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THE INFLUENCE OF MANGANESE ON THE DEVELOPMENT OF POTATO SCAB

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INTRODUCTION

The incidence of common scab on potatoes depends on a number of environmental factors affecting both the organism (*Streptomyces scabies*) and the host plant. Development of scab is favoured by an alkaline or slightly acid soil; it is generally accepted that scab will not develop to any great extent at pH's below 5.0. There is also general agreement that scab is worst under dry conditions, but the relationship between soil moisture and scab infection is not a simple one. Soil temperature and soil organic matter also appear to have an influence.

A review of the literature [45] indicates that the influences of environmental factors on the development and control of common scab are not fully explained, and that, in certain circumstances, the results of investigations are apparently inconsistent or contradictory. The type of scab formed and the severity of the attack are the result of a complex interaction of environmental factors with both the scab organism and the potato plant. Clearly, the problem of scab control has yet to be solved.

The economic importance of common scab is difficult to estimate. It is true that in many cases, only the skin of the tuber being affected, the value of the tuber is not greatly reduced. On the other hand, badly scabbed tubers are unsightly and unpopular with the consumer, a fact which is becoming more important with increasing sales of prepacked washed tubers. Further, if scabbed tubers are stored there is a greater liability of secondary infection with rot-producing organisms.

When tubers are grown for the seed trade the disease is probably most serious. The effects of planting scabbed tubers on land free from scab organisms was clearly shown by the work of Cairns, Greeves and Muskett [3]. They found that even when tubers of the varieties Kerr's Pink and Majestic were so slightly scabbed as to be regarded by the farmer as 'clean', severely scabbed crops were produced; since the incidence of scab was greatly reduced when the 'seed' was disinfected, most, if not all, of the infection must have been carried by the 'seed'.

The effects of planting scabbed 'seed' must depend on the soil conditions and is probably most serious on slightly acid to neutral soils. On more acid soils, where conditions are such that the potato may have a natural resistance to attack, the importance of clean 'seed' will not be so great.

The results obtained in 1962 [17] at a farm in Lanarkshire where, by applying manganese sulphate mixed with the fertiliser in the drill at planting time, a very marked reduction was obtained in the proportion of scabbed tubers, suggest that scab is intimately related to the manganese status of the soil and that environmental factors known to influence the development of the disease may be related only in so far as they affect the availability of manganese in the soil.

To confirm the effect of manganese applied to soils with pH's over 6.0 on the development of scab, further trials were conducted in 1963 at four selected centres in the West of Scotland.

EXPERIMENTAL

The effect of applying manganese sulphate in the drill along with a basal dressing of fertiliser at planting time was tested at four centres. Details of the pH and manganese status of the untreated soils are given in Table 1. The experiment consisted of a comparison of plots receiving manganese sulphate at rates of 28 lb and 56 lb per acre with control plots receiving no manganese. Simultaneously, all plots received a basal dressing of a compound fertiliser containing 6.25% N, 9.5% P_2O_5 and 12.0% K_2O, at the rate of 12 cwt per acre. There were six replicates of each treatment at each centre.

TABLE 1

Soil analysis data of composite sample taken from each experimental site

Centre	pH*	pC**	Extractable**		Loss on ignition %	Manganese – ppm			
			Ca mg/100 g	Mg mg/100 g		Water-soluble†	Exchangeable††	Reducible ††	Total
1	6.22	4.13	140	17	5.5	0.43	6.4	237	1007
2	6.23	3.43	413	9	13.2	0.31	6.8	64	330
3	6.91	3.73	262	7	6.3	0.19	3.9	45	85
4	6.16	3.76	342	8	11.9	0.21	4.5	43	288

* pH and pC (46) determined in soil suspension (soil:liquid ratio – 1/2.5)

** 2.5% acetic acid extract (soil:liquid ratio – 1/40)

† Water extract (soil:liquid ratio – 1/10)

†† Normal neutral ammonium acetate (soil:liquid ratio – 1/10). Soil re-extracted with normal neutral ammonium acetate containing 0.2% hydroquinone for reducible manganese determination (soil:liquid ratio – 1/10)

After cultivation the land was drilled and the manganese sulphate, which had been mixed with the compound fertiliser, was spread over the opened drills, then the tubers* were planted and covered by splitting the drills. This procedure effected a placement of manganese in the tuber-setting zone.

At harvest the total yield of tubers and the total number of tubers from each plot were recorded. A random sample of about 14 lb of tubers was taken from each plot and a scab index determined.

