Factors associated with loblolly pine mortality on former agricultural sites in the Conservation Reserve Program

By R. J. Mitchell, G. B. Runion, W. D. Kelley, D. H. Gjerstad, and C. H. Brewer

ABSTRACT: The Conservation Reserve Program (CRP) has resulted in substantial acreage planted to trees in the southeastern United States. Some CRP sites have experienced excessive pine seedling mortality, and multiple plantings on some sites have failed to achieve adequate stocking. This work attempted to identify factors or complexes of agents that may account for this pine seedling mortality. Application of the highest labeled rate of sulfometuron (even on soil with a pH as high as 6.5) decreased loblolly pine (Pinus taeda L.) mortality on CRP sites. Herbicide residuals from prior agronomic crops do not appear to explain loblolly pine mortality on prior agricultural sites. Carbofuran decreased mortality of loblolly pine seedlings and reduced the frequency of damage by root-feeding insects, such as white grubs and white-fringe beetle larvae. Root-feeding insects; fungi, such as Fusarium spp. and Macrophomina spp.; and nematodes were present on most CRP sites sampled and may be causing or exacerbating pine mortality.

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SUBSTANTIAL acreage planted to trees has resulted from the Conservation Reserve Program (CRP). Since the program's inception, producers have converted more than 648,000 ha (1.6 million acres) of erodible cropland from agronomic crops to tree production (*11*). Furthermore, tree planting in the CRP has been confined largely to southern pines; about 95% of all CRP acres planted to trees can be accounted for by pine planting in five southern states (*11*). In fact, in many of the southeastern states up to 90% of the enrolled acreage is earmarked for tree planting (*12*). Successful regeneration of southern pines on CRP sites is particularly important in view of the goal stated in the 1985 Food Security Act, which established the CRP, that not < 12.5% of the acreage placed in the CRP shall be dedicated to trees. However, < 6% of CRP acreage has been devoted to this land use (*12*).

Although the success of this program and its positive impact on tree planting has been well documented (*7, 11*), greater than 90% seedling mortality has occurred on some tracts, and multiple plantings on these sites have frequently failed to achieve adequate pine stocking. In a recently completed survey, as many as 21% of the CRP plantings failed (fewer than 400 trees survived after one growing season) in the state of Florida. Investigators also have observed significant rates of failure in Alabama, Georgia, Louisiana, North Carolina, and South Carolina. In several counties researchers observed failure rates as high as 40% (*7*).

Few data were available to evaluate the causes of such failures at the initiation of our studies. However, several causal agents had been speculatively discussed throughout the forestry community, including herbicide phytotoxicity, diseases, nematodes, root-feeding insects, and site factors such as plow pans. In this work we attempted to identify factors or complexes of agents that would, at least in large part, account for this pine seedling mortality.

The objective of our first study was to test the hypothesis that sulfometuron, a common herbicide used on pine-regenerated CRP land, was contributing to pine mortality, particularly at higher soil pH. Sulfometuron solubility increases in water at 25° C (77° F) from 10 mg/l to 300 mg/l (10-300 ppm) as pH increases from 5.5 to 7.0 (*6*). Because agronomic crops are often limed, cropland may have a higher soil pH than is encountered in typical southern pine forest soils. Although loblolly pine (*Pinus taeda* L.) has been shown to be quite tolerant of sulfometuron, these screening studies were

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conducted on acidic forest soils. The objective of our second study was to determine the role that soybean herbicide residuals play in southern pine mortality. Lastly, the objective of our third study was to determine if a broad-spectrum insecticide/nematicide or ripping to remove a plow pan significantly affected pine mortality.

Study methods

Sulfometuron study. We selected five sites, located in the Coastal Plain of Georgia near the towns of Eastman, Jesup, Oglethorpe, and Statesboro, to represent a range in soil pH (Table 1). The Agricultural Stabilization and Conservation Service had previously approved all sites for inclusion in the CRP. Mean pH across the sites ranged from 4.8 to 6.5. We collected soil for pH assessment with a push probe, sampling the upper 10 cm (4 inches) of soil at 2-m (7-foot) intervals in a grid pattern across each block. Soil from a block was then pooled and thoroughly mixed. We measured the pH using a 1:1 (v/v) ratio of soil and distilled water and determined the pH using a portable pH meter calibrated with standard buffers (pH 4.0 and 7.0) immediately prior to measurement. If soil pH of a block deviated more than ±0.2 of a pH unit, we did not use the block.

