The control of yield decline in sugarcane with fungicides

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Summary

A range of fungicides with different modes of action was screened in glasshouse experiments for control of sugarcane yield decline.

The highest non-phytotoxic soil-applied dose of each chemical was added to affected soil and growth responses measured. Benomyl, mancozeb, maneb and zineb each controlled root symptoms of yield decline and induced significant growth responses. Further research into the role of fungi in sugarcane yield decline appears warranted.

Introduction

The productivity of many crops decline with successive replanting when grown as a monoculture (Arneson and May 1976, Salt 1979, Suslow and Schroth 1982, Vos and van Loon 1989) and this phenomenon has been referred to as replant disease. Replant diseases are particularly acute in horticultural crops such as apples and peaches (Mai and Abawi 1978, Sewell 1981). Sugarcane is no exception and in Australia the reduced productivity of land cropped for extended periods to sugarcane is well documented (Bell 1935, Croft and Magarey 1991, Egan *et al.* 1984).

In many crops replant diseases are avoided through crop rotation (Salt 1979, Vos and van Loon 1989, Croft and Magarey 1991) or eliminated using soil fumigants. In Australia, crop rotation in sugarcane generally has not been viable for economic reasons and due to the lack of alternative rotation crops. Replant disease can be controlled by methyl bromide fumigation but this treatment is expensive and uneconomic. An intensive research program is in progress to determine the factors causing sugarcane yield decline so that controls can be implemented. Factors being considered include plant nutrition, soil physical characteristics, toxins and soil biology.

Root systems growing in mono-cultured caneland soils typically show reduced growth, poor fine root development, a browning of root surfaces, root lesions, and in many soils a rotting of the primary roots. In 1984, Croft and Magarey (1984) reported the isolation of a previously undescribed Oomycete, now described as *Pachymetra chaunorhiza* Croft and Dick, (Dick *et al.* 1989). Pathogenicity tests implicated this fungus as the causal agent of the primary root rot (Croft and Magarey 1984). A second Oomycete, *Pythium arrhenomanes* Drechsl., was isolated from diseased roots and shown to severely restrict sugarcane root systems in pure culture inoculations (Croft and Magarey 1984). However, detailed observations of roots growing in soils affected by yield decline indicated that organisms other than *Pythium* were responsible for the poor root growth (Magarey 1986).

A range of fungicides diverse both in action and target specificity, was screened in glasshouse experiments for their ability to improve root health and plant growth. This paper reports on the alleviation of sugarcane yield decline with fungicides.

Materials and methods

General methods

A series of 11 glasshouse experiments was conducted at the Tully Sugar Experiment Station (17°54'S, 146°E) in Queensland, Australia. Plants for these experiments were pre-germinated from single-bud cuttings of sugarcane grown in University of California potting mix type BII (Baker 1957). When plants were 10–20 cm high they were transplanted into 15 cm diameter clay pots containing 1.40 kg (dry weight) of either UC mix or yield decline-affected soil. Each pot contained one pre-germinated plant which was fertilized with 0.194 g of KCl, 0.459 g of $MgSO_4$, 0.352 g of $NaNO_3$ and 0.1 g of Fe chelate (UC mix) or 0.343 g of K_2HPO_4 and 0.153 g of NH_4NO_3 (soil) at the time of potting. Trace elements were applied as a basal dressing to yield decline-affected soils (1.65 g per pot of Hortico Trace Element Mixture which contains 22% K, 2% Mg, 1% Fe, 1% Mn, 0.8% Cu, 0.8% Zn, 0.2% B, 0.1% Mo, 13% S). In each experiment, plants were fertilized with 0.115 g of urea at 4 weeks.

Plants were maintained for six weeks in air-conditioned benches (Reghenzani 1984) operating between 25 and 30°C. Pots were sub-irrigated using 2 cm deep clay saucers with water maintained in the saucers with an automatic drip irrigation system.

At harvest, roots were washed free of soil and examined for phytotoxicity and/or disease symptoms. A subjective estimate of the density of secondary and tertiary roots in the fibrous root system (fine root rating), was applied with 10 assigned to the disease-free check. For example, a fine root rating of one implies a root system with a fine root density one-tenth of that in the check; a rating of 20 would imply a density twice that of the check.

Phytotoxicity screen

Fungicide phytotoxicity was assessed in experiments incorporating the cultivar Q90 growing in UC potting mix. Fungicides were applied at doses of 0, 5, 10, 20, 50, 100 and 500 ppm a.i. except as indicated. Reduced shoot or root weight, and particularly a reduction in fine root growth or an atypical whitening and/or stubbing of roots were used as indicators of phytotoxicity.

Application of fungicides

Fungicides were applied in aliquots from a stock solution to soil surfaces before the potting of the pre-germinated plants. When the fungicide solution had dried, the soil in each pot was thoroughly mixed to ensure even distribution of the fungicide. One pre-germinated plant was then immediately placed in each pot.

