Use of Systemic Fungicides Metalaxyl and Fosetyl-Al for Control of Sorghum Downy Mildew in Corn and Sorghum in South Texas. I: Seed Treatment

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ABSTRACT

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Metalaxyl gave nearly 100% control of sorghum downy mildew (*Peronosclerospora sorghi*) in corn (*Zea mays*) and sorghum (*Sorghum bicolor*) at seed treatment rates as low as 0.05 g a.i./kg. Stands of corn and sorghum were reduced at metalaxyl seed treatment rates higher than 1 g a.i./kg. Fosetyl-Al gave 91–99% control of sorghum downy mildew in sorghum at seed treatment rates of 5 and 10 g a.i./kg.

Sorghum downy mildew (SDM) caused by *Peronosclerospora sorghi* (Weston & Uppal) C. G. Shaw is endemic to South Texas and poses a continuing production threat to sorghum (*Sorghum bicolor* (L.) Moench) and a potential threat to corn (*Zea mays* L.) (5). The advent of SDM-resistant commercial sorghum hybrids during the past decade has reduced the immediate threat of SDM; however, most of these hybrids are susceptible to recently discovered pathotypes of *P. sorghi* (2).

Alternative controls for SDM are needed to provide interim control and to complement and conserve host plant resistance. The conservation of existing SDM resistance in commercial hybrids may be of the most immediate concern because of increasing presence of new pathotypes of *P. sorghi*. Alternative controls may be most beneficial through a reduction of selection pressure for these new pathotypes.

Various cultural types of controls have been described for SDM in sorghum and corn (5,6,10), but they may be neither economically feasible nor agronomically practical for all agricultural areas.

Chemical control of SDM did not appear feasible until the development of systemic fungicides active against the Peronosporales (9). The systemic fungicide metalaxyl (CGA-48988, Ridomil, Apron) controlled various downy mildews (3,11,12), including SDM on sorghum in India (1) when applied as a seed treatment and foliar spray.

Another systemic fungicide active against the Peronosporales, fosetyl-Al (Aliette, LS74-783), has not yet been investigated extensively for its effectiveness in controlling downy mildews of graminaceous plants.

This study evaluated the efficacy of metalaxyl and fosetyl-Al as seed treatments for control of SDM in South Texas. A companion paper evaluates the curative activity of these fungicides against SDM when applied as foliar sprays on sorghum and corn in South Texas (7).

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MATERIALS AND METHODS

Experimental design. Fungicide seed treatment studies are discussed as individual experiments conducted over four growing seasons from 1979 through 1982 and designated by crop/year/location. Each experiment used a randomized complete block design with three replicates of each treatment and 18 m of planted row (6 m in each of three adjacent rows) per replicate unless otherwise specified.

Seed of SDM-susceptible commercial sorghum and corn hybrids, a susceptible sorghum line, and a resistant hybrid was treated with the fungicides applied at various rates by the slurry method; the proper amount of fungicide was suspended in a minimum quantity of water that would cover all seed when mixed. Unless otherwise stated, the Ridomil 2E (24% a.i.) formulation of metalaxyl and Aliette 80WP (80% a.i.) formulation of fosetyl-Al were used in seed treatment experiments and applied within 1 mo of planting over an existing commercially applied captan treatment. The Apron 35SD (35% a.i.) formulation of metalaxyl was applied by shaking seed and fungicide inside a small, enclosed container. Controls in all experiments used seed commercially treated with captan unless otherwise stated.

Sorghum seed was planted in replicated field tests at sites with a history of high SDM incidence and soil with high numbers of soilborne oospores of *P. sorghi*. Planting dates (early March) were selected to provide an environment most conducive to SDM development in sorghum (soil temperatures <20 C at 10 cm deep) (5). The same evaluation procedure was followed for corn, except later planting dates were used to maximize SDM incidence in corn, which is favored by higher soil temperatures (soil temperature >20 C at 10 cm deep) (5).

Stand (number of plants per replicate) and SDM incidence (%) were evaluated 5–6 wk after planting unless otherwise stated. In some experiments, SDM incidence was additionally evaluated at later dates.

In sorghum/1979/Beeville-Robstown, seed of a susceptible commercial hybrid was either untreated or treated with metalaxyl (Apron 35SD) at increasing rates from 0.1 to 3.0 g a.i./kg. In addition to stand and SDM incidence, grain yields were compared after crop maturity (120 days) from 8.1×10^{-4} ha of each replicate. Grain was collected from a 2.8-m length in each of the three rows of the replicate and pooled to determine grain yield from the 8.4-m length (8.1×10^{-4} ha).