Treatments were sulfometuron (Oust 75DG) at rates of 0, 212, and 424 g a.i./ha (0, 0.19, and 0.38 pound/acre), applied with 187 l/ha (20 gallons/acre) water with a backpack sprayer. We replicated the three treatments four times in a randomized complete block design at each of the five sites. We located blocks by topographic position, but only accepted them within the described pH tolerance. We used 50 genetically improved loblolly pine seedlings, obtained from the Flint River nursery, per treatment per block on all five sites.

Data collected included mortality, sulfometuron phytotoxicity assessment, fungi associated with pine roots, and presence of root-feeding insects and nematodes. We recorded mortality in May, July, September, and December 1988. In May, we conducted phytotoxicity ratings based on standard procedures (*10*). Symptoms of sulfometuron phytotoxicity are yellow or chlorotic light green needles. When more than one-third of a seedling's needles showed phytotoxic symptoms, we gave the seedling a rating of 1; otherwise we assigned a rating of 0.

The criteria for collecting seedlings to identify fungi associated with pine roots varied with sampling date. In May, we collected all dead seedlings; in September, we took a maximum of three arbitrarily selected seedlings in each of three subjective health classes (healthy, unhealthy, and dead) from each plot; and in December, we randomly selected five live seedlings from each plot. We used roots from 74, 338, and 300 seedlings for fungal isolation in May, September, and December, respectively. The September sample included roots from 180 healthy, 48 unhealthy, and 110 dead seedlings.

Table 1. Location and description of Georgia sites used in the sulfometuron study.

Site and Location	Soil Series*	Soil pH	Previous Crop	Site Preparation†
1 Statesboro	Fuquay	4.8	Soybean	None
2 Jesup	Norfolk	5.5	Soybean	Ripped
3 Oglethorpe	Tifton	5.8	Soybean	Ripped
4 Statesboro	Tifton	6.2	Soybean	None
5 Eastman	Tifton	6.5	Peanut	None

*Soil series identified by local Agricultural Stabilization and Conservation Service personnel for application prior to inclusion in the CRP program.
†A well-developed plow pan was present on the study sites in Jesup, Oglethorpe, and Eastman. The sites at Jesup and Oglethorpe were operationally ripped by Georgia Forestry Commission personnel prior to installation of this study. Plow pans at both Statesboro sites were poorly developed or nonexistent.

We removed the stem above the root collar and rinsed roots briefly in 0.5% NaOCl to remove soil and decrease surface contamination. We removed all lateral roots. We severed two sections [5-6 cm (2-2.5 inches) in length] from the tap root, placed them on moist filter paper in sterile petri dishes, and incubated them in darkness for 14 days. We transferred fungi emerging from root sections to petri dishes containing acidified (1 ml/l 50% lactic acid) potato dextrose agar (PDA), subcultured them to ensure axenic cultures, and identified them to a genus.

At each sampling date, we removed each seedling from the ground with a volume of soil 30-40 cm (12-16 inches) in diameter and 25-30 cm (10-12 inches) deep; we carefully removed seedlings subsequently from this soil. For the May and September samples, we sieved the rhizosphere-rhizoplane soil associated with each seedling root mass through a no. 6 soil sieve [3.36-mm (0.13-inch) mesh] to collect potential root-feeding insects, particularly white grubs (common genera include *Phyllophga, Diplotaxis, Dichelonyx, Serica, Cotalpa,* and *Anomala*) and white-fringe beetle (*Graphognathus* spp.) larvae. We subsequently sieved soil that passed through the sieve into a no. 8 soil sieve (2.36-mm mesh) and used it for nematode assays. We extracted nematodes from a 100-ml (3-ounce) subsample of soil using a rapid flotation technique (*5*).

