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Control of clubroot of vegetable brassicas —1996

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1 EXECUTIVE SUMMARY

This report outlines progress in an ongoing project that aims to develop integrated control of clubroot (caused by the protozoan pathogen *Plasmodiophora brassicae*) of vegetable brassicas (*Brassica* spp.). The research approach concentrates on chemicals and disease resistance/tolerance as clubroot control strategies.

Field trials were carried out at four sites on commercial vegetable production units, two in the eastern central South Island (Woodend and Harewood), one in the southern North Island (Levin) and one in the northern North Island (Pukekohe). Two trials were carried out at each site, one to test chemical transplant drenches (and soil-incorporated treatments at one site) for efficacy against clubroot on Chinese cabbage Wong Bok (highly susceptible to clubroot), and the other to assess the reactions of eight resistant/tolerant cultivars to local *P. brassicae* populations. In each trial, glasshouse-raised seedlings were transplanted into field plots. About five months later, all plants were harvested by digging them from the soil and separating root systems from the aboveground plant parts. In the chemical control trials, fresh weights of tops were measured, and the plant root systems were individually scored for severity of clubroot. In the resistance trials, roots of plants were individually scored for clubroot severity. Soil from each of the trial sites was sampled and sown with seed of the European Clubroot Differential (ECD) series of host brassicas to characterise the population of *P. brassicae* present.

Some of the transplant drench treatments reduced plant growth. Fluazinam caused stunting of plants during early stages of growth at all of the trial sites, but this was translated into reduced harvested plant fresh weight only at one of the four sites. Transplant drench treatments of mancozeb (25 mg/plant) and benomyl (100 mg/plant) also reduced plant fresh weight at harvest, at one site each. A soil-incorporated treatment of flusulfamide at 1.8 kg/ha reduced plant fresh weight at harvest at the one site where this treatment was tested, an effect not detected when half this rate of chemical was applied.

The incidence and severity of clubroot that developed on plants differed at the four sites. Very little disease occurred at Harewood, while levels were moderate at Pukekohe and Levin, and very severe at Woodend. At Woodend, only the standard registered transplant drench treatment of benomyl at 100 mg/transplant reduced clubroot severity. At the Levin site, several transplant drench treatments with experimental chemicals, including fluazinam at 25 and 12.5 mg/transplant, flusulfamide at 0.3 mg/transplant and mancozeb at 25 mg/transplant, gave statistically significant reductions in clubroot severity, as did benomyl at 100 and 25 mg/transplant.

Several vegetable brassica cultivars shown previously to be resistant/tolerant to clubroot at one field site were similarly resistant/tolerant (relative to the susceptible cultivars Chinese cabbage Wong Bok and cabbage Stilon) at three of the four sites in the present study where the disease occurred. Cultivars more resistant than susceptible standards were broccoli Hanamori, Brussels

sprout Dolmic, cabbages Galaxy and Beverly Hills, cauliflower All Year Round, Chinese cabbage Chorus and Savoy cabbage Taler.

The populations of *P. brassicae* at two of the four sites were classified using the ECD host series, and were coded as Woodend, 16/02/30 and Levin, 16/15/31, suggesting that these populations differed in virulence. Levels of infection in plants grown in soils from the other two sites were too low to accurately classify the populations.

These results emphasise that chemical efficacy against clubroot, and degree of clubroot resistance/tolerance, differ at different field sites, probably depending on the levels of infestation and pathogenicity (virulence patterns) of the local *P. brassicae* populations. Soil and environmental conditions are also likely to affect efficacy of clubroot control methods.

This study confirms that chemicals and disease resistance/tolerance have potential as components of an integrated clubroot management strategy. Where the disease is very severe (e.g. Woodend), chemical control alone is unlikely to be effective, but it may still be profitable to grow resistant/tolerant cultivars (e.g. broccoli Hanamori, Brussels sprout Dolmic, Savoy cabbage Taler). Chemicals and resistant/tolerant cultivars could be used together to alleviate severe clubroot. At sites where intermediate levels of the disease occur (e.g. Levin) chemical treatments with fluazinam, flusulfamide, mancozeb or benomyl could be useful to reduce clubroot severity.

Future investigations on clubroot control should attempt to assess the use of several disease control methods used simultaneously, with the aim of developing fully integrated clubroot disease management strategies.

1.1 Conclusions and recommendations

- Chemicals (benomyl, fluazinam, flusulfamide, mancozeb) applied as seedling transplant drenches, and possibly as soil-incorporated treatments, reduce severity of clubroot where moderate levels of disease occur.

- Clubroot-resistant vegetable brassica cultivars give good control of the disease where it is severe, and across a range of *P. brassicae* populations with different virulence characteristics.

- Integrated clubroot management strategies, incorporating cultural, chemical, disease resistance, and possibly biological control methods, are likely to provide the most effective approach to reducing clubroot severity.

- Future research on clubroot control should further investigate cultural, chemical, disease resistance and biological control methods, and should test multi-component clubroot management strategies.

