Effects of Deep Tillage and Roguing of Diseased Plants on Oospore Populations of *Peronosclerospora sorghi* in Soil and on Incidence of Downy Mildew in Grain Sorghum

G. D. Janke, R. G. Pratt, J. D. Arnold, and G. N. Odvody

First and fourth authors are former research associate and assistant professor, Texas Agricultural Experiment Station, Texas A&M University Agricultural Research and Extension Center, P.O. Box 589, Corpus Christi 78410; second author is research plant pathologist, USDA-ARS, Department of Plant Pathology and Weed Science, Mississippi State University, Mississippi State 39762; and third author is associate professor, College of Agriculture, Texas A&I University, Kingsville 78363.

Portion of an M.S. thesis submitted by the first author to Texas A&I University.

Research supported by Hatch Project 6288, Texas Agricultural Experiment Station, and by U.S. Agency for International Development Grant AID/DSAN/XII/G-0149. Technical Article 18248 of the Texas Agricultural Experiment Station.

The authors are grateful to T. Priestly and the Board of Directors of the M. G. and Johnnye D. Perry Foundation, Robstown, TX, for providing land for this study and to R. A. Frederiksen for advice and technical assistance.

Accepted for publication 26 May 1983.

ABSTRACT

Janke, G. D., Pratt, R. G., Arnold, J. D., and Odvody, G. N. 1983. Effects of deep tillage and roguing of diseased plants on oospore populations of *Peronosclerospora sorghi* in soil and on incidence of downy mildew in grain sorghum. Phytopathology 73:1674-1678.

Deep tillage and roguing of diseased plants were evaluated for effects on oospore populations of *Peronosclerospora sorghi* in soil and for control of sorghum downy mildew in grain sorghum. Roguing was conducted to simulate effects of 1- to 3-yr rotations with resistant crops by preventing completion of the disease cycle and addition of new inoculum to soil. Deep tillage (moldboard plowing to 30–35 cm) was most effective when plowing was conducted in a downwind direction and not preceded by deep disking. Most oospores occurred at 0–20 cm in soil with conventional tillage, whereas they were redistributed to 20–40 cm with optimal deep tillage. Sorghum downy mildew incidence following optimal deep tillage was 14% of that obtained following conventional tillage. When deep tillage was conducted in an upwind direction or preceded by deep disking, oospore densities in upper soil and the incidence of sorghum downy mildew were less effectively reduced. Annual roguing of diseased plants from plots of susceptible cultivars reduced oospore densities to 22–27%, and systemic downy mildew incidence to 11–20% of levels observed in nonrogued plots after 3 yr. Results indicate that deep tillage, when properly conducted, and crop rotations or other treatments that prevent addition of new oospores to soil for 3 yr may provide economically beneficial control of sorghum downy mildew. However, some infection still occurred after almost 4 yr with little or no replenishment of oospore populations in soil.

Additional key words: cultural control, *Sorghum bicolor*.

Sorghum downy mildew, caused by *Peronosclerospora sorghi* (Weston & Uppal) C. G. Shaw (formerly *Sclerospora sorghi*), was first recognized in North America on grain sorghum in Texas in 1961 (10). Subsequently the disease spread north to Nebraska, Illinois, and Indiana, and east to Georgia, but it has continued to be most widespread and severe in Texas (4). Greatest losses occur in grain sorghum (5), but forage sorghums, sorghum-Sudan grass hybrids, and corn are also damaged (6).

Primary infection by *P. sorghi* occurs from oospores in soil, which germinate in response to growing roots of both host and nonhost plants (8). Germ hyphae penetrate roots and in susceptible seedlings the fungus grows internally to the apical meristem; it then invades portions of the interveinal tissue of new leaves as these differentiate and emerge from the whorl. This form of infection is termed "systemic" (6). Conidia produced on undersides of infected leaves may cause foliar leafspots and occasional systemic infections in very young seedlings (7). Leaves eventually become necrotic as oospores are formed (6). Oospores are released to soil by natural shredding of necrotic leaf tissue and during the combining and postharvest shredding operations.

Incidence of systemic downy mildew in grain sorghum is not always directly correlated with yield losses because growers frequently increase seeding rates to compensate for anticipated disease and because noninfected plants may respond to lessened competition by producing larger seed heads (4,13). Frederiksen estimates that economic losses are likely when systemic downy mildew incidence exceeds 20% (4).

