Ann. appl. Biol. (1981), **97**, 263–268
Printed in Great Britain

Control of pearl millet downy mildew by seed treatment with metalaxyl*

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(*Accepted 2 September 1980*)

SUMMARY

Three formulations of the systemic fungicide metalaxyl were tested in various seed treatments for the control of pearl millet downy mildew in three field experiments with downy mildew-susceptible pearl millet hybrid NHB-3. Uniform, high levels of sporangial inoculum of the causal fungus, *Sclerospora graminicola*, were provided throughout the growth of the test crops from inoculated infector rows of NHB-3, planted earlier between the test plots. Significant reductions in downy mildew were obtained with all fungicide treatments. Best control was obtained when seed was soaked in a 0·5% aqueous solution of a liquid formulation (mean infection index of 9·8% compared with 94·8% in the untreated check). The degree of control with the wettable powder formulations was directly related to fungicide dosage, and there were no significant effects of application method. Simple dusting of seed at 2 g a.i./kg, a rapid and simple operation requiring small quantities of fungicide and no special application equipment, gave a high level of control (infection index of 12·6% compared with 78·9% in the untreated check). In two experiments grain yields from all the treated plots were significantly greater than from the untreated plots (means of 1234 and 1534 kg/ha for treated plots compared with 485 and 743 kg/ha, respectively), and in the third, the treatment with the least downy mildew gave significantly more grain than the untreated check (1228 compared with 727 kg/ha).

INTRODUCTION

Downy mildew, caused by *Sclerospora graminicola* (Sacc.) Schroet., is the most widespread and destructive disease of pearl millet (*Pennisetum americanum* (L.) Leeke, syn. *P. typhoides* Stapf. and Hubb.) in Africa and Asia. From 1970 to 1976 downy mildew epidemics caused considerable yield losses in the Indian pearl millet hybrid crop (Safeeulla, 1977), and the disease remains one of the major factors preventing the use of improved millet hybrids and varieties in Africa. Considerable efforts have been made in India over the past 5 years to develop downy mildew-resistant hybrids, and several new hybrids are now being grown commercially in the sub-continent. These hybrids, however, become highly susceptible to the disease when exposed to high inoculum pressure, and/or when exposed to certain West African populations of *S. graminicola* (Anon., 1977; Williams & Singh, 1978). It is therefore possible that the resistance of these hybrids may 'break down' in India with expanding commercial cultivation. While the search continues for sources of stable downy mildew resistance, the recent development of the systemic fungicide metalaxyl, methyl *N*-(2-methoxyacetyl)-*N*-(2, 6-xylyl)-DL-alaninate (Ridomil, Ciba Geigy Ltd), which is highly effective against fungi in the Peronosporales (Urech, Schwinn & Staub, 1977), has provided a possible alternative or additive control measure. The fungicide has been reported to be effective in the Philippines for the control of downy mildew of maize (Exconde & Molina, 1978), and in India it has been successfully used experimentally, as a seed

* Journal Article no. 105 of the International Crops Research Institute for the Semi-Arid Tropics.

dressing, to control downy mildew of sorghum, maize, and pearl millet (Venugopal & Safeeulla, 1978). In this paper we describe results from three field trials with different formulations of the fungicide used in seed treatments for the control of downy mildew in pearl millet.

MATERIALS AND METHODS

Test cultivars, field plot details, and experimental design

The experiments were conducted at the ICRISAT Centre, during the 1977–78 post-rainy (dry, winter) and in the 1978 rainy (monsoon) seasons.

The downy mildew-susceptible commercial hybrid NHB-3 was used in all experiments, in four-row plots (3 m long in Expt 1 and 5 m long in Expts 2 and 3), with rows 75 cm apart and plants about 5 cm apart within the rows. Each treatment was represented in four replications, with a randomised complete block design.

The experiments were conducted in red Alfisol (clay 33%, sand 60%, silt 7%) of pH about 5·9. Ammonium phosphate (28% N, 28% P_2O_5) at 300 kg/ha, was broadcast prior to ridging and the plots were top-dressed with urea (44% N) at 100 kg/ha 25 days after planting.

Fungicide formulations and treatments

Experiment 1

Two metalaxyl formulations, a 10% w.p. and a 25% w.p., were applied to pearl millet seeds in three ways: (1) *DUST* – dry seeds were thoroughly shaken with the fungicide (8 g product/kg seed); (2) *SOAK* – seeds were stirred for 4 h in aqueous fungicide suspension (8 g product/L water/kg seed) and were then removed from the suspension and allowed to dry at room temperature; (3) *STICK* – seeds were stirred in a methyl cellulose-fungicide suspension (8 g product/750 ml 1% methyl cellulose/kg seed) until they were thoroughly coated, and were then removed from the suspension and allowed to dry.