2 INTRODUCTION

Clubroot (caused by the protozoan pathogen *Plasmodiophora brassicae*) is an increasingly severe problem for growers of vegetable brassicas (*Brassica* spp.) in New Zealand. The Fresh Vegetable Industry Development Committee of the New Zealand Vegetable & Potato Growers' Federation has identified the development of strategies for controlling clubroot as a high priority research requirement.

The first symptom of clubroot in brassica crops is the wilting of leaves of infected plants, especially on warm days, but affected plants appear to recover overnight. As the disease progresses, leaves of infected plants turn yellow and the plants become stunted. Infected plants may survive to harvest, but they are unlikely to produce marketable vegetables. In severe cases, infected plants wither and are eventually killed by the disease. The wilting of foliage and eventual death of infected plants is the direct result of damage to their root systems caused by *P. brassicae*. Infected roots become distorted, form galls and in severe cases become very enlarged and swollen (see Fig. 1). Heavily infected roots eventually decay. Root damage reduces the capacity of plants to obtain nutrients and water from the soil.

Clubroot can cause severe economic losses during vegetable brassica production. The disease reduces marketable yields from, and sometimes completely destroys, crops of cabbage, cauliflower, broccoli, Brussels sprout, Chinese cabbage, and related vegetable crops. The value of land for vegetable cropping, which is often determined by the ability to produce high quality brassicas, may decline when severe clubroot infestations develop. The costs of controlling the disease are usually very high, and often involve extensive rotations or expensive applications of general biocidal fumigants.

We have identified disease resistance, chemical, and biological control as possible components of an integrated disease management strategy against clubroot (Nott et al. 1994; Cheah & Marshall 1995; Nott et al. 1995a). Recently, progress has been made with two of these—disease resistance and chemicals. A field evaluation of a large number of brassica seedlines of several vegetable types carried out in a clubroot nursery (Nott et al. 1995b) demonstrated that some were resistant to the disease (developed low levels of clubroot) while others were tolerant to the disease (grew well while very severely infected).

A number of recently developed fungicides have promise for control of powdery scab of potato (Falloon et al. 1996), which is caused by *Spongospora subterranea* f. sp. *subterranea*, a pathogen closely related to *P. brassicae*. Preliminary glasshouse experiments (Nott et al. 1995b) demonstrated that some of these can reduce clubroot severity when applied as transplant drenches to soil infested with *P. brassicae*. Field

trials in Britain have also shown that one of these chemicals (flusulfamide) has good efficacy against clubroot (Dixon et al. 1994).

Field trials were undertaken during the winter of 1996 to evaluate chemicals and clubroot-resistant/tolerant seedlines on commercial vegetable brassica production units. Sites were chosen at geographically diverse locations, that were likely to have different levels of *P. brassicae* infestation, and where the populations of the pathogen may have been different. This report describes these trials and the results obtained.

3 MATERIALS AND METHODS

3.1 Field locations and soils

Field trials were carried out at four locations, all of which were commercial vegetable production units. Soil was removed from each site by taking two small samples (≈200 ml) of top soil from each of the chemical trial replicates (see below), and the pH of each sample (in reverse osmosis purified water) was measured in the laboratory. The locality and soil characteristics at each site were:

- **Harewood**, near Christchurch, Canterbury, central eastern South Island (Lat. 43° 30′ S, Long. 172° 57′ E), Selwyn sandy loam on sand (Cox 1978), mean pH 5.9 (range 5.5 to 6.2),

- **Woodend**, Canterbury (Lat. 43° 20′ S, Long . 172° 49′ E), Kaiapoi silt loam on sand (Kear *et al.* 1967), mean pH 6.7 (range 6.5 to 6.8),

- **Levin**, Horowhenua, southwestern North Island (Lat. 40° 37′ S, Long. 175° 19′ E); Dannevirke silt loam (Cowie 1981), mean pH 7.2 (range 7.1 to 7.4), and

- **Pukekohe**, Auckland, northern North Island (Lat. 37° 15′ S, Long. 174° 55′ E); Patumahoe clay loam (Orbell 1976), mean pH 6.2 (range 5.5 to 6.7).

The trial areas at each site were prepared for brassica transplanting by applying appropriate cultivation, and the crops of vegetable brassicas established in the trials (see below) were maintained using normal commercial crop management practices.

3.2 Chemical control of clubroot

Seed of Chinese cabbage 'Wong Bok' (*Brassica pekinensis*) was sown into potting soil, and seedlings were raised in glasshouses at Crop & Food Research stations at Lincoln, Levin and Pukekohe. When the seedlings were approximately four weeks old they were placed outside for about one week and then transplanted into the field. A randomised block trial was established in March or April 1996 at each of the trial sites. Chemicals (Table 1) were applied either as transplant drenches or incorporated into the soil prior to planting. Twelve treatments were applied at the Harewood trial, eight at Woodend, and nine each at Levin and Pukekohe. The registered transplant drench treatment of benomyl at 100 mg/transplant (New Zealand Agrichemical Manual 1995) was included in each trial as a standard. At each site, trial plots each consisted of 20 transplants in a row with 0.3 m spacings between plants, and 0.4 m between rows.