Pasteurization treatment

Pasteurization of soil was achieved by treating soil at 70°C for 90 minutes.

Statistical analysis

A randomized complete block design was used in each experiment. Analysis of variance was conducted with the Statistix 3 package (NH Analytical Software, Roseville, Minneapolis, USA).

Experimental phytotoxicity

The following fungicides were screened for phytotoxicity: chlorothalonil (Bravo), thiram (Barmac), oxycarboxin (Plantvax, ICI), fenaminosulf (Lesan DX, Bayer) tolclofos methyl (Rizolex, Shell), iprodione (Rovral, Rhône Poulenc), vinclozolin (Ronilan, Hoescht), procymidone (Sumisclex, ICI), anilazin (Dyrene, Bayer), pyrifenox (Rhône Poulenc), tridemorph (Calixin, Hoescht), mancozeb (Dithane M45, Rotec), maneb (Incitec), zineb (Incitec), ziram (Incitec), benomyl (Benlate, Du Pont), and metalaxyl (Ridomil, Ciba-Geigy). Metalaxyl was screened at doses of 0, 4, 8, 12, 24, 48 and 96 ppm and benomyl at doses of 0, 200, 400, 500 and 1000 ppm (a.i.).

Screening for growth responses in yield decline soil

Non-phytotoxic doses of the tested fungicides were selected for further testing in yield decline-affected soils. Experimental methods were as described for the phytotoxicity screening trials.

Experiment 1. The following fungicides were included at the indicated dose: metalaxyl (5 ppm), benomyl (600), mancozeb (400). The yield decline

affected soil was from Tully, northern Queensland.

Experiment 2. In this experiment the following fungicides were included: chlorothalonil (50 ppm), oxycarboxin (10), fenaminosulf (50), tolclofos methyl (50), iprodione (50), vinclozolin (20), anilazin (100), dichlofluanid (20), and mancozeb (400). The soil was the same as that used in experiment 1.

Experiment 3. In a yield decline soil from the Innisfail district the dose response relationship of mancozeb and benomyl was investigated. Mancozeb was applied at doses of 0, 50, 100, 200, and 400 ppm a.i. while benomyl was applied at 0, 75, 150, 300, and 600 ppm a.i.

Experiment 4. In a follow up experiment mancozeb was applied to a soil from El Arish, northern Queensland at doses of 0, 25, 50, 100, 200, and 400 ppm a.i.

Experiments 5 and 6. The activity of three other dithiocarbamate fungicides was tested in a yield decline-affected soil from Tully, northern Queensland. Zineb, ziram, maneb, and mancozeb were added at 400 ppm a.i. and Benomyl at 600 ppm a.i. The *Pachymetra*-resistant cultivar Q114 was substituted in this experiment for Q90. Experiment 6 was a repeat of experiment 5.

Soils used in the experiments were from the following soil associations: experiments 1, 2, 5 and 6 – Tully association; experiment 3 – Innisfail association; experiment 4 – Thorpe association (Murtha 1986).

Results

Phytotoxicity screen

Root symptoms of phytotoxicity, including whiter roots, root stubbing or reduced fine root growth, were evident in nine of the fungicides detailed in Table 1. Doses below phytotoxic levels were selected for further testing. The acute phytotoxicity of several fungicides precluded further testing, for example thiram, procymidone, and tridemorph. No obvious phyto-toxicity was seen with the dithiocarbamate fungicides, mancozeb, maneb, zineb, and ziram, or with benomyl.

Table 1. The highest non-phytotoxic dose of fungicides screened in experiment 1.

Fungicide	Dose (ppm)
Chlorothalonil	50
Oxycarboxin	5
Fenaminosulf	50
Tolclofos methyl	50
Iprodione	50
Vinclozolin	20
Anilazin	100
Pyrifenox	20
Dichlofluanid	20

Table 2. Plant growth responses to the application of the fungicides Benomyl, Mancozeb and Metalaxyl to a yield decline soil.

Treatment	Shoot Dry Weight (g)	Root Dry Weight (g)	Fine Root Rating
Untreated soil	4.67	1.57	5.5
Pasteurized soil	6.46	3.33	10.0
Untreated + Benomyl (600 ppm)	7.14	2.68	9.5
Untreated + Mancozeb (400 ppm)	6.16	2.58	9.5
Untreated + Metalaxyl (5 ppm)	4.81	1.95	6.5
LSD (P<0.05)	1.35	NS*	1.52

* not significant

Table 3. Plant growth responses to the application of a wide range of fungicides to yield decline-affected soil.

