United States
Department of
Agriculture

Forest
Service

North Central
Forest Experiment
Station

Research
Paper NC-229

1982

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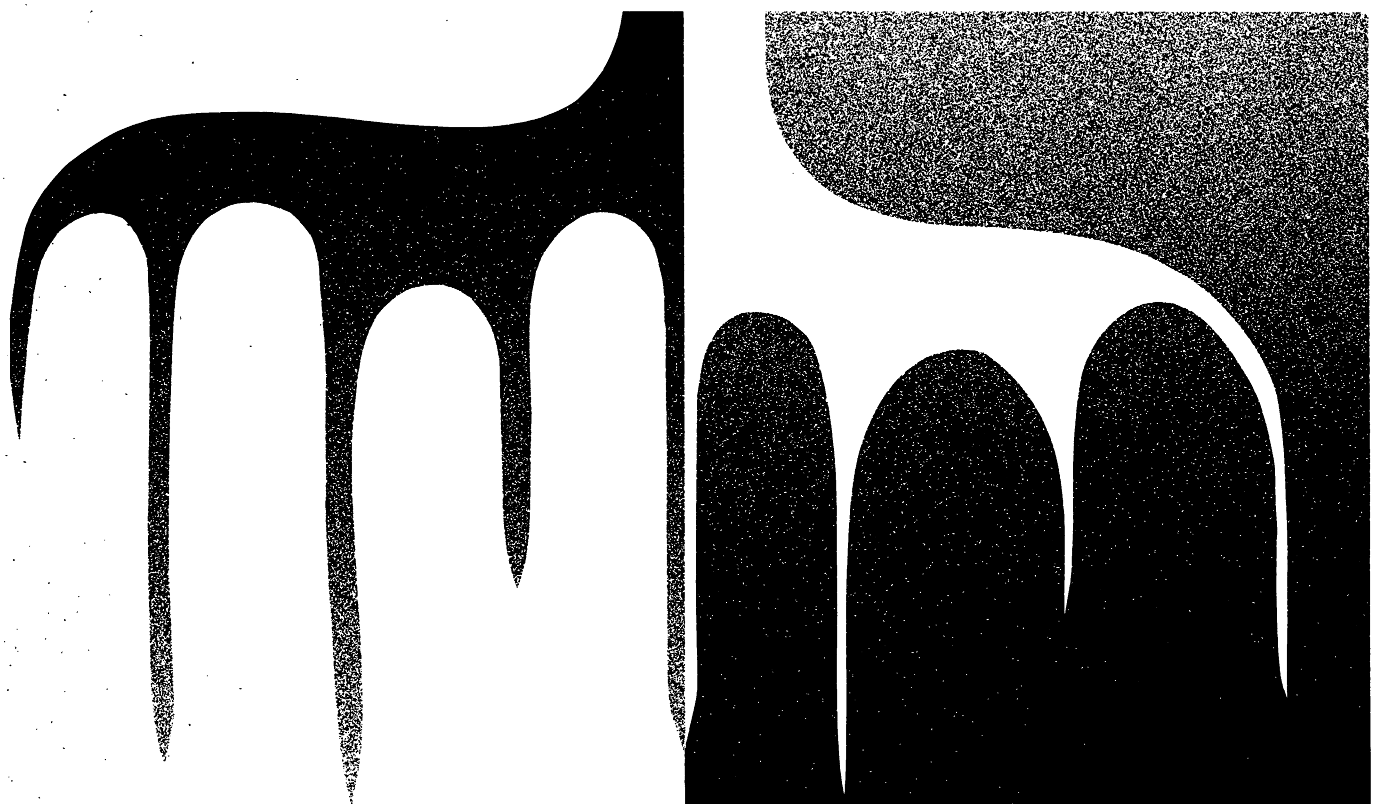
Kenneth J. Kessler, Jr.



