In: Haase, D.L. & R Rose (eds.). Symposium Proceedings: Forest Seedling Nutrition from the Nursery to the Field. Nursery Technology Cooperative. Oregon State University, Corvallis, OR. pp. 27-39. 1997.

Effects of Fertilizer on Selected Potential Plant Pathogens in Bareroot Forest Nurseries

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Abstract

Soil-borne microorganisms, including potential plant pathogens, respond to fertilizers and organic amendments. High levels of nitrogen usually result in increases of *Fusarium* populations and more severe disease; organic nitrogen sources encourage disease more than inorganic sources. Balanced nutrition of nitrogen, phosphorus, and potassium helps reduce *Fusarium* diseases. Reducing soil pH and avoiding excessive fertilization may help control *Phytophthora* diseases. Growers need to monitor disease and formulate fertilizer regimes that do not initiate or aggravate existing disease problems.

Introduction

Populations of soil microorganisms vary widely in response to soil type, moisture, and nutrients provided either by organic matter or by supplemental fertilizer. In undisturbed soils, populations of microorganisms often reach a balance because they are continually competing with each other for space, moisture and nutrients. This balance may be disturbed by agricultural practices such as tillage, amendments with organic matter, pesticides and fertilizers, and cultivating certain plants. Under undisturbed soil conditions, potential plant pathogenic fungi usually occur at relatively low populations, being balanced by other soil microorganisms. However, populations may significantly increase when soil balances are disturbed. If plant species susceptible to pathogens are introduced after microorganism balances have been disturbed, extensive disease may result.

Bareroot forest nurseries are agricultural crop systems. Extensive areas may be sown with one or a few tree species. If these tree species are susceptible to disease and potential pathogen propagules are present in soil in sufficient numbers, losses may be severe. Ideally, seedlings should be grown in soil where populations of pathogenic organisms are limited by competition with nonpathogenic microorganisms (James et al. 1993). However, this balance is often disrupted by necessary cultural activities which may favor certain groups of microorganisms, including plant pathogens.

One important, necessary disturbance factor in forest nurseries is amending soil with fertilizers required for proper seedling growth. Not all added fertilizer is used by crop plants; much of it may provide food for resident microorganisms (Sadasivan 1965). In addition, some excessive fertilizer may leach through soil and end up in groundwater.

Various forms of fertilizer and the nutrients contained in them affect microorganisms differently (Sadasivan 1965). Increasing nutrient availability may result in microorganism populations greatly expanding over relatively short time periods. If stimulated microorganisms are potentially pathogenic fungi, severe disease may result (Woltz and Jones 1981) even though fertilizer may improve seedling vigor.

Although many potential plant pathogenic fungi may reside in forest nursery soil, probably the most widespread and damaging group of pathogens are in the genus *Fusarium* (James et al. 1991). These soil-borne pathogens are responsible for several types of disease on many different conifer species and are usually present at some level in most forest nursery soil (James et al. 1991). *Fusarium*-associated diseases have usually been controlled by pre-plant soil fumigation (James 1989). However, alternatives to chemical soil fumigation are currently being developed because of the planned elimination of methyl bromide as a fumigant and desire of growers to reduce pesticide use in forest nurseries (James et al. 1994). Some potential alternatives will involve changes in cultural operations to favor non-pathogenic soil microorganisms (James et al. 1994, Stone et al. 1995). Since fertilizers potentially affect microorganism populations, changes in fertilizer practices may become an important part of integrated pest management strategies in nurseries.

Because of their widespread importance in bareroot forest nurseries, I will emphasize fertilizer effects on *Fusarium* spp. and associated diseases. A smaller portion will address potential effects on *Phytophthora* spp., another important group of plant pathogenic fungi that affect some forest nurseries. Because of the limited amount of research involving fertilizer effects on these two groups of pathogens in forest nurseries, much of the discussion will necessarily involve studies done on other agricultural cropping systems.

Effects on *Fusarium* Disease Severity

Many studies have concluded that high levels of nitrogen (N) fertilization encourages disease development by *Fusarium* spp. (McClellan and Stuart 1947; Sadasivan 1965; Woltz and Engelhard 1973; Woltz and Jones 1973a; Woltz and Magie 1975). This has especially been shown for responses of *F. oxysporum* Schlect. (Jones and Woltz 1975; Woltz and Engelhard 1973; Woltz and Jones 1973a, 1973b; Woltz and Magie 1975) and *F. solani* (Mart.) Appel & Wollenw. (Baker and Nash 1965; Maurer and Baker 1965; Papa vizas et al. 1968) to increasing rates of ammonium. Both nitrate and ammonium stimulate disease of loblolly pine seedlings caused by *F. subglutinans* (Wollenw. & Reinking) Nelson, Toussoun & Marasas (Solel and Bruck 1989). Severe conifer seedling damping-off has traditionally been linked to succulent seedling tissues enhanced by nitrogen fertilization (Tint 1945).

