed in. On the unlimed portions, the ploughed-in turf lay in undecomposed lumps on the surface after harrowing, whilst, on the limed soil, no evidence of the original turf remained. The potatoes planted were "Great Scot." Observations of the amount of scab on the respective crops were made at lifting time and determinations of the hydrogen-ion exponents for two of the soils—one heavily limed and the other untreated—were made. These data are given in the following table.

| Plot | | Treatment, rate per acre | | pH | Degree of scab |
|---|---|---|---|---|---|
| 14 | South | Quicklime 6 tons in 1898 | | — | Bad |
| 14 | North | Quicklime and ground chalk | 3 „ 1898<br>5 „ 1911 | 6·6 | Very bad—tubers scarcely distinguishable from the soil |
| Other plots, | North | Ground chalk, 5 „ 1911 | | — | Bad |
| „ | South | No lime or chalk | | 4·4 | Very little scab—the tubers were spotted to some extent and some showed mature scabs |

A photograph of the crops from plot 14 North and from the unlimed plots is shown on Pl. III, Fig. 3.

*Exp.* 8. This was carried out on a field (No. 112 *S*) at the University Farm in 1915. The lime-requirement of the soil was practically nil. Four plots, each consisting of one row 78 ft. long, were treated as follows:

| Plot | Lime applied per acre |
|---|---|
| 1 | Untreated |
| 2 | 5 tons |
| 3 | 10 tons |
| 4 | Untreated |

The lime, which was partially slaked, was applied in the rows on top of the dung; a little soil was raked down to cover it and the potatoes then planted.

The crops when examined were found to be all slightly scabbed but no difference whatever could be seen in the relative amount of scab on the four plots.

*Exp.* 9. This was carried out on a small plot at the University Farm in 1920. The lime requirement of the soil was 9 cwts. per acre, *i.e.* the soil was practically neutral. In this case, it was decided to make a test of magnesian as well as of carboniferous lime, since the former was said to possess a peculiar "burning" effect on root crops. The plot was divided into three parts, which were treated as follows:

| Plot | Lime applied per acre |
|---|---|
| 1 | Magnesian, 5 tons |
| 2 | Untreated |
| 3 | Carboniferous, 5 tons |

In both cases the lime was partially slaked. It was distributed over the surface of the soil and dug in. Dung was applied in the trenches at the rate of 20 tons per acre and the variety of potato planted was "Great Scot."

All the crops were found to be quite free from scab.

*Summary of Experiments* 6–9.

The soils on which these experiments were carried out may be divided into two groups according to their reaction before liming. Those of Exps. 6 and 7 were decidedly acid, whilst those of Exps. 8 and 9 were neutral or very nearly so. In the former cases, the application of lime was followed by scab, whilst in the latter, this had no effect. Many similar cases might be quoted and there is little doubt that many of the conflicting statements regarding the results of liming might be reconciled if the initial reaction of the soils treated was known. Superficially, these experiments might be taken to afford full confirmation of Gillespie and Hurst's(2) soil reaction theory for scab, but in the next section, it will be shown that they may be more satisfactorily explained on other grounds. There is no doubt, however, that, on light potato soils, the soil reaction, as measured by its lime-requirement or by its hydrogen-ion concentration may be an extremely useful guide in predicting the action of lime on scab.

The following experiments show that where scab appears on a soil after liming this effect may be counteracted by green manuring.

*Exp.* 10. This was carried out in 1919 at the University Farm. Two adjacent plots, Nos. IV and V, were chosen on light silty soil. The lime-requirements of the plots were found to be 37 and 38 cwts. per acre respectively. One half of each was given an application of lime at the rate of 50 cwts. per acre, and two days later plot IV was given a dressing of grass cuttings at the rate of 18 tons per acre which was forked in. No farmyard manure was given to either plot, but each received a standard dressing of artificials. Both plots were then planted with "British Queen" potatoes. The results were as follows:

| Plot | | Appearance of crop |
|---|---|---|
| V. Limed half | | Scabbed |
| Unlimed half | | Clean |
| IV. Limed half } Unlimed half } | green-manured | Clean |

A photograph of the crops from plot IV is shown on Pl. IV, Fig. 4.

In the case of plot IV, a few tubers lying at one edge of the plot, where they had escaped the "grass" treatment, showed scab and one of these is included in the photograph on the right hand side. Otherwise, there was no difference in the crops from the limed and unlimed parts of this plot and both showed the clean glossy skins so typical of the green-manurial treatment.

*Exp.* 11. This was similar to Exp. 10 excepting that a much smaller dressing of grass was used—not more than 2 to 3 tons per acre—on the green-manured plot. The results were almost identical, excepting that the crop treated with lime and grass, although quite free from obvious scabs, showed numerous pin head spots. These were not investigated for want of time, but, in view of the examination of such spots described in Part I(15) of this work, there is little doubt that many of them were very

young scabs. This is of interest, since it shows that where the supply of green-manure is too limited or becomes exhausted the potatoes subsequently may be attacked by the scabbing organisms.

A photograph of the spotted tubers from this plot is shown on Pl. IV, Fig. 5.