Scab index

A modification of the method of Walker, Larson and Albert [44] was used to determine the scab index, which is a measure of the surface area of the tuber scabbed.

The tubers were divided into five arbitrarily selected classes as follows:

1. Clean tubers.
2. Very slightly scabbed (approximately 1/16th of the surface area scabbed).
3. Slightly scabbed (approximately $\frac{1}{8}$th of the surface area scabbed).
4. Moderately scabbed (approximately $\frac{1}{4}$ of the surface area scabbed).
5. Severely scabbed (approximately $\frac{1}{2}$ or more of the surface area scabbed).

The scab index was calculated by multiplying the number of tubers in classes 1, 2, 3, 4 and 5 by 0, 1, 2, 3 and 4 respectively, summing the products, dividing the sum by the product of four times the total number of tubers, and then multiplying the quotient so obtained by 100 to give the scab index. A scale of 0 for clean tubers to 100 for severely scabbed tubers results.

RESULTS

A. *Incidence of Common Scab*

The effects of manganese sulphate treatments on the incidence of common scab are shown in Tables 2 and 3.

Manganese sulphate applied at 28 lb per acre gave a marked and highly significant reduction in the incidence of common scab as measured by the scab index, which was reduced by 41 per cent at Centre 1, 51 per cent at Centre 2, 63 per cent at Centre 3 and 65 per cent at Centre 4. At the higher rate of application of manganese sulphate the corresponding reductions were all greater at 50, 59, 67 and 72 per cent respectively, but the additional reduction due to the increase in manganese sulphate application was not statistically significant at any one centre.

The reduction in the amount of scab resulting from the manganese

* Potato varieties:– Centre 1: Kerr's Pink, Centre 2: Kerr's Pink, Centre 3: Majestic, Centre 4: Golden Wonder.

treatments was also shown by the increase in the number of tubers completely free from scab (Table 3). Highly significant results from both levels of treatment were obtained at all centres. At no centre, however, was there a significant difference in the response between the two levels of manganese sulphate applied, although the higher level always gave the greater response.

TABLE 2

Scab indices				
Treatment per acre	Centre			
	1	2	3	4
1. Nil	19.90	43.92	49.88	21.77
2. $MnSO_4$, 28 lb .	11.80	21.73	18.35	7.55
3. $MnSO_4$, 56 lb .	9.98	18.32	16.38	6.05
Probability, P%.	< 0.1	< 0.1	< 0.1	< 0.1
LSD at $P = 5$%.	2.50	6.14	12.76	3.28

TABLE 3

Percentage of tubers free from scab				
Treatment per acre	Centre			
	1	2	3	4
1. Nil	31.85	3.43	3.45	42.47
2. $MnSO_4$, 28 lb .	55.78	22.22	31.55	73.52
3. $MnSO_4$, 56 lb .	62.67	32.03	40.60	77.33
Probability, P%.	< 0.1	0.25	0.1	< 0.1
LSD at $P = 5$% .	7.84	12.95	15.56	7.50

B. *Incidence of Black Scurf*

At Centre 4 the manganese treatments gave significant reductions in the number of tubers affected with Black Scurf (*Rhizoctonia solani*) and the higher level of manganese sulphate was significantly more effective than the lower level (Table 4). At other centres the amount of Black Scurf was negligible.

TABLE 4

Percentage of tubers with Black Scurf at Centre 4	
Treatment per acre	Black Scurf, %
1. Nil	25.45
2. $MnSO_4$, 28 lb .	18.52
3. $MnSO_4$, 56 lb .	11.13
Probability, P%.	0.3
LSD at $P = 5$% .	6.67

C. *Weight and number yield of tubers*

Table 5 gives the results for the total weight yield of tubers, and Table 6 gives those for the total number of tubers produced.

TABLE 5

Yield of tubers (lb per plot)				
Treatment per acre	Centres			
	1	2	3	4
1. Nil	47.33	66.50	47.92	39.92
2. $MnSO_4$, 28 lb .	44.58	72.67	50.92	47.50
3. $MnSO_4$, 56 lb.	53.67	77.00	53.58	50.67
Probability, P%.	5.5	8.0	N.S.	< 0.1
LSD at P = 5%.	(7.40)	(9.14)	—	3.78

At Centre 4 both levels of manganese sulphate significantly increased the weight yields of tubers, 28 lb per acre producing an increase of 19 per cent in yield and 56 lb per acre rate giving an increase of 27 per cent. Although increased yields were also noted at other centres they were not statistically significant.

