Project title:	Assessment of the potential for placement of small quantities of fungicide in direct drilled crops.
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Location:	HRI Wellesbourne, and Grower site.
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PRACTICAL SECTION FOR GROWERS

The first year of laboratory based experiments concentrated on the construction, testing and evaluation of experimental equipment to precisely place fungicides onto seed before it is covered by the soil. This consisted of a modified seed drill, similar to that used in the precision placement of fertiliser. Control of seedling damping-off diseases was evaluated using the metalaxyl single isomer fungicide A9408 B, which has now been released as SL567 for horticultural use. This was applied at a rate of 0.6 kg active ingredient (a.i.)/ha, or twice that rate, by a modified drill.

The experimental spraying equipment was designed so that it could readily be fitted to most types of seed drill. This was achieved using an electrically-driven peristaltic pump powered from the tractor, rather than a land-wheel drive which would be different for each make of drill. The pump was mounted in a frame together with a 5 litre reservoir for the fungicide solution, a filter and an anti pulsing device. The pump delivered a fixed 212 ml/min. of a fungicide solution to a modified anvil nozzle. Coulters were modified to place the spray nozzle behind the scatter bar facilitating spraying onto seed on the soil surface prior to covering by the scrapers. At a fixed drilling speed of 2.6 km/hr. this was equivalent to 4.9 ml/m. This meant that seed was in intimate contact with soil treated with the fungicide whilst it was germinating. Different application rates were achieved by varying fungicide concentration.

The crop chosen for laboratory, and field, tests was coriander. The seeds were sown in rows in seed boxes of sieved soil collected from a site with a history of *Pythium* problems. The spraying equipment was used to apply either water (control) or metalaxyl single isomer fungicide A9408 B at a rate of 0.6 kg a.i./ha after sowing, before seeds were covered. The boxes were then incubated at 15°C in high humidity. After 14 days the emergence on the fungicide treated soil was 98 % compared with 89 % for the control treatment. The fungicide treatment clearly improved emergence under laboratory based conditions.

For field testing of the machinery it was necessary to have crops drilled at regular intervals through the growing season, which also would be expected to show emergence losses due to a soil-borne pathogen. The model system of the *Umbellifer* crop coriander, susceptible to both pre- and post-emergence loss due mainly to *Pythium*, was chosen. The metalaxyl single isomer fungicide A9408 B was used at two rates. Because of the mode of action of metalaxyl, any treatment benefits would be because of the control of *Pythium*. The system was used at 0.6 kg a.i./ha on 11 occasions in the second year (1997) and at both 0.6 kg a.i./ha and 1.2 kg a.i./ha on 15 occasions in the third year (1999).

In 1997 treatment with A9408 B, 0.6 kg a.i./ha, stabilised emergence in warm, wet weather, and reduced post-emergence loss. The target stand count, of 100 plants, was achieved on eight occasions in the metalaxyl treatment, but on only six occasions in the untreated control. The fungicide eliminated post-emergence loss, which in the untreated control rows accounted for 9.5 % of emerged seedlings.

In 1999, after discussion with the project co-ordinator, it was decided to also include brown roots, which lower the value of a crop, in the losses category. Treatment with A9408 B, 1.2 kg a.i./ha, stabilised emergence in the wettest periods (>15 mm rainfall/day), however the A9408 B, 0.6 kg a.i./ha, was more effective in wet and dry periods (<15 mm rainfall/day). Leaching of metalaxyl in wetter periods may dilute it; it is possible that the higher rate of metalaxyl (1.2 kg a.i./ha) negatively affects seed germination and emergence. The target stand count, of 50 plants, was achieved on 10 occasions with metalaxyl A9408 B 0.6 kg a.i./ha, 9 occasions with A9408 B 1.2 kg a.i./ha and 8 occasions with water only. Post-emergence loss due to disease in the untreated control rows accounted for 10 % of emerged seedlings. With the A9408 B, 0.6 and 1.2 kg a.i./ha it accounted for 12 % and 10 % loss respectively. So in 1999 the losses due to disease, including browned roots, was fairly uniform. Browning of roots was also associated with the presence of fusarium spp.

A major benefit for the grower, and the environment, from this approach is the relatively small amount of fungicide used when application is made only in the coulter of the seed drill. This will obviously vary with coulter width and number of rows per bed, but in the present system applied fungicide would routinely be less than 20 % of that which would be used for whole-field treatments.

INTRODUCTION

During the late 1980's and early 1990's equipment was developed at HRI Wellesbourne which allowed starter fertilisers or insecticides (or both) to be injected beneath the seed while it was being drilled. Fertilisers injected in this way were much more effective at increasing early growth than conventionally applied fertilisers. Similarly, insecticides applied using the same technique were more effective than conventionally applied insecticide granules. The reason for the increased effectiveness of both fertilisers and insecticides applied in this way appears to be due to the precision metering and placement of materials. Although there are many situations where precision placement of fungicides might be expected to be effective, no work has been done to confirm this. There are several potential benefits from the approach, the most important being the efficient use of relatively small quantities of fungicide compared with whole-field sprays. There would also be benefits with crops for which dry seed treatments may not be used, and from the application of water with the fungicide at the site where the seeds germinate. This in turn will reduce production costs and the amount of fungicide in the environment. It is also probable that smaller application rates will delay the onset of enhanced microbial degradation, which develops in some soils after repeated applications of a specific fungicide, and the development of resistance to the fungicide by the target pathogen.

The principle objective of this project was to test the effectiveness of the precision application of small amounts of fungicide applied close to seed during drilling. The primary objectives during the first year were to develop equipment to apply fungicides from the seed drill, and to carry out laboratory tests to evaluate the method under simulated field conditions. In the second and third years, the emphasis was on quantifying benefits from the use of the technology in commercial crops. Because such systems are only of value if they translate into commercial practice, it was necessary to ensure that the machinery could be placed easily on a seed drill with a suitable cradle. Also, that the modified coulter could work as normal when experimental drillings were not in progress. The volume of water was manipulated to give sufficient spray to cover soil within the width of the coulter, but not enough to cause caking on the rear components of the coulter.

The crop chosen for the study was fast-emerging coriander. Because of the nature of work done in commercial fields with great fluctuations in soil moisture levels at drilling, from almost air-dried soil through to warm and wet soil after heavy rain, it is accepted that interpretation of results from some drillings may centre on factors other than *Pythium* damage. Hence the need in this work for drillings over a number of months.

DESIGN AND CONSTRUCTION OF EQUIPMENT

The starter fertiliser equipment developed at HRI utilised a bank of peristaltic pumps driven directly from the drill wheels. Each pump delivered liquid fertiliser to an individual drill line. This arrangement had the advantage that the pump started automatically as the drill was lowered into work and stopped as it was raised. The pump rpm was also proportional to ground speed so that over a limited range the dose rate per metre of row was independent of ground speed.

The current requirement was for equipment which could be fitted to different makes of drill and would pump liquid fungicide to a single drill line. To avoid the construction of separate mechanical drives for each drill, a single peristaltic pump head (Watson-Marlow 303 series) was driven by a fixed speed (100rpm) 12 v electric motor (RS Catalogue No. 320-590) powered from the tractor (Figures 1 and 2). When fitted with a 4.8 mm bore tube the peristaltic pump delivered 212 ml/min to an anvil nozzle (Lurmark AN. 50, Figure 3). The nozzles were mounted on the drill so that they sprayed in a band directly above the drill line. At a drilling speed of 2.6 km/hr., this delivered 4.9 ml per metre of row. Variation in dose rate was achieved by adjusting the concentration of the fungicide solution.