In sorghum/1980/Beeville, seed of a susceptible commercial hybrid was treated with metalaxyl at rates from 0.1 to 2.0 g a.i./kg. Stand and SDM incidence were evaluated 7 wk after planting.

The sorghum/1980/Port Lavaca experiment had five replicates of each treatment in 24 m (four adjacent rows) of planted row per replicate and used seed of a susceptible and a resistant commercial hybrid treated with metalaxyl at 1 g a.i./kg.

In sorghum/1982/Beeville, seed of a susceptible line (SC 283) and a susceptible commercial hybrid was treated either with metalaxyl at rates from 0.05 to 3.0 g a.i./kg or fosetyl-Al at rates from 0.5 to 10.0 g a.i./kg. Stand and SDM incidence were evaluated 6 wk after planting and SDM incidence was evaluated again after flowering.

In corn/1980/Robstown, seed of a susceptible commercial hybrid (no captan) was treated with metalaxyl at rates from 0.1 to 2.0 g a.i./kg. Three planting dates in 1980 were employed at a single SDM-conducive location near Robstown, TX. The planting dates represented a potential increase in soil temperature with each planting date and a concomitant potential increase in SDM incidence in corn. Stand and SDM incidence were evaluated 6 and 9 wk after planting. Extreme drought precluded stand evaluations for the third planting as well as grain yield comparisons for the other two planting dates.

In corn/1982/Beeville, seed of a susceptible commercial hybrid was treated with either metalaxyl at rates from 0.05 to 3.0 g a.i./kg or fosetyl-Al at rates from 0.5 to 10.0 g a.i./kg. A single, late (5 April) planting date at Beeville, TX, in 1982 was employed to maximize SDM incidence in corn. Stand and SDM incidence were evaluated 6 wk after planting, but most evaluations were conducted after flowering because of the initial low SDM incidence noted at 6 wk.

Data analysis. The difference between means of SDM incidence from two treatments in sorghum/1980/Port Lavaca was evaluated for significance using Student's *t* test at $P = 0.05$. All data from other experiments evaluating the effect of fungicide seed treatment on SDM incidence were analyzed by simple linear regression at $P = 0.05$. To conduct linear regression analysis, the rate of fungicide seed treatment was transformed to the inverse of rate of fungicide seed treatment. Data on stand and yield had no significant differences when analyzed by simple linear regression but were graphed or stated to demonstrate possible effects of rate of fungicide seed treatment on these quantities.

RESULTS

In sorghum/1979/Beeville-Robstown, SDM incidence 5–6 wk after planting was greatest in plants from untreated seed (Fig. 1). Plants from seed treated with metalaxyl at rates greater than 0.5 g a.i./kg had no incidence of SDM (Fig. 1). Differences in SDM incidence among treatments were significant at Beeville ($r^2 = 0.9901$) and Robstown ($r^2 = 0.9653$). At both Robstown and Beeville, the highest stands were from seed treated with metalaxyl at the lowest rates (0.1–0.5 g a.i./kg) and the lowest stands were from either untreated seed or seed treated with metalaxyl at the highest rates (1.5–3.0 g a.i./kg) (Fig. 1). At both locations in plants of all treatments, there was a high incidence of systemic SDM in basal and nodal tillers that began growth after maturity of the grain on the uninfected primary plant. Compared with plants from untreated seed, grain yields of plants from seed treated with metalaxyl were 18–32% greater at Beeville and 14–31% greater at Robstown (Fig. 1).

In sorghum/1980/Beeville, SDM incidence 7 wk after planting was greatest in plants from untreated seed (15%) (Fig. 2). Except for one infected plant, there was no incidence of SDM in plants from seed treated with metalaxyl at rates of 0.5 g a.i./kg or higher (Fig. 2). Differences in SDM incidence among treatments were significant ($r^2 = 0.9845$). Seed treated with metalaxyl at the highest rates (1–2 g a.i./kg) produced the lowest stands and untreated seed and seed treated with metalaxyl at the lowest rates (0.1 and 0.5 g a.i./kg) produced the highest stands (Fig. 2).

