TOWARD PRODUCING DISEASE-FREE CONTINER-GROWN NATIVE WILDLAND PLANTS David L. Nelson

ABSTRACT: Methods and a fundamental philosophy for producing healthy planting stock of native wildland plants are presented. Drawing from the experience of agriculture, horticulture, and forestry, cultural and biological disease control methods are reviewed. The focus is placed on certification of planting materials, producing pathogen-free propagules, greenhouse design and management for disease prevention, controlling pathogens in plant growing medium, the role of native-host genetic variability, and managing biological control of soil-borne diseases.

INTRODUCTION

Interest is increasing rapidly in using native wildland plants to revegetate disturbed areas and improve wildlife and livestock ranges in the western United States. Producing healthy planting stock can enhance these activities. It is important to know when to take action in preventing and controlling diseases of plants. It is generally believed that if a disease is present it will be obvious and the plant will die, or if it does not die then it must not have a disease. A plant without obvious disease symptoms is not necessarily a disease-free or pathogen-free plant. There are also examples of viruses, bacteria, fungi, and nematodes that affect roots only slightly. The only visible injury is reduced top growth. Probably as much damage results from these "root nibblers" as from virulent pathogens that induce obvious symptoms and kill plants rapidly. Fungicidal treatment to prevent seedling diseases such as damping-off often only suppresses the pathogen which later induces further disease in the container plant or in the field after outplanting (Baker 1965).

A wise approach is to adopt rigid disease prevention methods regardless of present known disease problems. Currently, little if any research effort is directed toward controlling diseases in the production of wildland planting stock. The purpose here, therefore, is to relate facets of existing knowledge developed over the years in the horticultural and agricultural experience that may be of value in the wildland plant scene.

Becoming aware is a major step in preventing plant disease problems. A long-standing principle in plant pathology is that action must he taken in advance to prevent disease problems. The goal of producing disease-free Flarting stock is also a responsibility, from a biological standpoint, that must be considered. There are several basic reasons for emphasis on producing disease-free planting materials. Clearly, the production of healthy planting stock is essential. It is important to avoid introduction of seed-borne pathogens to new field sites via planting stock. After outplanting, failure of the plant from a disease that did not express obvious symptoms during container culture is an important but more subtle problem. The responsibility to produce disease-free stock extends beyond the marketing stage of containerized plants.

How can an emerging native wildland plant industry organize itself to discharge this responsibility? Through an interaction of private, State, and Federal interests, an improved certification program should be developed. Certification of various plant attributes is already in progress at State and private concerns, plant introduction stations, and plant material centers across the West. The purpose here is to stress certification against plant disease. Benefits can be realized. Disease prevention should focus on certification in three basic areas: (1) seed-borne and vegetative-propagule-borne pathogens, (2) producing disease-free planting stock, both bare-root and containerized, and (3) a rigidly dofinod and controlled genetic 1':ise for seed collections,

Various methods have been used to prevent plant disease in container-grown planting stock. These methods have included seed certification, cultural sanitation, chemical seed treatment, pesticidal drenches, soil fumigation, heat treatment of planting media, vegetative propagule disease indexing, apical shoot tip culture, biological control, and pathogen suppressive growing media. These constitute a broad area of information; and this discussion will be limited primarily to cultural and biological means of producing disease-free, container-grown wildland plants.

CULTURAL CONTROL

Sanitation is the most important single guideline in the cultural control of plant disease problems of container-grown plants.

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Sanitation is essential in the production, collection, cleaning, storage, and germination of seed. Sanitation also is an essential factor in maintaining greenhouse and shadehouse environments and in seedling transport and planting.

Pathogen-free Plant Propagules

Use of pathogen-free seed is an obvious first step in controlling diseases in container-grown plants as well as in nursery or direct field seeding. Several good references on seed-borne pathogens are: Baker 1956, 1Q72; Baker and Smith 1966; and Harman 1983. Plant pathogens may accompany seed independently as spores, resting structures, host debris, infested soil, and nematode galls. They may be carried passively, attached to the surface of seed or fruit parts, or they may be carried internally, imbedded in host seed tissue.