The unit mounted on the drill consisted of a 40 mm angle iron frame (315 mm long x 265 mm wide x 200 mm high) which, in addition to the pump, contained a 5 litre plastic reservoir, an anti-pulsing device to remove the pulses from the peristaltic pump, and a filter to prevent blockage of the nozzle. The unit was also used in the laboratory where it was powered by a separate 12 v supply, and was used to apply fungicide to seeds in trays of soil.

MATERIALS AND METHODS

LABORATORY TESTING OF PRINCIPLES

The crop chosen to test this system on was coriander, the seed of which is an achene (i.e. is in two halves, and unless separated will produce two seedlings at each station). The seed lots used had not been pre-treated with any fungicides.

Soil used for the trials was collected from a site known to have a long history of problems with *Pythium* on direct-drilled crops. The site was a re-claimed gravel pit and consisted of a sandy soil with both low water holding capacity and low organic matter content. The soil was passed through a 1 cm sieve to remove large stones and ensure thorough mixing, before being stored in polythene bags. The moisture content of the soil in each bag was determined from sub-samples; these were dried at 80°C for 24 hrs. The original bags were then amended to 10 % moisture content (w/w) before incubation at 15°C for 7 days.

The soil was re-sieved and then placed in trays (350 x 210 x 50 mm) before levelling without compaction. Three seed rows were produced in each tray by pressing a 25 x 25 mm cross section wooden rod into the soil, giving a triangular groove. Into each groove 20 complete achenes of coriander were sown at 15 mm spacing, and left uncovered.

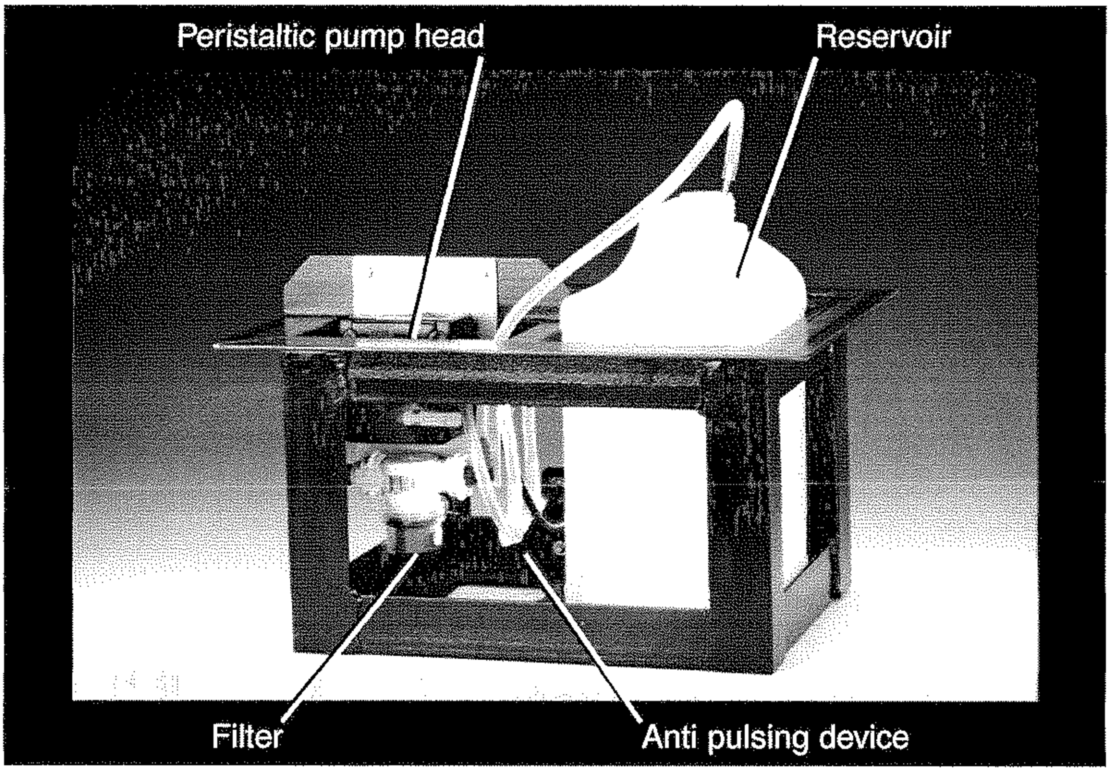


Figure 1 Front of pumping unit.

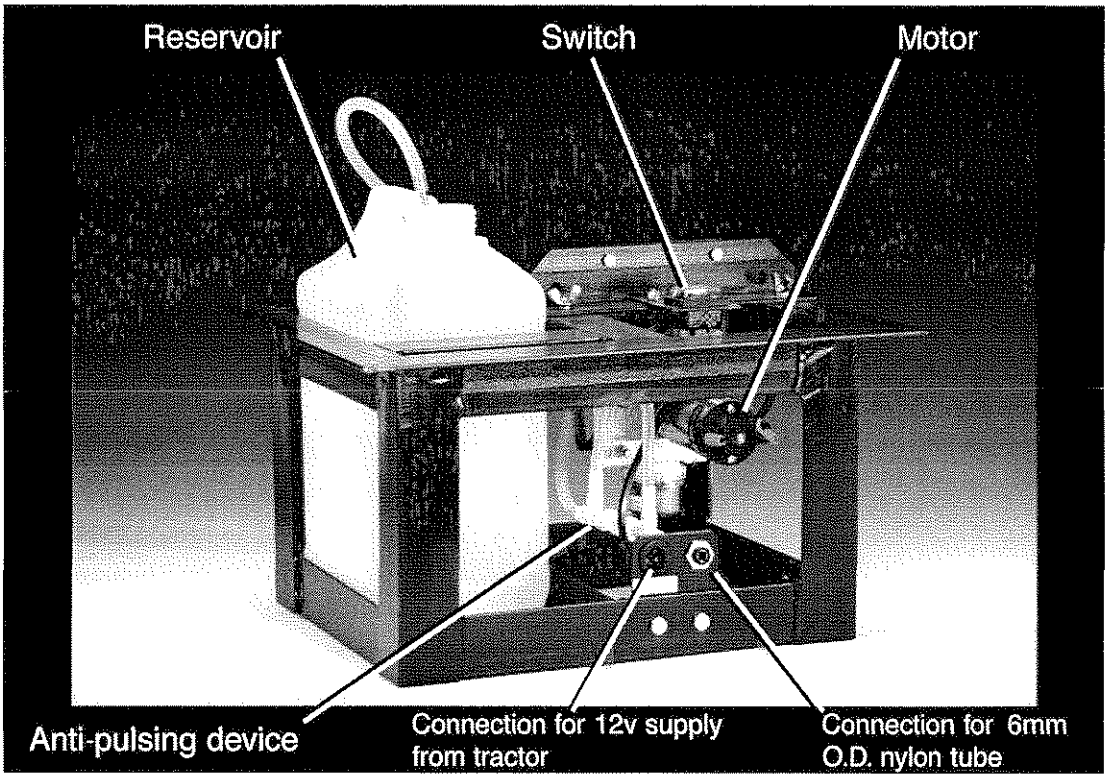


Figure 2 Rear of pumping unit.