These experiments prove therefore that where lime exerts a tendency towards the production of scab, this may be entirely counteracted by green-manuring. The significance of this result in its relation to the theories put forward to account for scab is considered in the next section.

## Section III. An examination of the theories advanced to account for the occurrence of scab and its prevention by green-manuring.

### 1. *The soil reaction theory.*

This theory doubtless owes its origin to the fact that scab occurs only to a very slight extent in distinctly acid soils. Gillespie and Hurst (2) have now placed this observation on a scientific footing by measurements of the hydrogen-ion concentration of such soils and have further attempted to establish the existence of a close relationship between the hydrogen-ion exponent of *any* soil and the incidence of scab. The conclusions arrived at by these workers are that soils having a hydrogen-ion exponent as low or lower than 5·2 *rarely* produce scab, whilst soils with much higher exponents *generally* produce scab.

We are in agreement with the first part of this statement, although at the same time it should be pointed out that instances of scab in soils of exponents less than 5·2 are not uncommon. Martin (7) has already cited two cases of rather severe scab at exponents of 4·82 and 4·6 respectively, and the present writer mentions the existence of scab in Exp. 7 of this paper, where the exponent was as low as 4·4.

It is, however, with the second part of Gillespie and Hurst's statement that we find ourselves in complete opposition. In the first place we note in the authors' own account of their work that a certain soil "No. 36," having an exponent of 6·22 and falling in the middle of their series of scab-producing soils, yet gave a clean crop of potatoes. This inconsistency was accounted for by supposing that the soil was uncontaminated with scab organisms, since it was "virgin" land. Some years previously, however, Jones and Edson (4) cited a case of scabby potatoes occurring on land which, presumably, had not been in cultivation for 25 years and a part of which had just been cleared of pine. In this case the soil may, of course, have been infected by the use of scabby sets, but it seems much more probable that the Actinomyces capable of producing potato scab are natural inhabitants of the soil.

In any case, however, the argument of "virgin soil" could not be applied in this country, where no kind of control over the planting of scabbed sets has ever been enforced, and where it is impossible that there remain any potato growing soils into which the scab organisms have not at some time or another been artificially introduced. Yet, on thousands of farms clean potato crops are raised and it would be absurd to suppose that in every case the soil was an acid one. Indeed, if we may take such physiological data as the production of a good crop of barley and the absence of acid indicating weeds such as Spurrey, Sheep's Sorrel and Bent on a soil to be a criterion of approximate neutrality, it is an easy matter to recall numbers of such neutral soils, where clean potatoes are regularly grown. In order to verify these observations, it was decided to collect samples of clean potato producing soils from various sources and to determine their hydrogen-ion exponents. The samples were obtained by the courtesy of mycologists, potato growers and gardeners in different parts of England and Scotland and, in each case, the complete or comparative absence of scab is vouched for by the senders. In several cases the land from which the samples were taken was well known to the writer and he is able to confirm the statements regarding absence of scab. The samples were taken to a depth of 6 to 8 inches and at the writer's request, obviously sour soils were avoided.

The values of the hydrogen-ion exponents[1] found are given in the table on p. 78.

Thus, out of 15 soil samples varying from a light sandy loam to heavy clays and including also two peat soils, none showed a hydrogen-ion exponent less than 6·0 whilst the majority gave exponents greater than 7·0. There is no doubt that the number of such neutral or alkaline soils producing clean potatoes could have been added to indefinitely.

These results are obviously a complete contradiction to the conclusions of Gillespie and Hurst who appear to have generalised too quickly from

[1] In estimating the hydrogen-ion exponents of the soils mentioned in this paper the procedure adopted was as follows:

The air dried soil was powdered as far as possible by finger pressure or by gentle pressure with a wooden block. A portion was then put through a 1 mm. sieve. 20 gm. of this was shaken into a specially cleaned flask with 50 c.c. of neutral distilled water and shaken 75 times. After standing for two days the supernatant liquid was filtered through filter paper, samples of which had been found by previous examination to have no effect on the hydrogen-ion concentration.

The earlier estimations were kindly carried out by Mr N. M. Comber, Lecturer in Agricultural Chemistry at this University, who used the colorimetric method of Gillespie (*Soil Science* 1920, IX, 115); the later estimations were made by the writer using the older colorimetric method of Clark and Lubs (*Journ. Bact.* II, Nos. 1, 2, 3). Comparative tests by Mr Comber and myself showed that the two methods gave closely approximating results.