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North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication September 29, 1982
1982

CONTROL OF BLACK WALNUT ROOT ROT DISEASES IN NURSERIES

Kenneth J. Kessler, Jr., *Principal Plant Pathologist, Carbondale, Illinois*

Historically, root rots have been one of the most serious pest problems nursery managers have confronted. As recently as 1977 a survey of 99 public and industrial nurseries in the United States reported that more than 85 percent had root rot problems requiring chemical or cultural control (Abbot and Fitch 1977). As energy costs have increased, production costs for nursery stock have increased correspondingly. Growing costs in 1977 for northeastern State nurseries averaged $22 per thousand for 1-0 stock (Abbott and Fitch 1977). Allison and Bridgewater (1977) found that for 18 eastern State nurseries growing 1-0 black walnut stock, dollar losses attributable to root rot averaged 17 percent of total production costs.

In recent years much of the research effort on walnut root rots has been concentrated on *Cylindrocladium* and *Phytophthora* root rots. Roth and Griffin (1979) studying *Cylindrocladium* in Virginia, and Cordell (1976) in North Carolina and Green and coworkers (Green 1975, Ploetz and Green 1977) studying *Phytophthora citricola* in Indiana have led the effort. Because control of most root rots involves destroying or reducing populations of pathogen propagules in the soil, much of the research on root rot control of other species also is relevant to black walnut.

This report first discusses the black walnut nursery ecosystem and the principal root rot pathogens in the eastern United States. The report then describes the present status of nursery root rot management and gives some conclusions and recommendations for future research.

THE WALNUT NURSERY ECOSYSTEM

The walnut nursery system has evolved into factorylike production that often seems to emphasize quantity at the expense of quality. Some especially notable features of the production system are dense planting of seed in nursery beds, routinely fumigating soils before planting, and mechanically lifting stock.

Walnut seed is usually collected in the fall and shortly after is planted in nursery seedbeds. Because seed generally germinates at a rate of 50 percent or less (Brinkman 1974), it must be planted at a dense enough rate to allow for a final seedling concentration of around 8 per square foot. Black walnut seed requires cold stratification for 3 to 4 months. Even under optimal stratification conditions the seed has a tendency to germinate over an extended period from April to mid-summer. During stratification seedbeds may be covered with screens to exclude rodents and with several kinds of mulch materials to minimize the harmful effects of alternate freezing and thawing. Commonly used nursery organic soil amendments include sawdust, peat, manure, rotted bark, wood chips, and mushroom compost (Abbott and Fitch 1977). Seed stratified overwinter in cold storage facilities or in outdoor pits is sometimes spring planted.

Sufficient growth to permit outplanting for 1-year-old seedlings requires that the embryos remain attached to their cotyledons during the early developmental period. Detachment from the cotyledons or loss of cotyledons through attack by rot organisms can reduce growth 50 percent or more.

Most nurseries plant cleaned seed after the hulls have been removed by mechanical hullers. In the course of mechanical hulling, shells of some seed may become chipped and cracked providing entry courts for pathogens. Following hulling, seeds are floated on water to detect unfilled seed.

After germination, height growth begins slowly but soon assumes a rapid rate and is essentially completed within 2 months (Schlesinger and Funk 1977).

Diameter growth continues after height growth terminates and may continue into late summer. Root growth ends in early fall around the time leaves are becoming senescent prior to being shed. Black walnut loses its leaves earlier in the fall than most other tree species. The growth period varies from 90 to 135 days from north to south over its range.

Initially, the development of the seedling taproot is more rapid than that of the corresponding stem. Lateral roots soon form on the taproot and an extensive system of primary and secondary roots develops. Initially, roots are devoid of mycorrhizal infection. Gradually, the root system becomes infected with endotrophic mycorrhizal fungi. In some nurseries where soils are fumigated prior to planting, many roots may remain uninfected by mycorrhizal fungi. In well-drained nursery soils taproots may extend several feet deep. During lifting the portion of the taproot below about 1 foot is severed and remains in the soil. Some nurseries use a cutting device to prune root systems midway through the season to encourage a compact root system more suitable for transplanting. Taproot length also can be regulated somewhat by controlling irrigation.