Transplant drench treatments were applied to each transplant seedling by pouring the required amount of chemical solution (Table 1) into the transplant hole, allowing the solution to drain into the soil, then placing the transplant seedling in the hole, covering the roots with soil, and firming the soil around the roots. Soil-incorporated treatments were applied prior to transplanting by spraying chemical solutions onto the soil surface of treated plots. The solutions were applied in bands about 200 mm wide along each treated row at 200 ml per row, using a compressed air spray gun (Sagola 475®) at 200 kPa pressure. The chemical was then incorporated into the soil using a hand roto-tiller. Transplants were then planted into the soil (as above), with 200 ml water applied to each seedling to assist establishment.

Table 1: Chemicals tested as transplant drench or soil-incorporated treatments for control of clubroot in four field trials.

Treatment name	Product	Rate of chemical (a.i.) and water
Transplant drench		
Benomyl 100	Benlate® (50% WP[1])	100 mg/plant in 200 ml water
Benomyl 25		25 mg/plant in 200 ml water
Flusulfamide 3.0	MTF-651 (5% liquid)	3 mg/plant in 200 ml water
Flusulfamide 0.3		0.3 mg/plant in 200 ml water
Flusulfamide 0.03		0.03 mg/plant in 200 ml water
Fluazinam 25	Shirlan® (50 % SC[1])	25 mg/plant in 100 ml water
Fluazinam 12.5		12.5 mg/plant in 100 ml water
Mancozeb 25	Penncozeb® (75% WDG[1])	25 mg/plant in 200 ml water
Soil-incorporated		
Flusulfamide 1.8		1.8 kg in 800 ℓ water/ha
Flusulfamide 0.9		0.9 kg in 800 ℓ water/ha
Fluazinam 0.75		0.75 kg in 800 ℓ water/ha
Water	—	200 ml/plant

[1] Formulations: WP = wettable powder; SC = suspension concentrate; WDG = water dispersible granule.

At about five months after transplanting, all of the plants were dug from the soil. The root system was cut from each plant and the fresh weight of the aboveground plant parts (top) was measured for 10 plants from each plot. The roots of all plants from each plot (Levin trial 10 plants only) were washed to remove soil and then individually assessed for clubroot severity using a five-point disease severity key (Fig. 1). Fresh weights and clubroot severity scores were statistically analysed by analysis of variance after log and square root transformations respectively, to stabilise variances.