In sorghum/1980/Port Lavaca, stand at 5 wk after planting was greatest from untreated seed of the susceptible (207) and resistant (147) hybrids compared with stand from metalaxyl-treated (1 g a.i./kg) seed of the susceptible (161) and resistant (124) hybrids, respectively. Incidence of SDM in the susceptible hybrid 5 wk after planting was significantly greater in plants from untreated seed (22%) than in plants from the metalaxyl-

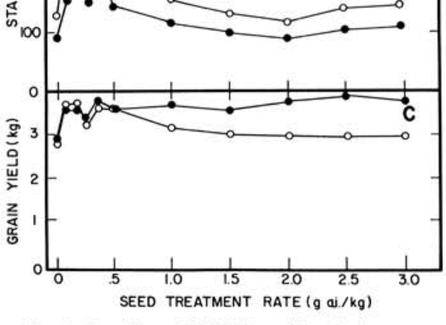

Fig. 1. Sorghum/1979/Beeville-Robstown. Effects of metalaxyl seed treatment on **(A)** percent incidence of sorghum downy mildew, **(B)** stand, and **(C)** grain yield of an SDM-susceptible hybrid. The metalaxyl formulation was Apron 35SD, stand was average number of plants per replicate, and grain yield was determined from an 8.4-m length of row per replicate (kg/8.1×10^{-4} ha).

treated seed ($<$1%) according to Student's *t* test. There was no evidence of SDM in plants from untreated or metalaxyl-treated seed of the resistant hybrid.

In sorghum/1982/Beeville, SDM incidence in the susceptible hybrid 6 wk after planting was greater in plants from untreated seed than in plants from seed treated with either fosetyl-Al or metalaxyl at any rate (Fig. 3). Differences in SDM incidence among treatments of the hybrid were significant for metalaxyl ($r^2 = 0.9914$) and fosetyl-Al ($r^2 = 0.9868$). By 6 wk after planting, SDM incidence in the sorghum line SC 283 was greater in plants from untreated seed than in plants from seed treated with either fosetyl-Al or metalaxyl at any rate (Fig. 3). Differences in SDM incidence among treatments of the line were significant for metalaxyl ($r^2 = 0.8319$) but not for fosetyl-Al. Erratic stands of the line may have contributed to the lack of significance in the SDM data for fosetyl-Al. Plants from seed of both sorghums treated with fosetyl-Al at 5 and 10 g a.i./kg had low incidences of SDM that were similar to those in plants from seed of both sorghums treated with metalaxyl at 0.05, 0.1, and 0.2 g a.i./kg (Fig. 3). From seed of all treatments of both sorghum cultivars, there was late-season occurrence of SDM in a few primary plants that had been symptomless 6 wk after planting. There were no apparent differences in stand among treatments of either sorghum.

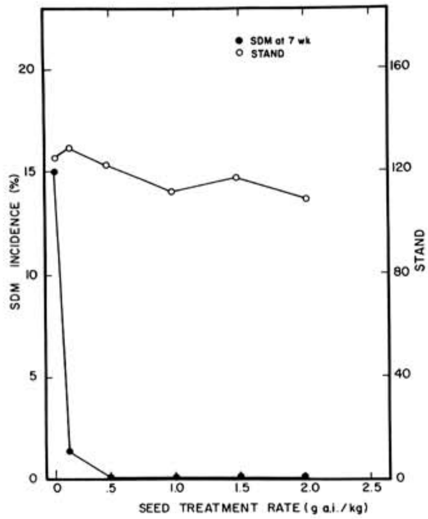

Fig. 2. Sorghum/1980/Beeville. Effects of metalaxyl (Ridomil 2E) seed treatment on percent incidence of sorghum downy mildew and stand (average number of plants per replicate) in a susceptible sorghum hybrid.

Six weeks after the first planting date in corn/1980/Robstown, no incidence of SDM was noted in plants of any treatment. By 9 wk after the first planting date and by both 6 and 9 wk after the second planting date, incidence of SDM was greater in plants from untreated seed than in plants from seed treated with metalaxyl at any rate (Fig. 4). Differences in SDM incidence among treatments were significant at 9 wk for the first planting date ($r^2 = 0.8153$) and at both 6 wk ($r^2 = 0.9908$) and 9 wk ($r^2 = 0.9971$) for the second planting date. On both planting dates, stand was lowest from seed treated with metalaxyl at 1.5 and 2.0 g a.i./kg and highest from untreated seed and seed treated with metalaxyl at 0.1 and 0.5 g a.i./kg (Fig. 4).

