Research reports

The effect of fungicide sprays on root development, green leaf area and yield of wheat in the absence of disease

R. Balasubramaniam and **R.E. Gaunt** Department of Agricultural Microbiology, Lincoln University College of Agriculture, Canterbury, New Zealand

Summary

The effect of fungicide applications on plant growth and crop yield was investigated in the field. Four sprays of benomyl and two of triadimefon were applied at commercially recommended rates to wheat. Green leaf area, total leaf area, root length, yield and yield components were not affected by the chemical applications. There was no evidence for phytotonic effects in this trial. It is suggested that phytotonic effects, associated with nutritional, growth regulatory or resistance mechanisms, occur only under certain conditions and will be the result of crop, chemical and environment interactions.

Introduction

Fungicides are an important input to intensive wheat production in Europe and some other parts of the world. Approximately 6.5 million hectares of cereals in Europe received at least one foliar fungicide application in 1979 (Jenkins and Lescar 1980), including 50%, 27% and 29% of the cereal production areas in the United Kingdom, France and Germany respectively.

Increased yield associated with fungicide application has usually been attributed to disease control. However, Jenkins *et al.* (1972) commented that control of low disease severities could not explain observed yield increases in some field trials. Griffiths and Scott (1977) suggested that some fungicides may stimulate plant growth and cause a 'phytotonic' effect independent of disease control. Phytotonic effects of fungicides were reported on coffee in East African countries (Gillett 1942, Griffiths 1971) and on cereals grown in glasshouses (Griffiths and Scott 1977, Peat and Shipp 1981). Applications of benomyl, carbendazim, ethirimol, tridemorph, triadimefon and captafol increased yields in the field more than would have been expected from control of low disease severities (Griffiths 1981, Priestley 1981).

Delayed senescence has been implicated in the mechanism of phytotonic effects of fungicides. Direct effects of fungicides on senescence, similar to the effects of cytokinins, have been reported for methyl benzimidazole carbamate (MBC) fungicides in cereals (Dickinson and Walpole 1975, Ellen and Spiertz 1975, Staskawicz *et al.* 1978, Peat and Shipp 1981). Delayed senescence will contribute to yield increases only when yield production is limited by insufficient green leaf area duration. This may occur, for example, when the supply of photosynthates is not sufficient to realise the carbohydrate storage potential of the number of grains set during grain filling. Since cytokinins also promote cell division, it is possible that fungicides with cytokinin-like properties may increase yield by effects on spikelet and floret development or endosperm cell number.

Tolstrop and Smedegaard-Petersen (1984) reported that saprophytic fungi, mostly *Cladosporium* spp., were associated with senescence in barley. Smedegaard-Petersen and Tolstrop (1985) suggested that observed yield increases with fungicide application were attributable to a reduction in energy cost to the host for resistance mechanisms which prevented infection. They suggested that this was similar to the energy cost associated with defence against avirulent pathogens (Smedegaard-Petersen and Stolen 1981). Dickinson (1981a, 1981b) suggested that saprophytic fungi may behave as weak pathogens, becoming more active as the crop senesces. These facultative parasites may be of greater importance than previously recognized, and their direct control by fungicides may increase green leaf area, and possibly yield, thus causing an apparent phytotonic effect.

It is imperative that phytotonic effects on yield are studied in field-grown crops, and it is likely that phytotonic effects will be expressed only under some environmental conditions. There are no reported studies on the effect of foliar fungicide application on root growth. In this paper, the effects of foliar fungicide applications to a wheat crop with minimal disease severity on shoot growth, root growth and yield are reported.

Materials and Methods

Wheat seed (cv. Kopara) treated with captan (100 g a.i. 100 kg^{-1} seed) was sown (150 kg ha^{-1}) on 24th June 1980 on a silt loam soil at Lincoln, New Zealand. At GS 12 (Zadoks *et al.* 1974) four randomised blocks of four treatment plots (12 x 10 m) were marked out, with a mown access path (0.5 m) bordering each plot within the blocks. Benomyl (250 g a.i. ha^{-1}) was applied at G.S. 12, 23, 25 and 33 and triadimefon (125 g a.i. ha^{-1}) was applied at GS 40 and 82 in the full spray treatment. No sprays were applied to one plot (nil spray) in each replicate. Fungicide sprays were applied from each side of the plots by a tractor mounted 6 m boom at 300 L ha^{-1} at 3.45 x 10^5 N m^{-2} pressure.