Herbicide residual study. In July 1988, we established a study near Union Springs, Alabama, to test the influence of soybean herbicide residuals on pine mortality. We tested five herbicides (pendimethalin as Prowl 4EC, trifluralin as Treflan 4EC, bentazon as Basagran 4L, acifluorfen as Blazer 2EC, and imazaquin as Scepter 1.5EC) commonly used in soybean culture, the major prior crop use represented in CRP participation in the South. We incorporated pendimethalin and trifluralin with a rototiller. We applied each herbicide at one, two, and four times the labeled rates; control plots received no soybean herbicide. We arranged the study in a randomized complete block design with four blocks located based on topographic position. In December 1988, we planted 50 seedlings from the Flint River Nursery in each plot. We then split each plot in half, and in one randomly selected split-plot, we applied sulfometuron at 211.7 g a.i./ha (0.19 pound/acre).

We recorded mortality several times during the growing season. Because the soil-incorporated herbicides pendimethalin and trifluralin have inhibited root growth in nursery-grown pines, we harvested five randomly selected seedlings from each split-plot for the control and for the four-times rate of each soil incorporated herbicide in December 1989 to assess inhibition of root growth.

Carbofuran-ripping study. The first year's work suggested that we needed more information to determine the effects of plow pans, root-feeding insects, nematodes, and fungi on repeated failures of planted pines on CRP sites. Three selected sites, located near Eastman, Cochran, and Soperton, Georgia, were planted more than three times without obtaining sufficient pine stocking [< 120 trees/ha (49 trees/acre) were present even though multiple operational plant-

Table 2. Percent* mortality of loblolly pine seedlings in the sulfometuron study.

Site	Location	Percent Pine Mortality by Sulfometuron Concentration (g a.i./ha)			
		0	212	424	Average
1	Statesboro	7.9def†	3.1def	3.1def	4.7x
2	Jesup	16.7cd	9.1def	6.7def	10.9xy
3	Oglethorpe	8.6def	2.4ef	0.6f	3.9x
4	Statesboro	23.0c	15.8cde	9.6def	16.2y
5	Eastman	73.2a	45.7b	51.5b	56.8z
	Average	25.9z	15.2y	14.3y	18.5

*Percents are from data collected in December and are based on 161 to 167 seedlings.
†Among the treatments and among each group of averages, means followed by the same letter are not significantly different (α = 0.05), according to Duncan's new multiple range test.

ings of more than 1,500 trees/ha (607 trees/acre) had occurred.] All sites had well-developed plow pans.

In December 1988, we blocked the sites according to topographic position and we randomly assigned treatments in a factorial design within four blocks on each site. We used ripping treatments with a single-row chisel plow to a depth of 1 m (3 feet) or left the plow pan undisturbed. In each ripping treatment, we dipped seedlings in a clay slury [1.9 L of water (0.50 gallons) with 0.9 kg (10 pounds) of kaolin clay] with or without 1.8 g a.i. (0.06 ounce) carbofuran (Furdan 4F) immediately prior to planting in February 1989.

We assessed pine mortality monthly. We carefully removed all dead seedlings and recorded evidence of damage from root-feeding insects. In July 1989, pine tip moth (*Rhyacionia* spp.) infestations in carbofuran plots indicated that additional treatment was necessary. In August 1989, we applied Furdan 15G at 3.4 g (0.12 ounce) a.i. to the soil around the base of each seedling, carefully incorporating and covering it with a thin layer of soil. Several times throughout the growing season, we recorded the presence or absence of root-feeding insects in the soil. In December 1989, we systematically sampled the plots for nematodes. We used a soil push probe to sample the upper 10 cm (4 inches) of the soil at intervals of 2 m (7 feet) in an M-pattern across each plot. We thoroughly mixed the soil from each plot and sent a subsample from each plot to the University of Georgia for elutriation and identification of nematodes.

We rinsed the root system from each dead seedling briefly in water to remove soil. We removed all lateral roots. We systematically removed four sections [5-6 cm (2-2.5 inches) in length] from the stem and tap root of each seedling, beginning about 2 cm (1 inch) above the root collar. We surface-disinfested the sections in a continuously stirred solution of 1.5% NaOCl, 1 ml/L (1,000 ppm) lactic acid and 1 ml/l (1,000 ppm) Tween 20, as a surfactant, for 5 minutes. We then dipped the sections in 95% ETOH and flamed and placed them in petri dishes containing acidified PDA. We subcultured all fungi to ensure axenic cultures and identified them to a genus.