Organic nitrogen sources have been shown to favor disease more than inorganic sources (Toussoun et al. 1960; Walker 1971; Warren and Kommedahl 1973). Urea applied to tomato plants retarded wilt caused by *F. oxysporum* f. sp. *lycopersici* (Bloom and Walker 1955). However, urea applied to bareroot Douglas-fir seedlings resulted in increased disease mortality (Sinclair et al. 1975). For diseases caused by *F. oxysporum*, nitrate, when furnished as the principal nitrogen source, sometimes inhibited disease development, but the inhibition was not as rate-dependent as for ammonium (Woltz and Jones 1973a). Nitrate has also been shown to inhibit disease caused by *F. oxysporum* (Loffler et al. 1986a). In another study, *Fusarium* inoculum cultured with ammonium was more virulent than that grown with nitrate (Woltz and Jones 1973a). It has been speculated that supplemental nitrogen not only provides a nutrient source for soil pathogens (Lopez and Fergus 19 65; Solel and Bruck 1989; Stoddard 1947), but may also reduce host resistance to pathogens (Martin et al. 1991).

Effects of nitrate and ammonium on disease are apparently related to soil pH (Schuerger and Mitchell 1992); nitrate causes an elevation in soil pH, whereas ammonium causes a reduction (Woltz and Jones 1981). Plants grown in soil receiving nitrate plus lime had less disease than those receiving ammonium plus lime (Woltz and Jones 1973a). Effects of lime and nitrate in controlling *Fusarium* are most likely related to lowering the concentrations of other nutrients in soil solutions, mostly phosphorus, magnesium, sulfur and copper. Lacking these nutrients and iron, manganese, and zinc in adequate amounts, *Fusarium* spp. are less likely to establish significant inoculum levels in soil (Woltz and Jones 1981). In addition, different *Fusarium* spp. have different pH optima for growth. For example, *F. proliferatum*'s (Matsushima) Nirenberg optimum is 5.5, the pH optimum for *F. moniliforme* Sheldon is 7.0 (Marin et al. 1995) and best growth and survival of *F. oxysporum* occurs at pH 5-7 (Manandhar and Bruehl 1973; Oritsejafor 1986).

Several potentially-pathogenic *Fusarium* species survive in soil as inactive resting structures called chlamydospores (Guerra and Anderson 1985) which may persist and remain viable in fallow soil for two of more years (Elmer and Lacy 1987). Chlamydospores require exogenous sources of carbon and nitrogen to germinate (Cook and Schroth 1965; Davey et al. 1996; Hendrix and Toussoun 1964), especially at higher spore concentrations (Griffen 1970b). Ammonium may stimulate chlamydospore germination more than nitrate sources (Cook and Schroth 1965; Loffler et al. 1986b). Nitrogen also favors early penetration and subsequent pathogenesis of the host by *Fusarium* spp. (Stoddard 1947; Toussoun et al. 1960). Nitrogen deficiencies may inhibit chlamydospore maturation and stimulate spore lysis (Griffin 1970a, 1976).

Incorporation of plant residues with high carbon/nitrogen (C/N) ratios have sometimes reduced *Fusarium* disease severity (Maurer and Baker 1965). At high C/N ratios, available nitrogen may be immobilized and disease severity lessened (Mauer and Baker 1965; Wall 1984). Carbohydrates, such as sucrose and dextrose, have generally reduced disease by restricting chlamydospore formation and enhancing spore lysis (Sequeira 1962). Acids from pine needles may also reduce disease by enhancing chlamydospore germination and lysis in the absence of susceptible host material (Hammerschlag and Linderman 1975).

Incorporating green manure crops such as oats, rye, and red clover before sowing may result in increased disease levels in conifer seedlings (Wall 1984). Any green manure crop is potentially damaging if incorporated into soil immediately before planting, even those of *Brassica* spp. which were grown for their potential for disease control (James et al . 1996). Peat and sawdust as sources of organic matter are less detrimental than green manure crops (Wall 1984). If green manure crops are used, fallow periods of several months are recommended before conifer seed are sown (Griffin and Pass 1969).