Since the early 1970s, control of sorghum downy mildew was attained by use of resistant cultivars (4,6). However, recent evidence for physiologic specialization in *P. sorghi* (11) and development of new pathotypes in Texas (2–4) indicates that resistant cultivars will not always provide reliable disease control in the future.

Possibilities for cultural control of sorghum downy mildew have received less attention than host resistance. Nevertheless, certain cultural practices may control or reduce the disease, presumably by reducing the number or infectivity of oospores in surface soil. Tuleen et al (14) reported that deep moldboard plowing reduced systemic downy mildew incidence to low levels at two locations in Texas; bioassays of soil samples indicated that most inoculum was buried 10 cm or more following deep tillage (14). They also observed reductions in the disease following short-term growth of host and nonhost crops in infested soil in the greenhouse; root growth by these crops may have stimulated oospores to germinate and consequently reduced inoculum (8). Tuleen et al (14) suggested that short-term crop rotations might be utilized for cultural control of downy mildew in the field.

Incidence of sorghum downy mildew is reduced with frequent watering of potted sorghum seedlings (1) and in stands that receive rainfall 4–7 days after planting (13). These effects, which may be related to inhibition of oospore germination with frequent watering of soil (8), suggest that irrigation following planting might contribute to cultural control. Some evidence indicates that delayed planting may also reduce incidence of the disease (1,14).

The previous studies on cultural control did not determine how

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be hereby marked "*advertisement*" in accordance with 18 U.S.C. § 1734 solely to indicate this fact.

---

practices affected oospore populations of *P. sorghi* in soil because assay techniques were not available. However, in 1978, Pratt and Janke (9) described a technique for estimating oospore densities of *P. sorghi* in naturally infested soils. This technique concentrates oospores among silt particles, where they can be observed and counted. Correlations were obtained between oospore densities and downy mildew incidence in the field when soil texture (percentage clay content) was taken into account (9).

This study was undertaken to evaluate effects of two cultural practices, deep tillage and the roguing of diseased plants, on oospore densities of *P. sorghi* in soil, and to relate these effects to the incidence of sorghum downy mildew in grain sorghum.