Results and discussion

Sulfometuron study. Sulfometuron decreased mortality on all sites, although the differences were not always statistically significant (Table 2). Thus, we reject the hypothesis that higher soil pH would increase seedling mortality due to sulfometuron toxicity. However, increasing the rate of sulfometuron increased the percentage of seedlings showing phytotoxicity (Table 3). The most acidic site had the lowest percentage of pines with phytotoxicity symptoms. We observed less substantial differences among the other sites, particularly at the highest rate of sulfometuron. Thus, a reasonably high percentage of seedlings can exhibit sulfometuron phytotoxicity, but this does not explain mortality.

By December, mortality at Eastman was 73%, 46%, and 52% for the 0, 212, and 424 a.i./ha (0, 0.19, and 0.38 pounds/acre) of sulfometuron treatments, respectively (Table 2). All other sites had mortality < 25% regardless of treatment. The Oglethorpe and Eastman sites were planted a year prior to this study, and both sites experienced near-complete pine mortality. These were the only sites that had well-developed plow pans. However, just prior to this study the Oglethorpe site was ripped to break up the plow pan and mortality was < 10%. Although these are circumstantial observations, they suggest that further work is needed to precisely define the role of plow pans in pine mortality on former agricultural land.

The Eastman site had the highest numbers

Table 3. Percentage* of loblolly pine seedlings symptomatic of phytotoxicity† in the sulfometuron study.

Site	Location	Soil pH	Percent Pine Phytotoxicity Symptoms by Sulfometuron Concentration (g a.i./ha)		
			0	212	424
1	Statesboro	4.8	0a†	5b	19c
2	Jesup	5.5	0a	73b	88b
3	Oglethorpe	5.8	0a	53b	88c
4	Statesboro	6.2	0a	60b	84b
5	Eastman	6.5	0a	34b	81c

*Percentages are based on 200 seedlings for each concentration at each site.
†Seedlings with more than one-third of their needles yellow or chlorotic light green were considered to show phytotoxicity.
‡Within a row, means followed by the same letter are not significantly different (∝ = 0.05), according to Duncan's new multiple range test.

Table 4. Recovery frequency[6] and number[6] of nematodes from pine seedling rhizospheres for the various sites for the May sampling date in the sulfometuron study.

Site	No. Samples	Nematodes Type: Ring	Spiral	Lesion	Dagger	Stunt	Cyst	Root Knot	Total
		%							
Statesboro	(69)	2.9c‡	42.0b	65.2b	0.0d	0.0b	8.7b	0.0a	81.2b
Jesup	(72)	1.4c	2.8c	20.8c	43.1b	8.3b	25.0a	2.8a	66.7c
Oglethorpe	(63)	19.1b	46.0b	0.0d	28.6c	1.6b	0.0c	0.0a	60.3c
Statesboro	(74)	1.4c	67.6a	78.4a	10.8d	0.0b	1.4bc	0.0a	98.7a
Eastman	(94)	55.3a	14.9c	31.9c	67.0a	31.9a	1.1bc	1.1a	90.4ab
Average	(372)	18.3	33.3	39.8	32.3	9.9	7.0	0.8	80.6
		Number							
Statesboro	(69)	0.04b	2.09b	2.42b	0.00b	0.00b	0.28b	0.00a	4.83b
Jesup	(72)	0.01b	0.21b	0.22c	1.32b	0.32b	1.10a	0.04a	3.22b
Oglethorpe	(63)	0.44b	1.98b	0.00c	0.51b	0.03b	0.00b	0.00a	2.96b
Statesboro	(74)	0.01b	22.95a	6.68a	0.14b	0.00b	0.03b	0.00a	29.81a
Eastman	(94)	1.52a	0.21b	0.66c	11.19a	9.21a	0.01b	0.01a	22.82a
Average	(372)	0.47	5.38	1.99	3.20	2.40	0.27	0.01	13.72

*Frequency is the percentage of seedling rhizospheres in which the nematode was present.
†Number is the average number of nematodes per 100 ml soil.
‡Within a column for each parameter, means followed by the same letter are not significantly different (∝ = 0.05), according to Duncan's new multiple range test.