Seed dissemination of pathogens is a natural biological mechanism that has evolved as a mode of transmission in space, from season to season and from plant generation to generation. Seed-borne pathogens are not always transmitted, but when they are, they are usually a source of severe loss. Viruses are frequently seed transmitted. They usually infect gametes and persist during seed development. Mechanically transmitted viruses infest seed coats and arc then transmitted to seedlings. Bacteria commonly infect developing embryos. They also enter the seed through the funiculus and reside in cavities of the seed coat or on outer layers of the embryo and endosperm. Fungi have numerous mechanisms for infecting seed and transmission to seedlings. The smuts of grasses invade embryos, and Fungi Imperfecti commonly infect seed coats and pericarps.

Injuries to seed during cleaning, for example, cracked seed coats, serve as entry points for both seed and plant pathogens and should be avoided. Pathogen propagules such as the sclerotia (ergots) of Claviceps and seeds of Orobanche and Cuscuta that accompany seed can he removed by separation during seed cleaning. Externally borne pathogens can usually be controlled by surface chemical treatment, but internally borne pathogens are more difficult to control requiring penetrating chemicals. To some extent thermotherapy has been successful in killing internally borne pathogens. Hot water, dry hot air, and aerated steam have been used effectively to eliminate pathogens. Aerated-steam treatment of seed has promising advantages (Baker 1969). Temperature can be controlled more accurately, seeds are left drier, there is less leaching, there is less damage to seeds, and the margin between pathogen thermal death point and seed damage is wider.

Prevention of seed-borne pathogens begins in the field with production of disease-free plants. Other methods include apical meristem culture, indexing and certification. Certification programs should be organized to establish tolerance levels for seed-borne pathogens. In the emerging native wildland seed industry what is the status of knowledge on seed-borne pathogens? Has action been taken to establish even the potential of what is inevitable? In the wildland scene a sound program must begin with gaining knowledge of seed-borne pathogens and their recognition by the collector.

Greenhouse design

Having achieved acceptable control of seedborne pathogens, the focus can then turn to seed germination and growth of containerized plants in greenhouse culture. Commonly, if not almost universally, prevention of plant disease is not considered in the design of greenhouses. Here again, enhancing sanitation to reduce sources of contamination should be the guideline. Greenhouses and adjoining headhouses are seldom designed by persons with insight into plant disease prevention. Although elaborate systems can be devised to exclude pathogens for special purposes, relatively simple design considerations can make big improvements in routine operations.

Contamination can be avoided or greatly reduced if, in the headhouse, container and equipment cleaning and preparation and media treatment activities are in a room separate from container filling and planting activities. These rooms should be separated by a buffer room to reduce contaminate passage. A vestibule should join the headhouse and greenhouse planting growing rooms to allow independent access to rooms with distinct activities (fig. 1). The usual single-room thoroughfare type headhouses or separate buildings that require outside transport of materials to greenhouses are unacceptable because contamination is likely.

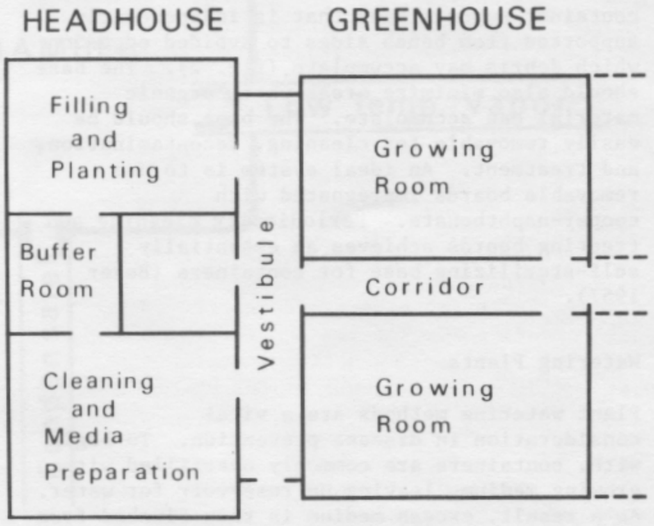

Figure 1.--Basic headhouse-greenhouse design for plant disease prevention.