Ten plants per plot were sampled randomly during the growth season (GS 12-79) from rows at least one metre from the edge of the plots to avoid plants influenced by edge effects and interplot interference (James and Shih 1973, James *et al.* 1973). Percentage leaf area occupied by disease was recorded on all green leaves of the main stem using standard area diagrams (Anon 1972). The leaf lamina was removed and the area determined using leaf area meter (Li-cor Model 3100, USA). Total green leaf area was calculated as described by Lim and Gaunt (1981).

Soil cores were extracted from a position at least 1 m from the edge of the plots at GS 12 (two cores/plot) and GS 89 (three cores/plot). The cores were pooled for each plot and cut into segments at 10, 20, 35 and 50 cm depths. The roots were separated from the soil using an automated washing system (Bohm 1979) and live root length was measured by the grid intercept method (Marsh 1971). The total root length to 50 cm depth is presented as length/unit area of soil (cm cm^{-2}). Root length in individual segments of a core is presented as length/unit volume of soil (cm cm^{-3}).

When harvest ripe, plants in five 0.1 m^2 quadrats were sampled randomly on each side of the 1.5 m central strip in each plot. The total number of plants and the number of ear bearing tillers were measured. A central 10 x 1.5 m strip was machine harvested (Walter and Wintersteiger Universal Seed Master, Austria), and the yield and mean grain weight determined.

Results

Minimal symptoms of speckled leaf blotch first appeared at GS 24 (Table 1) as small chlorotic areas on the lower leaves. Pycnidia did not develop and disease was not present from GS 33 onwards. Symptoms of leaf rust appeared at GS 69, but severity was very low and there were no significant differences between treatments up to GS 71.

There were no significant differences between treatments in mean percentage green leaf area and total leaf area (Table 1). Total

Table 1. The effect of fungicide application on disease development and leaf area on main stems of Kopara wheat.

Variable	Fungicide treatment	Disease variables at growth stages[A]									
		12	22	23	24	25	32	33	69	71	79
Mean % disease severity[B]	Full	0.00	0.00	0.00	0.02	0.03	0.06	0.00	0.00	0.02	1.26
	Nil	0.00	0.00	0.00	0.02	0.07	0.23	0.00	0.10	0.09	2.26
LSD (P=0.05)		0.00	0.00	0.00	0.07	0.06	0.18	0.00	0.25	0.19	0.53
Mean % green leaf area	Full	100.0	100.0	93.8	98.9	98.9	88.8	79.1	78.8	77.6	60.1
	Nil	100.0	100.0	90.6	98.9	98.5	90.0	78.9	76.6	76.5	59.7
LSD (P=0.05)		0.0	0.0	4.1	0.5	0.7	9.1	9.5	12.6	5.1	9.4
Total leaf area (cm^2)	Full	1.5	4.4	5.5	10.0	15.0	20.6	49.4	43.6	56.9	51.5
	Nil	1.4	4.0	5.1	9.5	14.3	21.4	47.1	40.9	51.2	46.5
LSD (P=0.05)		0.6	1.2	1.6	0.5	1.4	3.6	13.2	2.8	10.0	6.0
Total green leaf area (cm^2)	Full	1.5	4.4	5.9	10.6	15.9	20.8	46.6	37.2	46.7	30.0
	Nil	1.4	4.0	5.3	10.3	15.0	21.1	45.0	36.4	41.4	27.3
LSD (P=0.05)		0.4	1.2	0.6	0.6	1.3	2.2	5.8	6.3	9.5	4.2

[A] Based on a sample of 10 main stems per replicate for each growth stage as defined by Zadoks *et al.* (1974).
[B] Based on total of any diseases present.

Table 2. The effect of fungicide application on root length of wheat

Growth stage[A]	Fungicide treatment	Root lengths in soil profile zones (cm)				
		0-10[B]	10-20[B]	20-35[B]	35-50[B]	0-50[C]
21	Full spray	0.69	0.67	0.29	0.20	21.0
	Nil spray	0.96	0.83	0.36	0.18	26.0
LSD P=0.05		0.21	0.47	0.25	0.26	11.1
89	Full spray	7.69	4.30	1.55	0.94	157.3
	Nil spray	8.64	4.89	1.78	1.17	179.6
LSD P=0.05		0.99	2.38	0.20	0.86	23.7

[A] Defined by Zadoks *et al.* (1974)
[B] Root length per unit volume (LV) of soil ($cm\ cm^{-3}$)
[C] Root length per unit area (LA) of soil ($cm\ cm^{-2}$)