Although walnut trees develop best on deep, well-drained, moist fertile soils, seedlings can develop on less favorable nursery soils as long as the soils drain well. Nursery soils with nutrient and humus imbalances can be carefully manipulated to serve as adequate substrates for growing black walnut seedlings.

Seedbed preparation often begins with cover cropping the planting area 1 year before planting the seeds. Cover crops include rye, sudan grass, peas, oats, soybeans, sorghum, millet, wheat, vetch, and alfalfa (Abbott and Fitch 1977). After incorporating the cover crop and before planting, the soil is generally fumigated to eliminate weed seeds as well as to control fungal pathogens and parasitic nematodes. Although fumigation may eliminate pathogen propagules in treated nursery soil, they can sometimes be quickly reintroduced from contaminated irrigation water (Shakes and McCarter 1979). Fumigation has greatly reduced the need for cultivation during the summer months, although some hand weeding may be required. Walnut nursery beds are routinely irrigated as needed.

At some nurseries walnut stock is lifted in the fall and kept in cold storage facilities or heeling-in areas out of doors. Fall lifting is useful if spring lifting is difficult either because of other higher spring nursery priorities or to avoid excessively wet field conditions.

Bed planting of walnut where the foliage of individual seedlings creates an unbroken bed cover creates a humid leaf zone area susceptible to infection by leaf pathogens such as the anthracnose fungus, *Gnomonia leptostyla*.

THE ROOT ROT ORGANISMS

Phytophthora

The *Phytophthora* species associated with black walnut in nurseries are *P. cinnamomi* (Crandall *et al.* 1945), *P. cactorum* (Crandall and Hartley 1938) and *P. citricola* (Ploetz and Green 1977). The root rots caused by *Phytophthoras* are primarily of concern during cool, wet weather. *Phytophthora* fungi produce spores capable of moving long distances in the soil. Nutrients exuded from roots of host plants attract the motile spores. After reaching the surface of a root, the spore is inactive for a brief period before it releases enzymes that dissolve epidermal cell walls. At this point it rapidly invades the root and under continuing cool conditions adjoining portions of the root system are invaded until entire root systems are colonized. Depending on the *Phytophthora* species involved, a number of spore types are produced. These spores, some of which develop in the root rhizosphere while others develop in the roots, can survive for 1 or more years under conditions varying from a moist, cool soil (Zentmeyer and Mircetich 1966) to a dry warm soil (Hoppe 1966). The germination of these dormant spores requires favorable soil conditions plus the presence of substances exuded by host roots.

Cylindrocladium

Cylindrocladium scoparium, C. floridanum, and *C. crotalariae* attack black walnut (Roth and Griffin 1979). These fungi do not produce motile spores but spread to a limited extent through the soil by hyphal threads, the mycelium. Generally the hyphae originate from sclerotia, small dormant structures in the soil. The sclerotia may be visible to the naked eye and resemble small aggregated sand particles. The *Cylindrocladium* fungi prefer warm soil conditions and thus are a more serious problem in southern nurseries. *Cylindrocladium* strains adapted to cooler soils have been associated with nursery root rots in northern nurseries, however (Bugbee and Anderson 1963, Thies and Patton 1970). Because their resting structures, the sclerotia, are large and possess cells resistant to chemical attack, they are difficult to eliminate from soil by chemical sterilization techniques.

Pythium

These fungi, which typically cause damping-off diseases of seedlings, were associated with a root rot of 2-year-old outplanted walnut seedlings in Louisiana. Infection of the seedlings was associated with high population levels of *Pythium* spp. in the originating nursery (Affeltranger *et al.* 1980). *Pythiums* and *Phytophthoras* are closely related and both belong in the fungus family, Pythiaceae.

Sclerotium and *Phymatotrichum*

Sclerotium rolfsii (*Pellicularia rolfsii*) and *Phymatotrichum omnivorum* root rots occasionally affect black walnut in southern United States nurseries (Ezekiel and Nelson 1941, Streets and Bloss 1973). Like *Cylindrocladium* spp., these fungi produce sclerotia as survival propagules in the soil. Development and survival of *S. rolfsii* and *P. omnivorum* require warm soils. *Phymatotrichum* root rot is largely confined to alkaline, calcareous soils.