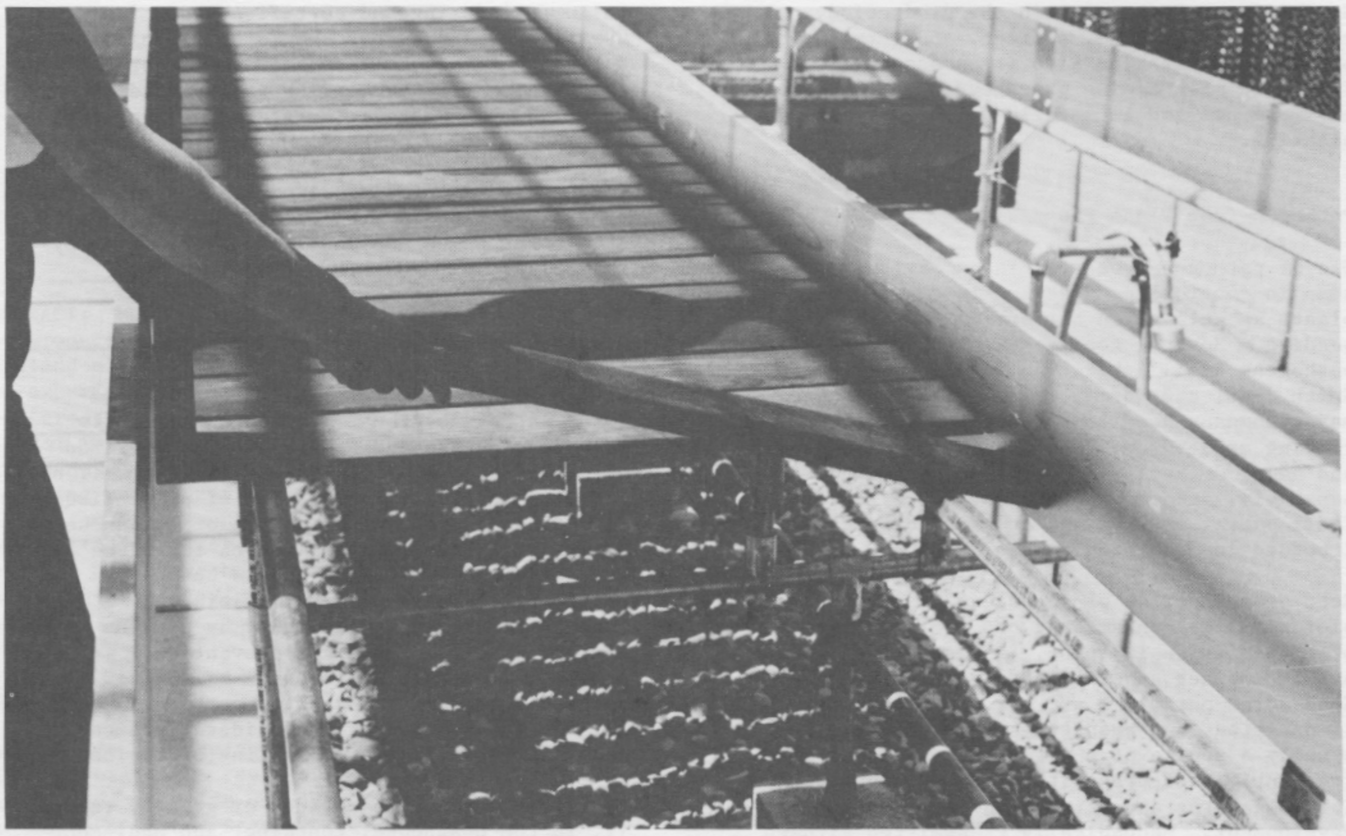

Figure 2.--A greenhouse bench designed to prevent plant disease. Note bench sides are not fixed to board support pipes, and removable boards act to minimize accumulation of debris.

Container filling and planting operations should not take place in greenhouse growing rooms because soil or other planting media spillage serves as an organic substrate for growth of pathogens on greenhouse floors.

Greenhouse benches come in almost every form and design imaginable and unfortunately many are conducive to creating disease problems. A well-designed greenhouse bench should feature a container support base that is independently supported from bench sides to avoided edges on which debris may accumulate (fig. 2). The base should also minimize areas where organic material can accumulate. The base should be easily removable for cleaning, decontamination, and treatment. An ideal system is to use removable boards impregnated with cooper-naphthenate. Periodically cleaning and treating boards achieves an essentially self-sterilizing base for containers (Baker 1957).

Watering Plants

Plant watering methods are a vital consideration in disease prevention. To begin with, containers are commonly overfilled with growing medium, leaving no reservoir for water. As a result, excess medium is then flushed from containers and accumulates under benches to provide an organic base for microorganisms. Individual watering nozzles should be hung up and not allowed to contact the greenhouse Floor where they can become contaminated with disease-inducing organisms.