Table 3. The effects of fungicide application on yield and yield components of wheat

Variable	Yield and yield components		
	Fungicide treatments		LSD
	Full spray	Nil spray	P=0.05
Plant number m^{-2}	275	270	32.8
Ear number per plant	2.40	2.48	0.37
Grain number per ear (calculated)	31.4	29.8	11.1
Individual grain weight (mg)	40.8	40.8	1.4
Header yield (t ha^{-1}) at 14% moisture content	5.73	5.65	0.48

green leaf area, calculated from the percentage green leaf area and total leaf area was also not affected (Table 1).

There were no significant differences in root length between treatments at GS 21 except in the 0-10 cm zone (Table 2). At GS 89, after six fungicide applications, there were no significant differences between treatments, except in the 20-35 cm segment (Table 2). In this segment, the root length in fungicide sprayed plants was 12% less than in the unsprayed plants. Total root length down to 50 cm was not affected by treatment.

There was no significant difference in yield attributable to fungicide spray application (Table 3) and there were no effects on the number of plants/square metre, grain number/ear nor on mean grain weight.

Discussion

Disease severity was very low, reaching a maximum of 2.3% and 1.3% at GS 79 in the unsprayed and sprayed plants respectively, and not exceeding 0.23% and 0.06% at other assessments. By comparison disease severity in the previous year, when there was a severe disease epidemic, reached a maximum of 21% in unsprayed plants (Thomson and Gaunt, 1986).

The application of fungicides had no effect on green leaf area nor total leaf area, in contrast to the effects reported by Griffiths and Scott (1977), Cook (1981), Dickinson (1981a), Griffiths (1981), Jordan (1981) and Priestley (1981). Root growth was also not affected by foliar fungicides applied throughout the season. The absence of significant effects on the number of plants per unit area, number of grains per ear, the mean grain weight, or yield suggests that the other yield components (spikelet number per ear and grains per spikelet) were also not affected. It was concluded that fungicide applications had no phytotonic effect on crop growth throughout the crop cycle.

The results obtained were specific to the crop species, cultivar, soil, climate (temperate) and agricultural practices in the trial, which differed from those of similar investigations. Glasshouse studies (e.g. Griffiths and Scott 1977, Peat and Shipp 1981) are not directly relevant to phytotonic effects in the field, and the use of higher than recommended rates of fungicides (e.g. Peat and Shipp 1981) may not be indicative of potential yield responses with usual practices.

Griffiths and Scott (1977) concluded that the evidence for phytotonic responses to fungicides was inconclusive, but suggested three ways in which the effects may be produced. The fungicides may affect plant

growth directly; control of even small amounts of recognized diseases may, at critical times, have large effects on yield; and control of phylloplane organisms and weak pathogens may, in certain circumstances, cause yield increases. Yield increases from the control of low amounts of disease at critical stages and from the control of facultative pathogens are examples of unrecognized disease effects on yield, and should not, therefore, be considered as phytotonic effects. On the other hand, phytotonic effects may be produced by the nutritional properties of fungicides or by the energy costs involved in resistance mechanisms associated with avirulent pathogens or saprophytic fungi (Snedegaard-Petersen and Stolen 1985).

Under different circumstances to this investigation, phytotonic effects in the restricted sense defined above may well occur. If such phytotonic effects are shown to be significant, they should be considered in investigations of disease effects on yield in which fungicides are used to create different amounts of disease.

Acknowledgements

Thanks are expressed to the Commonwealth Scholarships Committee for financial assistance (R. Balasubramaniam); to Lincoln College and Commercial Companies for funding trial expenses; to I. Perry, J. Sutcliffe and J.I. Symons and to the Field Service Centre staff for technical assistance.

References

Anon. (1972) Guide for the assessment of cereal diseases. Plant Pathology Laboratory, Harpenden, Herts. Ministry of Agriculture, Fisheries and Food, United Kingdom.

Bohm W. (1979) Methods for studying root systems. Ecological Studies; V. 33. Springer-Verlag, Berlin 188 pp.

Cook R.J. (1981) Unexpected effects of fungicides on cereal yields. *European and Mediterranean Plant Protection Bulletin* 11, 227-285.

Dickinson C.H. (1981a) Leaf surface microorganisms as pathogen antogonists and as minor pathogens. *In*: 'Strategies for the control of cereal diseases' (Ed. by J.F. Jenkyn and R.T. Plumb), pp. 109-121. Blackwell Scientific Publications, Oxford.