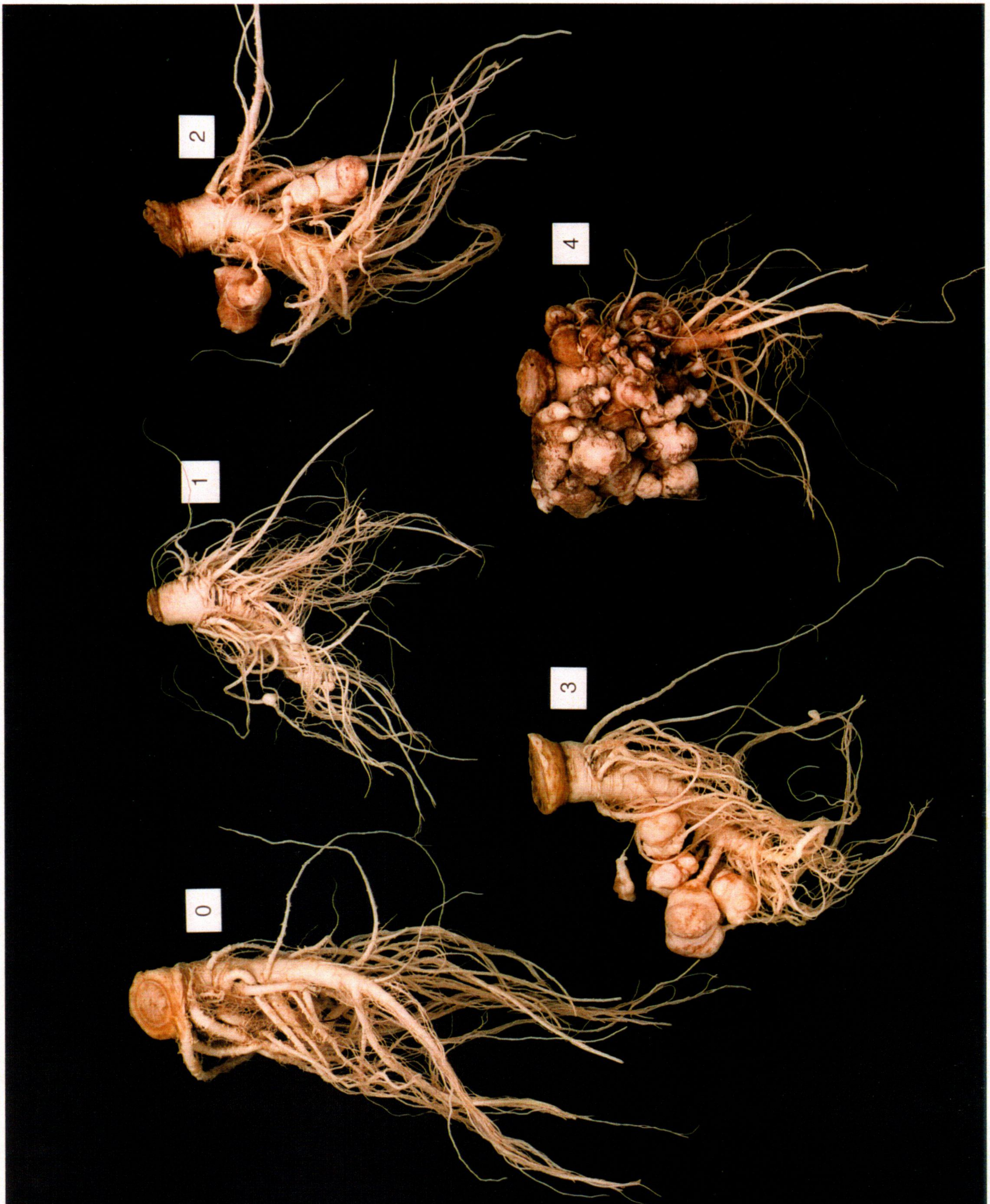

Figure 1: Clubroot severity key used to assess the amount of disease on root systems of vegetable brassica plants harvested from field trials (photo; Robert Lamberts).

3.3 Clubroot resistance

Eight vegetable brassica cultivars shown previously by Dr S Gowers (Nott et al. 1995b) to be resistant/tolerant to *P. brassicae* in the Crop & Food Research clubroot nursery at Gore, Southland, and two highly susceptible cultivars (Table 2), were tested at the four field sites. Seed of each cultivar was sown into potting soil (see above), and resulting seedlings were transplanted into randomised block trials (10 treatments in four replicates) at the four trial sites. Each trial plot consisted of a row of 10 plants at 0.3 m spacings, with 0.4 m between rows. At transplanting, water (approx. 200 ml) was applied to each seedling to assist establishment. About five months after transplanting, the resulting plants were dug from the soil and root systems were assessed for clubroot severity using the five-point severity key (Fig. 1). Clubroot severity data were statistically analysed using analysis of variance after square root transformation to stabilise variances.

Table 2: Cultivars of vegetable brassicas planted into four field trials. Eight had been previously shown to be resistant/tolerant to *Plasmodiophora brassicae*, and two were very susceptible, in a previous field trial (Nott et al. 1995b).

Cultivar name	Vegetable type	Botanical name
Resistant/tolerant		
Hanamori	Broccoli	*Brassica oleracea* var. *italica*
Shigemori	Broccoli	
Dolmic	Brussels sprout	*B. oleracea* var. *gemmifera*
Galaxy	Cabbage	*B. oleracea* var. *capitata*
Beverly Hills	Cabbage	
All Year Round	Cauliflower	*B. oleracea* var. *botrytis*
Taler	Savoy cabbage	*B. oleracea* var. *bullata*
Chorus	Chinese cabbage	*B. campestris* f. sp. *chinensis*
Susceptible		
Stilon	Cabbage	
Wong Bok	Chinese cabbage	

3.4 Classification of *Plasmodiophora brassicae* populations

Several kilograms of topsoil (to about 15 cm depth) were removed from each of the four trial areas and returned to Crop & Food Research, Lincoln. Soil from each site was diluted with potting mix (Woodend and Levin–one part field soil to eight parts potting

mix; Harewood and Pukekohe–1:4), and 600 ml of mixture was placed into each of 90 plastic pots (800 ml capacity). Six pots of each of the four soils were sown with seed (five seeds/pot) of each of the 15 European Clubroot Differential (ECD) series of host brassicas (Buczacki et al. 1975), and left on a glasshouse bench for seven weeks (temperature 18-25°C) with the pots regularly watered to keep the soil moist. All surviving plants from each pot were then washed free of soil and each plant was scored for clubroot severity using the five-point severity key (Fig. 1). The *P. brassicae* populations from each trial site were classified using the procedure of Buczacki et al. (1975), taking "positives" for each host as those giving mean severity scores of 1.0 or more. This procedure codes *P. brassica* populations using summed denary numbers. The host differential set comprises three species groups. The hosts in each group are assigned a denary number (Table 6), and the denary numbers for each host in each group infected by the test pathogen population are summed. This process assigns a three-figure code to each pathogen population.

4 RESULTS

4.1 Chemical control of clubroot

4.1.1 Growth of plants and fresh weight at harvest

At all of the trial sites, Chinese cabbage Wong Bok plants drenched with fluazinam at both of the rates tested were smaller than the plants from all the other treatments during the early part of the trial period, although in most cases the plants later recovered and appeared normal. Early stunting of plants due to fluazinam only resulted in a reduction ($P<0.01$) in plant fresh weight at harvest at Pukekohe (see below). At Harewood, the soil-incorporated fluazinam treatment did not stunt plants.