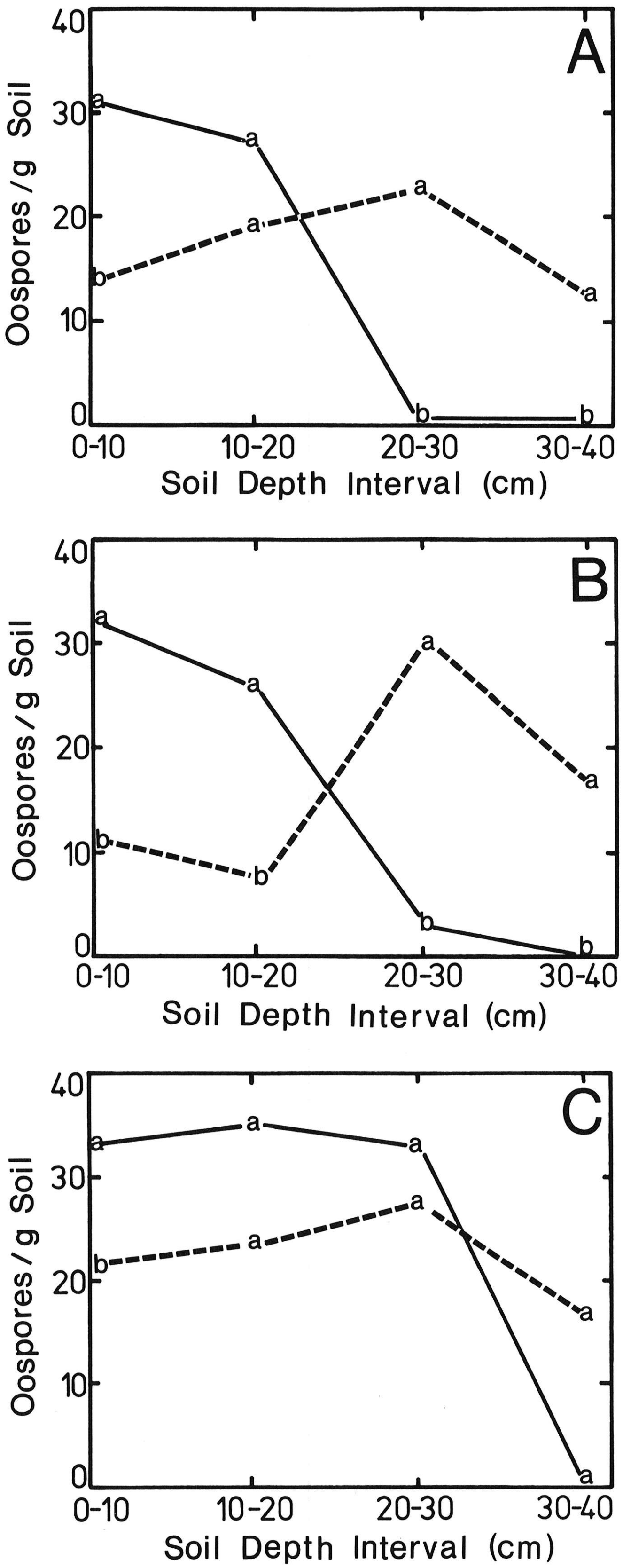

Fig. 1. Oospore densities of *Peronosclerospora sorghi* in soil profiles following conventional (——) and deep (- - - -) tillage treatments in three experiments in south Texas. **A,** Experiment 1, Texas Agricultural Experiment Station, Corpus Christi, 1977–1978, where deep tillage proceeded in an upwind direction. **B,** Experiment 2, Perry Foundation Farm, Robstown, 1977–1978, where deep tillage proceeded in a downwind direction. **C,** Experiment 3, Perry Foundation, 1978–1979, where deep tillage proceeded downwind but was preceded by deep disking. For each soil depth within each experiment, different letters on curves indicate a significant difference ($P = 0.05$) in oospore densities between treatments.

MATERIALS AND METHODS

Experimental sites, agronomic practices, and cultivars. Experiments were conducted at two locations from 1977 to 1980: the Texas Agricultural Experiment Station at Corpus Christi and the M. G. and Johnnye D. Perry Foundation Farm at Robstown. Soil at Corpus Christi was a Victoria clay (fine, montmorillonitic, hyperthermic Udic Pellusert) and soil at Perry Foundation was a Clareville loam (fine, montmorillonitic, hyperthermic Pachic Arguistall). All experiments were located on land previously planted to downy mildew-susceptible grain sorghum and which was considered to be uniformly infested within each site based on disease incidence in the previous year's crop and on oospore counts (9) prior to planting. Commencing after combine harvest of grain in July of each year, the following sequence of practices was followed in all experiments except where noted: shredding of stalks, (+/−) deep moldboard plowing (late summer), tandem disking to 15 cm deep twice (fall), shaping raised beds 98 cm apart (fall), reshaping the middles to control weeds (winter), knifing in 20-10-0 liquid fertilizer at 337 or 367 kg/ha (winter), planting grain sorghum (7.9 kg/ha) (1 March), preemergence broadcasting of atrazine (1.8 kg/ha) and propachlor (5.6 kg/ha), and cultivating to further control weeds. Sorghum seed was purchased locally. Four downy mildew-susceptible cultivars (T-E Total, T-E Y-101, Dorado M, and Oro) were used in different seasons because of withdrawal of some cultivars from the local market and unavailability of seed during certain years.

Deep tillage vs conventional tillage. Three similar experiments were conducted to compare effects of deep vs conventional tillage: experiment 1 at Corpus Christi in 1977–1978 with T-E Y-101, experiment 2 at Perry Foundation in 1977–1978 with T-E Y-101, and experiment 3 at Perry Foundation in 1978–1979 with Oro. Deep tillage was accomplished with a John Deere two-bottom rollover moldboard plow which produced furrows 30–35 cm deep at all sites. Plowing progressed upwind in experiment 1 and downwind in experiments 2 and 3. Land in experiment 3 was disked to 23 cm deep prior to deep plowing.

Plots were 6.0 × 16 m for experiments 1 and 2 and 11.6 × 16.5 m for experiment 3. Three replicate plots of each treatment (deep and conventional tillage) were arranged in a randomized complete block design for each experiment. Downy mildew incidence was determined at the four-leaf stage by counting plants with systemic symptoms among 100 adjacent plants in each of three randomly selected rows in each plot. To determine oospore densities in the soil profile, holes 40 cm deep were dug at three random points in each plot, and a soil sample (~150 g) was collected from each 10-cm depth interval. Soil samples were sieved (7.4-mesh per centimeter screen), composited for each 10-cm interval within a plot, and assayed for oospores. A single count was made for each composite sample as previously described (9).