Treatment	Shoot Dry Weight (g)	Root Dry Weight (g)	Fine Root Rating
Untreated soil	6.36	3.98	4.5
Pasteurized soil	10.03	8.38	10.0
Untreated + Chlorothalonil	5.33	3.48	3.5
Untreated + Oxycarboxin	6.05	3.75	4.0
Untreated + Fenaminosulf	6.49	4.03	4.5
Untreated Tolclofosmethyl	4.64	3.81	4.0
Untreated + Iprodione	6.30	5.00	5.5
Untreated + Vinclozolin	5.52	3.76	3.0
Untreated + Anilazin	7.96	5.58	6.0
Untreated + Pyrifenox	6.80	4.25	4.0
Untreated + Dichlofluanid	6.75	4.78	4.5
Untreated + Mancozeb	9.13	6.60	9.0
LSD (P<0.05)	1.80	1.20	0.9

Screening for growth responses

Experiment 1. A large response in shoot and root growth resulted from soil pasteurization suggesting that yield decline was reducing sugarcane growth in this soil (Table 2). The application of metalaxyl gave very little response suggesting that Pythium root rot was not a significant factor in this soil. Unpublished data suggests that metalaxyl at doses as low as 2 ppm may eliminate Pythium root rot. The addition of benomyl and mancozeb each resulted in excellent root health (the elimination of disease symptoms) and significant improvements in shoot growth and fine root rating.

Experiment 2. Little improvement in root health was noted with any fungicide except mancozeb, and to a lesser extent anilazin (Table 3). The pasteurization of the yield decline soil resulted in excellent root health and significant responses in shoot and root growth, and fine root rating.

Experiment 3. Mancozeb and benomyl greatly improved root health at doses of 200 ppm and 600 ppm respectively (Table 4). In pasteurized soil, mancozeb at 400 ppm slightly reduced shoot and root growth while benomyl at 600 ppm increased these parameters.

Experiment 4. Mancozeb again greatly improved root health at doses of 50 ppm and above (Figure 1). Root systems growing in mancozeb treated soil had a similar appearance to those growing in pasteurized soil. Roots growing into untreated soil were discoloured, shortened, and lacking in secondary and tertiary roots. Those growing in mancozeb treated soil were much longer with a high density of secondary and tertiary roots and root surfaces were not discoloured. A large increase in shoot and root dry weights was associated with improvements in root health.

Experiments 5 and 6. Of the four dithiocarbamate fungicides, mancozeb, maneb and zineb all resulted in excellent root growth and elimination of yield decline symptoms (Table 5). Pasteurization had a similar effect. Ziram treatment gave little improvement in root health. Significant (P<0.05) increases in shoot weight were associated with the application of zineb, maneb, and mancozeb. Due to variability in the data, no root growth responses were significant.

In the repeat experiment, each of the dithiocarbamates, except ziram, improved shoot and root dry weights, though of the fungicides only the response with maneb reached significance for shoot and root weight (Table 6). Each of the dithiocarbamates, except ziram, significantly increased the fine root rating relative to the untreated soil; ratings in these treatments were not significantly

Table 4. Plant growth responses to the application of Mancozeb and Benomyl to a yield decline-affected soil.

Treatment	Shoot Dry Weight (g)	Root Dry Weight (g)	Fine Root Rating
Untreated soil	5.36	2.08	6.3
Pasteurized soil	6.46	3.18	10.0
Untreated + Benomyl (75 ppm)	3.82	1.87	6.3
Untreated + Benomyl (150 ppm)	4.11	2.15	7.7
Untreated + Benomyl (300 ppm)	5.67	1.98	8.0
Untreated + Benomyl (600 ppm)	7.87	3.12	10.3
Untreated + Mancozeb (50 ppm)	5.50	1.97	6.7
Untreated + Mancozeb (100 ppm)	6.40	2.41	8.3
Untreated + Mancozeb (200 ppm)	7.85	2.98	9.0
Untreated + Mancozeb (400 ppm)	7.80	2.89	10.6
Pasteurized soil + Benomyl (75 ppm)	6.92	3.22	9.7
Pasteurized soil + Benomyl (600 ppm)	7.32	3.88	11.7
Pasteurized soil + Mancozeb (50 ppm)	6.10	2.17	9.0
Pasteurized soil + Mancozeb (400 ppm)	4.62	NA*	NA*
LSD (P<0.05)	2.36	0.95	1.9