Data of plant fresh weights at harvest (aboveground plant parts) are summarised in Table 3. At **Harewood**, reductions ($P<0.05$) in plant fresh weight relative to the controls were detected from soil-incorporated flusulfamide 1.8 (25% decrease) and the transplant drench mancozeb 25 treatments (26% decrease). At **Woodend**, increases ($P<0.05$) in plant fresh weight relative to the controls were detected from the mancozeb 25 (48% increase) and the two benomyl treatments (84% increase). At **Levin**, the high rate of benomyl reduced ($P<0.05$) plant fresh weight relative to the controls (23% decrease). At **Pukekohe**, the fluazinam 12.5 and 25 treatments reduced ($P<0.01$) mean plant fresh weight relative to the controls by 46 and 74% respectively.

4.1.2 Clubroot incidence and severity

Different levels of clubroot developed at the four sites. Almost no disease developed at Harewood (mean soil pH = 5.9), moderate to severe disease occurred at Pukekohe (pH = 6.2) and Levin (pH = 7.2), while at Woodend (pH = 6.7) very severe clubroot developed on the trial plants. The levels of disease that developed at each site were not related to soil pH.

In Table 4 clubroot severity following treatment with different chemicals at the four trial sites is summarised. At **Harewood**, very few plants had clubroot; only 6% of the plants (seven of the 113 plants) from the control treatment were infected. While several of the treatments reduced mean disease severity scores compared with the controls, none of these reductions were statistically significant ($P>0.05$). For the soil drench treatments, no clubroot was found on plants from the benomyl 100 treatment, and very few plants were infected (proportions in parentheses) following the flusulfamide 3.0 (0.7%) and 0.03 (2.7%) treatments. The soil-incorporated flusulfamide 1.8 treatment also gave no clubroot infection. In contrast, at **Woodend** very severe clubroot occurred on the plants. Every plant harvested had clubroot-infected or severely decayed roots (100% incidence). Only the benomyl 100 treatment reduced ($P<0.01$) the mean clubroot

severity score. At Levin and Pukekohe, levels of clubroot were intermediate to those recorded at Harewood and Woodend. At **Levin**, 82% of the water-treated plants were infected with clubroot, and several of the treatments (benomyl 100 and 25, fluazinam 25 and 12.5, flusulfamide 0.3 and mancozeb 25) reduced ($P<0.05$) clubroot incidence and mean clubroot severity scores. The most effective treatments at this site were benomyl 100 (25.0% of plants infected) and fluazinam 25 (30.1% infected). At **Pukekohe** none of the treatments reduced clubroot severity ($P>0.05$).

Table 3: Mean plant fresh weights (roots removed) for Chinese cabbage Wong Bok plants harvested from plots at four different trial sites. Different treatments were applied as transplant drenches or incorporated into soil prior to transplanting.

	Harewood		Woodend		Levin		Pukekohe	
Treatment	Log[1]	Weight (kg)[2]	Log	Weight (kg)	Log	Weight (kg)	Log	Weight (kg)
Transplant drench (mg/plant)								
Benomyl 100	-0.08	0.96	-0.55**	0.41	-0.21*	0.74	-0.18	0.88
Benomyl 25	-[4]	-	-0.52**	0.44	-0.06	1.07	-0.14	0.96
Flusulfamide 3.0	-0.02	1.10	-	-	-0.06	1.05	-0.20	0.83
Flusulfamide 0.3	0.07	1.37	-0.68	0.30	-0.06	1.05	-0.12	1.01
Flusulfamide 0.03	-0.01	1.13	-0.70	0.28	-0.01	1.19	-0.20	0.83
Fluazinam 25	0.01	1.18	-0.89	0.18	-0.20	0.76	-0.85**	0.18
Fluazinam 12.5	-0.05	1.04	-0.84	0.20	-0.13	0.91	-0.54**	0.37
Mancozeb 25	-0.15*	0.83	-0.62*	0.34	-0.12	0.93	-0.14	0.95
Soil incorporation (kg/ha)								
Flusulfamide 1.8	-0.14*	0.84	-	-	-	-	-	-
Flusulfamide 0.9	-0.02	1.10	-	-	-	-	-	-
Fluazinam 0.75	-0.03	1.09	-	-	-	-	-	-
Control								
Water	-0.01	1.12	-0.78	0.23	-0.10	0.96	-0.28	0.69
LSD ($P<0.05$)[3]	0.09		0.14		0.10		0.121.1	
LSD ($P<0.01$)	0.12		0.19		0.14		7	

* and ** indicate means for each site that are different ($P<0.05$ and 0.01 respectively) from the mean of the control.

[1] Log and [2] back transformed (bias-adjusted) means.

[3] LSDs for comparisons with the control mean (df: Harewood = 49, Woodend = 35, Levin and Pukekohe = 40).

[4] Treatment not tested.

Table 4: Mean clubroot severity scores (0 = no disease, 4 = very severe clubroot) for root systems of Chinese cabbage Wong Bok plants harvested from plots at four different trial sites. Different chemical treatments were applied as transplant drenches or incorporated into soil prior to transplanting.

