

EFFECTS OF PESTICIDES ON MYCORRHIZA IN FIELD-GROWN BARLEY, MAIZE AND POTATOES

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Vesicular-arbuscular mycorrhizal (VAM) fungi are common in arable soils and can enhance plant nutrient uptake and growth (Gerdemann, 1975; Hayman, 1978; Mosse & Tinker, 1980). Hence the value of applying pesticides to field crops might be partially counterbalanced by side effects on the VAM fungal population. In glasshouse pot experiments, VAM infections were reduced by various pesticides (Hayman, Macdonald & Spokes, 1978), including fungicides (Nesheim & Linn, 1969; Jalali & Domsch, 1975; El-Giahmi, Nicolson & Daft, 1976); benomyl was especially active (Bailey & Safir, 1977; De Bertoldi *et al.*, 1977; Boatman *et al.*, 1978). Conversely, the nematicide DBCP (1,2-dibromo-3-chloropropane) increased VAM infection in cotton (Bird, Rich & Glover, 1974). With peanuts the nematicide/insecticide carbofuran reduced mycorrhiza in both pot and field experiments (Backman & Clark, 1977). VAM populations in field-grown potatoes were reduced by the insecticide aldrin and in tomatoes by the insecticide metasystox (Kruckelmann, 1973), but were little affected by other pesticides on field beans (Salt & Hornby, 1971). Spore numbers of VAM fungi in field-grown peas were affected by fungicides, but not consistently (Stewart & Pflieger, 1977). Soil fumigants have stronger effects; for example formalin greatly reduced VAM populations in a wheat field (Hayman, 1970) and methyl bromide usually eliminates the VAM population almost completely, for example in citrus nurseries (Kleinschmidt & Gerdemann, 1972).

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The variability of results from arable fields prompted us to examine mycorrhizal populations of pesticide-treated plots in field trials of barley, maize and potatoes at the Rothamsted (clay loam) and Woburn (sandy loam) farms, as follows:

(1) Barley (*Hordeum vulgare* L. 'Julia') in Butt Close, Woburn: benomyl at 22 kg ha⁻¹, dazomet (general biocide) at 224 kg ha⁻¹, aldicarb (primarily a nematicide) at 6 kg ha⁻¹ and controls. All plots had received annually 27 kg ha⁻¹ of P and 52 kg ha⁻¹ of K as compound fertilizer and either 38 (N-1) or 75 (N-2) kg ha⁻¹ of N as 'Nitro-chalk' 25.

(2) Barley ('Julia') in Long Hoos field V, Rothamsted: benomyl at 4 kg ha⁻¹, aldicarb at 6 kg ha⁻¹, chlorfenvinphos (insecticide) at 2 kg ha⁻¹, chlortoluron (herbicide) at 2 kg ha⁻¹ and controls. All plots had been initially treated with the herbicide 2,4-D and given annual dressings of 54 kg ha⁻¹ of P and 205 kg ha⁻¹ of K as compound fertilizer and 125 kg ha⁻¹ of N as 'Nitro-chalk' 25.

(3) Maize (*Zea mays* L. 'Anjou 210') in Butt Furlong, Woburn: dazomet at 450 kg ha⁻¹ and controls. All plots received annually 61 kg ha⁻¹ of P and 232 kg ha⁻¹ of K as compound fertilizer and 50 kg ha⁻¹ of N as 'Nitro-chalk' 25.

(4) Maize ('Calderon 535') in Long Hoos field VI, Rothamsted: benomyl at 11.2 kg ha⁻¹, dazomet at 450 kg ha⁻¹, aldicarb at 4.5 kg ha⁻¹, phorate (insecticide) at 1.65 kg ha⁻¹, a mixture of benomyl + dazomet + phorate at their respective rates and controls. All plots received annually 59 kg ha⁻¹ of P and 225 kg ha⁻¹ of K as com-

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pound fertilizer and 50 kg ha⁻¹ of N as 'Nitro-chalk' 25.

(5) Potatoes (*Solanum tuberosum* L. 'Pentland Crown') in Great Hill, Woburn: benomyl, thiabendazole (fungicide), and carbofuran, all at 22 kg ha⁻¹, and controls. All plots had been given N, P and K at 242, 106 and 309 kg ha⁻¹, respectively, as compound fertilizer.

In October 1977, three replicate root-soil samples were collected from each of two to four replicate plots per treatment, depending on the experiment. Each sample consisted of five bulked subsamples taken from the top 10 cm of soil along the plant rows. After thorough mixing, 50 g was wet-sieved (Gerdemann & Nicolson, 1963) for counts of VAM spores. A random root sample of twenty 1 cm pieces was examined at $\times 160$ magnification after staining with trypan blue (Phillips & Hayman, 1970). VAM infection was

recorded as before (Ocampo, Martin & Hayman, 1980). The data were analysed statistically on log transformations.