High levels of potassium fertilizer have been found to reduce disease severity, but these effects seem to be related to the balance between potassium and nitrogen in soil (Sadasivan 1965; Stack and Langhaus 1986; Woltz and Jones 19 81). If nitrogen is in surplus supply over potassium, disease development may be more severe, and as potassium is supplied, disease development is inhibited (Walker 1971). Under normal crop production, adequate levels of both nitrogen and potassium are required; excessive rates of nitrogen should be avoided (Woltz and Jones 1981).

Relatively low levels of calcium appear more conducive to *Fusarium* diseases than normal levels (Corden 1965; Edgington and Walker 1958; Tint 1945; Woltz and Jones 1981), but excessive calcium may increase disease severity (Spiegel et al. 1987). Cations competitive with calcium, such as sodium, adversely affect disease resistance in many host plants (Standaert et al. 1973). Calcium nitrate has been shown to suppress disease (Elmer 1989).

When multiple nutrient deficiencies prevent normal rates of plant growth, an applied nutrient that partially overcomes growth limitation may affect disease response. Several *Fusarium* spp. produce plant toxins (James et al. 1991); nitrogen stimulated production of trichothecene toxins by *F. graminearum* Schwabe (Miller and Greenhalgh 1985). By increasing plant growth, effects of some toxins may be minimized because they become diluted in plant tissues (Egli 1969). On the other hand, cell membranes from plants grown at high nitrate dosages were less sensitive to fusaric acid, a toxin produced by *F. oxysporum* f. sp. *lycopersici* (Barna et al. 1983).

Control of *F. oxysporum* has been obtained in some horticultural plants by adjustments of soil acidity and fertility (Woltz and Jones 1981). For example, sandy soils that were uniformly limed to pH 6.5-7.5 were less conducive to disease than unlimed soils. This was due at least in part by limiting micronutrient availability to the fungus (Jones and Woltz 1967, 1969, 1970, 1972). Investigations have shown that *F. oxysporum* requires 12 nutrients and an organic source of energy for normal growth (Woltz and Jones 1981). These are absolute requirements which, if unsatisfied, will limit growth, sporulation, pathogenicity, and survival of the fungus (Hendrix and Toussoun 1964; Saraswathi-Devi 1958; Smith and Snyder 1975; Woltz and Jones 1968).

Raising pH toward or slightly above neutrality appears to be a common denominator in cultural control of *F. oxysporum* causing wilt diseases (Griffin 1976; Wilson 1946). These diseases are commonly associated with acidic, sandy soils rather than heavier soils with higher pH values (Oritsejafor 1986; Woltz and Jones 1981). These effects may be due to increasing competitive abilities of bacteria and actinomycetes at higher pH values (Marshall and Alexander 1960; Woltz and Jones 1981).

Soil micronutrients may be important for *Fusarium* control since the fungus is more vulnerable to micronutrient deficiencies than host plants (Woltz and Jones 1981). Some work has shown that boron deficiency in host plants may increase disease severity (Keane and Sackston 1970). Guerra and Anderson (1985) found that iron and boron deficiencies resulted in greater virulence by *F. solani*. A critical amount of iron is required for chlamydospore production in *F. oxysporum* (Simeoni et al. 1987). The iron may be chelated by siderophore-producing bacteria and as such may not be available to the pathogen.

In general, balanced nutrition of nitrogen, phosphorus, and potassium often results in less disease caused by *Fusarium* spp. (Walker and Foster 1946). It is when an unbalanced nutrition regime results in either diminished concentrations of potassium or high concentrations of nitrogen that disease occurs (Stack and Langhaus 1986; Walker and Foster 1946).

Effects on *Phytophthora* Disease Severity

Moderate to high balanced fertility has been reported to increase severity of a number of diseases caused by *Phytophthora* spp. (Schmitthenner and Canaday 1983). Effects of nitrogen on *Phytophthora* diseases vary with different host-pathogen combinations. There are as many examples of nitrogen increasing disease severity as there are of the element decreasing disease severity (Schmitthenner and Canaday 1983). For example, in a disease of southern pines called littleleaf (caused by *P. cinnamomi* Rands.), heavy nitrogen fertilization increased disease incidence in New Zealand (Newhook and Podger 1972). However, in the USA, littleleaf disease was first treated as a nitrogen deficiency because application of nitrogen fertilizer greatly improved condition of infected trees and halted disease spread (Campbell and Copland 1954; Hepting et al. 1945; Roth et al. 1948).