For each individual experiment, mean plot values were used in performing an analysis of variance for downy mildew incidence. For oospore densities, it was performed separately for each depth interval within each experiment.

Roguing vs nonroguing. The experiment was initiated in March 1977, and continued to the 1980 growing season. It was replicated three times at two sites near Corpus Christi and one at the Perry Foundation. Although three downy mildew-susceptible cultivars were grown during the four seasons, all sites were planted to the same cultivar in a given year and similarly managed.

At each site, a single block of land 58 × 142 m, considered to be uniformly infested with *P. sorghi*, was divided into two equal plots (58 × 71 m). One plot was rogued annually and the other was not. The experimental treatment (roguing) was applied prior to harvest, or before oospores are released and disseminated. Therefore, use of large plots was judged essential to prevent or minimize contamination of rogued areas by oospores from nonrogued plots and adjacent stands, all of which were combine-harvested and shredded. The large plot areas precluded use of more than one rogued and one nonrogued plot at each site. Each site was considered to be one block of a single randomized complete block experiment involving two treatments.

Prior to planting, each plot was divided into three equal sampling areas. At the four-leaf stage of plant growth, a soil sample (~150 g) was collected from the upper 10 cm at 20 random points within each sampling area. All samples from each one-third plot were composited and sieved. A single oospore count was made from each composite sample (9). A mean value for the oospore density in surface soil of each plot was determined from the three counts. Following stand establishment, sorghum downy mildew incidence was determined from five random counts of 100 adjacent plants in each one-third plot.

Roguing was initiated after disease incidence was determined. All plants with symptoms of systemic downy mildew were pulled from the soil in rogued plots and removed from the field. Rogued plots were reinspected at 2- to 3-wk intervals during each season to remove escapes and late-developing, systemically infected tillers. Analysis of variance was performed separately with data obtained each year.

RESULTS

Deep tillage vs conventional tillage. The deep tillage treatment reduced oospores in upper soil most effectively and provided best control of downy mildew in experiment 2, where plowing proceeded downwind (Fig. 1B). During plowing in this experiment, the tractor was driven perpendicular to the direction of prevailing wind so that each successive pass with the moldboard plow covered land downwind of that previously plowed. Oospore density profiles were almost opposite between the two treatments; most oospores occurred in the upper 20 cm of soil with conventional tillage and in the lower 20 cm with deep tillage (Fig. 1B). Differences in oospore densities between the treatments were significant at all depths. Downy mildew incidence was 2.0–4.7% in the three deep tillage plots and 11.0–36.7% in the three conventional tillage plots; however, differences between the treatments were not significant at $P = 0.05$.

In experiment 1, where plowing proceeded in an upwind direction, it was observed that as soil was cut and lifted by the plow, some surface soil and debris was picked up by the wind and distributed over adjacent, newly plowed land. Differences in oospore densities between the two treatments were less at several depths than in experiment 2, and they did not differ significantly at 10–20 cm (Fig. 1A). Downy mildew incidence was 7.7–22.0% in deep tillage plots and 13.7–32.3% in conventional tillage plots. Although the difference between treatment means was numerically less than in experiment 2, data were more consistent between replicates and the difference was significant at $P = 0.05$.

Deep tillage was least effective for redistribution of oospores in the soil and for control of downy mildew in experiment 3 (Fig. 1C), where the whole experimental area was disked to 23 cm deep prior to plowing. Oospore densities differed significantly ($P = 0.05$) between treatments only at the 0–10 cm depth. Downy mildew incidence was 20.0–29.2% in deep tillage plots and 28.3–38.7% in conventional tillage plots; treatment means did not differ significantly.

Roguing vs nonroguing. In rogued plots, oospore densities appeared to decrease steadily during the 3 yr, and progression curves were similar for all sites (Fig. 2). The greatest numerical decreases occurred within the first 2 yr. Oospore densities in nonrogued plots, in contrast, appeared to decrease, remain constant, or increase in different years. Means of oospore densities differed significantly between the two treatments in 1978 and 1980.