Table 1 summarizes the results. Spore populations were rather low compared to numbers generally reported for arable soils (see Hayman, 1978). The laminate type (Mosse & Bowen, 1968), similar to *Glomus macrocarpum* var. *geosporus* (Gerdemann & Trappe, 1974) was predominant in all five sites, comprising 70 to 90% of the total population. A few white reticulate and yellow vacuolate types (Mosse & Bowen, 1968) and some unidentified spores were also found. Consistently fewest spores were found in the benomyl-treated plots. Dazomet also reduced spore numbers, especially in maize, as did phorate. The effects of aldicarb were variable; it had little effect on spore populations in barley and maize at Rothamsted but increased spore production in

Table 1. Mycorrhizal populations of field crops of barley, maize and potatoes treated with different pesticides

Crop/Site	Pesticide	Spores/100 g soil	Root length infected (%)	Root cortex infected (%)	Entry points/cm root	Vesicles/cm root		
Barley:	Butt Close, N-1	None	63 ^a	8 ^a	3.7 ^a	4.5 ^a	6.3 ^a	
		Benomyl	38 ^b	5 ^a	1.4 ^a	2.2 ^a	5.3 ^a	
		Dazomet	46 ^b	4 ^a	1.6 ^a	2.3 ^a	4.0 ^a	
		Aldicarb	94 ^c	58 ^b	46.3 ^b	23.7 ^b	166.8 ^b	
	Butt Close, N-2	None	43 ^a	3 ^a	1.1 ^a	2.7 ^a	0.5 ^a	
		Benomyl	27 ^b	< 1 ^b	0.1 ^b	0.2 ^b	0 ^a	
		Dazomet	42 ^a	1 ^b	0.2 ^b	0.8 ^c	0.7 ^a	
		Aldicarb	50 ^a	4 ^a	1.7 ^a	1.8 ^a	4.7 ^b	
	Long Hoos	None	56 ^a	3 ^a	0.9 ^a	1.4 ^a	0	
		Benomyl	35 ^b	2 ^{ab}	0.4 ^a	1.0 ^a	0	
		Aldicarb	49 ^a	3 ^a	0.7 ^a	1.5 ^a	0	
		Chlorfenvinphos	79 ^c	3 ^a	0.9 ^a	1.2 ^a	0	
Chlortoluron		76 ^c	1 ^b	0.4 ^a	0.9 ^a	0		
Maize:	Butt Furlong	None	25 ^a	24 ^a	19.0 ^a	6.9 ^a	0.4 ^a	
		Dazomet	5 ^b	4 ^b	2.5 ^b	2.1 ^b	0.2 ^a	
	Long Hoos	None	205 ^a	60 ^a	34.1 ^b	23.0 ^a	7.0 ^a	
		Benomyl	97 ^{bc}	29 ^b	17.5 ^b	15.7 ^{ab}	0 ^b	
		Dazomet	136 ^{ab}	31 ^b	17.5 ^b	15.7 ^{ab}	0 ^b	
		Aldicarb	167 ^{ab}	44 ^a	25.7 ^a	20.0 ^{ab}	1.3 ^{ab}	
		Phorate	124 ^{abc}	27 ^b	14.9 ^b	11.7 ^b	0 ^b	
		Benomyl + Dazomet + Phorate	104 ^c	14 ^c	7.5 ^c	6.3 ^c	0.7 ^b	
	Potato:	Great Hill	None	8 ^a	2 ^a	0.5 ^a	1.3 ^a	0
			Benomyl	6 ^{ab}	2 ^a	0.6 ^a	1.3 ^a	0
Thiabendazole			3 ^b	1 ^a	0.2 ^a	0.7 ^a	0	
Carbofuran			9 ^a	5 ^a	1.1 ^a	3.7 ^a	0	

Data analysed on log transformation and *t* test. Within each group, means differ significantly ($P = 0.05$) where not followed by the same letter.

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ly at Woburn. In the potato experiment VAM vesicles were too sparse for treatment differences to be evaluated.