Table 5. Recovery frequency* and number† of nematodes from pine seedling rhizospheres for the various sites for the September sampling date in the sulfometuron study.

Site	No. Samples	Nematodes Type: Ring	Spiral	Lesion	Dagger	Stunt	Cyst	Root Knot	Total
		% Frequency							
Statesboro	(58)	5.2b‡	31.0b	46.6b	15.5c	0.0b	3.5ab	0.0b	69.0b
Jesup	(73)	1.4b	4.1c	24.7c	63.0b	0.0b	5.5a	5.5a	78.1b
Oglethorpe	(58)	8.6b	22.4b	1.7d	29.3c	0.0b	0.0b	1.7ab	46.6c
Statesboro	(69)	0.0b	82.6a	84.1a	17.4c	0.0b	0.0b	0.0b	97.1a
Eastman	(80)	78.8a	8.8c	43.8b	87.5a	16.3a	0.0b	1.3ab	100.0a
Average	(338)	21.3	29.0	41.1	45.6	3.8	1.8	1.8	80.2
		Number							
Statesboro	(58)	0.10b	2.62b	3.76b	1.10b	0.00b	0.10a	0.00a	7.68c
Jesup	(73)	0.03b	0.16b	0.85b	8.47b	0.00b	0.14a	1.04a	10.69c
Oglethorpe	(58)	0.24b	2.41b	0.03b	3.24b	0.00b	0.00a	0.21a	6.13c
Statesboro	(69)	0.00b	121.97a	24.12a	1.10b	0.00b	0.00a	0.00a	147.19a
Eastman	(80)	13.65a	0.47b	6.33b	32.68a	5.88a	0.00a	0.40a	59.41b
Average	(338)	3.30	25.91	7.25	10.53	1.39	0.05	0.36	48.79

*Frequency is the percentage of seedling rhizospheres in which the nematode was present.
†Number is the average number of nematodes per 100 ml soil.
‡Within a column for each parameter, means followed by the same letter are not significantly different (∝ = 0.05), according to Duncan's new multiple range test.

Table 6. Frequency of recovery of various fungi from all seedlings for the various sites for all sample dates in the sulfometuron study and the carbofuran-ripping study.

Study and Site	No. Trees Sampled	Fusarium subglutinans	Fusarium Species	Macrophomina Species	Rhizoctonia Species	Phytophthora Species	Others	Total
		% Frequency						
1988 sulfometuron								
Statesboro	(129)	78	52	1	4	4	75	214
Jesup	(145)	83	86	4	9	3	86	271
Oglethorpe	(121)	9	60	6	2	1	77	155
Statesboro	(143)	79	61	9	2	6	57	214
Eastman	(174)	82	69	14	2	1	54	222
Total	(712)	331	328	34	19	15	349	1,076
1989 carbofuran								
Cochran	(76)	43	13	31	11	2	59	159
Eastman	(56)	37	14	10	13	4	48	126
Soperton	(51)	20	13	20	8	2	57	120
Total	(183)	100	40	61	32	8	164	405

*Others include fungi from 20 other genera for the sulfometuron study and from 30 other genera for the carbofuran-ripping study.

and frequencies of dagger (*Xiphinema* spp.), stunt (*Tylenchorhynchus* spp.), and ring (*Criconemella* spp.) nematodes in both the May (Table 4) and September (Table 5) samples. However, the rapid flotation technique used in this study may underestimate ring nematodes (*5*). The second Statesboro site (Site 4) had the highest numbers and frequencies of spiral (*Helicotylenchus* spp.) and lesion (*Pratylenchus* spp.) nematodes at both sampling dates (Tables 4 and 5).