PRESENT STATUS OF THE ROOT ROT MANAGEMENT SYSTEM

Biological Monitoring

It has been difficult to attribute walnut root rot injury in nurseries to specific causal agents. A principal problem has been the lack of a universal scheme for comparing the incidence of the several walnut root pathogens in particular nurseries. Pathologists with specific expertise in particular pathogens often have conducted surveys emphasizing either *Cylindrocladium* or *Phytophthora*.

Population counts of pathogen propagules in soil prior to planting seem to be of little use. Such populations vary drastically in response to soil conditions such as temperature and moisture and independently from the presence of host plants (Schmitthenner 1970). Severe outbreaks of *Cylindrocladium* root rot have occurred in nurseries with low soil populations of infectious propagules (Roth and Griffin 1979).

Disease symptoms, the use of highly susceptible species as trap crops, and population counts of the fungi responsible are the principal means of following the development of outbreaks.

The *Phytophthora* root rot symptoms differ somewhat from *Cylindrocladium* root rot particularly in the early stages of development. *Phytophthora* lesions first appear as water-soaked, greenish black discolorations usually located at the root collar (Green 1975). *Cylindrocladium* lesions are at first small and blackish and are scattered over the laterals as well as the taproot. Later the lesions may coalesce and engulf the whole taproot and look much like a well-developed *Phytophthora* infection. Longitudinal cracking of the taproot often occurs with *Cylindrocladium* infections, but such cracking occurs less often with *Phytophthora* infections (Cordell and Skilling 1975, Roth and Griffin 1979). Severely rotted seedlings may have wilting and chlorotic foliage with both *Phytophthora* and *Cylindrocladium* infections.

Geranium leaf, azalea leaf, and alfalfa seedling traps appear to be the methods of choice for bioassaying walnut nursery soils for the presence of *Cylindrocladium* (Newhouse and Hunter 1980, Linderman 1972, Thies and Patton 1966). These methods produce general information on numbers of trap plants attacked and more specific information on particular *Cylindrocladium* spp. involved when the fungi are isolated using specific media.

Wet-sieving soils to recover microsclerotia of *Cylindrocladium* spp. has been used to obtain population counts of these primary infectious propagules (Thies and Patton 1970a). Because of the microsize of *Phytophthora* propagules, no comparable method exists for them.

Several specific isolation media have been developed to increase the recovery efficiency of *Cylindrocladium* and *Phytophthora* from soils and infected roots. The better *Phytophthora* isolation media utilize polyene antibiotics such as nystatin, which *Phytophthora* spp. tolerate well but which inhibits most other fungi (Flowers and Hendrix 1969). Cultural media specific for *Cylindrocladium* have also been developed (Krigsvold and Griffin 1975, Griffin 1977). These contain thiabendazole and quaternary ammonium compounds as suppressants of other competitive fungi. A summary of methods for differentiating between *Cylindrocladium* and *Phytophthora* root rot diseases is presented below:

	Phytophthora	*Cylindrocladium*
I. Symptoms	Water-soaked greenish discolorations at root collar.	Scattered lesions on laterals as well as taproots. Longitudinal cracking of taproots.
II. Detection in soil with trap plants	Citrus fruit Apple fruit	Azalea and geranium leaves. Alfalfa seedlings.
III. Recovery of propagules from soil	—	Wet-sieving and den settling in water.
IV. Isolation from soil and infected tissue onto culture media	Media containing polyene antibiotics.	TBZ medium. Sucrose-QT medium.

Cultural Management of Disease

Some promising experiments have been conducted on the effects of organic materials added to the soil on reducing root rots. Cotton wastes as a soil amendment gave good control of *Phytophthora* root rot of avocado under laboratory conditions (Zentmeyer 1963). Alfalfa meal was also good. These materials produced an ammonium level in the soil that was toxic to the *Phytophthora* fungus. Hadi (1974) reduced Cylindrocladium root rot propagules in soil by planting flax or sorghum-sudangrass cover crops the year before tree planting.