High rates of potassium are generally thought to decrease disease severity by *Phytophthora* spp. Conversely, effects of phosphorus on *Phytophthora* diseases have been inconsistent (Schmitthenner and Canady 1983). High phosphorus was associated with less late blight disease of potatoes (caused by *P. infestans* deBary); these effects were the opposite of those found for nitrogen (Awan and Struchtemeyer 1957; Borys 1966; Herlihy 1970). For littleleaf disease of pine in New Zealand, correction of phosphorus deficiency halted disease spread and resulted in recovery of diseased trees (Newhook 1970; Newhook and Podger 1972; Weston 1956), similar to the effect of nitrogen additions in the USA (Hepting et al. 1945). However, overall, phosphorus appears to have fewer effects on *Phytophthora* diseases than other major chemicals (Schmitthenner and Canady 1983).

Calcium may often have direct effects on some *Phytophthora* diseases (Schmitthenner and Canady 1983). For example, suppression of *P. cinnamomi* disease in Jarrah (Australia) occurred by application of calcium carbonate (Boughton et al. 1978). However, high calcium had no effect on disease severity of susceptible *Eucalyptus* spp., but increased root disease of nearby tolerant species (Halsall 1980). Although high calcium is one of the characteristics of soil suppressive to *P. cinnamomi* (Broadbent and Baker 1974), in general, high calcium increases severity of *Phytophthora* diseases (Schmitthenner and Canady 1983).

Micronutrients may be important in influencing *Phytophthora* disease severity. However, effects of most micronutrients have not been evaluated. Boron added to a complete fertilizer reduced disease severity of *P. cinnamomi* in pine (Roth et al. 1948). However, addition of heavy metals was ineffective in disease control.

High pH usually results in more severe disease caused by *Phytophthora* spp. (Schmitthenner and Canady 1983). Application of sulfur to reduce soil pH has been quite effective in controlling some *Phytophthora* diseases. For example, diseases caused by *P. cinnamomi* are controlled when soil pH is below 3.8 (Bingham and Zentmyer 1954). Of course, lowering pH with sulfur can only be used when acid-tolerant plants are grown. In most cases, conifer seedlings should do well in acidic environments. Therefore, lowering pH may be a practical way to reduce *Phytophthora* diseases in forest nurseries.

For controlling *Phytophthora* diseases, five factors involving chemical nutrition should be considered (Schmitthenner and Canady 1983):

1. Incorporate high rates of organic nitrogen before planting to stimulate toxicity of ammonia and nitric acid to *Phytophthora* propagules in soil. These chemicals may cause inactivation or lysis of pathogen propagules (chlamydospores, oospores and zoospores) in soil so that by the time of planting, pathogen populations will be greatly reduced.

2. Reduce soil pH to below 4.0 in fields used to grow acid-tolerant plants. Additions of sulfur to reach this desirable pH may be necessary.

3. Reduce soil pH to below 5.0 in high-aluminum soil for aluminum-tolerant plants.

4. Apply deficient nutrients judiciously to optimize uptake by host plant root systems that may be diseased by *Phytophthora* spp.

5. Avoid indiscriminate overfertilization in attempts to maximize productivity. Although manures, composted sludge, plant residues, or agricultural waste material may be good sources of organic matter, they may provide nutrients that enhance populations of potentially-pathogenic soil, thus disrupting microorganism balances in soil. This may result in greater disease because of increases of pathogens relative to competitors.

Conclusions

Disease-causing organisms in soil respond to changes in nutrients provided by amendments of fertilizer and organic materials. Some specific nutrients stimulate pathogen populations, thus increasing potential disease, whereas others may reduce populations and potential disease. Relationships among different nutrients probably are as important as the amount of an individual nutrient added. Also, the relative amount of particular nutrients used by crop plants in relation to amounts added is also important. In general, additions of just enough fertilizer required by seedlings is best. Providing too much may cause problems with disease organisms and potential leaching into groundwater.

Probably no single characteristic of soil is more significant to disease severity than pH (Chapman 1970). Solubility and availability of many chemicals are strongly influenced by soil pH. For example, initial effects of soil acidification are usually to increase solubility of calcium, magnesium, sodium, and phosphorus, as well as zinc, manganese, boron, lithium, copper, iron, nickel, and other elements. Substantial amounts of nitrite accumulate under neutral and alkaline soil conditions whenever a significant amount of ammonia or ammonium ion is present; nitrites accumulate and may persist for several months before being converted to useable nitrates (Chapman and Liebig 1952).

Growers need to carefully monitor disease and make sure that fertilizer regimes do not aggravate diseases. Excessive fertilization may not only be detrimental to seedling crops, but may aggravate disease by providing nutrients for buildup of soil-borne pathogen populations. Therefore, careful control of fertilization regimes should be an important part of integrated pest management programs in forest nurseries.

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