| | Source | Type of soil | *p*H | Remarks |
|---|---|---|---|---|
| 1. | Nostell, Yorkshire | Medium loam | 7·7 | Sent by a head gardener who had never known scab to occur on it. The 1921 crop was examined by the writer and found to be perfectly clean |
| 2. | Doncaster, Yorkshire | Light loam | 7·7 | No scab known to occur on this soil before 1921 when the crop was very slightly scabbed |
| 3. | Wedmore, Somerset | Medium loam | 7·9 | From the writer's own garden where scab is unknown |
| 4. | „ „ | „ „ | 7·6 | Scab unknown |
| 5. | „ „ | „ „ | 7·8 | „ „ |
| 6. | Sand, Somerset | Sandy loam | 7·4 | Ploughed out grass land in 1917. Subsequent crops free from scab |
| 7. | „ „ | Heavy loam | 7·8 | Scab very rare |
| 8. | „ „ | Heavy clay | 7·6 | „ „ „ |
| 9. | Wellington, Somerset | Sandy loam | 7·7 | „ unknown |
| 10. | Settle, Yorkshire | Light loam | 6·1 | These soils overlie limestone. Crops invariably clean |
| 11. | „ „ | „ „ | 6·0 | |
| 12. | Moorland, Somerset | Peat | 7·1 | Clean crops always produced |
| 13. | Fen district, Cambridgeshire | „ | 7·6 | „ „ |
| 14. | Innerswick, Dunbar, Scotland | Red Sandstone | 7·1 | The clean potatoes grown in this district are well known |
| 15. | „ „ | „ „ | 7·1 | |

their work on the Caribou and Washburn soil types. It becomes apparent, therefore, that although a high hydrogen-ion concentration may serve as an indication of the absence of scab in a soil, the converse statement is by no means true.

Some neutral and alkaline soils produce clean crops and others produce scabbed crops, and the reaction of the soil cannot, therefore, be regarded as the determining factor in the incidence of scab.

### 2. *The preferential food theory.*

This theory was advanced by the writer in an earlier report (8). It was there named the "Decoy" theory, but may here be more accurately described under the name given above. It is based on the established fact that when a sufficient quantity of green vegetable matter is introduced into a scabbing soil, clean potato crops may be grown and a practical point on which some stress has been laid is that the more intimately the soil and green-manure are mixed, the better are the results of the treatment.

Adherents of the soil reaction theory have naturally attempted to explain these results by suggesting that the inhibitory effect of the green-manure was due to a rise in the hydrogen-ion concentration of the soil brought about by its decay. Stephenson (10) has shown, however, that

vegetable matter such as Rape and Soy Beans, when applied in a dry state at the rate of 10 tons per acre actually reduced the hydrogen-ion concentration. A few tests were made by the writer during the summer of 1921 on some green-manured and untreated soils which had been ridged up for potatoes in the ordinary way. The green-manure had been applied as short grass at the rate of 20 tons per acre. Estimations of the hydrogen-ion exponents of the green-manured and untreated soil ridges gave the following results:

| Date 1921 | *p*H values | |
|---|---|---|
| | Green-manured soil | Untreated soil |
| May 25 | 4·7 | 4·5 |
| July 28 | 4·8 | 4·4 |
| Aug. 15 | 4·8 | 4·4 |
| Oct. 14 | 4·9 | 5·0 |

It should be pointed out that the samples taken were from ridges 6 ft. long and composite samples were not made from the whole of the ridge. This may possibly account for the curious increase in the exponent for the untreated soil between the two last dates on which samples were taken.

In the case of the green-manured soil, however, the figures show a gradual decrease in the hydrogen-ion concentration and thus agree with Stephenson's results.

It appears impossible therefore to account for the effect of green-manuring by the soil reaction theory.

The preferential food theory makes the assumption that *Actinomyces scabies* is primarily a saprophytic organism living on organic remains in the soil and showing a partiality for the more undecomposed parts of vegetable matter. Only when the supply of such food stuff is deficient does it attack the potato tubers.

Shapovalov (9) has already called attention to the saprophytic nature of the organism and its "parasitic possibilities."

The writer has found that sterilised grass cuttings make the finest medium known for rapid growth of strains of *A. scabies* and that sterilised samples of the peat soil from Somerset mentioned on p. 78 also permitted good growth. Photographs of the cultures made on these two media may be seen in the Report (8) mentioned.

On the assumption made, it is easy to understand the scab-inhibiting effect of green-manure and the necessity for a close admixture of the green stuff with the soil, but the theory receives its strongest support from the remarkable way in which it accounts for the established facts concerning scab. These may be considered as follows:

(1) True peat soils irrespective of their hydrogen-ion concentration are comparatively free from scab, and this may now be explained by the fact that, in such soils, the large natural reserve of organic matter serves as a constant food supply to the Actinomyces present. In a recent review of the writer's Decoy theory, Drayton(1) states that he was unable to find any Actinomyces in certain soils, principally peat, or peat and clay, which were of high hydrogen-ion concentration. It will be remarked however that the maximum count given by this author in an examination of 23 soils is less than one million per gram, which is a very low figure. Although, therefore, without any standardised method of making Actinomyces counts, the relative figures of different investigators are of little value, we suspect that Drayton's technique is at fault in finding soils totally devoid of these organisms.

The present writer found as many as 700,000 Actinomyces per gram of the soil mentioned in Exp. 7 which had a hydrogen-ion exponent of 4·4 and on which slight scabbing occurred. The counts for neutral or alkaline soils are however generally much higher and the writer does not question the statement that acidity depresses the Actinomyces flora, and thus reduces the likelihood of scab. This does not in any way vitiate the application of the preferential food theory to peat soils. Thus, the Actinomyces count for the Somerset peat soil mentioned on p. 78 and having a hydrogen-ion exponent of 7·1 was 5,000,000 per gram. Yet, this soil yields perfectly clean crops each year.