Experiment 2

The 25% w.p. formulation was thoroughly shaken with dry seeds at three rates: 0·5, 1·0, and 2·0 g a.i./kg seed.

Experiment 3

Seeds were stirred in an aqueous suspension of metalaxyl liquid formulation for 6 h (6 ml fungicide formulation + 994 ml water/kg seed), 12 h (6 ml fungicide formulation + 1194 ml water/kg seed), and 24 h (6 ml fungicide formulation + 1194 ml water/kg seed).

The treated seeds for the three experiments were dried at room temperature and maintained at 20 °C in an incubator overnight until sowing. Untreated seeds were used to plant check plots in each experiment.

Inoculum provision

The trials were conducted in a part of the ICRISAT downy mildew-resistance screening nursery. Unknown numbers of oospores were present in the field which had been used twice a year for downy mildew resistance screening since the 1976 rainy season. Sporangial (zoospore) inoculum was continually provided throughout the period of crop growth from inoculated infector rows of NHB-3, which had been planted 3 wk prior to the test plots in single rows between the four-row test plots. During the post-rainy season and during rain-free periods in the rainy season, mist irrigation was provided for 30 min in the late evenings, three times a week, to promote sporulation and infection. Under these conditions, the downy mildew-infected infector-row plants sporulated profusely each night for several weeks providing high inoculum pressure over the whole trial area.

Downy mildew incidence and severity ratings

At about 18, 31, and 54 days after planting the number of downy mildew-infected plants per plot was recorded and a slim red-topped bamboo peg was positioned alongside each infected plant so that if the plant died and disappeared it would still be counted during subsequent recordings. At the final recording (61 to 76 days after planting) each plant was rated according to the following scale: 1 – no downy mildew symptoms; 2 – only aerial tillers infected; 3 – less than 50% basal tillers infected; 4 – more than 50% basal tillers infected; 5 – all tillers and main shoot infected.

Two infection parameters were calculated – the incidence (%) of infected plants at each scoring date, and the infection index (%) derived by the following formula from the data on the numbers of plants in each of the five reaction categories at final scoring:

$$\frac{X_2 + 2X_3 + 3X_4 + 4X_5}{4N} \times 100$$

where X_2 to X_5 are the numbers of plants in disease categories 2 to 5, and N is the total plant number.

Arcsin transformations of percentage values were used in the statistical analyses.

Yield measurements

In all experiments the entire plots were harvested at full grain maturity and the weight of sun-dried threshed grain was recorded.

RESULTS

Experiment 1

Plots planted with treated seed (treated plots) developed significantly less downy mildew and produced significantly more grain than plots planted with untreated seed (check plots) (Figs 1 and 2, Table 1).

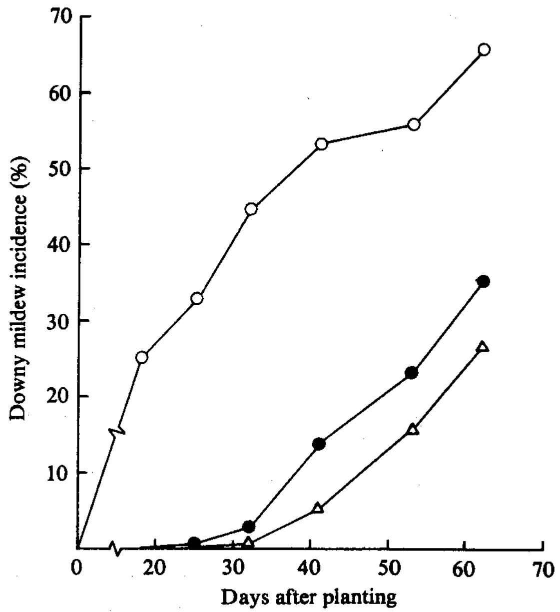

Fig. 1. Downy mildew incidence in NHB-3 pearl millet grown from seed treated with two formulations of metalaxyl (25% w.p. [△] & 10% w.p. [●]) and from untreated seed (○).