In corn/1982/Beeville, SDM incidence was low (5% maximum in plants from untreated seed) and disease expression occurred from 4 to 10 wk after planting. The lack of disease development did not allow for comparisons among treatments but SDM incidence did occur in some plants from seed treated either with fosetyl-Al or metalaxyl at any rate. There were no apparent differences in stand among treatments.

DISCUSSION

Metalaxyl effectively controlled SDM in both sorghum and corn when used as a seed treatment in field tests at three SDM-conducive South Texas locations over four growing seasons (Figs. 1–4). Metalaxyl controlled SDM at seed treatment rates as low as 0.05 g a.i./kg, but the rates providing the greatest and most consistent control were 0.5 g a.i./kg or greater.

Results varied with the year, but in sorghum, low metalaxyl seed treatment rates (0.1–1.0 g a.i./kg) sometimes increased stand compared with untreated seed with only a standard fungicide treatment (Fig. 1). Metalaxyl seed treatments may help protect against seedling disease problems incited by *Pythium* spp., but this beneficial effect may be overestimated because increased stand was not observed in other sorghum and corn tests in subsequent years (Figs. 2 and 4).

Phytotoxicity of metalaxyl in either the Apron 35SD or Ridomil 2E formulations began to reduce stand of corn and sorghum at seed treatment rates of 1 g a.i./kg and stand depression was readily observed at rates of 2 g a.i/kg or greater (Figs. 1, 2, and 4). Simple linear regression did not detect significant differences in stand (Figs. 1, 2, and 4) because metalaxyl affected stand in both a negative (phytotoxic) and positive (possible protection against Pythium

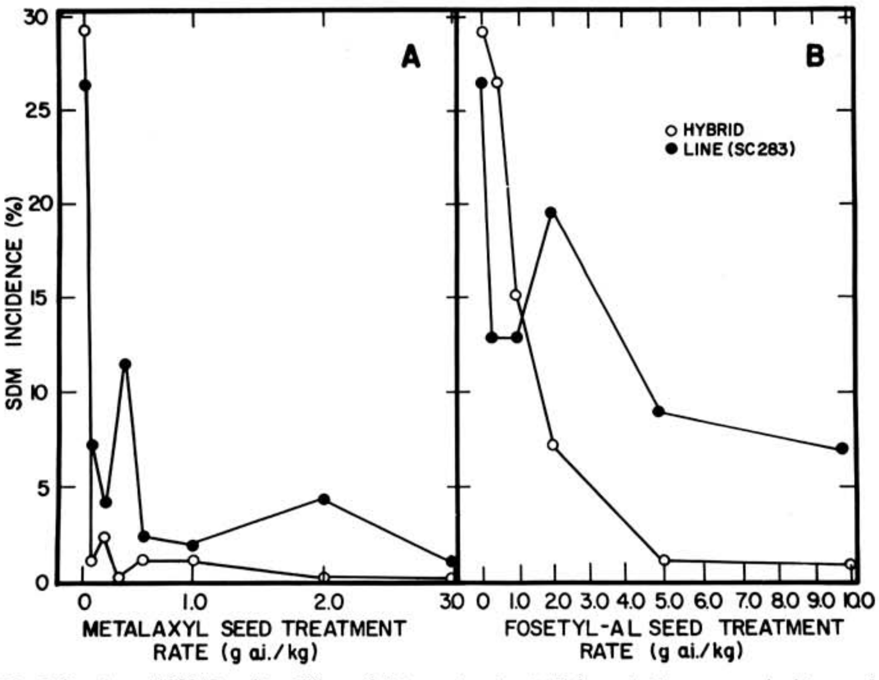

Fig. 3. Sorghum/1982/Beeville. Effects of **(A)** metalaxyl and **(B)** fosetyl-Al on percent incidence of sorghum downy mildew in a susceptible sorghum hybrid and line. Formulations used were Ridomil 2E for metalaxyl and Aliette 80WP for fosetyl-Al.

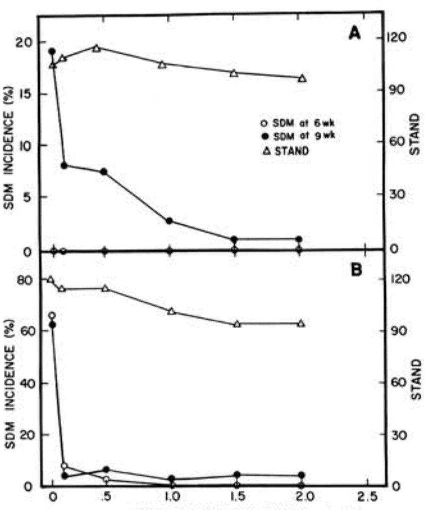

Fig. 4. Corn/1980/Robstown. Effects of metalaxyl seed treatment on percent incidence of SDM and stand in a susceptible corn hybrid planted on **(A)** 6 March and **(B)** 26 March.

damping-off) manner.