Several genera of nematodes recovered from these study sites are known to damage pine seedlings (*14, 15*). Spiral nematodes are associated with declining slash pine (*Pinus elliottii* Engelm. var. *elliottii*) seed orchard trees in Georgia (*16*). Ring nematodes are associated with decline of several tree species (*17*), and their pathogenicity on pine seedlings is under investigation (J. P. Noe, personal communication). Nematodes feeding on pine roots may reduce growth, induce mortality, and diminish the tree's ability to survive other stresses, such as drought. Nematode feeding damage also may provide infection courts for pathogenic fungi (*14, 15*).

Eastman was the only site that yielded white-fringe beetle larvae. Thirteen of 114 sampled seedlings had white-fringe beetle larvae in the excised soil. We saw root feeding and decortication, symptomatic of white-fringe beetle larvae, on many of the dead seedlings collected from this site.

Fungi were isolated from root systems from all sites. Fungi representing 24 genera were isolated from 712 seedlings. Several of these genera contain species pathogenic to pines (Table 6). *Fusarium* spp. were isolated from 63% of the seedlings and accounted for 61% of all fungi isolated. *Fusarium subglutinans* (Wollenw. & Reink.) Nelson, Toussoun & Marasas, was the most frequently recovered fungus and accounted for 31% of all fungi isolated. *F. subglutinans* was isolated from 46.5% of all seedlings and isolated from 47% to 60% of seedlings from four of the study sites; it occurred on only 7% of seedlings from the Oglethorpe site (Table 6).

The frequency of *F. subglutinans* recovery is high; however, it is cosmopolitan (*13*), and occurs on a large number of host plants (*4*) and in soil (*3, 8*). The fungus can colonize and survive on dead stem segments of soybean [*Glycine max* (L.) Merr.] and other plants (*3*), which may explain the high incidence of recovery in this study. However, many isolates of *F. subglutinans* are not pathogenic on pines (*9*).

Macrophomina spp. were recovered from approximately twice as many seedlings on the Eastman site, which had 58% mortality, compared with the other sites, which had 5% to 15% mortality (Table 6). No differences in recovery of fungi occurred among test treatments.

Because pine root systems were not surface disinfested, we cannot determine the exact role of recovered fungi on mortality. Many of the isolated fungi could have been surviving saprophytically as epiphytes. Live seedlings were included in the latter sampling dates to gain information on the overall presence of fungi on the study sites.

The fact that most fungi occurred on live and dead seedlings with similar frequency indicates the ubiquitous nature of these organisms. This also suggests that other factors (that is, environmental conditions, type and abundance of wounding agents, etc.) are involved in the role these fungi play in mortality of pine seedlings on CRP sites. *F. subglutinans* requires a wound to gain entrance into a pine host (*2*), and root-feeding insects and/or nematodes might provide suitable infection courts (*14, 15*).

Herbicide residual study. Pine mortality was not affected by any of the herbicides tested (Table 7). However, rainfall patterns were such that during the study the seedlings experienced little if any drought stress [average monthly rainfall was 12.2 cm (4.8 inches) with only one month below 6.3 cm (2.5 inches)]. Although some root inhibition occurred due to pendimethalin at four times the labeled rate, inhibition was much greater with sulfometuron (Table 7).

Residual levels of soybean herbicides had an insignificant effect on pine mortality in this study. However, sulfometuron has been reported to inhibit root growth of loblolly pine (*1*), and it substantially decreased seedling root mass in this study (Table 7). The increase in soil moisture associated with weed control must compensate for the reduced root growth because mortality de-

Table 7. Percent* mortality and root dry weight† for seedlings in the herbicide residual study.

	Sulfometuron Treatment‡			
	With Sulfometuron		Without Sulfometuron	
Soybean Herbicide	Mortality (%)	Weight (g)	Mortality (%)	Weight (g)
Control	13	5.6c§	15	17.6a
Pendimethalin	16	5.9c	19	11.7b
Trifluralin	17	5.1c	20	14.5ab
Bentazon	9	—	7	—
Acifluorfen	14	—	13	—
Imazaquin	8	—	11	—

*Percent mortality is based on 300 seedlings per treatment.
†Mean root dry weight is based on 20 seedlings per treatment only from plots receiving the highest (four times) concentration of each herbicide. Dashed lines (—) indicate that no data were collected.
‡Sulfometuron was applied at 212 g a.i./ha in a split-plot design.
§Means followed by the same letter are not significantly different ($\alpha = 0.05$). according to Duncan's new multiple range test.

creased with increasing sulfometuron concentration during periods of drought, as in the sulfometuron study where rainfall for the Eastman site was 19.9 cm (7.8 inches) from May to August 1988 compared with 59.8 cm (23.5 inches) during the same period in 1989.