(2) Scab is most prevalent and most virulent on light sandy or gravelly soils. The well aerated condition of such soils is peculiarly suited to the development of the *A. scabies* group, and probably of the majority of the genus. Bacterial action is also rapid and thus manure, whether farmyard or vegetable, tends to disappear quickly. The condition thus brought about in such soils is the reverse of that in a peat soil and scabbing ensues. Clean potatoes may sometimes be obtained on such soils by early lifting. It is on land of this type that heavy green-manuring is particularly efficacious.

(3) Lime produces or aggravates scab under certain conditions.

From the experiments described in Section II the following facts stand out:

(*a*) The presence or absence of scab on neutral soils is unchanged by liming.

(*b*) The addition of lime to a distinctly acid soil tends to produce or increase scabbing.

(*c*) This deleterious effect may be counteracted, if heavy dressings of green-manure are applied to the limed soil.

As already pointed out (*a*) and (*b*) if considered alone might be taken as confirmation of the soil reaction theory. A point in connection with liming results is however generally overlooked. According to the soil reaction theory, we have to assume that soils of a certain degree of acidity are void of scab organisms. When, however, such soils are limed, intensely scabby crops may be produced and we may well ask from what source the scab organisms appear in such numbers as to produce this effect.

When next we consider (*a*), (*b*) and (*c*) together, it will be seen that the whole case cannot be explained by the change in soil reaction, since it has already been shown that green-manuring, though exerting only a slight effect on the soil reaction, tends to move it in the same direction as lime.

The facts are however easily accounted for by the Preferential food theory. Lime favours the development of the Actinomyces both by neutralising acidity and by opening the soil. At the same time, it hastens the decay of plant residues in the soil. Thus, on the one hand, the scab organisms are multiplied and, on the other, their natural food supply dwindles. The potatoes are then attacked. If, however, the deficiency in the food supply is made good by the addition of green stuff, the tubers remain free from infection. In the case of (*a*), it is obvious that, where no deficiency of lime exists, a further addition will produce no ill effect. In this case, if the soil is well supplied with vegetable matter in a palatable state for the scab organisms, the crops will be clean, and, if it is not, they will be scabbed.

Some critics of this theory have urged that the green matter introduced, if so favourable a medium for Actinomyces, would be quickly smothered with these organisms and disappear in a very short time. This, however, is not the case, since Actinomycetal action at soil temperature is much less rapid than at the higher temperatures adopted in artificial cultures. In fact, in the green-manuring experiments described, which were carried out on light dry soils, a certain amount of the grass added was invariably seen when the potatoes were lifted.

Others, whilst accepting the idea of the green organic matter as a preferential food have raised the objection that the spores of the Actinomyces will naturally germinate *in situ* and, in some cases, this must be on the potato itself. We are bound to admit that this objection seems very sound. It should, however, be remembered that spore formation in *A. scabies* is very variable. In cultures, it may often be retarded indefinitely by an abundance of food; it is also much checked by an acid reaction of the medium, and by low temperatures. Again, the power

to produce an aerial mycelium with spore formation is often entirely lost by continuous cultivation of the fungus on the same medium. To what extent these various factors affect spore formation of the fungus in a soil highly enriched with vegetable matter, we are not prepared to say. It is an interesting fact, however, that on potato scabs themselves, the aerial mycelium bearing the spores of the fungus is very scanty.

There is lastly the possibility that the latent parasitic power in the scab organisms is developed only under the stress of hunger and thus, spores or fragments of mycelium from a parent mycelium growing luxuriantly on a saprophytic diet are powerless to attack the potato tuber. In 1921, an attempt was made to test this point by inoculating growing potato tubers with a strain of *A. scabies* previously cultured on sterilised grass cuttings for six generations of one week each. In some cases, the skin of the potato was first scratched with a sterile needle and the inoculum rubbed on the scratch with a platinum loop, whilst, in others, drops of the culture emulsion were spotted on to the tubers. In all, 10 tubers were inoculated. Seven of these showed no signs of infection whilst the remaining three showed only two or three very small scabs. Thus, whilst it would be unwise to draw definite conclusions from a single test, the results certainly suggest a loss of parasitic power in the organisms following a generous saprophytic diet.

There does not appear therefore to be any insuperable objection to the Preferential food theory, which may not be removed by an extended knowledge of the morphological and physiological characters of the Actinomyces group.

3. *Soil moisture and soil temperature as factors in scab production.*

Observations extending over a number of years have shown that common scab is much more prevalent and occurs with far greater virulence in dry than in wet seasons. An illustration of this is afforded by recent years. Thus in 1919 and 1921, the growing season was exceptionally dry and the disease very severe, whereas in 1920, which was very wet, little scab appeared.