Dickinson C.H. (1981b) Biology of *Alternaria alternata*, *Cladosporium cladosporioides* and *C. herbarum* in respect of their activity on green plants. *In*: 'Microbial ecology of the phylloplane' (Ed. by J.P. Blakeman), pp. 169-184. Academic Press, London.

Dickinson C.H. and Walpole, P.R. (1975) The effect of late application of fungicides on the yield of winter wheat. *Experimental Husbandry* 29, 23-28.

Ellen J. and Spiertz J.H.J. (1975) The influence of nitrogen and Benlate on leaf area duration, grain growth and pattern of N-, P- and K- uptake of winter wheat (*Triticum aestivum*). *Zeitschrift fur Acker und Pflanzenban* 141, 231-239.

Gillett S. (1942) Results and observations of spraying trials using Bordeaux mixture on coffee at the Scott Agricultural Laboratories. Coffee Board of Kenya, Monthly Bulletin, No. 75, 30-31.

Griffiths E. (1971) 'Negative' effects of fungicides in coffee. Proceedings of the 6th British Insecticide and Fungicide Conference, pp. 817-825.

Griffiths E. (1981) Role of fungicides in maximizing grain yield of barley. *European and Mediterranean Plant Protection Organisation Bulletin* 11, 347-354.

Griffiths E. and Scott S.W. (1977) Possible "phytotonic" effects of fungicides on barley. *In*: 'Crop protection agents - their biological evaluation' (Ed. by N.R. McFarlane), pp. 465-477. Academic Press, London.

James W.C. and Shih C.S. (1973) Relationship between incidence and severity of powdery mildew and leaf rust on winter wheat. *Phytopathology* 63, 183-187.

James W.C., Shih C.S., Callbeck L.C. and Hodgson W.A. (1973) Interplot interference in field experiments with late blight of potato (*Phytophthora infestans*). *Phytopathology* 63, 1269-1275.

Jenkins J.E.E. and Lescar L. (1980) Use of foliar fungicides on cereals in Western Europe. *Plant Disease* 64, 987-994.

Jenkins J.E.E., Melville, S.C. and Jemmett J.L. (1972) The effect of fungicides on leaf diseases and on yield in spring barley in South-west England. *Plant Pathology* 21, 49-58.

Jordan Y.W.L. (1981) Effect of fungicides on *Septoria nodorum* and wheat green leaf area. *European and Mediterranean Plant Protection Organisation Bulletin* 11, 355-356.

Lim L.G. and Gaunt, R.E. (1981) Leaf area as a factor in disease assessment. *Journal of Agricultural Science* 97, 481-483.

Marsh B.a'B. (1971) Measurement of length in random arrangements of lines. *Journal of Applied Ecology* 8, 265-267.

Peat W.E. and Shipp D.M. (1981) The effects of benomyl on the growth and development of wheat. *European and Mediterranean Plant Protection Bulletin* 11, 287-293.

Priestley R.H. (1981) Fungicide treatment increases yield of cereal cultivars by reducing disease and delaying senescence. *European and Mediterranean Plant Protection Bulletin* 11, 357-363.

Smedegaard-Petersen, V. and Stolen, O. (1981) Effect of energy-requiring defence reactions on yield and grain quality in a powdery mildew-resistant barley cultivars. *Phytopathology* 71, 396-399.

Smedegaard-Peterson, V. and Tolstrup, K. (1985) The limiting effect of disease resistance on yield. *Annual Review of Phytopathology* 23, 475-90.

Staskawicz B., Kaur-sawhney R., Slaybaugh R., Adams W. and Galston A.W. (1978): The cytokinin-like action of methyl-2-benzimidazolecarbamate on oat leaves and protoplasts. *Pesticide Biochemistry and Physiology* 8, 106-110.

Thomson, W.J. and Gaunt, R.E. (1986) The effect of speckled leaf blotch on apical development and yield in autumn sown wheat in New Zealand. *Annals of Botany*, 58: 39-48.

Tolstrup, K. and Smedegaard-Petersen, V. (1984) Saprophytic leaf fungi on barley and their effect on leaf senescence and grain yield. *Vaxtskydalsnotiser* 48, 66-75.

Zadoks J.C., Chang T.T. and Konzak C.F. (1974) A decimal code for the growth stages of cereals. *Weed Research* 14, 415-421.