Manganese treatments reduced the number of tubers produced. At Centres 1, 2 and 4 the reductions were significant, the 28 lb per acre application reducing the tuber numbers by 9.0, 15.5 and 15.0 per cent respectively whilst the 56 lb per acre application reduced the tuber numbers by 10.5, 22.0 and 23.0 per cent respectively. Only at Centre 4 was the difference between the two levels of manganese treatment significant. The reduction in tuber numbers at Centre 3 was not significant.

TABLE 6

Number of tubers per plot				
Treatment per acre	Centres			
	1	2	3	4
1. Nil	438	288	279	331
2. $MnSO_4$, 28 lb .	398	243	257	280
3. $MnSO_4$, 56 lb .	392	224	260	256
Probability, P%.	0.9	1.9	N.S.	<0.1
LSD at P = 5% .	28	41	—	16

The combination of increased yield and reduction in number of tubers produced following the manganese sulphate treatments resulted in marked increases in the average weight of tuber (Table 7).

The lower level of manganese treatment gave significant increases of 31 and 41 per cent at Centres 2 and 4 respectively and the higher level of manganese sulphate gave significant increases of 27, 53, and 64 per cent respectively at Centres 1, 2, and 4. At Centre 3 the higher level produced an increase of 20 per cent but this was only significant at the 7 per cent level of probability.

TABLE 7

Mean weight of tubers (lb)				
Treatment per acre	Centres			
	1	2	3	4
1. Nil	0.108	0.231	0.173	0.121
2. $MnSO_4$, 28 lb .	0.112	0.302	0.199	0.170
3. $MnSO_4$, 56 lb .	0.137	0.353	0.208	0.198
Probability, P%.	1.6	0.9	7.1	<0.1
LSD at $P = 5\%$.	0.019	0.067	(0.030)	0.010

SUMMARY OF RESULTS

Development of scab on these four slightly acid to neutral soils has been shown to be greatly influenced by applications of manganese sulphate to the soil; also, yield increases were produced in some cases. The results of these experiments confirm the findings of a similar type of experiment conducted in 1962 [17] and may be summarised as follows:

a. The amount of common scab on potato tubers was greatly reduced by the soil application of manganese sulphate. This was shown by the very marked reduction in the scab index and by the increase in the number of tubers completely free from scab. Although a rate of application of 56 lb manganese sulphate per acre gave better control of scab than a rate of 28 lb per acre, the difference was not statistically significant at individual centres and the extra manganese sulphate may not be justified commercially.

b. Black Scurf was found only at Centre 4, but the results of this experiment indicate the possibility of controlling this disease by soil application of manganese sulphate and suggest that the resistance of the tubers to attack by disease organisms in general has been greatly increased.

c. The total yield of tubers was increased at three of the centres but at only one centre was the effect highly significant. However, the combination of this effect with the reduction in the number of tubers produced resulted in an increase in the average weight of tuber. The actual yield of ware tubers would be appreciably increased. The results at Centre 3 were anomalous; despite the very low level of manganese in this soil the yield and average weight of tuber produced were not significantly increased by the manganese sulphate treatments.

DISCUSSION

Common Scab appears to be prevalent on light gravelly soils, alkaline or slightly acid in reaction and of low humus content. Temperature and moisture also play important roles, high temperature and low moisture being predisposing factors in the production of a severely scabbed crop. Environmental factors are not, however, precise in their effects, apparently conflicting results occurring frequently. For example, even within this present set of experiments at Centre 1 where the soil is very light textured and gravelly with a pH of 6.2, the crop of the very susceptible Kerr's Pink variety might have been expected to be severely scabbed but very little scab was found.

Clearly the importance of environmental conditions thought to influence the development of scab must depend only upon the presence of factors which affect the nutrition and resistance of the crop or the virulence of the organism directly or through interaction with some other factor, so far unnoticed, in the soil.

The results of these experiments indicate that the development of scab is controlled by the amount of easily available manganese in the soil. It, therefore, appears possible that the part played by environmental factors might be due to their direct influence on the level of available manganese in the soil.