Sorghum downy mildew incidence differed significantly between rogued and nonrogued plots in 1978 and 1980, and differences were greatest after 3 yr. However, in rogued plots at the Corpus Christi sites, more than 20% of plants developed systemic downy mildew even after replenishment of oospore populations was prevented for 1 or 2 yr (Fig. 2).

DISCUSSION

Results of this study demonstrate that deep tillage and roguing of diseased plants can reduce oospore densities of *P. sorghi* in upper soil and reduce incidence of downy mildew in grain sorghum to below economic thresholds (4). Deep tillage was evaluated as a practice that growers could use directly to control disease. Roguing, in contrast, was evaluated to simulate effects of crop rotations rather than as a practice which would be recommended to growers.

Results of the deep tillage experiment confirm previous reports (14) that this cultural practice may effectively control sorghum downy mildew. The presumed cause, that oospore densities are reduced near the soil surface (14), is also verified. Results also identify two factors that appear to have significant influence on the effectiveness of deep tillage for redistribution of oospores in soil and reduction of disease: plowing direction relative to wind direction, and associated disking practices. The plowing treatments for experiments 1 and 2 were applied within a 2- to 3-hr period. After apparent contamination of plowed land was observed in experiment 1, plowing direction was intentionally reversed for experiment 2. Although soil types differed at the two locations, the same sorghum cultivar was used and management practices were similar. The much more favorable oospore profiles obtained after deep plowing in experiment 2 (Fig. 1), therefore, appear to have resulted from the change in plowing direction relative to prevailing wind direction. Experiment 3 was conducted 1 yr after experiment 2 and a different susceptible cultivar was used, but it was located on an adjacent site. Management practices were similar except that land was disked to 23 cm before plowing in experiment 3. The ineffectiveness of deep tillage for redistribution of oospores and control of sorghum downy mildew in experiment 3 appears attributable to the prior deep disking. This study indicates, therefore, that when deep tillage is recommended to growers for control of sorghum downy mildew, details concerning plowing direction relative to prevailing wind and associated disking practices also need to be specified. Further studies are needed to confirm these results and to identify other management practices that also may influence the effectiveness of deep tillage for control of sorghum downy mildew.

No field studies on the potential of crop rotations to control sorghum downy mildew have yet been reported from North America. Such studies are difficult because large areas of uniformly infested land are needed to compare rotations with different crops for different lengths of time. Roguing was utilized here, rather than true crop rotations, because it appeared that similar information could be obtained by using much smaller land areas. We suggest that the effects of annual roguing on *P. sorghi* oospore densities and on incidence of sorghum downy mildew, as demonstrated here, may be predictive of effects that would result from 1- to 3-yr rotations with row crops of resistant sorghum, corn, or cotton in south Texas. With both roguing and true crop rotations, growth of roots can stimulate germination of oospores in soil (8), but the disease cycle is not completed and no new inoculum is added to soil after harvest.

In the one study of crop rotation effects on sorghum downy mildew using plants grown in trays of infested soil in the greenhouse (14), incidence of the disease in susceptible sorghum was greatly reduced following 15 days prior growth of numerous host and nonhost plants in the soil. The authors suggested that short-term rotations might also provide disease control in the field (14).

Results of the roguing experiment do not fully support the suggestion that short-term rotations, at least with row crops, may provide effective control of sorghum downy mildew. When addition of new oospores to soil was prevented for 1–2 yr by roguing plots at Corpus Christi, residual oospores still caused more than 20% downy mildew incidence in the following sorghum crops. This suggests that 1- to 2-yr rotations with row crops at these sites also would have given less disease in subsequent sorghum, but that economic losses still might have occurred.

The likely reason for the favorable crop-rotation effects in greenhouse experiments is that roots stimulated oospore germination without subsequent infection and inoculum levels were reduced (8,14). If this is true, then results of similar magnitude