In this country, dry summers are usually accompanied by heat and wet summers with cold. Thus, in the action of climatic conditions on the disease, two factors, soil temperature and soil moisture, either or both of which may play an important part, must be considered. In America, L. R. Jones and McKinney (5, 6) have attempted to establish a relationship between soil temperature and scab development. They point out that scab is more prevalent in the southern and warmer regions than in the northern and cooler States. They have not so far given any figures

for the temperatures of these soils, but have shown by greenhouse experiments that the optimum temperature for the development of the scab organism in the soil is about 24° C. The geographical evidence in this country is scarcely in support of these observations since scab is, if anything, more general and severe in the north of England than in the south. In fact, the disease appears to have been a serious problem to farmers in Yorkshire long before it was given any attention at all in the south of England.

Following on the hypothesis of Jones and McKinney, a suggestion was made to the writer by Dr Pethybridge of the Royal College of Science and Technical Instruction for Ireland that the beneficial effect of green-manuring for scab might be due to a reduction of temperature in the treated soil such as would result from a mulch. It was decided therefore to carry out experiments to ascertain (1) what reduction of temperature was actually brought about by mulching, (2) the effect, if any, which such a reduction produced on scabbing, and (3) the reduction of temperature, if any, brought about by a green-manuring carried out on the lines of the previous experiments.

An account of the experiments (Nos. 12 and 13) is given below.

*Exp.* 12. This was carried out in 1921. A plot 22 ft. × 6 ft. was chosen on soil of a scabbing nature. Its lime-requirement was found to be 33 cwts. per acre and a dressing of lime was applied at the rate of 2½ tons per acre. Later, the plot was dunged at the rate of 15 tons per acre and planted with "Great Scot" potatoes. It was then divided into three parts, *A*, *B* and *C*. In order to carry out the mulching as effectively as possible, the potatoes were not earthed up on any part of the plot. When the tops were about 6 ins. above the ground, *A* and *C* were given heavy mulches about 3 ins. thick of grass cuttings and farmyard manure respectively, whilst *B* was left untreated. A thermometer enclosed in lead piping was then inserted to a depth of 6 ins. between two plants in a row in each of the three plots. Eleven readings were taken at intervals throughout the season from June 18 to October 12 and were as follows:

| Date 1921 | Temperature ° C. | | |
|---|---|---|---|
| | *A* (Grass mulch) | *B* (Untreated) | *C* (Manure mulch) |
| June 18 | 16·0 | 18·5 | 16·0 |
| „ 25 | 19·0 | 21·5 | 18·5 |
| „ 28 | 17·0 | 20·0 | 18·0 |
| July 6 | 16·0 | 17·0 | 16·0 |
| „ 14 | 18·0 | 20·0 | 19·0 |
| „ 26 | 18·5 | 20·0 | 18·5 |
| Aug. 3 (after rain) | 15·0 | 15·5 | 15·5 |
| „ 15 „ „ | 15·0 | 16·0 | 15·5 |
| „ 22 | 17·5 | 18·0 | 17·25 |
| „ 27 | 16·0 | 16·5 | 17·0 |
| Oct. 12 | 14·5 | 15·0 | 14·5 |
| Average of readings | 16·6 | 18·0 | 16·9 |

From the above it will be seen that the reduction in temperature effected by the grass and dung mulchings was practically the same and that this amounted only to an average of 1·25° C.

A good crop of potatoes was lifted in spite of being grown on the flat and the results as regards scab were as follows:

| | |
|---|---|
| Part *A* (grass mulched) | Only moderately scabbed. |
| „ *B*, untreated | Badly scabbed. |
| „ *C* (dung mulched) | „ „ |

No difference whatever between *B* and *C* was apparent, so that obviously the reduction of temperature effected on plot *C* had exerted no retarding action on the scabbing and the diminished amount of scab of plot *A* cannot therefore be ascribed to this cause. It may, however, be accounted for by an observation made on lifting the crop, namely, that a certain amount of the fine grass used had partially rotted and become incorporated with the uppermost layer of the soil. Thus, since the crop lay very close to the surface of the soil, a large proportion of the tubers were growing in a mixture of soil and grass such as they would get in a green-manurial treatment carried out in the ordinary way.

*Exp.* 13. On a second plot, a green-manurial experiment was put down on half of which grass cuttings were applied and forked in at the rate of 20 tons per acre. Thermometers were inserted in one ridge of the "grassed" soil and one ridge of untreated soil adjacent to each other and readings taken at intervals. These were as follows:

| Date 1921 | Temperature ° C. "Grassed" soil | Untreated soil |
|---|---|---|
| July 14 | 22·0 | 23·0 |
| „ 25 | 22·0 | 22·5 |
| Aug. 3 | 17·5 | 18·5 |
| „ 15 | 19·0 | 20·5 |
| „ 22 | 19·25 | 21·0 |
| „ 27 | 17·0 | 18·0 |
| Sept. 28 | 15·5 | 16·5 |
| Oct. 12 | 15·0 | 16·0 |
| Average reading | 18·4 | 19·5 |