Most mycorrhizal infection occurred in maize, especially in the control (no pesticide) plots at the Hoos field where the percentage of root length infected was double that present in plots treated with benomyl, dazomet or phorate. The positive effect of dazomet on mycorrhiza in maize was even more marked at Woburn (Butt & Close). Barley at the lower level of N at Butt Close field showed the biggest pesticide treatment effect of all the experiments, with VAM infection in the aldicarb plots reaching more than seven times that in the controls. In the other experiments, however, aldicarb had no significant effect either increasing or decreasing infection. Benomyl and dazomet generally had a negative effect on infection, and phorate significantly reduced infection at the one site where it was tested. Thiabendazole, carbofuran, chlorfenvinphos and chlortoluron had no obvious effect. Differences between pesticide treatments were difficult to evaluate statistically in the potato and maize (high N) experiments because mycorrhizal infection was sparse.

Qualitative differences in infection are evident in vesicle production, with most vesicles being found in barley in Woburn soil. Numbers of root points were usually influenced by pesticides in much the same way as VA infection of the root system was affected.

The greatly increased VAM infection associated with aldicarb at Butt Close was especially interesting. Bird *et al.* (1974) explained similar observations with DBCP on cotton by suggesting that nematocides might eliminate nematodes competing for the same root sites as VAM fungi, or might directly affect the physiology of the fungus or root. Higher levels of N seemed to reduce the aldicarb effect.

Our findings from the five experiments described indicate that populations of VA mycorrhizal fungi in arable fields are affected, not only by fungicides and general biocides, but also by insecticides and insecticides. Sometimes their effects were slight or even positive, but usually decreased mycorrhizal infections and spore numbers, an effect that occurred most consistently with benomyl. Since some crops (e.g. maize) are naturally strongly mycorrhizal, and many plants grow better with mycorrhiza, the possibility that plant protection chemicals indirectly affecting yield by their effects on VA mycorrhiza should receive more attention. In our study,

pesticide effects may have been lessened by the presence of abundant fertilizer because high N and P levels generally decrease VAM infection and spore numbers (Hayman, 1970, 1978) and plant responses to mycorrhiza are generally greatest in soils deficient in phosphate. It is likely that pesticides could be more deleterious in less fertilized soils by inhibiting a larger indigenous mycorrhizal population in a situation where its stimulatory effects on plant nutrient uptake were more important to the crop.

REFERENCES

- BACKMAN, P. A. & CLARK, E. M. (1977). Effect of carbofuran and other pesticides on vesicular-arbuscular mycorrhizae in peanuts. *Nematologica* 7, 13-17.
- BAILEY, J. & SAFIR, G. (1977). Uptake and effect of benomyl in mycorrhizal soybean plants. *Proceedings of the American Phytopathological Society* 4, 93 (Abstr.).
- BIRD, G. W., RICH, J. R. & GLOVER, S. U. (1974). Increased endomycorrhizae of cotton roots in soil treated with nematocides. *Phytopathology* 64, 48-51.
- BOATMAN, N., PAGET, D., HAYMAN, D. S. & MOSSE, B. (1978). Effects of systemic fungicides on vesicular-arbuscular mycorrhizal infection and plant phosphate uptake. *Transactions of the British Mycological Society* 70, 443-450.
- DE BERTOLDI, M., GIOVANNETTI, M., GRISSELLI, M. & RAMBELLI, A. (1977). Effects of soil applications of benomyl and captan on the growth of onions and the occurrence of endophytic mycorrhizas and rhizosphere microbes. *Annals of Applied Biology* 86, 111-115.
- EL-GIAHMI, A. A., NICOLSON, T. H. & DAFT, M. J. (1976). Effects of fungal toxicants on mycorrhizal maize. *Transactions of the British Mycological Society* 67, 172-173.
- GERDEMANN, J. W. (1975). Vesicular-arbuscular mycorrhizae. In *The Development and Function of Roots* (ed. J. G. Torrey and D. T. Clarkson), pp. 575-591. London: Academic Press.
- GERDEMANN, J. W. & NICOLSON, T. H. (1963). Spores of mycorrhizal *Endogone* species extracted from soil by wet sieving and decanting. *Transactions of the British Mycological Society* 46, 235-244.
- GERDEMANN, J. W. & TRAPPE, J. M. (1974). The Endogonaceae in the Pacific Northwest. *Mycologia Memoir* 5, 1-76.
- HAYMAN, D. S. (1970). *Endogone* spore numbers in soil and vesicular-arbuscular mycorrhiza in wheat as influenced by season and soil treatment. *Transactions of the British Mycological Society* 54, 53-63.
- HAYMAN, D. S. (1978). Endomycorrhizae. In *Interactions between Non-pathogenic Soil Microorganisms and Plants* (ed. Y. R. Dommergues and S. V. Krupa), pp. 401-442.
- HAYMAN, D. S., MACDONALD, R. M. & SPOKES, J. R. (1978). The effects of pesticides on VA mycorrhiza. *Rothamsted Report for 1977, Part 1*, p. 238.

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