	Harewood		Woodend		Levin		Pukekohe	
	Square		Square		Square		Square	
Treatment	root[1]	Score[2]	root	Score	root	Score	root	Score
Transplant drench (mg/plant)								
Benomyl 100	0.71	0.00	1.78**	2.68	0.96**	0.47	1.17	0.89
Benomyl 25	-[4]	-	1.98	3.42	1.26**	1.16	1.27	1.13
Flusulfamide 3.0	0.71	0.01	-	-	1.41	1.54	1.05	0.62
Flusulfamide 0.3	0.74	0.05	2.11	3.98	1.20**	1.00	1.29	1.18
Flusulfamide 0.03	0.73	0.03	2.08	3.85	1.66	2.33	1.44**	1.59
Fluazinam 25	0.79	0.13	2.09	3.86	0.88**	0.33	0.99	0.50
Fluazinam 12.5	0.76	0.08	2.06	3.76	0.99**	0.54	0.96	0.45
Mancozeb 25	0.87	0.26	2.03	3.62	1.39*	1.50	1.25	1.09
Soil incorporation (kg/ha)								
Flusulfamide 1.8	0.71	0.00	-	-	-	-	-	-
Flusulfamide 0.9	0.75	0.06	-	-	-	-	-	-
Fluazinam 0.75	0.73	0.03	-	-	-	-	-	-
Control								
Water	0.78	0.11	2.10	3.91	1.70	2.44	1.16	0.86
LSD (P<0.05)[3]	0.13		0.14		0.30		0.19	
LSD (P<0.01)	0.18		0.19		0.41		0.26	

* and ** indicate means for each site different (P<0.05 and 0.01 respectively) from the mean of the control.

[1] Square root and [2] back transformed (biased-adjusted) means.

[3] LSDs for comparisons with control means (df: Harewood = 49, Woodend = 35, Levin and Pukekohe = 40).

[4] Treatment not tested.

4.2 Clubroot resistance

Table 5 summarises clubroot severity data obtained from plants of different cultivars of vegetable brassicas grown at the four sites. At **Harewood**, only one Chinese cabbage Wong Bok plant of a total of 333 surviving plants of the 10 cultivars was infected with clubroot at harvest, so differences in susceptibility between the cultivars could not be detected. At the other three sites, clubroot was found on some plants of each of the resistant cultivars. At **Pukekohe**, low levels of clubroot were recorded on the two susceptible cultivars (mean clubroot severity scores for Chinese cabbage Wong Bok = 0.49, cabbage Stilon = 1.20). Chinese cabbage Chorus had a mean score that was not different (P>0.05) from Wong Bok. The mean scores for all of the resistant/tolerant *B. oleracea* cultivars were less than 1 (0.04 to 0.86). Only broccoli Shigemori had a score not different (P>0.05) from the susceptible standard cabbage Stilon. At **Levin**, Chinese

cabbage Wong Bok was severely diseased, while Chorus had a very low mean severity score that was less ($P<0.01$) than that for Wong Bok. Four of the *B. oleracea* cultivars (broccoli Shigemori, cabbages Galaxy and Beverly Hills, and Savoy cabbage Taler) had mean scores that were not different ($P>0.05$) from that for cabbage Stilon. Broccoli Hanamori, cauliflower All Year Round and Brussels sprout Dolmic had mean disease scores that were less ($P<0.05$) than the susceptible standard cabbage Stilon. At **Woodend** severe clubroot developed on Chinese cabbage Wong Bok, while less severe disease ($P<0.05$) occurred on Chorus. Four of the *B. oleracea* cultivars (Savoy cabbage Taler, Brussels sprout Dolmic, cabbage Galaxy and broccoli Hanamori) had mean severity scores that were less ($P<0.05$) than that for cabbage Stilon.

4.3 Classification of *Plasmodiophora brassicae* populations

In Table 6 clubroot severity scores are summarised for plants of the ECD series grown in pots containing soil from the four field trial sites. Clubroot was moderate to severe on plants grown in soils from the Woodend and Levin sites, but only slight on plants in soils from Harewood and Pukekohe. For this reason, only the Woodend and Levin populations could be accurately classified using the system of Buczacki et al. (1975), and these were coded as follows:

- Woodend, 16/02/30, and
- Levin, 16/15/31.

Table 5: Mean clubroot severity scores (0 = no clubroot; 4 = very severe clubroot) for vegetable brassica cultivars grown at four different field sites. These cultivars had been shown previously (Nott et al. 1995b) to be resistant/tolerant or susceptible to *Plasmodiophora brassicae*.

	Harewood		Woodend		Levin		Pukekohe	
Cultivar	Square root[1]	Score[2]	Square root	Score	Square root	Score	Square root	Score
Resistant/tolerant								
Brassica oleracea								
Broccoli Hanamori	-[3]	0.00	1.38*	1.42	1.09**	0.77	0.94**	0.41
Broccoli Shigemori	-	0.00	1.74	2.56	1.81	2.85	1.16	0.86
Brussels sprout Dolmic	-	0.00	1.19**	0.94	1.24*	1.13	0.93**	0.38
Cabbage Galaxy	-	0.00	1.38*	1.42	1.89	3.14	0.84**	0.23
Cabbage Beverly Hills	-	0.00	1.43	1.56	1.62	2.22	0.98*	0.48
Cauliflower All Year Round	-	0.00	1.52	1.85	1.17*	0.95	0.72**	0.04
Savoy cabbage Taler	-	0.00	1.19**	0.93	1.49	1.80	0.81**	0.18
B. campestris f. sp. *chinensis*								
Chinese cabbage Chorus	-	0.00	1.68*	2.34	0.81**	0.25	1.11	0.78
Susceptible								
B. oleracea								
Cabbage Stilon	-	0.00	1.63	2.19	1.81	2.86	1.29	1.20
B. campestris f. sp. *chinensis*								
Chinese cabbage Wong Bok	-	0.02	1.99	3.47	1.80	2.81	0.99	0.49
LSD (P<0.05)[4]	-		0.25		0.49		0.23	
LSD (P<0.01)	-		0.34		0.67		0.31	

* and ** indicate means at each site different (P<0.05 and 0.01 respectively) from the relevant susceptible cultivar.