The average reduction of temperature therefore due to the admixture of the grass is just over 1° C. and in view of the results of Exp. 12, we must conclude that this reduction can have no appreciable effect in inhibiting scab. In any case, it would be scarcely possible to suppose that so small a difference in temperature would retard the growth of the scab organism to more than a very slight degree. The temperatures noted in the last table certainly approach the optimum of 24° C. given by Jones and McKinney(6) for the scab organism and in such a summer as that of 1921 it is more than probable that the high soil temperature would favour the development of these organisms. On the other hand, however, soil temperatures taken in 1914, on a plot which produced a very scabby crop were considerably lower. Thus, 12 readings taken at 11 a.m. at intervals from July 28 to August 17 gave an average temperature of

13·2° C. and a maximum temperature of 14·3° C., whilst 12 readings taken at 1 p.m. at intervals from August 18 to September 2 gave an average temperature of 16·0° C. and a maximum of 18° C. Such temperatures are much the more normal for this part of the country, but they fall considerably below the optimum for *A. scabies*.

Whilst admitting, therefore, that, provided other conditions are favourable to the disease, a high soil temperature will favour its development, we do not think that this factor can exert more than a secondary rôle in the incidence of scab. It appears far more probable that the moisture content of the soil is the seasonal factor of greater importance.

*Soil moisture.* In the report(8) on Common Scab already referred to, experiments were described which led us to abandon the hypothesis of the moisture content of the soil being the factor directly responsible for the presence or absence of scab on any given soil and the factor which appeared to us to be fundamental in scab control has already been discussed in this section.

Nevertheless, on soils already favourable to scab, the water content appears to exert an indirect but often powerful influence. It should first be pointed out that the climatic conditions affecting scab only do so when they are very pronounced. Thus, a very dry year brings much scab and a very wet year little, but a moderately wet or moderately dry year has little effect one way or the other.

It is well known that dryness means high soil aeration especially of the surface layers of the soil and excessive wetness means that, except on extremely light soils, the pores of the soil will be constantly choked with water and aeration will be poor.

Previous workers on the Actinomyces group have shown that these organisms are very sensitive to the air supply. Waksman(13) states that out of a large number of species isolated from the soil none grew under strictly anaerobic conditions. Similarly, Mr S. Burr, Demonstrator in Agricultural Botany at this University, has found that none of 12 strains of *A. scabies* examined gave any growth under strictly anaerobic conditions. Most of the strains were able to make some growth under partially anaerobic conditions, as, for example, at the bottom of a liquid culture, but this was greatly increased with a further supply of air. It may safely be assumed therefore that the members of the *A. scabies* group are preferential aerobes. They are, moreover, extremely resistant to drought and cultures which were allowed to dry up have been found viable after a period of two years. Many strains, indeed, produce their spores most readily in culture when the medium begins to dry up.

Thus, it would seem that the continuously high aeration of the soil in a dry year is particularly favourable to the development of the scab organisms, and, in the light of this conclusion, it is possible to explain two facts regarding the incidence of scab which seem incapable of explanation in any other way. Thus (1) certain very gravelly or sandy soils are so totally unaffected by climatic conditions that they produce badly scabbed crops in all seasons. An instance of this type of soil may be found in an account of potato scab by Seton and Stewart(12) and the soil there referred to is well known to the writer. Such soils are so porous that they are never clogged with water even in the wettest seasons and the Actinomyces in them do not suffer at any time from lack of air. (2) Clay soils are far less liable to produce scab than lighter soils. Here, again, this partial immunity to scab would seem to be closely associated with the restricted air supply which is at a minimum in a heavy soil. Soil aeration therefore appears to be the dominant factor in the influence exerted by dry and wet seasons on scab.

## SUMMARY OF PARTS I AND II.

1. Common Scab consists of a number of types of scab, which vary considerably in general appearance. Of these, the two most marked types have been called "Raised" and "Pitted" respectively. Other types are intermediate between these extremes.

The causal organism in all cases examined belongs to the Actinomyces genus. The different strains isolated exhibit considerable differences in culture but, for the present, they may be placed in a single Actinomyces scabies group.

2. The incidence of scab is closely associated with soil type. It occurs most commonly and with greatest virulence on light, sandy or gravelly soils, especially on those of a "hungry" nature. Conversely, it is rarely found on peat soils.

3. The disease may be inhibited by the application of sufficiently liberal dressings of green-manure to the soil. Spent hops have also proved to be of value in this respect and leaf mould has long been used by gardeners with good results.

4. The action of lime or chalk on scab production depends largely upon the initial reaction of the soil. On neutral soils, it exerts little or no effect. On distinctly acid soils, it tends to produce or aggravate the disease unless the soil contains a large reserve of vegetable organic matter. This effect may be counteracted by green-manuring.

5. The hydrogen-ion concentration of the soil is not the direct factor

of control in the occurrence of scab and this statement is borne out by the following facts:

(*a*) Scab is found to only a slight extent in soils of a high hydrogen-ion concentration, yet, it *may* occur and Actinomyces have been found in large numbers in soils with a *p*H value as low as 4·4.

(*b*) In more nearly neutral soils, there is no relation between the hydrogen-ion exponent of the soil and the occurrence of scab.