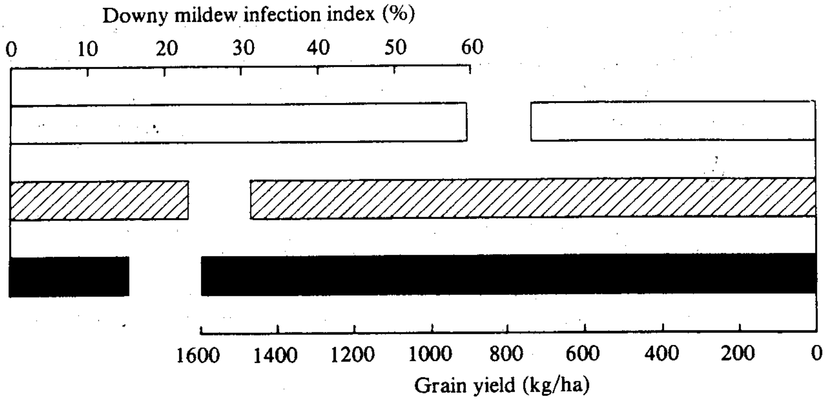

Fig. 2. Downy mildew infection index and grain yield in NHB-3 pearl millet grown from seed treated with two formulations of metalaxyl (25% w.p. [solid bars] and 10% w.p. [hatched bars]) and from untreated seed (open bars).

Table 1. *Components† of analysis of variance comparing the effects of two fungicide formulations applied in three ways for the control of downy mildew in, and effects on grain yield of pearl millet*

		Infection index‡			Grain yield		
Source of variation	D.F.	MS	F	Sig.	MS	F	Sig.
Treated vs non-treated	1	2161	75	***	1 930 294	44	***
Formulations (f)	1	203	7·06	*	75 263	1·72	NS
Application methods (a)	2	55	1·89	NS	85 810	1·98	NS
Interaction (f × a)	2	11	0·38	NS	32 782	0·75	NS
Replication	3	93	3·22	*	28 381	0·65	NS
Error	18	28·8	—	—	43 871	—	—

† D.F., MS, F, Sig., *, ***, NS are, respectively, degrees of freedom, mean square, F-ratio, significance, significant at the 5% probability level, significant at the 0·1% probability level, not significant.
‡ Analysis of the arcsin transformed data.

The plots treated with the 25% w.p. formulation developed significantly less downy mildew than plots treated with the 10% w.p. formulation indicating a dosage effect. There were no significant effects of application methods (Table 1).

The grain yields of the treated plots were inversely related to the infection indices (Fig. 2), but the differences between the fungicide treatments were not statistically significant (Table 1). The mean grain yields from the treated and check plots were 1534 and 743 kg/ha, respectively.

Experiment 2

All treated plots had significantly less downy mildew than the check plots on all scoring dates (Table 2). Among the treated plots the least disease and the greatest grain yield (169% of the check) occurred at the highest fungicide rate, and the most disease and least grain yield (124% of the check) occurred at the lowest fungicide rate (Fig. 3). Grain yield differences were statistically significant only between the check plots and the plots treated at the highest fungicide rate.

Experiment 3

Treated plots had significantly less downy mildew and significantly more grain yield than the check plots, and there were no significant differences among the treated plots (Table 3). Downy

Table 2. *Downy mildew incidence 18, 29, 50, and 71 days after planting in NHB-3 pearl millet grown from seed treated with a 25% w.p. formulation of metalaxyl at three rates, and from untreated seed*

Application rate (g a.i./kg seed)	Incidence (%)			
	18 days	29 days	50 days	71 days
2·0	0	3·4 (10·3)*	15·4 (23·0)	29·6 (32·9)
1·0	0	8·5 (16·8)	23·7 (29·0)	36·3 (36·9)
0·5	1·5	21·9 (27·6)	35·0 (36·1)	43·0 (40·9)
0	37·6	78·1 (62·1)	85·1 (67·3)	87·5 (69·4)
S.E. ±	—	— (1·76)	— (1·64)	— (1·74)

* Data in parentheses are arcsin transformed values.

Table 3. *Downy mildew incidence 20, 31, 52, and 76 days after planting, downy mildew infection index 76 days after planting, and grain yield in NHB-3 pearl millet grown from seed soaked in a liquid formulation of metalaxyl for 6, 12, and 24 h, and from untreated seed*

Treatment time (h)	Incidence (%)				Infection index (%)	Grain yield (kg/ha)
	20 days	31 days	52 days	76 days		
24	0·1	4·6	12·1 (20·4)*	19·2 (25·9)	9·3 (17·7)	1205
12	0	4·8	12·7 (20·6)	19·2 (25·8)	9·5 (17·8)	1274
6	0	4·9	15·1 (22·7)	21·0 (27·3)	10·5 (18·8)	1224
0	83·0	91·3	92·5 (74·5)	97·6 (81·9)	94·8 (76·7)	485
S.E. ±	—	—	— (0·94)	— (2·02)	— (1·19)	69·7

* Data in parentheses are arcsin transformed values.