[1] Square root and [2] back transformed (biased-adjusted) means.

[3] Statistical analysis not carried out.

[4] LSDs for comparisons between means (df = 27).

Table 6: Mean clubroot severity scores (0 = no clubroot; 4 = very severe clubroot) for plants of the European Clubroot Differential series of host brassicas grown in soil from four field sites. Denary number as in Buczacki et al. (1975).

ECD host code	Denary number	Harewood	Woodend	Levin	Pukekohe
Brassica rapa					
01 fodder turnip	1	0.00	0.00	0.44	0.00
02 fodder turnip	2	0.00	0.00	0.00	0.00
03 fodder turnip	4	0.00	0.00	0.07	0.00
04 fodder turnip	8	0.00	0.00	0.00	0.00
05 Chinese cabbage Granaat	16	0.58	4.00	4.00	1.00
B. napus					
06 fodder rape Nevin	1	0.00	0.55	3.61	0.14
07 giant rape commercial	2	1.00	4.00	4.00	1.50
08 giant rape selection	4	0.32	0.00	4.00	0.48
09 rape NZ resistant	8	0.25	0.00	3.59	0.00
10 swede Wilhelmsburger	16	0.57	0.29	0.55	0.83
B. oleracea					
11 cabbage Badger Shipper	1	0.21	0.72	2.41	0.00
12 cabbage Bindsachsener	2	0.00	1.63	2.44	0.00
13 cabbage Jersey Queen	4	0.00	4.00	3.74	0.07
14 cabbage Septa	8	0.00	4.00	4.00	0.00
15 fimbriate kale Verheul	16	0.00	1.14	1.64	0.03

5 DISCUSSION

The trials reported here have demonstrated that chemicals and disease resistance have potential as components of an integrated strategy for control of clubroot, designed to alleviate the severe problems caused by this disease in commercial vegetable brassica crops.

The use of several trial sites in this study has shown that the degree of clubroot alleviation achieved with chemicals and clubroot-resistant cultivars is site-dependent. This is probably due to the different levels of soil infestation with *P. brassicae* (as demonstrated by the different levels of disease severity that occurred). This could also be due to different virulence characteristics of populations of the pathogen at the sites (as indicated by the different ECD population classifications obtained for two of the sites). Other factors (soil and environment) are also likely to have affected the clubroot levels that occurred. While the disease has often been associated with acid to neutral soils, field-grown plants may be infected over a broad pH range (4.1-8.5; Karling 1968). Soils at the trial sites in the present study had pHs within this range, so pH differences are unlikely to have caused the differences in disease severity.

Chemical control of clubroot using transplant drench treatments was not effective where very severe clubroot occurred (Woodend). The only treatment that reduced disease severity at this site was the standard registered treatment of benomyl at 100 mg/transplant, although the severity of infection resulting from this treatment was still high. At the site where the disease was relatively much less severe (Pukekohe), none of the transplant chemical drench treatments reduced clubroot severity. Only at the site where intermediate levels of clubroot occurred (Levin) were statistically significant reductions in clubroot severity detected due to the chemical treatments. These results suggest that a chemical clubroot control strategy used alone may not be a reliable approach to reducing problems caused by the disease. Nevertheless, results from the Levin trial demonstrate that chemicals shown to be efficacious against *P. brassicae* in glasshouse pot trials (Nott et al. 1995b), and against the closely related potato powdery scab pathogen (Falloon et al. 1996), can reduce the severity of clubroot in field-grown plants. Furthermore, these chemicals gave levels of control equivalent to that achieved with the standard registered benomyl transplant drench treatment (New Zealand Agrichemical Manual 1995), but at much lower active ingredient application rates than required for benomyl (mancozeb at least four times less, fluazinam eight times less and flusulfamide more than 300 times less).

The use of Chinese cabbage Wong Bok in the chemical control trials in this study may have caused some bias in the results. This cultivar is highly susceptible to clubroot, which may have caused the lack of response to chemical treatments where the disease was very severe. Furthermore, Chinese cabbage is very susceptible to herbicides

known to be safe for use on other vegetable brassica cultivars (Cheah L-H unpublished). Reductions in plant growth and fresh weight at harvest caused by some of the treatments tested may have reflected high chemical sensitivity in this cultivar, and it is possible that other brassica cultivars may not be adversely affected when treated with anti-protozoan chemicals.