Thus, for example, one soil having a *p*H value of 7·0 may yield absolutely clean crops, whilst another with the same exponent may produce very scabby crops. This distinction cannot be explained by supposing the former soil to be virgin and uncontaminated with scab organisms.

(*c*) In the treatment of scab by green-manuring, any change brought about in the soil reaction appears to be towards a decrease rather than an increase in the hydrogen-ion concentration.

6. The established facts concerning the common occurrence of scab on light soils, its comparative absence on peat soils, the action of lime and the cure of the disease by green-manuring may be explained by the Preferential food hypothesis. According to this theory, the scab organisms are primarily saprophytic living on vegetable remains in the soil. They remain so until their natural food supply is exhausted and develop their parasitic tendencies only under the stress of hunger.

7. Scab is more prevalent in dry than in wet seasons. This is no doubt due in some small degree to the higher soil temperature obtaining in dry seasons. The climatic factor of greatest importance, however, would seem to be rainfall which modifies the air content of the soil and thus regulates the development of the scab organisms which are strongly aerobic. The effect is most marked in clay soils where scab is almost entirely inhibited by a wet season.

The writer wishes to express his sincere thanks to the following colleagues: Mr F. T. Bennett, Mr S. Burr, Mr N. M. Comber, Dr J. A. Hanley, Mr J. Manby, Professor Seton and Miss L. Scott.

## EXPLANATION OF PLATES III AND IV

Fig. 1. Effect of green-manuring on scab. Left: green-manured. Right: untreated. (Reproduced from *Report* No. 118, University of Leeds and Yorkshire Council for Agricultural Education.)

Fig. 2. The effect of liming on scab. Experiment 6. Left: chalked. Right: untreated.

Fig. 3. The effect of liming on scab. Experiment 7. Left: limed and chalked. Right: untreated.

Fig. 4. The effect of lime counteracted by green-manuring. Experiment 10. Left: green-manured but unlimed. Right: green-manured and limed.

Fig. 5. The effect of lime partially counteracted by green-manuring. Experiment 11. Note the pin point scabs on all the potatoes.

*Note.* The blocks for the above plates have been kindly lent by the University of Leeds and the Yorkshire Council for Agricultural Education.

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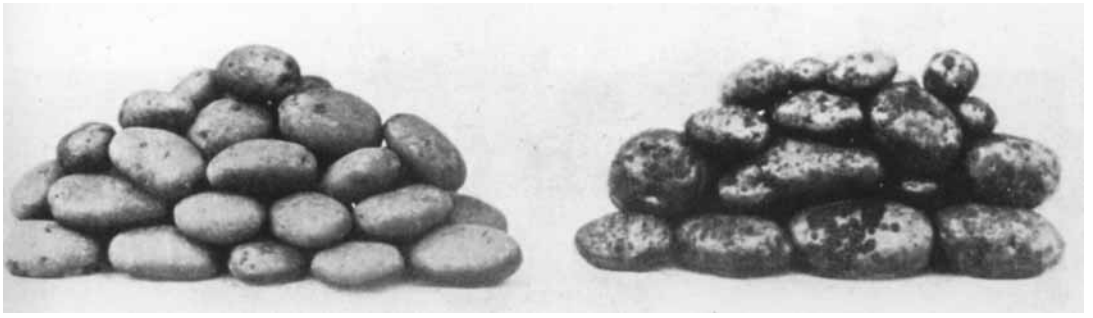

Fig. 1.

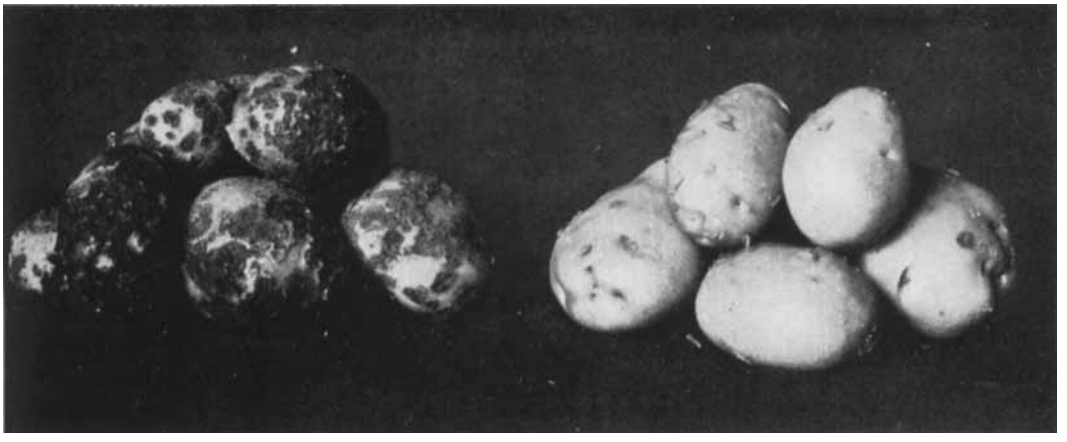

Fig. 2.