Selecting the best nursery planting locations for black walnut helps minimize root rot problems. Lowlying, heavy, poorly drained soils should be avoided (Green 1975) because their impaired drainage provides good conditions for disease propagules to survive and germinate.

Tiling of medium to light soils to improve drainage is helpful. On heavier soils tiling has not been as helpful except close to the drainage tiles (Wilkinson and Millar 1981).

Selection of seed planting date suggests itself as a root rot avoidance strategy. If seed can be held in cold storage until late spring or early summer, it should be possible to avoid the dangerous spring period with its moist soils most favorable to root rot development. The determinate growth pattern of black walnut with the ability of germinated black walnut seed to produce good-sized seedlings in a few months should allow for the development of adequate-sized seedlings following late planting.

Fertilization with chemical fertilizers has not had much effect on walnut root rot incidence in nurseries.

Flooding has been successfully used to kill resting structures of root rot organisms in the soil (Moore 1949, Stoner and Moore 1953). However, most walnut nurseries cannot be easily flooded. When picking new nursery locations, consideration could be given to sites amenable to periodic flooding if so desired.

Solar heating soils to kill pathogen propagules appears promising as a safe, relatively inexpensive control method (Ashworth 1980, Elad *et al.* 1980, Grinstein *et al.* 1979, Katan *et al.* 1976, Pullman and Devay 1977, Stapleton and Devay 1980). The method has given best results with soils kept moist by trickle irrigation under clear plastic tarps maintained in place for from 3 to 5 weeks. Pullman and Devay (1977) reduced pathogen propagules by 72 percent and annual winter weeds by 92 percent with plastic tarps. Highest temperatures reached were 43°C (109°F) at a 6-inch soil depth and 55°C (131°F) at a 2-inch soil depth.

Biological Control

Many examples have been found of soil fungi, bacteria, and actinomycetes parasitizing dormant propagules, germinating spores, and active mycelium of root pathogens in soil (Ayers and Adams 1979a, 1979b, Ayers and Lumsden 1977, Broadbent *et al.* 1971, Elad *et al.* 1980a, Hoch and Abawi 1979, Huang 1977, Kelly 1976, Sneh *et al.* 1977, Turner and Tribe 1976, Wells *et al.* 1972). However, many of the studies were done under unnatural conditions in the laboratory or greenhouse and a few attempts have been made to apply the experimental findings to control in the field. The principal reason for this seems to be that laboratory conditions required for successful biological control, although achievable in the field, are too costly to be practical. For example, Wilhelm (1951) determined that to translate one successful laboratory study to control *Verticillium* wilt in the field would require 1.5 tons of an organic soil amendment such as cottonseed meal per acre foot of treated soil.

The practically routine practice of fumigating nursery soils provides particularly favorable conditions for introducing and increasing numbers of parasites that attack root rot pathogens. Many laboratory biological control studies noted a favorable affect of steam sterilization on populations of particular mycoparasites (Broadbent *et al.* 1971). Parasites with good saprophytic competitive ability to colonize soil organic matter should be especially favored following fumigation.

Best opportunities for biological control are probably in the upper soil profile where gas concentrations, temperature, and moisture conditions are most favorable for biological activity. Little is known of the presence of parasites favored by anaerobic or poorly aerated soil conditions. But recent finding of amoeboid parasites of soil pathogens indicates that other types of parasites may be found if unusual soil conditions are searched in the right way (Homma *et al.* 1979).

Chemical Management

Fumigants such as methyl bromide are routinely used to control or eliminate root rot pathogens and weed seeds from nursery soils. Nurseries in which nematodes are a problem may be fumigated with pre- and post-emergence nematocides, which may indirectly provide some root rot control through reducing the number of nematode root wounds that can serve as entry points for pathogens (Diomande and Beute 1979).