Container-grown plants are almost universally overwatered, which usually leads to seedling root rot problems. Wildland plants present a special problem in this regard because of their innate variability. Wide variation in germination rate, growth rate, and form requires selective watering. The nonselectivity of large automatic watering systems is a particular problem. Many desirable western U.S. native plants are adapted to semiarid environments and grow in soils with extremely low water potentials compared to the average domesticated ornamental. Little literature is available on the specific soil water potential requirements of seedlings. The role of soil water potential and the ecology of plant pathogens have been studied for some agricultural plant diseases (Cook and Papendrick 1970). Some unpublished data on wildland shrubs (Welch and others, USDA Forest Service, Shrub Sciences Lab., Provo, Utah), indicate that various species, sagebrush for example, grown in containers show little evidence of water stress even at -25 to -30 atmospheres. Visual judgment of the soil moisture a plant needs will probably result in overwatering. Critical measurement of soil moisture requirements is necessary to plan watering methods and consequently prevent disease.

Controlling Pathogens in Growing Media

Pathogen-free plant propagules and sanitary greenhouse management are of no avail without use of a controlled-pathogen growing medium. A vital component of native soil is the array of living microorganisms that exist in a dynamically fluctuating equilibrium. The system is controlled by the unique physical, chemical, and biological environmental characteristics of specific soil and vegetative types (Baker 1961; Elton 1958). The system is biologically buffered and permanent changes occur only with major environmental shocks. Such disruptions occur, for example, as a result of the numerous modifications incident to agricultural, greenhouse, or nursery operations.

Containerized plant growing media can be categorized as either containing soil or as soilless. The two types require different treatments to manage pathogens and retain proper biological and physical plant growth factors (Baker 1957, 1962a, 1962b). It cannot be assumed that soilless media ingredients, for example, peat, sawdust, ground bark, perlite, or vermiculite are or will remain pathogen-free. It can he more safely assumed that what these media do have are low or poorly balanced microorganism populations. Treatments to eradicate or control pathogens must contend with these unique features.

Fumigation of media with chemicals is a widespread practice, although there are attending disadvantages (Baker 1957, 1961, 1965). Toxic chemicals are difficult to contain in greenhouse operations and their use may become legally complicated in urban areas. Toxic residues may remain even after long periods of aeration. Fumigants move through the soil in a concentration gradient resulting in nonuniform treatment. Broad spectrum fumigants such as cloropicrin and methyl bromide tend to "overkill" and result in biological vacuums. More specific fungicides, for example , PCNB, Dexon, carbon disulphide, and Nemagon are available. However, pathogen populations are selected for resistance more rapidly by the more specific chemicals. Steam sterilization of media by heating to 212° F also results in biological vacuums. Both chemical and heat methods have the danger of recontamination. The drastically reduced competition in these treated soils results in rapid uninhibited growth of introduced pathogenic organisms. Loss to disease may he more severe than in untreated media. Phytotoxic compounds are also formed in soils that are treated at high temperatures.

Aerated-steam treatment of plant growing media avoids most of these problems (Baker 1962a). With this system, air is injected into the steam mass, producing a lower temperature vapor (fig. 3). By careful adjustment of vapor temperature, organisms can be selectively eliminated from the soil. Parasitic organisms tend to have more specialized enzyme systems than saprophytic organisms and thus tend to have lower thermal death points. Most weed seeds and many pathogenic fungi, bacteria, and viruses can be eliminated or inactivated in soil by aerated-steam treatment at 140° F for 30 minutes, leaving a beneficial population of microorganisms (fig. 4). Remaining fungi, bacteria, and actinomycetes then increase in number and antagonistic members act to inhibit invasion by contaminate pathogens. Fungistatic soil factors are initially lowered, but return to normal. Any phytotoxins produced are at low levels. Fire molds or "weed fungi" that grow profusely in sterilized soil are suppressed. The use of aerated steam is less expensive than steam sterilization because of the reduced temperature and treatment time required.