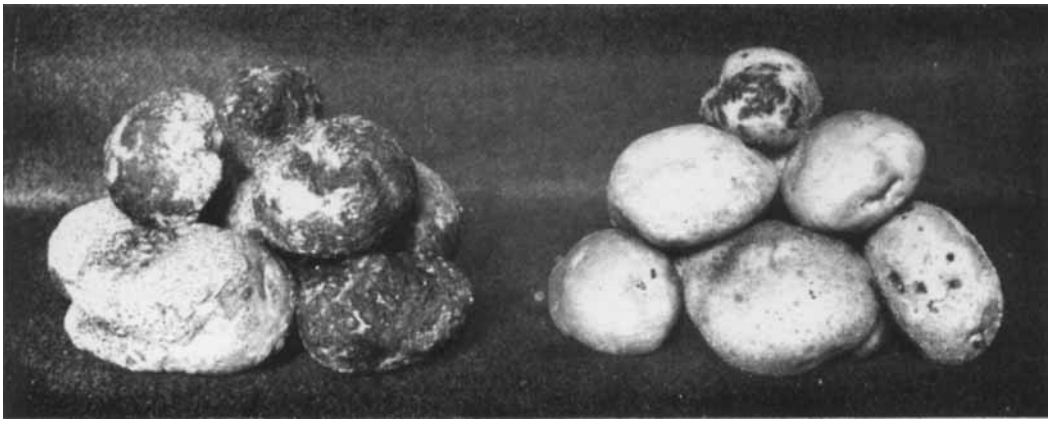

Fig. 3.

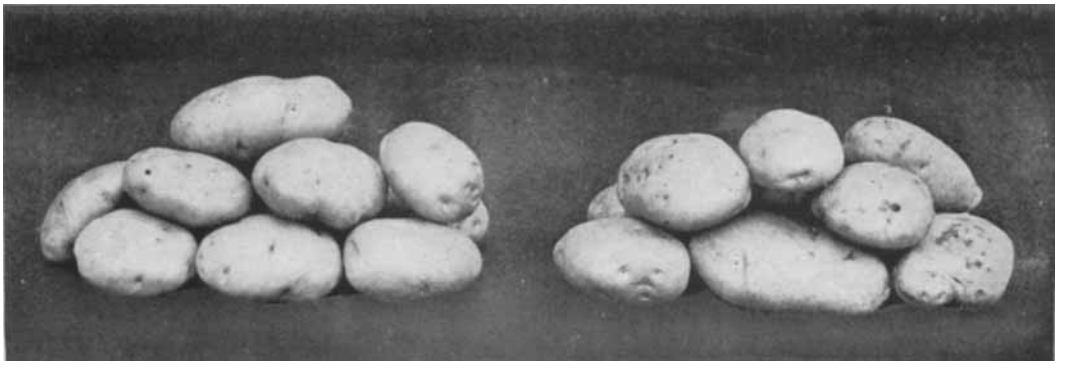

Fig. 4.

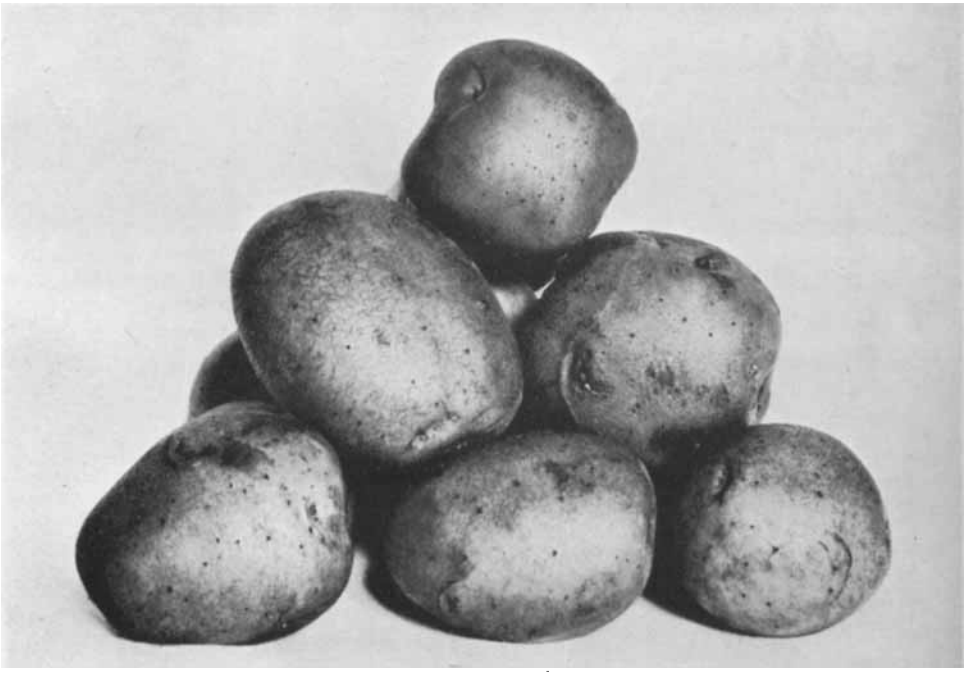

Fig. 5.