Apart from the fact that scab appears to be more severe in soils of low humus content there is little evidence of the importance of soil humus in the control of the disease. In some instances the addition of easily decomposable vegetable matter has provided a means of reducing the amount of scab. Millard [21] showed that a very appreciable amount of control could be obtained by ploughing in green crops such as rye, mustard or vetches. More recently, Atkinson and Rouatt [1] and Oswald and Lorenz [28] have shown that the addition of soyabean green manure crops to soils infested with Streptomyces scabies reduced the disease and, according to Atkinson and Rouatt, increased the acidity of the soil.

Millard explained the effect of green manuring by his 'preferential food' hypothesis, but Sanford [32] suggested later that the success of green-manuring is due to the inhibiting influence of certain micro-organisms on the development of *Streptomyces scabies*. This was supported by Millard and Taylor [22] who indicated that failure to control scab in some cases of green manuring is due to the absence from the soil of certain saprophytic species of Streptomyces the growth of which is encouraged by green manuring and leads to the suppression of the scab organism.

The effect of additions of easily decomposable vegetable matter might be explained by an effect on the solubility of manganese compounds in the soil. Christensen, Toth and Bear [5] showed that the decomposition of organic matter in soil results in an increase in the level of exchangeable manganese. They suggested that the release of manganese by the decomposition of organic matter is probably brought about by the reducing conditions prevalent in the area of decomposition, by direct reduction of the manganese by organic compounds produced in the process and by a reduction in the pH due to organic acids present. Where the soil had been heavily limed the effect of organic matter decomposition on the soil manganese was limited to the period of decomposition, since under these more alkaline conditions the available manganese was quickly changed into less soluble forms. With more acid soils, however, the effect on manganese availability was more long-lasting. Fujimoto and Sherman [11] also found that the biological oxidation of organic matter of high carbon: nitrogen ratio increased the level of exchangeable manganese and the plant absorption of manganese.

With the rapid decomposition of sufficient quantities of organic matter the effect of liming on manganese availability might, at least for a time, be overcome. The control of scab may, in fact, be due to increased supplies of soluble manganese resulting from the decomposition of the green manure. The effectiveness of control of scab by green-manuring in this way must vary with soil conditions affecting decomposition, the quantity of easily reducible manganese and the pH of the soil. Green manuring could be expected to be most efficient under moist and warm conditions in moderately limed soils containing reasonable amounts of easily reducible manganese.

The evidence, in many cases, of the effect of soil moisture on the development of scab is conflicting, but there appears to be general agreement that scab is worst in dry years. According to Millard[21] no effect is seen until the moisture content is sufficient to alter the aeration of the soil and this will vary with texture. Thus heavy rain may cause water-logging of clay soils and complete inhibition of scab. McKay[19] however, has shown that with gravelly soils there may be an actual increase in scab in a wet year. Sanford[33] reached the conclusion that, although improved aeration resulting from the reduction in soil moisture content will give the best conditions for scab development, the disease can be equally severe on wet soils in which effective competition from associated saprophytes is at a minimum.

It would appear to be broadly true that dry conditions promote scab infection and that increased moisture content tends to reduce the disease, control being effected through a reduction in the degree of aeration of the soil. It might be argued that the scab organism does not develop so well when the supply of oxygen is limited, but even in heavy soils it is doubtful if potato crops are ever grown for sufficient time under soil conditions so water-logged as to inhibit the growth of the organism through insufficient aeration. There is no doubt, however, that the incidence of scab varies from year to year and tends to be greater in dry years.

Changes in soil moisture sufficient to alter the aeration of the soil may increase the supply of available manganese. It has been noted that in dry years in the West of Scotland, the number of cases of Grey Speck in oats is greater than when wetter conditions prevail. Piper[31], Conner[7], Leeper[15], and Steenbjerg[39] have stressed the importance of oxidation-reduction reaction of the soil in relation to the availability of manganese. Furthermore, several workers[4 7 12 20] have demonstrated that water-logging also increases the exchangeable manganese in the soil. There appears to be little doubt that manganese availability and absorption are increased by reducing conditions in poorly aerated soils. Godden and Grimmet[12] showed that the manganese content of oats and mustard was greater when grown in undrained soil than when grown in drained soils. Piper[31] was able to increase the uptake of manganese in oats by water-logging soils a week before seeding. He also showed that more manganese was absorbed by oats grown in soils kept at 90% water saturation than when grown at lower moisture contents.

Because drier soil conditions (usually associated with more severe scab attack) result in a reduction in the availability and absorption of manganese, the effect of soil moisture on the development of scab may be explained in terms of manganese.