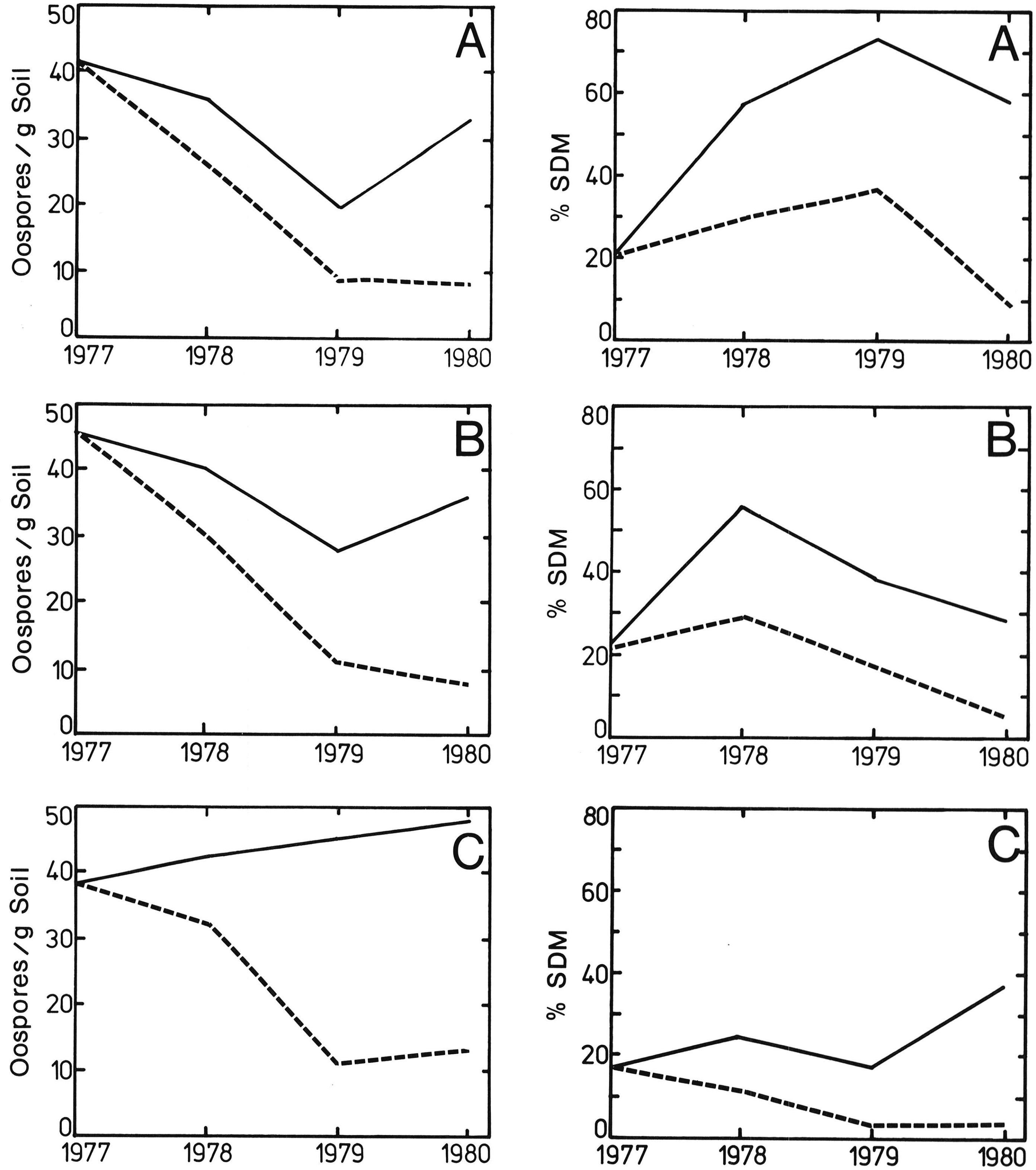

Fig. 2. Oospore densities of *Peronosclerospora sorghi* in surface soil and the incidence of sorghum downy mildew (SDM) in grain sorghum in nonrogued (——) and rogued (-----) plots at three sites in south Texas. Incidence was determined in cultivars T-E Total (1977), T-E Y-101 (1978, 1980), and Dorado M (1979). **A and B,** Two sites at the Texas Agricultural Experiment Station, Corpus Christi; **C,** one site at the Perry Foundation Farm, Robstown. Each site represents one block in a randomized complete-block experiment.

might not occur in the field because permeation of soil by roots is much less with row crops grown in the field than with the same crops grown in containers. Accordingly, fewer oospores are likely to be stimulated to germinate in the field than in containers of soil. If effectiveness of crop rotations for control of sorghum downy mildew is partly a function of the extent of root growth in soil, then the most effective rotations might be with the crops that give the greatest penetration of the upper soil layer by growing roots. Small grains grown in narrow rows or broadcast-seeded annual legumes, therefore, might be better rotation crops for control of sorghum downy mildew than resistant grain sorghum, corn, or cotton grown in standard wide rows. Rotations with these winter crops might enable continued annual planting of grain sorghum in the spring; annual legumes could also reduce or eliminate the need for nitrogen fertilizer in subsequent sorghum (12).