PRESENT STATUS OF INTEGRATED PEST MANAGEMENT

Soil fumigation has been the most useful technique for controlling root rot pathogens. Recently fumigated soil appears to provide a most suitable environment for introducing microorganisms with biological control potential into the nursery ecosystem with better than average chances to maintain them at levels adequate for good control results.

Many of the cultural practices used in nurseries, arrived at empirically, may provide some root rot control. Avoiding poorly drained soils reduces the opportunities for optimum moisture conditions favoring root rot organisms (Pratt 1974). Planting densities that allow for some seedling loss, particularly through pre-emergence mortality, help to maintain adequate stocking of nursery beds. Monitoring bed moisture levels and only irrigating when absolutely necessary helps to maintain soils at sub-moisture saturation levels less favorable for root rot pathogens. Crop rotation, fallowing, and monoculturing may regulate pathogen populations in some nurseries. Hard evidence on the effects of these practices is not available, however.

Grading to remove severely affected seedlings prior to shipping is useful. Moderately affected seedlings often will recover when outplanted (Hansen *et al.* 1980, Smith 1967).

RECOMMENDATIONS

Research on walnut root diseases has been episodic and often in response to crisis situations. Occasional broad surveys such as Cordell's (Cordell 1973, Cordell 1976, Cordell and Matuszewski 1974) give some indication of the impact of specific root rot diseases on walnut seedling production. Much of the research effort has emphasized life history and chemical control. New studies that integrate chemical, biological, and cultural control promise to be particularly fruitful. Such studies require the cooperation of extension service pathologists to monitor disease and pathogen development, research pathologists to establish experiments, and nursery managers to provide and maintain experiments under nursery conditions. Pathogen and biological control agent populations in particular need to be related to cultural practices and nursery soil types and microclimates. Some specific studies recommended for initiation are:

1. Effect of seed planting date on root rot development.
2. The introduction of biological control agents into recently fumigated soils.
3. Methods for deeper soil application of fumigants to control *Cylindrocladium* root rot.
4. Solar fumigation of soils.
5. Selection and maintenance of soils naturally suppressive to root rot (Broadbent and Baker 1973, Toussoun 1973).
6. Effect of soil flooding during fallow period preceding planting.
7. Effect of walnut monoculture on pathogen populations (Shipton 1973).
8. Effects of organic amendments (cover crops, compost, sewage sludge, etc.) on pathogen populations (Hoitink 1976, 1977).
9. Effect of planting in raised beds on root rot severity (Benson and Jones 1979).
10. Establishment of an annual industry-wide survey of root rot losses attributable to specific pathogens to be maintained for several years to provide baseline data.

In the absence of sophisticated integrated control procedures for black walnut root rots, the following procedures are advised:

1. Fumigate problem soils. Closely follow directions for particular fumigant used. Pay special attention to proper soil temperature, moisture, and tilth. *Cylindrocladium* sclerotia within dry soil clods are especially difficult to fumigate. Rototill cloddy soils to reduce soil particle size for better fumigant penetration.
2. Avoid or correct drainage of chronically wet nursery beds.
3. Grade lifted seedlings from rot-affected beds. Eliminate seedlings with upper part of taproot severely rotted. Seedlings with a rotted taproot tip or partially rotted laterial roots often will recover when outplanted.
4. Maintain good nursery records. Note practices, particularly cultural, that appear to affect root rot incidence. Follow up with pilot testing of these procedures.
5. Irrigate only when absolutely necessary and allow soils to dry before re-irrigating. Remember that black walnut is taprooted and can tolerate moisture stress better than many other hardwoods.
6. Avoid bringing nursery stock and machinery from other nurseries into clean nurseries.

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Control of black walnut root rot diseases in nurseries. Res. Pap. NC-229. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 8 p.

Current nursery methods used to control black walnut root rot diseases are considered in terms of integrated pest management. Suggestions for future root rot control research studies and procedures to minimize root rot problems are provided.

KEY WORDS: *Juglans nigra, Phytophthora, Cylindrocladium, Pythium, Sclerotium, Phymatotrichum,* fumigation, biological control.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1983—665-661/194