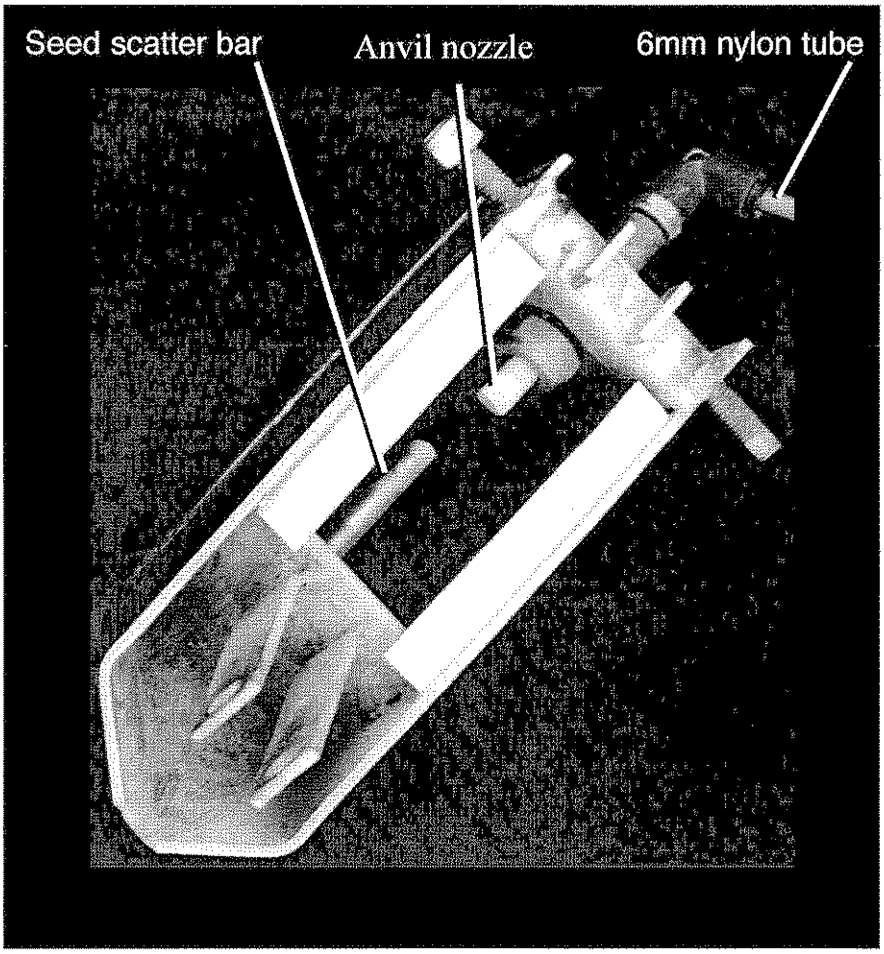


Figure 3 Modified seed coulter showing anvil nozzle.

The fungicide treatment consisted of the new metalaxyl single isomer fungicide A9408 B used at a rate calculated to be that which would be applied to carrot crops for the control of cavity spot (0.6 kg a.i./ha.). This was applied by moving the trays past the spray jet in the requisite number of seconds. A control treatment was set up with water applied in the same way. Further soil was then added to cover the seed in both treatments as would be the case following drilling in the field. There were four replicate trays for each treatment.

The trays were placed in inflated polythene bags and transferred to a growth room at 15°C with lighting from twin high pressure sodium lamps for 16 hr/day. Emergence was counted daily, from the first day when seedlings had cotyledons clear of the soil. At 14 days from sowing the final stand was determined, and the number of seedlings with post-emergence damping-off was recorded. Both damped-off and apparently healthy seedlings were plated onto corn meal agar amended with rifamycin (30 mg/l) and pimaricin (100 mg/l) to give direct isolation of *Pythium*.

FIELD TESTING

A system was devised whereby set portions of the coriander crop were identified at drilling, and marked by Ringot flexible plastic canes. Four replicate 1 m rows were marked for each treatment for each drilling. The drilling rate was initially 80 achenes/m in 1996, with the aim of achieving 100 plants/m and 40 achenes/m in 1999, with the aim of achieving 50 plants/m. Drilling was arranged to give one row of crop treated with metalaxyl applied at 0.6 kg a.i./ha, and/or metalaxyl applied at 1.2 kg/ha, adjacent to a row which received water only. Experimental rows were placed between rows of commercial crop. The 0.6 kg/ha rate of metalaxyl used was the equivalent to that applied for control of carrot cavity spot, but it was applied only to the width of the coulter.

Coriander drillings

Drillings of coriander were monitored from 1 May through to 12 August 1997 in year 2 and from 5 April to 23 July 1999 in year 3. Counts of emergence were made on two occasions for each drilling. At an occasion as close to commercial harvest as possible all plants between the Ringots were harvested and returned to Wellesbourne. The number of plants at harvest was recorded and each replicate was weighed. Because of variation in plant size at different harvests, the ratio of the weight of plants from either metalaxyl treatment was compared to the weight of plants from the water only treatment. The roots of plants showing browning, or of dead plants, were selected for isolation of *Pythium* on the selective medium corn meal agar with the antifungal agent pimaricin and the antibiotic rifamycin. Plates were incubated at room temperature, and *Pythium* isolates were identified to species level.

Aspects of weather were to be measured by the grower's own weather station during the course of the work. However, due to uncertainty over some rainfall data from this station the weather station at the adjacent Heathrow Airport was substituted (Tables 1 and 2). Figures 4 and 5 shows the distribution of drillings of the two crops with rainfall and soil maximum and minimum temperatures for the two years.

Table 1 Rainfall and P.c.m. Minimum - P.c.m. Maximum soil temperature data for 1997 from Heathrow Airport as used in Figure 4.