Carbofuran-ripping study. Rainfall patterns were nearly ideal for seedling establishment and survival during the 1989 growing season, and mortality in the three study sites was low (only 183 of 2,400 seedlings died). Nevertheless, significant differences in percent mortality occurred among treatments (Table 8). Treating seedlings with carbofuran significantly reduced mortality (only 61 seedlings died in carbofuran plots compared with 122 in the noncarbofuran plots). Ripping had no effect on mortality.

Root feeding and decortication, characteristics of white-fringe beetle larvae and/or white grub damage (*18, 19*), were present on all sites. White-fringe beetle larvae and white grubs were also found on all three sites.

We extracted nematodes from this study with elutriation, and the numbers of ring nematodes were higher than in the sulfometuron study, supporting the hypothesis that the rapid flotation technique underestimated ring nematodes (*5*). The Soperton site had more ring, spiral, and lesion nematodes than the other sites; and Eastman had more ring nematodes than did the Cochran site (Table 9).

Fungi were isolated from root systems from all sites. Fungi representing 34 genera were isolated from 183 seedlings. *Fusarium* spp. were isolated from 66% of the seedlings and accounted for 35% of all fungi isolated. *Fusarium subglutinans* was, as in the sulfometuron study, the most frequently recovered fungus. It was isolated from 54.6% of the seedlings and accounted for 25% of all fungi isolated (Table 6).

F. subglutinans was recovered at similar rates from surface-disinfested (carbofuran-ripping study) and nondisinfested (sulfometuron study) roots, indicating that most isolates were colonizing internal root tissues. However, the recovery frequency of other *Fusarium* spp. was lower in the sulfometuron study, indicating many of these were on pine root surfaces.

Macrophomina spp. were recovered from more seedlings in this study than the sulfometuron study except at the Eastman site, where recovery was similar in both studies (Table 6). No differences in recovery of fungi occurred among test treatments. Because sampled seedlings had recently died and all root systems were surface disinfested, isolated fungi probably contributed, as either primary or secondary pathogens, to their death. However, some of these fungi could have saprophytically colonized roots.

Table 8. Percent* mortality for seedlings in the carbofuran-ripping study.

Carbofuran‡ Treatment	Percent Mortality by Ripping Treatment† Ripped	Nonripped	Average
	%		
Carbofuran	4.7b§	5.5b	5.1b
No carbofuran	10.3a	10.0a	10.2a
Average	7.5a	7.8a	7.6

*Percents are based on 600 seedlings per treatment.

†All sites had a well-developed plow pan and ripping was conducted with a single-row chisel plow to a depth of 1 m.

‡Treatment included a root dip using Furadan 4F at 1.8 g a.i. in 1.9 L water with 0.9 kg kaolin clay at planting, and Furadan 15G at 3.4 g a.i. per seedling 6 months after planting.

§Among the four treatments and among each group of averages, means followed by the same letter are not significantly different ($\alpha = 0.05$), according to Duncan's new multiple range test.

Conclusions

Application of the highest labeled rate of sulfometuron on soil with a pH as high as 6.5 decreased loblolly pine mortality. Therefore, using sulfometuron on CRP sites is unlikely to result in mortality. However, if all other vegetation is eliminated from sites containing root-feeding insects, their damage to pine seedlings may be exacerbated. This risk could be reduced by using band applications of herbicides, leaving vegetation for the insects to feed on between pine rows. Also, the role of agronomic herbicide residuals in pine mortality appears to be minor. From our data, we discount the role of herbicides in multiple failures on CRP sites.