A surprising discovery in this study was that oospore populations in soil were not always increased in nonrogued plots which 8 mo previously had contained high levels of *P. sorghi*, and from which large numbers of oospores had been added to soil after harvesting. This situation occurred in nonrogued plots at the two Corpus Christi sites in 1978–1979. It suggests that annual increases in oospore populations which result from even high levels of downy mildew may sometimes be offset by factors of attrition.

Yearly fluctuations in sorghum downy mildew incidence in the roguing experiment were not always related to changes in oospore populations in soil in either rogued or nonrogued plots (Fig. 2). These results are consistent with previous observations that sorghum downy mildew incidence is strongly influenced by environmental factors (4,6,13,14), some of which have been identified (13).

Previous studies indicated that some oospores of *P. sorghi* could cause infection after at least 36 mo in soil and leaf tissue stored at 1–10 C (6). This study similarly indicates that some oospores can survive in the field and infect sorghum at least 44 mo after harvest of an infected crop in Texas.

LITERATURE CITED

1. Balasubramanian, K. A. 1974. Role of date of seeding, soil moisture, temperature, and pH in the incidence of downy mildew in sorghum. Plant Soil 41:233-241.
2. Craig, J., and Frederiksen, R. A. 1980. Pathotypes of *Peronosclerospora sorghi*. Plant Dis. 64:778-779.
3. Craig, J., and Frederiksen, R. A. 1982. Differential sporulation of pathotypes of *Peronosclerospora sorghi* on inoculated sorghum. Plant Dis. 66:278-279.
4. Frederiksen, R. A. 1980. Sorghum downy mildew in the United States: Overview and outlook. Plant Dis. 64:903-908.
5. Frederiksen, R. A., Amador, J., Jones, B. L., and Reyes, L. 1969. Distribution, symptoms, and economic losses from downy mildew caused by *Sclerospora sorghi* in grain sorghum in Texas. Plant Dis. Rep. 53:995-998.
6. Frederiksen, R. A., Bockholt, A. J., Clark, L. E., Cosper, J. W., Craig, J., Johnson, J. W., Jones, B. L., Matocha, P., Miller, F. R., Reyes, L., Rosenow, D. T., Tuleen, D., and Walker, H. J. 1973. Sorghum downy mildew. ... A disease of maize and sorghum. Texas Agric. Exp. Stn. Res. Monogr. 2. 32 pp.
7. Jones, B. L., and Frederiksen, R. A. 1971. Technique for artificially inoculating sorghum with *Sclerospora sorghi*. Proc. 7th Grain Sorghum Res. and Utilization Conf. 7:45-47.
8. Pratt, R. G. 1978. Germination of oospores of *Sclerospora sorghi* in the presence of growing roots of host and nonhost plants. Phytopathology 68:1606-1613.
9. Pratt, R. G., and Janke, G. D. 1978. Oospores of *Sclerospora sorghi* in soils of south Texas and their relationships to the incidence of downy mildew in grain sorghum. Phytopathology 68:1600-1605.
10. Reyes, L., Rosenow, D. T., Berry, W. R., and Futrell, M. C. 1964. Downy mildew and head smut diseases of sorghum in Texas. Plant Dis. Rep. 48:249-253.
11. Schmitt, C. G., and Freytag, R. E. 1977. Response of selected resistant genotypes to three species of *Sclerospora*. Plant Dis. Rep. 61:478-481.
12. Touchton, J. T., Gardner, W. A., Hargrove, W. L., and Duncan, R. R. 1982. Reseeding crimson clover as a N source for no-tillage grain sorghum production. Agron. J. 74:283-287.
13. Tuleen, D. M., and Frederiksen, R. A. 1981. A crop loss model for sorghum downy mildew. (Abstr.) Phytopathology 71:909.
14. Tuleen, D. M., Frederiksen, R. A., and Vudhivanich, P. 1980. Cultural practices and the incidence of sorghum downy mildew in grain sorghum. Phytopathology 70:905-908.