1997

DATE	APRIL Minimum (°C)	APRIL Maximum (°C)	APRIL Rainfall (mm)	MAY Minimum (°C)	MAY Maximum (°C)	MAY Rainfall (mm)	JUNE Minimum (°C)	JUNE Maximum (°C)	JUNE Rainfall (mm)	JULY Minimum (°C)	JULY Maximum (°C)	JULY Rainfall (mm)	AUGUST Minimum (°C)	AUGUST Maximum (°C)	AUGUST Rainfall (mm)	SEPTEMBER Minimum (°C)	SEPTEMBER Maximum (°C)	SEPTEMBER Rainfall (mm)
1	6.7	9.7	0	10.6	15.7	0	17	21.4	0	13.8	14.8	0	17.4	19.7	0	17.6	19.7	0
2	7	9.6	0	11.3	16.7	0	17.1	20	0	13	14.9	0.4	18.2	20.1	0	17	19.2	0
3	8.6	9.6	0	12.2	15.7	0.6	16.1	20.8	0	12.9	14.5	8	18	19.3	2.1	17.4	18.1	2
4	7.4	8.9	0	13.2	15.3	0.2	16.9	22.2	0	13.4	15.3	2.2	17.8	18.8	9.5	17.5	19.9	0
5	8.8	10.8	0	12.5	14.3	6.8	17.9	21.6	0.4	13.9	17.1	0	17.7	18.8	0	17.1	18.6	0.4
6	9.5	10.8	0	9.1	12.3	0	17.7	20.6	11.8	15	17.8	0	17.8	19.3	31.6	15.6	18.2	0
7	7.6	10	0	6.7	12.1	1.8	17.9	19.7	0	16.3	19.3	0	18.6	20.8	0	16.6	19	0
8	7.4	9.9	0	8.5	11.9	1.4	16.4	18.6	2.4	17.5	19.9	0.8	19.3	25.6	0	16.4	20.1	0
9	7.5	10.6	0	9.1	13.1	4.4	15.6	19.5	0	18.2	20.8	0	21.7	25.3	0	16.8	20.6	0
10	7.6	11.1	0	9.3	13	0.2	16.9	21.2	2.8	17.9	19.7	0	21.9	25.8	0	16.6	19.5	0
11	8.9	10.5	0	9.3	13.4	0.4	18.2	19.8	4.6	17.6	19.7	0	22.8	24.9	0	16.6	19	0.4
12	7.3	9.6	0	9.7	13	3	17.4	18.3	0	17.6	20.5	0	22.3	25.2	2.4	16.1	18.1	4
13	8	10.4	0	8.9	14.5	0.2	16.7	19.3	0	18.5	20.1	1.8	22.8	24.9	0	14	16.3	0
14	9	10.4	0	9.7	17.9	0	16.7	18.1	0	17.9	20.1	0.2	21	24.4	0	13.3	16.1	0
15	8.9	10.5	0	11.3	16	0	15.8	17.6	0.2	17.9	20.8	0	21.1	24.9	0	13.8	16	0
16	7.5	9.6	0	12.4	17.3	2.2	16	18.1	0	18.5	19.7	0.4	21.3	25.2	0.2	14.2	17.2	0
17	8.6	9.7	0	13.6	19.7	0	16	18.5	1	17.9	19.1	0.4	22	23.8	0	14.5	18.4	0
18	7.5	8.9	0.1	16	18.8	0	16.4	18.9	3	16.9	17.9	1.6	20.9	24.9	0	15.3	19	0.2
19	7.2	8.8	0	14.7	16.9	1	15.4	17.9	1.6	16.6	20.1	0	21.6	25.7	0	16.7	18.1	0
20	6.3	7.5	0	12.9	15.3	5.4	13.8	15.2	3.8	17.9	21.4	0	22	24.4	0	16	17.8	0
21	5.6	8.2	0	12.6	13.8	0	14	15.3	7.4	19	22.4	0	21.6	23.8	0	14	17.2	0
22	7.5	8.9	0	11.2	14.9	0.6	13.8	15.1	4.6	19.6	22.8	0	21.9	22.7	0	13.8	17.2	0
23	7.6	9.6	0	11.6	14.9	0	14.3	16.1	*******	19.3	21.9	0	21.6	23.4	0	14	17.3	0
24	8.2	10.1	0	10.1	17.8	0	13.9	15.3	*******	19.6	21.2	3.8	21.8	22.7	7.3	14.4	16.9	0
25	8.9	9.7	8.4	11.3	19.8	0	14	15	4.8	18.1	19.7	0	20.8	22	1.6	15.8	17.5	0
26	9.2	10.6	1.3	13	21.5	0	14.5	15.3	21	18	19.1	7.6	18.4	21.6	0.2	15.6	18.1	0
27	10	12.7	0	14.5	19.8	0	13.5	14.5	4.6	17.7	19.6	0	18.8	20.2	9.4	16	17.8	0
28	11.2	13	0	13	21	0	13	14	0	17.7	20.5	0	17.1	19.4	0.4	14.9	17	0
29	10.8	12.7	0	14.4	22.6	0	14	15.1	0	18.4	21.7	1.2	17	18.6	5.2	15.1	17.9	0
30	9.8	14.5	0	16.3	23.7	0	13.6	14.8	0	19.3	21.2	0.2	17.6	19.2	0.4	16.8	18.5	0
31	--	--	--	17.1	23	0	--	--	--	17.8	19.7	6	17.5	20	0	--	--	--
Mean/ month	8.20	10.23	0.33	11.81	16.64	0.91	15.68	17.93	2.64	17.22	19.46	1.12	20.01	22.43	2.27	15.65	18.14	0.23

******* Data not available

Figure 4: Coriander drilling dates with lines to harvest dates, together with graphed data for rainfall and maximum and minimum soil temperatures for the months of sequential drillings in 1997.

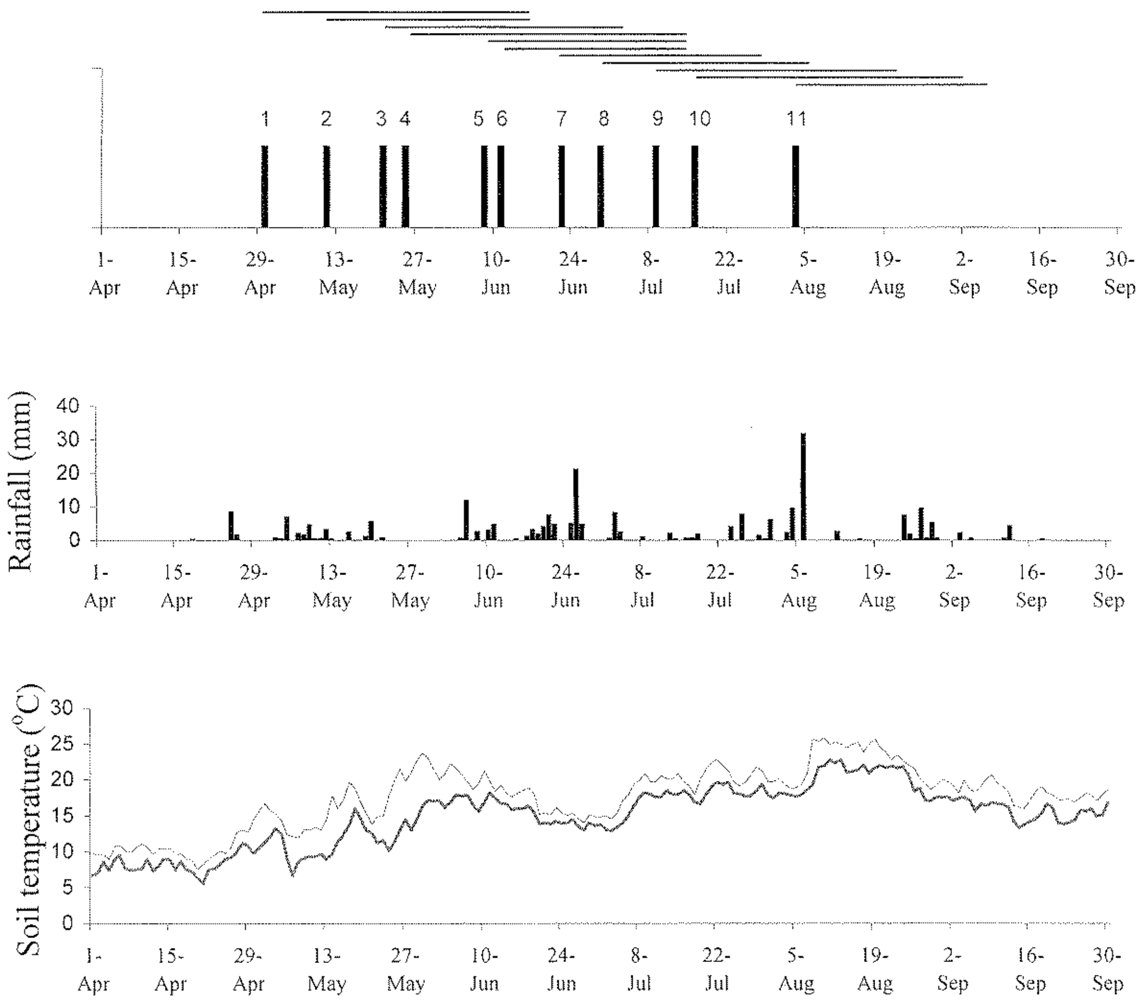
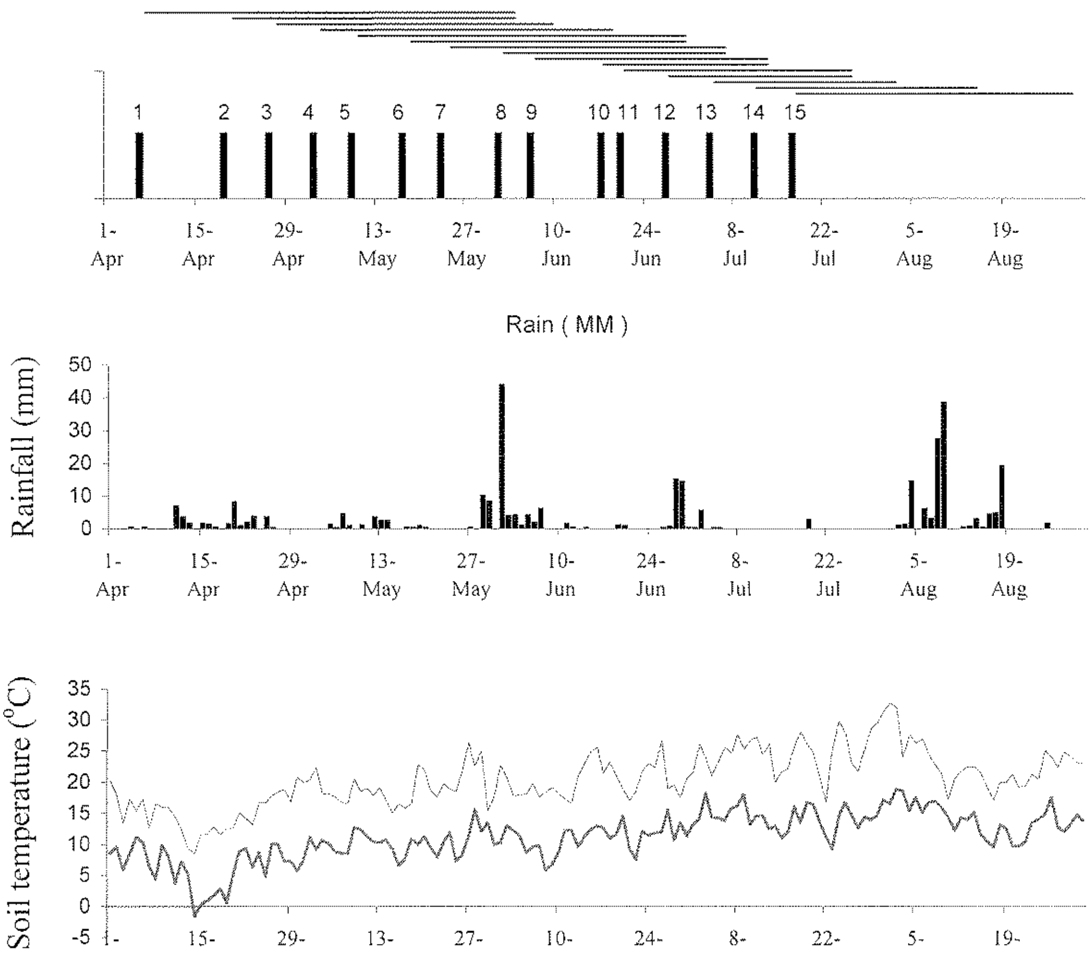


