CLUBROOT CONTROL IN CAULIFLOWER AND BRUSSELS SPROUTS WITH BENZIMIDAZOLE TRANSPLANTING DRENCHES AND SOIL pH MANIPULATION

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Summary

Benzimidazole drenches at transplanting to control clubroot (*Plasmodiophora brassicae*) in cauliflower (*Brassica oleracea*) and brussels sprouts (*B. oleracea*) did not prevent severe yield loss except in one crop which matured within 10 weeks. Raising soil pH to above 7 to inhibit clubroot was both impractical for certain soils and ineffective in others, as it did not prevent heavy infection when soil was wet. Under drier soil conditions, high soil pH prevented clubroot or promoted vigorous root growth above clubbed parts, enabling one crop to recover from an early infection. Boron deficiency symptoms occurred with heavy liming. Combining the transplant drench with elevated soil pH showed promise in cauliflower but was not successful in brussels sprouts.

INTRODUCTION

In previous studies, a benzimidazole transplant drench was successfully used to control clubroot in cabbages (*B. oleracea*) (Tate 1977). This paper describes attempts at preventing yield loss due to clubroot in cauliflower and brussels sprouts by transplant drenching and soil pH manipulation.

METHODS

Effect of soil pH on clubroot: glasshouse pot trial

Lime requirement was determined in the laboratory on Manawatu silt loam, Levin silt loam, Ohakune silt loam (high in organic matter), Patumahoe clay loam and Waimairi peat. Lime types compared were calcium hydroxide ($\text{Ca}(\text{OH})_2$), or finely ground calcium carbonate (fine CaCO_3). One hundred and fifty gram samples of sieved soil were mixed with lime at rates equivalent to 0, 2.5, 5, 10 or 20 t/ha. They were then incubated at field capacity for 15 weeks in closed incubation pots at room temperatures. At 4, 9 and 15 weeks, pH was determined using 10 g of oven dried sample/25 ml water. Each soil was then adjusted with $\text{Ca}(\text{OH})_2$ to pH levels between 5.7 and 8.0, using the data plotted in Fig. 2 and a further high-pH saline soil Tangoio sandy loam included in the test. Six week cabbage seedlings were used as the test crop. They were inoculated in early spring by spraying the roots with 10^6 spores/ml of *P. brassicae*, transplanted at five per 15 cm pot and watered in. Pots were arranged on the glasshouse bench and trickle irrigated for 6 weeks at air temperatures of 15-23°C under natural light. Then all plants were lifted and recorded for presence or absence of clubroot. Soil pH was monitored at 0, 2, 4 and 6 weeks growth.

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Field liming and transplant drench trials

Five trials were conducted on Levin silt loam at the Horticultural Research Centre or commercial properties, using 'Phenomenal' cauliflower or 'Jade Cross Hybrid' brussels sprouts. Details of timing and soil moisture conditions are given for each trial in Fig. 1, where root infection periods are indicated by zero soil moisture deficits (Watson 1965), caused by either rainfall or irrigation. Fine CaCO_3 or Ca(OH)_2 was soil-incorporated 2-4 weeks pre-planting with a rotary hoe and soil pH was monitored for each trial. The benzimidazole fungicides tested were carbendazim (50% WP) and benomyl (50% WP) at 200 ml of 0.05% a.i. per transplanting hole. Trial areas were either naturally infested with clubroot spores or artificially infested by adding a spore suspension or peatspore mixtures (Tate 1977) to each planting hole. Healthy seedlings were planted by hand at 18 per 6 x 3 m plot. Summer irrigation was applied to all Research Centre trials while grower trials relied on natural rainfall. At crop maturity curds were cut and trimmed, weighed and the root systems lifted and rated for clubroot intensity (Watson 1965).

Fig. 1. Soil moisture deficits and timing of five field trials. Clubroot infection periods are indicated by precipitations resulting in zero soil moisture deficit.

RESULTS

Benzimidazole drenches

In the first field trial on non-irrigated summer cauliflowers ('Phenomenal 4 month'), a benomyl transplanting drench gave adequate yields with 81% saleable heads and an average curd weight of 1.6 kg (Table 1). However, considerable lateral root clubbing occurred in the 16 week period and curd weight was much lower than in certain limed plots in the same trial.