The most important single factor influencing the incidence of scab is undoubtedly the acidity of the soil. Many workers [2 10 21 26 34 35 41] have demonstrated the importance of soil reaction in scab development. Increases in soil pH through the range of 4.8 to 7.0 have been shown to result in increased scabbiness, and a soil reaction of pH 5.0 to 5.5 is frequently recommended for the best yield with the least amount of scab. Millard [21] qualifies his agreement with the importance of soil acidity by pointing out that severe attacks have been recorded in soils of pH 4.4 and that, although the organism may be assumed to be omnipresent in soils in this country, clean crops have been raised from soils of pH 7.0. In his view the operation of other factors may reduce or even obliterate the effect of soil acidity. Many cases have been reported [6 8 14 16 26 41] of reduction in the incidence of scab following the acidification of the soil with sulphur, aluminium sulphate or acid-producing fertilisers.

On liming soil the amount of soluble manganese is greatly reduced, sometimes to such an extent that deficiency conditions are produced [18 27 29 30 31 37 38 40]. On the other hand, acidification of the soil with sulphur or other acid-producing fertilisers increases the soluble or exchangeable manganese and results in increased uptake of manganese by the plant [11 23 42 43]. This intimate relationship between manganese availability and soil reaction, together with the importance of soil acidity in the development of scab, suggests that the resistance to scab associated with acid soils is due to the higher levels of soluble manganese found in these soils and not to the acidity itself.

The effect of lime additions and acidification on the available manganese status will vary from soil to soil depending on the total amount and types of manganese compounds present. Not all soils if limed to near neutrality will prove to be deficient in manganese; in fact, in many soils the amounts of available manganese might still be sufficient to give a relatively clean crop, especially if a more resistant variety were grown.

Schroeder and Albrecht [36] and Greis [13] suggested that the ratio of exchangeable calcium to potassium in the soil might be an important factor in the development of the disease but more recent work by Doyle and MacLean [9] failed to confirm this hypothesis: they concluded that the rise in soil pH resulting from the application of lime is the main factor influencing the occurrence and severity of scabbiness and that changes in the Ca: K ratio due to liming are not related to scabbiness.

Schroeder and Albrecht's work, however, does demonstrate that potato scab is not entirely a matter of variety and virulence of the infecting organism but is also a matter of proper plant nourishment in terms of the fertility of the soil. They made the important observation that soil acidity may be playing its role in connection with scab inhibition merely by helping to deliver more nutrients and thus producing healthier plants less susceptible to infection.

Mortvedt *et al.* [24] working with sand culture experiments have shown that by increasing the manganese concentration in the tuber-setting zone, scab infection can be markedly reduced. In later work [25] they found that application of manganese sulphate at a rate of 150 lb per acre broadcast in the tuber zone resulted in a significant decrease in scab. Greenhouse studies failed to show a significant correlation between the manganese content of the tuber periderm and the incidence of scab but an investigation of twenty-two commercial fields of potatoes revealed a significant negative correlation between the manganese content of the tuber periderm tissue of scab-susceptible varieties and their scab index. They suggest that the amount of manganese absorbed by the plants is not so important in the control of the disease as is the direct effect of the water-soluble soil manganese on the organism itself.

Our experiments indicate that the available manganese status of the soil is one of the most important single factors in the development of scab and that marked reduction in the incidence of scab can be achieved with an application of as little as 28 lb per acre of manganese sulphate. It is not possible from these experiments, however, to say precisely how the control takes place. With soils of relatively high pH, a soil application of 28 or 56 lb manganese sulphate per acre (even as a placement in the tuber-setting zone) can only increase the water-soluble soil manganese effectively for a limited period; it seems unlikely that the soluble manganese concentration in the soil at the time of tuber formation would be sufficiently high to control the organism. Increased supplies of available manganese during the early part of the growing season will, however, result in an increased uptake of manganese which may improve metabolism and thus increase the resistance of the plant to attack.

The result also indicate that in many soils with relatively high pH in the West of Scotland, manganese may be a factor limiting yield. In many cases the cost of reducing scab infection may be well compensated by increased yields of ware tubers.

SUMMARY

The development of common scab on potato crops growing in slightly acid to neutral soils has been shown to be greatly reduced by application of manganese sulphate to the soil at planting time. A general improvement in health and appearance of tubers was noted and increased yields of marketable tubers were obtained. The possibility that environmental factors known to influence the development of scab are only important in so far as they affect the solubility of soil manganese is discussed.

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