* results not available

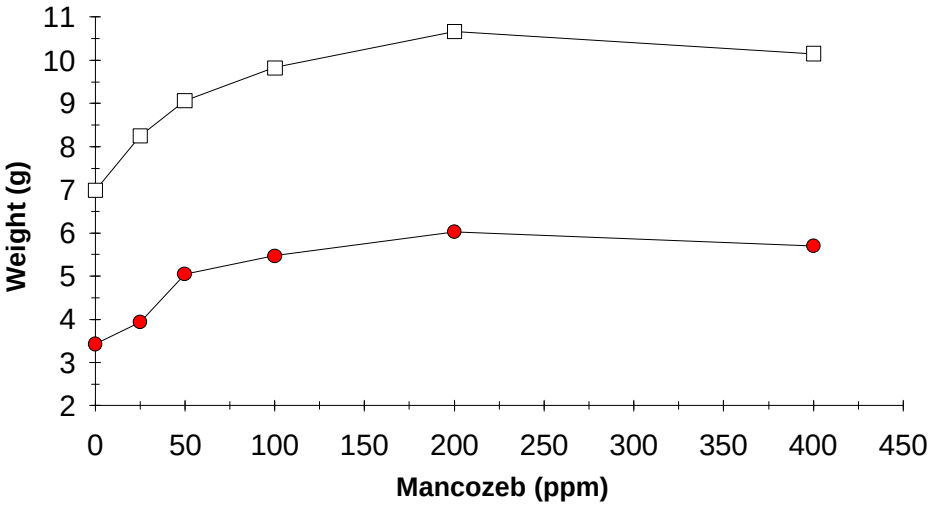

Figure 1. Sugarcane shoot growth (□) and root growth (●) response to the application of mancozeb to a yield decline-affected soil from El Arish, northern Queensland.

different (P<0.05) than the pasteurized check.

Discussion

This paper provides one of the few reports on the activity of the dithiocarbamate fungicides, mancozeb, maneb, and zineb on replant disease (Slykhuis and Li 1985). Mancozeb is used extensively as a foliage protectant. The activity of zineb and maneb is not surprising since each fungicide has the same basic chemical structure as mancozeb. Mancozeb is a complex of the base molecule with Zn and Mn ions, zineb contains only the Zn ion and maneb is a complex with the Mn ion. It is unlikely that the plant growth responses result from better nutrition since:

i. basal dressings of Zn and Mn were applied across all treatments,
ii. equally good responses were obtained when either Zn and Mn were not included in the composition of the added fungicide,
iii. root health was substantially improved by the fungicides,
iv. an unrelated general fungicide, benomyl, also gave marked improvements in root health.

Ziram, a dithiocarbamate fungicide with a different base molecule, failed to control yield decline.

Of significance in the experiments reported here was the increase in fine root growth, the elimination of root surface browning and improvements in root health afforded by the application of the dithiocarbamates and benomyl. These were consistent across all experiments. The control of sugarcane yield decline with general fungicides from different groups, suggests that soil fungi could be the causal agents of the root disease. Of the fungi present in yield decline soils research presented in this paper and elsewhere (Magarey 1986) suggests that Pythium root rot is not the cause of yield decline. Unpublished data suggests that other recognized soil pathogens such as *Thielaviopsis*, *Phoma*, and *Rhizoctonia* though present in affected soils, are not the primary cause of sugarcane yield decline.

The agents responsible for replant diseases have not always been clearly elucidated. The causes of ARD (apple-replant disease) for example have been attributed to actinomycetes (Westcott *et al.* 1987), nutrition, nematodes and other factors (Caesar and Burr 1987, Jaffee *et al.* 1982). The confusion as to the nature of the causal agent(s) is indicative of the complexity of the disease. Extensive research in the 1950s and 1960s by the Hawaiian Sugar Planters' Association and the USDA failed to implicate causal agents to sugarcane yield decline in Hawaii and Florida (Coleman 1974).

The results from experiments reported here suggest that the role of fungi as a cause of sugarcane yield decline should be investigated. Research is continuing into this important sugarcane disease.

Acknowledgments

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Table 5. Plant growth response to the application of four dithiocarbamate fungicides to yield decline-affected soil (experiment 5).

Treatment	Shoot Dry Weight (g)	Root Dry Weight (g)	Fine Root Rating
Untreated	1.53	1.09	3
Pasteurized	2.87	3.03	10
Pasteurized + Mancozeb (400 ppm)	3.28	1.92	8
Pasteurized + Zineb (400 ppm)	3.18	2.71	9
Pasteurized + Ziram (400 ppm)	1.63	0.99	4
Pasteurized + Maneb (400 ppm)	2.92	2.47	8
LSD (P<0.05)	1.03	NS*	–

* not significant

Table 6. Plant growth response to the application of dithiocarbamate fungicides to yield decline-affected soil (experiment 6).

Treatment	Shoot Dry Weight (g)	Root Dry Weight (g)	Fine Root Rating
Untreated	3.56	3.48	6.0
Pasteurized	7.52	5.66	10.0
Untreated + Mancozeb (400 ppm)	4.72	3.99	9.3
Untreated + Zineb (400 ppm)	4.83	4.22	9.3
Untreated + Ziram (400 ppm)	4.04	2.91	7.0
Untreated + Maneb (400 ppm)	6.35	4.89	9.0
LSD (P<0.05)	1.51	0.87	1.4

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