In two further trials on irrigated summer cauliflowers and brussels sprouts (14 and 20 weeks duration respectively) benomyl drenches failed to prevent total loss of marketable yield from clubroot. Also, the earlier infection occurred after the initial 4-5 weeks fungicide protection, the

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more serious yield loss appeared to be. In the non-irrigated trial (Fig. 1A) infection conditions (soil at zero moisture deficit) occurred several times after the first month, in the irrigated trials (Fig. 1B), at many separate times.

Soil pH manipulation

In the pot trial of six soils at pH levels of 5.7-8.0, clubroot frequency was high between pH 5.7 to 6.7, declined to lower levels between pH 6.7 and 7.2, and was absent at higher pH levels (Table 2). However, to achieve high soil pH in Ohakune silt loam and Waimairi peat, excessive rates of lime were required (fig. 2). For other soils at pH 6, 10-20 t/ha of $\text{Ca}(\text{OH})_2$ or greater amount of fine CaCO_3 was required to achieve pH 7. Weight for weight, $\text{Ca}(\text{OH})_2$ was 1.3 - 1.7 times more effective than fine CaCO_3 in raising soil pH.

Fig. 2. Effect on lime type and dosage on pH response of five soils in closed pots in the laboratory.

In the non-irrigated summer cauliflower trial (Table 1), a root health and yield response to soil pH resulted but potential yield was not realised by any treatment. Curd weight was high in the high-pH plots but rejection rates were also high, and though rejection rate was low for benomyl-drenched plants, mean curd weight was also low. Early infection occurred (Fig. 1A) in high-pH plots while the benomyl drench prevented this infection. The infected plants collapsed but later recovered by making new root growth further up the hypocotyl, the degree of recovery depending on soil pH and aided by the generally low soil moisture level at the soil surface. By contrast, benomyl-drenched plants produced deeper, initially healthy root systems, which subsequently became quite severely clubbed.

Combined effects

An indication of the combined effect of high pH soil and a transplanting drench was first observed in benomyl-drenched guard plants on the perimeters of high-pH plots in the cauliflower trial of Table 1. These plants were of uniformly high quality and curd weight, surpassing that of plants within the plots.

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Table 1. Effect of soil pH and a benomyl drench on clubroot and yield in non-irrigated, April harvested cauliflower.

Mean soil pH for 16 wk crop duration	Clubroot intensity at harvest ¹	Saleable plot ² yield (kg)	Saleable curds (%)	Saleable curd weight (kg)
7.2	3.4 d	22.7 a	61 b	2.1
7.1	3.8 c	19.7 ab	52 bc	2.1
7.0	4.0 bc	15.6 bc	51 bc	1.7
6.8	4.2 b	9.8 cd	27 de	2.0
6.6	4.7 a	4.9 de	17 de	1.6
6.4	4.6 a	3.0 e	12 e	1.4
6.4 ³	2.9 e	23.6 a	81 a	1.6

¹ 0 = roots healthy; 5 = roots completely clubbed.

² Marketable yield from 18 plants per plot.

³ Benomyl transplant drench at 200 ml of 0.05% w/v per plant.

In a further trial on irrigated, February harvested cauliflower ('Phenomenal 3 month') a soil pH of 6.9-7.1 combined with a carbendazim transplant drench resulted in low root disease and high yields, while the higher soil pH by itself did not prevent clubroot and heavy yield loss during the 10 week growth period (Table 3). Boron deficiency symptoms (hollow heart) were present in all plots. Infection conditions occurred many times during growth (Fig 1C).

Table 2. Effect of soil pH on clubroot at 6 weeks growth.

Soil Type	Fraction of pots with clubbed plants at soil pH ranges									
	5.51 -5.8	5.81 -6.1	6.11 -6.4	6.41 -6.7	6.71 -7.0	7.01 -7.3	7.31 -7.6	7.61 -7.9	7.91 -8.2	8.21 -8.5
Patumahoe clay loam	—	4/4	1/3	3/6	0/7	1/4	0/4	0/4	0/3	—
Manawatu silt loam	—	—	—	—	—	3/5	0/4	0/3	—	—
Waimairi peat	—	—	—	4/4	4/8	1/6	1/2	0/5	0/3	—
Ohakune silt loam	4/5	2/2	4/8	2/4	0/3	0/1	—	—	—	—
Levin silt loam	—	4/4	3/5	6/13	1/5	0/7	0/3	0/3	—	—
Tangoio sandy loam	—	—	—	—	—	—	—	0/26	—	—
Mean frequency all Soils (%)	80	100	50	56	22	22	0	0	0	—

A total of 164 pots each containing five plants was used. Highest and lowest pH levels at which clubroot was recorded were 7.2 and 5.7 respectively.