Anahosur and Patil (1) did not get full-season control of SDM in India unless they used a foliar application of metalaxyl at 1 mg a.i./ml 40 days after planting seed treated with metalaxyl at either 1 or 2 g a.i./kg. In South Texas, we determined that primary plants and tillers of sorghum from metalaxyl-treated seed that were without symptoms of systemic SDM by 5–6 wk after planting remained free of SDM for the remainder of the season and had normal head and grain development. In 1979, a large percentage of basal and nodal tillers of sorghum plants in all treatments developed SDM if they began growth after grain maturation in the primary head. These late-season tillers do not contribute to grain yield in the field and would be important only in production of oospore inoculum for the next host crop. In 1982, a few primary sorghum plants from seed treated with metalaxyl at any rate were symptomless 6 wk after planting but developed SDM before heading and remained sterile. This occurrence, however, was minimal as was development of SDM in late-season tillers in most other sorghum experiments at all locations during the previous 3 yr.

The threat of SDM to corn in South Texas is generally minimal because seed is normally planted when soil temperatures are not conducive to SDM incidence in corn (<20 C) (5). However, in other geographic areas and in South Texas when susceptible corn is planted under higher soil temperature conditions conducive to SDM development, metalaxyl seed treatments could provide the needed control for SDM. In 1980, there was a low incidence of late-season SDM in primary plants of corn from seed treated with any rate of metalaxyl that had been symptomless 6 wk after planting (Fig. 4). Further evaluation is needed to determine if metalaxyl seed treatments on corn would consistently fail to give full-season protection against SDM.

When sorghum yields were evaluated at SDM-conducive sites in 1979, plants from metalaxyl-treated seed demonstrated a yield advantage over plants from untreated seed (Fig. 1). Because plant population (or stand) affects the amount of yield reduction imposed by a given percent incidence of SDM (5), not all experiments evaluating metalaxyl seed treatments would demonstrate yield advantages at the disease incidences we observed (Fig. 1). Simple linear regression did not detect significant differences in yield because there was either low or no incidence of SDM in plants of all metalaxyl treatments and stands were variable (Fig. 1).

Because plant-pathogenic fungi have already demonstrated an ability to develop tolerance to metalaxyl (8), all means need to be employed to contribute to the use-longevity of this fungicide. The primary inoculum for systemic infection of hosts by *P. sorghi* in South Texas is soilborne, oospore inoculum. Oospores produced during the current season are effective inoculum only after distribution into the soil from their site of production in host leaves. Local lesion infections from several cycles of conidial production rarely develop into the systemic infections necessary for oospore production, and conidia themselves are very short-lived (4,5). Thus, the oospore-production cycle occurs only once each season. The processes for development or selection of metalaxyl-tolerant strains probably would occur only once each season.

The occurrence and distribution of pathotypes of *P. sorghi* in South Texas suggests the selection and increase of specific pathotypes that already exist as a minute proportion of the oospore population within that field (2,5). If fungicide-tolerant strains are selected and increased in the manner suggested by pathotypes, a metalaxyl seed treatment rate should be used that is sufficient to consistently give 100% or as near 100% control of SDM as possible without posing phytotoxicity problems. Although the seed treatment rate of 0.5 g a.i./kg provides this type of control most of the time, there was sufficient sporadic disease incidence to justify a rate of 1 g a.i./kg. To further minimize development of metalaxyl-tolerant strains of *P. sorghi* and to protect our eroding popular sources of host plant resistance from development of pathotypes of *P. sorghi*, we suggest that metalaxyl be predominantly used on SDM-resistant sorghum hybrids at a seed treatment rate of 1 g a.i./kg. Where necessary, a similar control approach using these seed treatment rates on resistant corn hybrids would be justified.

Fosetyl-Al may be effective in SDM control on sorghum when used at seed treatment rates of 5–10 g a.i./kg. If fosetyl-Al remains consistent in its performance as a control of SDM in sorghum, it would represent an additional fungicide and control treatment that could be deployed with metalaxyl, host plant resistance, and cultural controls to best contribute to control of SDM and the use-longevity of both the fungicides and host plant resistance.

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