Table 2 Rainfall and P.c.m. Minimum - P.c.m. Maximum soil temperature data for 1999 from Heathrow Airport as used in Figure 5.

DATE	APRIL Minimum (°C)	APRIL Maximum (°C)	APRIL Rainfall (mm)	MAY Minimum (°C)	MAY Maximum (°C)	MAY Rainfall (mm)	1999 JUNE Minimum (°C)	JUNE Maximum (°C)	JUNE Rainfall (mm)	JULY Minimum (°C)	JULY Maximum (°C)	JULY Rainfall (mm)	AUGUST Minimum (°C)	AUGUST Maximum (°C)	AUGUST Rainfall (mm)
1	0	8.6	20.4	7.4	19.9	0	10.3	22.7	43.8	13.3	21.5	0.2	16.5	32.7	0
2	0	9.6	17.9	11.1	20.3	0	13	20.7	3.8	14	26	5.4	18.8	31.9	1
3	0	5.9	13.4	9.2	22.4	0	12.2	17.7	4	18.2	23.9	0	18.6	23.9	1.2
4	0.4	8.5	17.4	10.7	18.1	0	11.2	17.9	1	14.3	21	0.2	15.3	27.6	14.4
5	0	11.1	15.3	10.1	18.1	1.2	8.7	18	4	14.2	23.2	0.2	17.5	26.2	0
6	0.4	10.4	17.3	8.8	17.6	0.2	9.6	19.7	1.8	13.8	25.5	0	15.1	26.9	6
7	0	6.5	12.6	8.5	16.7	4.4	9.8	17.6	6	15.7	24.7	0	16.7	24.4	3
8	0	4.4	16.5	8.6	16.5	0.8	5.7	18.3	0	16.1	27.6	0	16.9	22.7	27.4
9	0	9.9	16	12.7	20.5	0	6.7	19.1	0	18	25.2	0	15.9	21.3	38.4
10	0	8	15.9	12.4	18.4	1	8.7	18	0	13.2	26.6	0	14.4	17.2	0
11	6.8	3.7	14.4	11.3	19	0	12.3	17.3	1.4	14.6	27.2	0	12.2	20.5	0
12	3.4	7.3	12.4	10.4	17.8	3.4	12.3	16.5	0.2	14.6	24.4	0	14.2	21.7	0.4
13	1.6	5.2	9.3	10.3	19.1	2.4	9.6	20.9	0	12.4	26.1	0	13.9	22.4	0.6
14	0	-1.6	8.5	10.7	17.2	2.4	11.2	23	0.2	13	19.9	0	15.2	22.4	2.8
15	1.6	0.3	11.5	9.3	15	0	12.4	24.9	0	11	21.6	0	11.5	21.4	0.2
16	1.2	1	11.6	6.6	16.5	0	13	25.5	0	11.9	22.1	0	10.4	19.1	4.2
17	0.4	1.7	12.9	7.7	15.8	0.4	12.6	21.4	0	16.1	25.9	0	9.5	17	4.6
18	0	2.8	11.5	10.9	16.5	0.2	10.9	23.2	0	13.5	28	0	13.1	19.9	19
19	1.4	0.6	12.6	10	22.8	0.8	11.6	21	1	16.7	26	2.6	12.5	19.9	0
20	8	5.1	12.6	11.3	22	0.2	14.5	18.9	0.8	16.4	24.7	0	9.7	21.2	0
21	0.8	8.9	15.1	9.5	18.6	0	9.4	17	0	13.6	20.8	0	9.7	19.1	0
22	1.8	9.4	14.1	7.9	17.6	0	7.5	18.4	0	11.2	16.8	0	10.4	19.3	0
23	3.6	6.3	13.1	10.3	19.7	0	12.1	21.7	0	9.2	25.5	0	13.5	21.2	0
24	0	8.7	16.7	11.9	18.9	0	11.4	23	0	14.5	29.8	0	14	20.4	0
25	3.4	4.8	16.6	7.3	18.4	0	11.8	22.3	0	16.7	27.8	0	14.8	25	1.6
26	0.2	10.1	17.8	8.3	21.7	0	11.9	26.7	0.2	14.6	23	0	17.5	24	0
27	0	10	18.4	11.2	26.4	0.2	15.5	18.9	0.6	12.6	21.7	0	12.7	22.3	0
28	0	7.3	18.8	15.6	22.5	0	10.6	19.5	15	14.4	25.3	0	12	24.8	0
29	0	7.3	16.8	12.1	25	10	13.4	17.5	14.2	13.9	28.6	0	13.3	24	0
30	0	5.7	20.8	13.5	15.4	8.2	11.3	20.5	0.2	14.6	29.4	0	14.7	23	0
31	--	--	--	9.9	17.7	0	--	--	--	17.1	31.3	0	13.7	23	0
Mean/ month	1.17	6.25	14.94	10.18	19.10	1.15	11.04	20.26	3.27	14.30	24.87	0.28	14.01	22.79	4.03

Figure 5: Coriander drilling dates with lines to harvest dates, together with graphed data for rainfall and maximum and minimum soil temperatures for the months of sequential drillings in 1999.