All sites that had experienced multiple failures had root-feeding insects. Also, trees that died on these sites frequently had damage characteristic of feeding by white-fringe beetle larvae and/or white grubs. Carbofuran both reduced the frequency of root-feeding symptoms and decreased mortality. If unexpectedly high mortality occurs following agronomic crop production, root-feeding insects, particularly white-fringe beetle larvae and white grubs, should be monitored. However, few effective silvicultural tools are available to alleviate the problem. A carbofuran (Furdan 4F) root dip [$10-$15/ha ($4-$6/acre)] is the only insecticidal treatment cost-shared (50%) by the Alabama Forestry Commission on CRP land. However, this material can be hazardous to handle, and care must be taken to protect tree planters. Furthermore, Furadan did not provide season-long control in our study. Trichlorofen (Dylox 80WP) at 3.3-6.6 kg a.i./ha ($75-$150/ha) [2.9-5.9 pounds/acre ($30-$60/acre)] may be effective in controlling white grubs (P. P. Cobb, personal communication). However, this compound must be watered-in, may require weed control in order to contact the soil, and may require multiple applications due to the variable life cycles of white grubs. White-fringe beetle larvae are resistant to most insecticides (P. P. Cobb, personal communication).

Leaving the site fallow may reduce populations of root-feeding insects to negligible levels. However, white grub populations can build up on fallow land (*18, 19*). On the Cochran site, no agronomic crop production had occurred for 5 years, and white-fringe beetle larvae and white grubs were still present. These insects feed on roots from a wide range of hosts, and many were recovered from root systems of dogfennel (*Eupatorium compositifolium* Walter). Therefore, they may reside on sites for long periods. It is difficult to determine the relationship between number of insects and risk of pine mortality. Populations of white grubs as low as five insects/m^2 (four insects/square yard) have caused high levels of pine mortality (*18*).

Nematodes from nine genera were recovered, with numerous lesion, spiral, ring,

Table 9. Recovery frequency* and number† of nematodes from soil for the various sites for the December sampling date in the carbofuran-ripping study.

Site	No. Samples	Nematodes Type: Ring	Spiral	Lesion	Dagger	Stunt	Stubby Root	Root Knot	Total
		% Frequency							
Cochran	(16)	12.5b‡	25.0a	0.0c	6.3a	25.0a	0.0a	0.0b	50.0b
Eastman	(16)	100.0a	25.0a	25.0a	18.8a	18.8a	12.5a	18.8a	100.0a
Soperton	(15)	100.0a	60.0a	100.0a	13.3a	6.7a	13.3a	0.0b	100.0a
Average	(47)	70.2	36.2	40.4	12.8	17.0	8.5	6.4	83.0
		Number							
Cochran	(16)	1.87c	1.25b	0.00b	0.13a	0.63a	0.00a	0.00a	3.88b
Eastman	(16)	49.25b	1.88b	1.00b	0.38a	2.25a	0.25a	3.38a	58.39b
Soperton	(15)	200.53a	6.80a	76.00a	0.40a	0.13a	0.40a	0.00a	284.26a
Average	(47)	81.40	3.23	24.60	0.29	1.02	0.21	1.15	111.91

*Frequency is the percentage of samples in which the nematode was present.

†Number is the average number of nematodes per 100 ml soil.

‡Within a column for each parameter, means followed by the same letter are not significantly different ($\alpha = 0.05$), according to Duncan's new multiple range test.

and dagger nematodes on one or more sites. Because the relationship between number of nematodes and pine mortality is not known, the implications of these data are unclear. Nematodes may increase the incidence of fungal root diseases of pines. Additional studies are required to determine the effects of nematodes on pine mortality and productivity and on the conditions under which damage occurs.

Fungi from a large number of genera were found on seedlings. However, it is likely that only a few of these are pathogenic to pines. *Fusarium* spp. and *Macrophomina* spp. were recovered from roots of a large number of pine seedlings. These are common pathogens on pines and numerous agronomic crops and are probably contributing to mortality on CRP sites. *Fusarium* spp., *F. subglutinans* in particular, are likely involved in complex interactions with root-feeding insects and/or nematodes. The role of pathogenic fungi in pine mortality and the conditions under which this occurs on CRP sites requires further investigation.

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