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In a following trial on irrigated brussels sprouts of 16 weeks duration however, carbendazim-drenched plants in high-pH soil became severely clubbed and failed to yield even though some root system recovery occurred at the highest pH level. Infection conditions occurred at 1, 15 and 56 days (Fig. 1C) after which carbendazim-drenched plants began to deteriorate from clubroot while water-drenched 'controls' at similar pH levels were infected at planting out and died.

Table 3. Effect of high soil pH and carbendazim transplant drench on clubroot severity and yield in irrigated, February harvested cauliflower.

Transplant drench (200 ml)	Mean soil pH for 10 week crop duration	Clubroot intensity at harvest ¹	Saleable plot ² yield (kg)	Mean Saleable curd weight (kg)
carbendazim ³	7.1	0.7 bB	39.1 aA	2.2
carbendazim ³	6.9	1.1 bB	38.3 aA	2.1
water	7.0	4.9 aA	12.8 bB	0.7

¹ 0 = roots healthy, 5 = roots completely clubbed.

² Marketable yield from 18 plants per plot.

³ 0.05% w/v.

DISCUSSION

The most severe infection and club development occurs when soil is wet, high spore concentrations are present, soil temperatures are near 20°C and light intensity is high (Colhoun 1958). Infection will also occur at 9°C but minimal club development occurs. This explains the degrees of clubbing encountered in the different trials. In the irrigated summer trials under high soil temperatures both clubbing and effects on yield were severe. In the non-irrigated trial clubroot was severe after summer rainfall but in the following dry period healthy new root growth enabled the plants to partially recover. In the glasshouse pot trial, rather low soil temperatures, moisture and inoculum levels and overhead light intensities all contributed to conditions marginal for clubroot infection and development and clubbing was slight.

Benzimidazole drenches were not successful in the trials that took longer than 10 weeks to mature; despite protection against clubroot infection being excellent for the first 4-5 weeks. In most trials infection occurred soon after this during rainfall or irrigation and severe clubbing developed. In the rapid-maturing 'Phenomenal 3 month' cauliflower however, yield was unaffected because late infections had insufficient time to produce severe clubbing before the crop matured (Table 3). Ability of the planting drench to prevent yield reduction from clubroot therefore depends upon the use of rapid-maturing cultivars such as 'Phenomenal 3 month' cauliflower or equally fast maturing broccoli. The treatment has little prospect of protecting longer term crops such as brussels sprouts.

The results showed that raising soil pH by itself to prevent clubroot was impracticable for certain soils due to the excessive rates of lime required and ineffective in others if wetting to field capacity occurred. Also, at pH levels necessary for clubroot inhibition, boron deficiency symptoms resulted. It was also difficult to time the pH-response to the growth stage when pH inhibition of the fungus was required, between 5 to 12 weeks after transplanting. The only situation where high soil pH was clearly beneficial was in the non-irrigated summer crop where soil moisture

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was low most of the time. In this case the crop recovered from early collapse by making vigorous root growth into the limed zone, a good recovery depending upon high pH level. Since summer crops are always the worst affected by clubroot and require irrigation however, there would be little chance of avoiding severe clubroot even in high-pH soil unless rapid drying of the root zone occurred after each irrigation or rainfall, perhaps in free draining soils or aided by growing plants on low ridges.

Combining the transplant drench with high soil pH offered promise but was still not successful on long term crops, since irrigations after 5 weeks provided infection conditions. According to Colhoun (1958) a high soil pH does not prevent clubroot infection under ideal infection conditions, but merely narrows the range of conditions under which infections occur. This was the case in the pot experiment (Table 2). It is possible that the 10 week cauliflower crop drenched with carbendazim (Table 3) would have matured normally without the heavy liming. However, liming improved root growth and yield in infested soil under drier conditions, indicating that raising soil pH to at least 6.8 is desirable where it can be economically achieved. On Levin silt loam, peak pH response occurred in 2-4 weeks after incorporating $\text{Ca}(\text{OH})_2$ or fine CaCO_3 , after which a decline occurred. Incorporation immediately before planting would delay this peak response until the third or fourth week, closer to the fall-off in fungicide protection.

Further work will investigate clubroot control in rapid maturing cauliflower cultivars with lime and benzimidazole drenches and also mechanisation of the chemical drench.

For brussels sprouts neither chemical transplant drenches nor heavy liming hold any promise and alternative approaches are necessary.

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