RESULTS OF LABORATORY BASED EXPERIMENTS

Emergence of both untreated and metalaxyl treated coriander started on the eighth day from sowing (Figure 6) and was slightly more rapid from the fungicide treatment, with 50 % emergence at 9.25 days compared with 10 days for the untreated control. After 14 days, total emergence from treated trays was 98.1 %, and that from untreated trays was 89.4 %. Post-emergence damping-off reduced final stands to 90 % in treated trays, and to 82 % in untreated trays. Isolations from healthy seedlings yielded no *Pythium* spp. Damped-off seedlings were infected primarily with *Pythium sylvaticum* and *P. ultimum*, with a small number of unknown isolates. This was consistent with earlier isolations from plants grown in the test soil.

RESULTS OF FIELD TRIALS

Emergence counts

Figure 7 shows the emergence counts for 1997 and 1999. Target numbers of plants were set by the grower; 100 plants/m in 1997 required an achene rate of 80 achenes/m, and 50 plants/m in 1999 required 40 achenes/m. In 1997 the target stand count, of 100 plants, was achieved on eight occasions in the metalaxyl treatment, but on only six occasions in the untreated control. The fungicide eliminated post-emergence loss, which in the untreated control rows accounted for 9.5 % of emerged seedlings. In 1999 it was decided, after discussion with the project co-ordinator, to include brown roots, which lower the value of the crop, with the losses. After this consideration was taken into account the target stand of 50 plants was achieved on 10 occasions with metalaxyl A9408 B 0.6 kg a.i./ha, 9 occasions with A9408 B 1.2 kg a.i./ha and 8 occasions with water only. Post-emergence loss due to disease in the untreated control rows accounted for 10 % of emerged seedlings. With the A9408 B 0.6 and 1.2 kg a.i./ha it accounted for 12 % and 10 % loss respectively.

Coriander characteristics

Table 3 shows that there was considerable variation in the plant stand data in the 1997 trial, with lowest stand counts of 45/m and 39/m and the highest of 150/m and 140/m for the water only and metalaxyl treatments respectively. During the 1999 trial comparable variation was observed. The lowest stand counts were 27/m, 25/m and 28/m, the highest 82/m, 100/m and 84/m for the water only, 0.6 kg a.i./ha metalaxyl and 1.2 kg a.i./ha metalaxyl treatments respectively.

From the 1997 water only treatment 9.5 % of the plants were classified as infected (brown root systems) or dead, reducing the final mean plant stand to 52.5 %. The number of infected plants in the metalaxyl treatment was negligible. In 1997 the metalaxyl single isomer applied at 0.6 kg a.i./ha was significantly better than water only with a 95 % confidence interval (see Annexe 1).

From the 1999 trial there was a significant difference in seedling stand between 0.6 kg/ha and water only with a 95 % confidence interval (Annexe 1). Within the water only treatment 10 % of plants were classified as infected or dead reducing the final mean plant stand to 56 %. From the 0.6 kg a.i./ha metalaxyl treatment 12 % of plants were classified as infected or dead reducing the final mean plant stand to 63 %; this was

Figure 6: Percentage germination of coriander achenes under laboratory based conditions for metalaxyl (0.6 g a.i./ha) and water control.

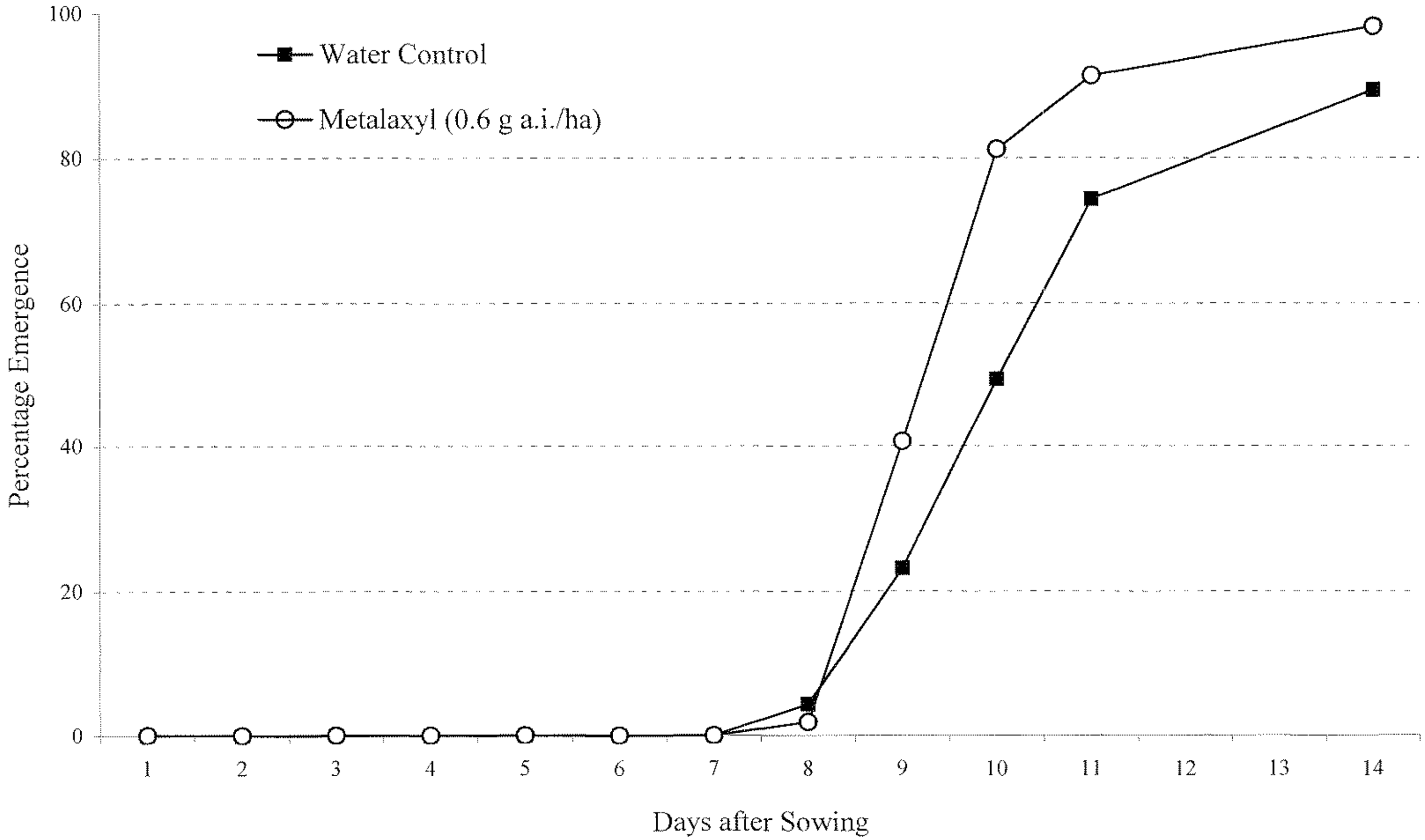


Figure 7: Treatment effects on emergence counts from drillings, sown with 80 and 40 Coriander achenes per metre during 1997 and 1999 respectively. Target stand numbers are shown as dotted lines from the Y axis.