None of the resistant brassica cultivars tested in this study were immune to infection by *P. brassicae*. However, seven of the eight tested cultivars developed less clubroot than the susceptible standards at some or all of three sites where clubroot occurred, and some cultivars developed relatively little disease, even where levels of infestation were high. In a previous test of 95 cultivars of vegetable brassicas for susceptibility to clubroot, carried out by Dr S Gowers at the Crop & Food Research clubroot nursery at Gore, Southland (Nott et al. 1995b), 18 *B. oleracea* cultivars had moderate to high levels of field resistance (which is usually not race-specific) to the disease. Some Chinese cabbages (including Chorus) were highly susceptible, but yielded well in the presence of severe clubroot (indicating tolerance to the disease). The *P. brassicae* population at Gore was classified (Buczacki et al. 1975) as 17/15/12. The results of the present study generally confirm the Gore results. Exceptions were with Chinese cabbage Chorus at Woodend and Levin, where this cultivar had less severe clubroot than Wong Bok suggesting this cultivar may have resistance to the Woodend and Levin *P. brassicae* populations, and with broccoli Shigemori which was as susceptible as cabbage Stilon at Woodend, Levin and Pukekohe.

The results of the present study confirm that disease resistance has excellent potential for alleviating clubroot in soils where the disease is likely to cause problems, although the virulence pattern of the *P. brassicae* population at a particular site may affect the response of particular resistant cultivars. Several cultivars have resistance or tolerance to the disease, and those shown to be in these categories by Dr S Gowers (Nott et al. 1995b) were:

- **Resistant**
  broccolis Atsumori, Foed Hook, Hanamori, Shigemori, and Kyowa Seeds No. 131,
  Brussels sprouts Content, Dolmic, Earlypick, Pantera, and Titural,
  cabbages Beverly Hills, Galaxy, and Rondy,
  cauliflower All Year Round,
  kale Palm Tree,
  kohl rabis Gigante and Purple Vienna,
  Savoy cabbage Taler, and

- **Tolerant**
  Chinese cabbages Chorus, Komachi, Yuki, and (possibly) Nozaki Seed No. NS25.

While clubroot of vegetable brassicas has always been very difficult to control, the best approach to reducing the effects of the disease is likely to result from a combination of several effective control methods. A number of potentially useful control methods have been identified previously (reviewed by Nott et al. 1995a). Using resistant or tolerant cultivars in combination with chemical treatments may give acceptable levels of clubroot control where the disease potential is severe. Raising soil pH can reduce severity of the disease (Tate & Cheah 1983). It is also possible that 'safe' chemicals and fertilisers (e.g. calcium and sodium salts), or other soil treatments (e.g. calcium cyanamide; Cheah 1995) could provide alternatives to pesticide compounds such as those tested in the present study. Biological control could have potential for alleviating clubroot problems (Nott et al. 1995a; Cheah & Marshall 1995), and cultural control methods (e.g. extended crop rotations and bait crops; Tate 1977) may also be useful for control of the disease. Future investigations on clubroot control should attempt to assess the use of several disease control methods used simultaneously, with the aim of developing fully integrated clubroot disease management strategies.

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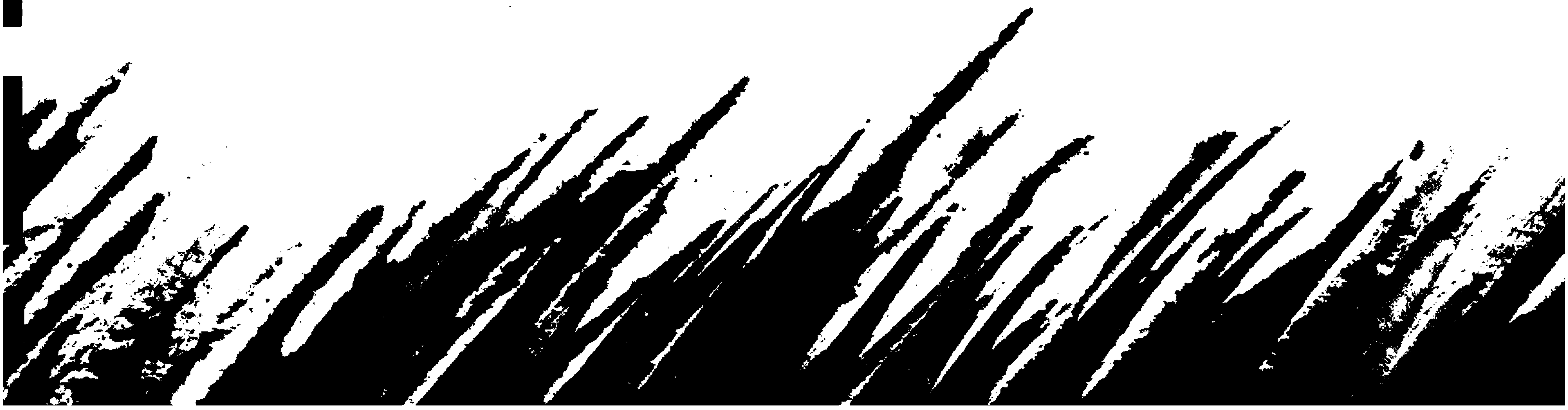

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