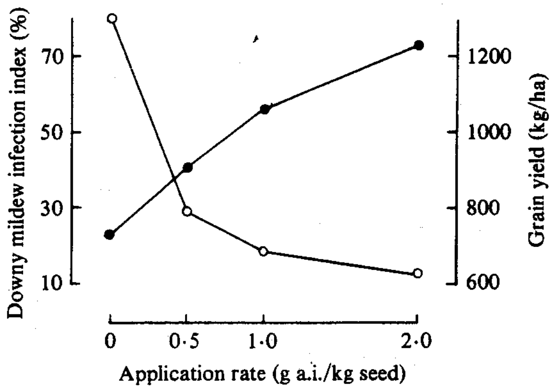

Fig. 3. Downy mildew infection index (○) and grain yield (●) in NHB-3 pearl millet grown from seed treated with metalaxyl at three rates and from untreated seed.

mildew levels remained extremely low in the treated plots throughout crop development. Mean grain yield of the treated plots was 254% of the grain yield of the check plots.

DISCUSSION

In three field experiments, in which there was continual high inoculum pressure throughout crop development, the systemic fungicide metalaxyl used in seed treatments on the highly downy mildew-susceptible pearl millet hybrid NHB-3 gave significant control of downy mildew with consequent significant yield increases. The greatest degree of control was obtained following the soaking of seeds in aqueous solution of a 25% a.i. liquid formulation. The level of disease control with wettable-powder formulations was directly related to application rates, with greatest control obtained with the highest application rate, 2 g a.i./kg seed.

In all experiments the downy mildew incidence in almost all treated plots was very low for 31 days after planting and thereafter increased steadily up to final scoring. This late disease development is due to the infection, by sporangia from the infector rows, of later-formed basal and aerial tillers, which in pearl millet are continually formed until maturity. These late-formed tillers are unlikely to be protected by a fungicide applied as a seed dressing, particularly when the plants are continually exposed to heavy inoculum. It is probable that such late infection would not occur, or would occur at a low level, in farmers' fields in which pearl millet seed was treated with metalaxyl. In these circumstances the fungicide would be likely to control virtually all primary seedling infection from soil-borne oospores and thus there would be few or no sporangia to infect the later-formed unprotected tillers. It is pertinent to note that in maize, a non-tillering cereal, complete control of downy mildew has been obtained by seed treatment with metalaxyl (Exconde & Molina, 1978).

Subsequent to these experiments we have initiated multilocational testing of metalaxyl in cooperation with scientists in national programmes in several African countries and in India, utilising a new metalaxyl seed-dressing formulation. We have also begun to examine the effects of dosage on a range of hybrids with varying degrees of downy mildew susceptibility.

As pearl millet in the semi-arid tropics is grown predominantly by resource-poor farmers on small farms, seed treatment is likely to be the only economically feasible method of using fungicides, for small quantities are used and no expensive application equipment is required.

We are grateful to Ciba Geigy Ltd for providing the fungicide used in this study, and to the technical staff of the millet pathology team, particularly Mr M. N. Pawar and Mr P. Malla Reddy, for assistance with the field trials. The advice of Mr Bruce Gilliver on the statistical analyses is gratefully acknowledged.

REFERENCES

ANON (1977). Pearl Millet Pathology. In *ICRISAT Annual Report 1976–77*, pp. 64–68. International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India.

EXCONDE, O. R. & MOLINA, A. B. (1978). Note: RIDOMIL (Ciba Geigy), a seed-dressing fungicide for the control of Philippine corn downy mildew. *Philippine Journal of Crop Science* **3**, 1–5.

SAFEEULLA, K. M. (1977). Genetic vulnerability: the basis of recent epidemics in India. In *Genetic Basis of Epidemics in Agriculture*, pp. 72–85. Ed. P. R. Day. Annals of the New York Academy of Sciences.

VENUGOPAL, M. N. & SAFEEULLA, K. M. (1978). Chemical control of the downy mildews of pearl millet, sorghum and maize. *Indian Journal of Agricultural Science* **48**, 437–439.

URECH, P. A., SCHWINN, F. & STAUB, T. (1977). CGA 48988, a novel fungicide for the control of late blight, downy mildews and related soil borne diseases. In *Proceedings of the 1977 British Crop Protection Conference*, pp. 623–631.

WILLIAMS, R. J. & SINGH, S. D. (1978). International screening for pearl millet downy mildew resistance. In *Abstracts of Papers*, p. 297. 3rd International Congress of Plant Pathology, München, 16–23 August, 1978.

(*Received 16 May 1980*)