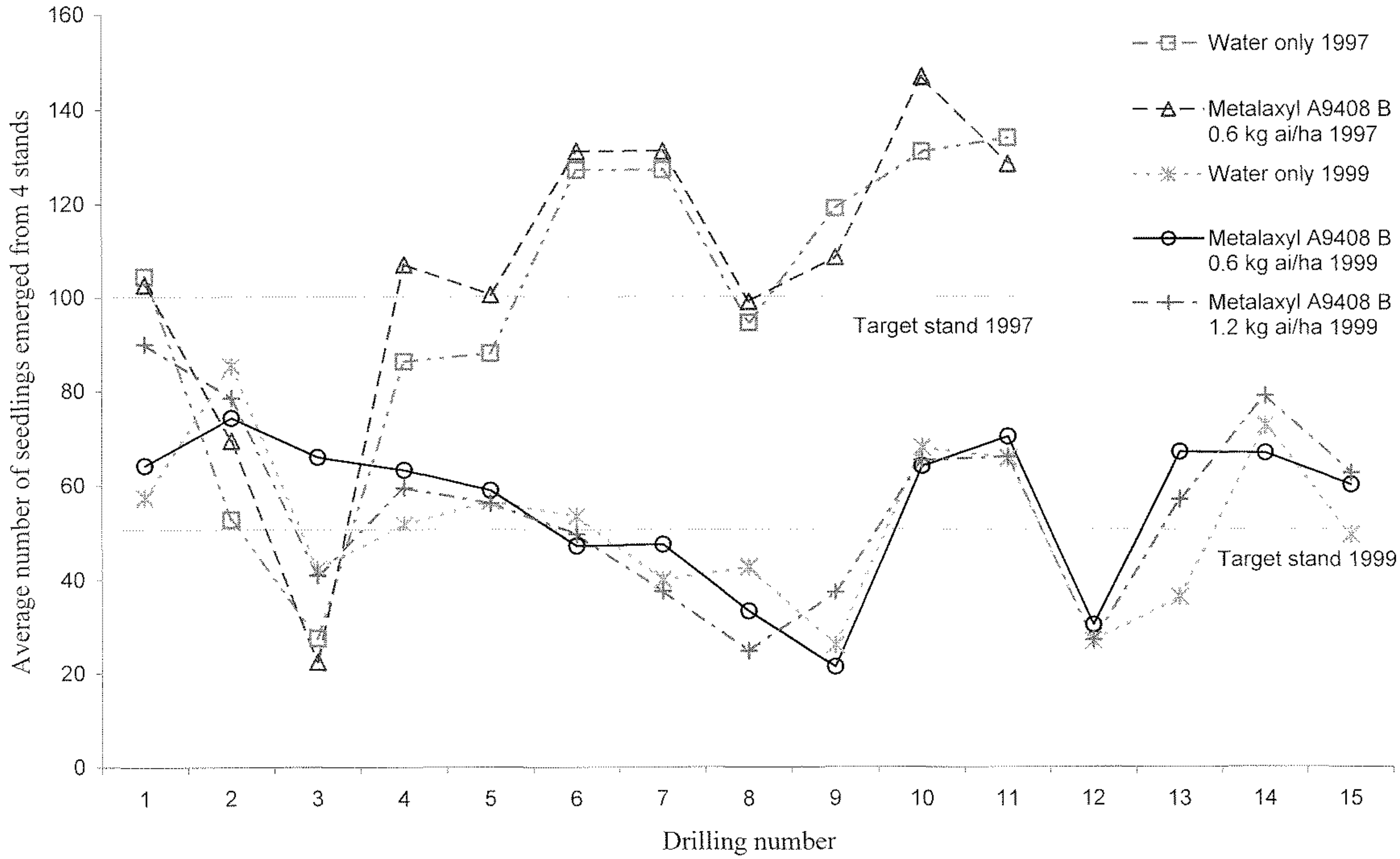


Table 3: Plant number per stand of coriander drilled on eleven (1997) and fifteen (1999) occasions in the field.

	Treatment				
	1997		1999		
Drilling	Water Only	Metalaxyl A9408 B 0.6 kg a.i./ha	Water Only	Metalaxyl A9408 B 0.6 kg a.i./ha	Metalaxyl A9408 B 1.2 kg a.i./ha
1	107	104	71	100	70
2	49	68	82	76	84
3	45	39	45	59	40
4	106	128	54	60	58
5	54	59	53	59	57
6	150	140	53	43	47
7	128	136	41	48	39
8	105	124	45	44	31
9	110	103	31	25	40
10	122	137	76	69	78
11	118	128	68	70	70
12	--	--	27	32	28
13	--	--	38	67	58
14	--	--	80	73	83
15	--	--	38	76	71
Mean number	99	106	53	60	57
% of sown*	62	66	66	75	71
% diseased**	9.5	0	10	12	10

* Expected achene rates for 1997 and 1999 were 80 and 40 respectively (each achene produces two plants).

** Percentage is derived from the expected achene number (see *) not of the germinated achenes.

significantly more than from the water only treatment (Annexe 1). From 1.2 kg a.i./ha metalaxyl treatment 10 % of plants were classified as infected or dead reducing the final mean plant stand to 61 %. Significantly more healthy plants were seen with the 0.6 kg/ha metalaxyl treatment than for water alone.

During both trial years, mean plant weight showed no significant difference between treatments (Annexe 1). Table 4 shows that the mean ratios between treated and control plants were between 1 and 1.2. The approximate weight of each plant was 3-3.5 g. Early drillings in 1997 tended to produce smaller plants from the metalaxyl treatment than the water only treatment. Plant size varied little in 1999 for either treatment.

Isolation of *Pythium*

Diseased seedlings were found in drillings 3, 4, 6, 8 and 10, during the 1997 trial and in all drillings in the 1999 trial. To gauge the most important species of *Pythium* associated with the damage, the different species were isolated, and the number from each drilling determined (Table 5). The 1999 results were further split into treatments to determine their effectiveness, shown in Table 6. The main species from 1997: *Pythium* HS Group, *P. oligandrum* and *P. sylvaticum*, continue to be dominant in 1999. However two previously unseen *Pythium* spp. *P. sulcatum* and *P. irregulare* are also seen; *P. sulcatum* was observed in large numbers. The *Pythium* species isolated from the three different treatments in 1999 are mostly at lower levels for the two metalaxyl treatments. However, except for *P. sulcatum*, the same or greater numbers are isolated from the 1.2 kg a.i./ha treatment than from the 0.6 kg a.i./ha treatment. Many of the browned roots were also infected with intermittent infections of *Fusarium* spp. in the 1999 trial.

DISCUSSION

For crops grown from direct drilled seed, benefits were shown from the use of metalaxyl fungicide placed in the seed drill; the benefits were in emergence and survival of plants through to harvest, without significant disease symptoms. Several of the diseased plants produced no *Pythium* spp. on inoculation and other pathogens were found such as *Fusarium* spp. which this trial was not designed to test for. These may have artificially increased the number of diseased plants in the treatments.

Weather conditions in 1997 showed considerable variation in the period of the drillings (Figure 4 and Table 1), and reduced stand numbers in drillings 2, 3 and 5; this reflects the dry April, followed by minimal rain in May. Through June and July rainfall was regular and sometimes heavy. In this period, while emergence from untreated seed was at high levels, damage due to *Pythium* was commonplace and stand benefits were seen from treatment with metalaxyl.

Weather conditions in 1999 were less varied, Figure 5 and Table 2, with regular rainfall until a dry period in July. This dry period was preceded by 10 days of heavy rain, stopping the soil from drying out. Other periods of heavy rain were seen at the end of May and the beginning of August. During these periods of heavy rain (>15 mm/day), drillings 9, 14 and 15, treated with metalaxyl at 1.2 g a.i./ha gave better emergence than the other treatments. However with lower rainfall (<15mm/day), stands 3,4,5,7,11,12 and 13, the metalaxyl applied at 0.6 g a.i./ha gave better emergence rates and final

Table 4: Ratio of the weight of coriander plants from the metalaxyl A9408 B treatments : weight from water only treatments. Data from both trial years and both concentrations is presented.

	1997	1999	
Drilling	Metalaxyl A9408 B 0.6 kg ai/ha : water only	Metalaxyl A9408 B 0.6 kg ai/ha : water only	Metalaxyl A9408 B 1.2 kg ai/ha : water only
1	1.1	1.2	1.0
2	0.7	0.9	1.6
3	0.7	0.9	0.9
4	0.8	1.3	1.5
5	0.6	1.2	1.2
6	2.0	0.6	1.3
7	1.3	0.8	0.6
8	0.8	1.0	0.7
9	1.0	0.7	1.3
10	1.4	0.9	0.6
11	1.1	0.9	1.0
12	--	1.1	1.0
13	--	1.6	1.3
14	--	1.5	1.4
15	--	0.8	1.8
Mean	1.0	1.0	1.1
Mean after		1.0	1.2

Table 5: Isolation of *Pythium* from diseased coriander roots for the two trial years.

Pythium spp.	Total number	
	1997*[1]	1999*[2]
P. aphanidermatum	1	0
Pythium HS Group	9	54
P. irregulare	0	9
P. oligandrum	19	58
P. rostratum	2	3
P. sulcatum	0	20
P. sylvaticum	21	39
P. ultimum	1	1
Unknown	9	6

*[1] = Results from 5 of 11 drillings
*[2] = Results from 15 of 15 drillings

Table 6: Isolation of *Pythium* from diseased coriander roots from 15 drillings and 3 different treatments in Trial 2, 1999.

Pythium spp.	Total number		
	Water Only	Metalaxyl A9408 B 0.6 Kg a.i./ha	Metalaxyl A9408 B 1.2 Kg a.i./ha
Pythium HS Group	32	8	14
P. irregulare	3	3	3
P. oligandrum	26	14	18
P. rostratum	3	0	0
P. sulcatum	12	6	2
P. sylvaticum	17	11	11
P. ultimum	1	0	0
Unknown	1	4	1

harvest numbers. The water only treatment was better only in the extreme conditions, drilling 8 was waterlogged by 44 mm of rain soon after sowing and drillings 6 and 10 were sown during periods where little rain fell (see Figures 5 and 7).

When soils are dry and temperatures are rising, fungicides do not give emergence benefits and they may reduce yield as seen by stand weights in early 1997, Table 4. However in warm wet conditions metalaxyl treatments stabilised emergence and significantly increased the number of healthy plants harvested, by up to 7%.

The most effective concentration of metalaxyl was the 0.6 g a.i./ha which during periods of warm wet weather had increased emergence and greater numbers of surviving healthy plants. The success of the higher concentration metalaxyl 1.2 g a.i./ha treatment in the wettest conditions may be due to leaching resulting in dilution. Under less extreme conditions this more concentrated metalaxyl treatment may negatively affect seed germination and emergence.

Overall the major benefit to the grower of this system is an increase in the number of healthy plants from those drillings where temperature and rainfall were both high.

Data for *Pythium* isolations confirmed the importance of *P. sylvaticum* in these fields and with the present crops. The *Pythium* HS Group isolates were of the type thought to be a primitive form of *P. ultimum*. This data confirms earlier isolation work both from the soils and from plants on the importance in this system of the fast-growing plant pathogenic species of *Pythium*. Slow growing *Pythium* were not seen in great number in either year with the exception of *P. sulcatum* a new arrival in 1999 and this was observed in the water only treatments the majority of the time.

The observation of *P. oligandrum* in all samplings is of considerable interest. *P. oligandrum* is not a pathogen of higher plants. It is a mycoparasite which is known to attack other *Pythium* species and a wide range of other fungi. *P. oligandrum* is likely to be widely distributed in the present land, and could be of considerable benefit to the grower if it were possible to move the balance of species away from the fast-growing plant pathogens.

CONCLUSIONS

The concept of tailoring a machine to apply fungicide directly into the seed drill coulter has been successfully tested, in the context of *Pythium*-induced disease of the coriander crop, in laboratory and under field conditions. It would not be technically difficult to apply the concept to all coulters on a drill instead of the single coulter used in this study.

Initial laboratory trials showed that when used with the fungicide metalaxyl single isomer A9408 B the equipment increased the emergence of coriander from soil with a history of *Pythium* problems

With fungicide application, emergence and plant stand benefits were obtained when the weather was beneficial to *Pythium*. The use of small quantities of fungicide to act as insurance over sequential drillings in the course of a season is obviously preferable to whole field treatment.

Problems arising because cropping patterns encourage the common, fast-growing plant parasitic pythia may clearly be managed. It is likely that other crop/pathogen combinations, such as the *Fusarium* spp. seen in 1999, would benefit from this approach, with other fungicides.

The routine presence of *P. oligandrum* in isolations is of interest in the context of non-chemical disease control. The mycoparasite was clearly interactive with the plant pathogens in diseased roots. To determine ways to enhance its activity could reduce dependency on synthesised fungicides.

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Annexe 1

Analysis of variance, total numbers 1997

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	649.2	216.4	0.99	
Replicate.*units* stratum					
Harvest	10	95266.6	9526.7	43.76	<.001
Treatment	1	910.1	910.1	4.18	0.045
Harvest.Treatment	10	2666	266.6	1.22	0.293
Residual	63	13714	217.7		
Total	87	113205.9			

Analysis of variance, total weights 1997

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	0.00428	0.00143	0.02	
Replicate.*units* stratum					
Harvest	10	77.21303	7.7213	105.18	<.001
Treatment	1	0.04997	0.04997	0.68	0.412
Harvest.Treatment	10	1.60862	0.16086	2.19	0.03
Residual	63	4.62498	0.07341		
Total	87	83.50088			

Analysis of variance, total numbers 1999

Source of variation	d.f. (m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	261.3	87.1	0.85	
Replicate.*units* stratum					
Harvest	14	49629.1	3544.9	34.56	<.001
Treatment	2	1374.5	687.2	6.7	0.002
Harvest.Treatment	28	9079.9	324.3	3.16	<.001
Residual	129 (3)	13231.4	102.6		
Total	176 (3)	72818			

Analysis of variance, total weight 1999

Source of variation	d.f. (m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	0.43194	0.14398	1.56	
Replicate.*units* stratum					
Harvest	14	49.7393	3.55281	38.6	<.001
Treatment	2	0.31845	0.15923	1.73	0.181
Harvest.Treatment	28	7.10704	0.25382	2.76	<.001
Residual	129 (3)	11.87259	0.09204		
Total	176 (3)	68.86521			

Annexe 1 (continued)

Analysis of variance, total numbers diseased 1999

Source of variation	d.f. (m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	82.95	27.65	1.3	
Replicate.*units* stratum					
Harvest	14	14999.92	1071.42	50.28	<.001
Treatment	2	169.4	84.7	3.97	0.021
Harvest.Treatment	28	2372.04	84.72	3.98	<.001
Residual	129 (3)	2749.14	21.31		
Total	176 (3)	20219.57			

Analysis of variance, total numbers healthy 1999

Source of variation	d.f. (m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	129.29	43.1	0.45	
Replicate.*units* stratum					
Harvest	14	43632.95	3116.64	32.19	<.001
Treatment	2	694.24	347.12	3.58	0.031
Harvest.Treatment	28	8111.62	289.7	2.99	<.001
Residual	129 (3)	12490.63	96.83		
Total	176 (3)	64159.73			

Analysis of variance, total weight diseased 1999

Source of variation	d.f. (m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	2.192	0.971	0.88	
Replicate.*units* stratum					
Harvest	14	319.967	22.855	20.61	<.001
Treatment	2	3.536	1.768	1.59	0.207
Harvest.Treatment	28	29.947	1.07	0.96	0.523
Residual	129 (3)	143.018	1.109		
Total	176 (3)	488.929			

Analysis of variance, total weight healthy 1999

Source of variation	d.f. (m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	0.2802	0.0934	0.86	
Replicate.*units* stratum					
Harvest	14	40.1416	2.8673	26.28	<.001
Treatment	2	0.4213	0.2107	1.93	0.149
Harvest.Treatment	28	7.6083	0.2717	2.49	<.001
Residual	129 (3)	14.0743	0.1091		
Total	176 (3)	62.1962			