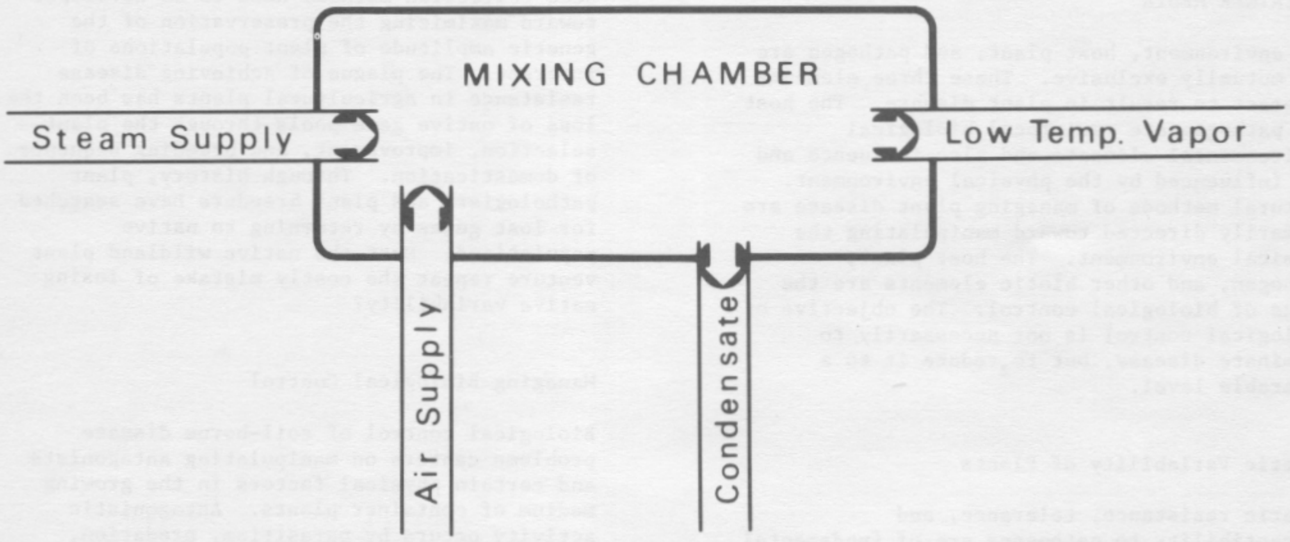

Figure 3.--Diagram illustrating the method of aerated-stream production for heat-treatment of plant growing media.

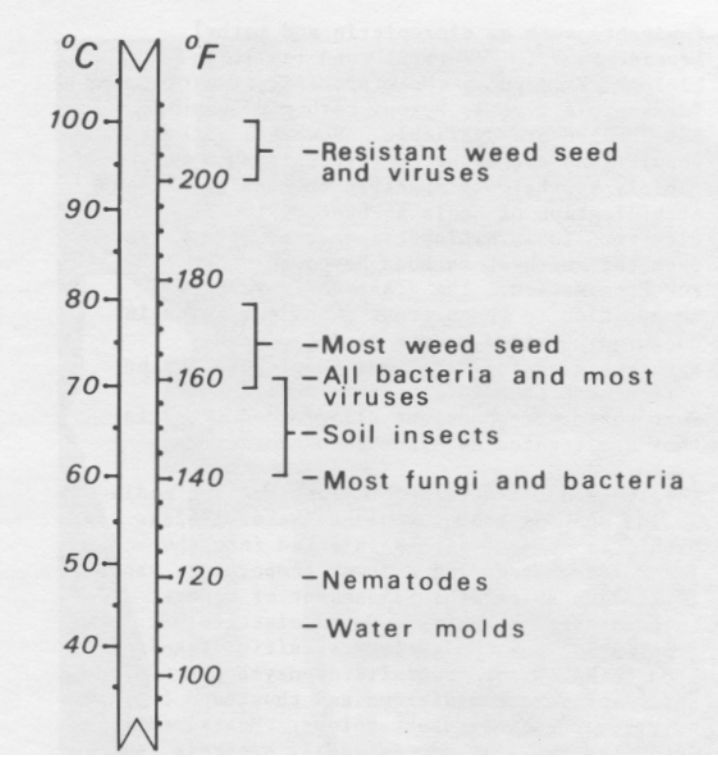

Figure 4.--Temperature scale illustrating the thermal death zones of plant pathogenic fungi, bacteria, viruses, and other soil organisms and weed seeds when subjected to moisture and heat, in most cases for 30 minutes (adapted from Baker 1957).

Aerated-steam treatment of soil is a prelude to and a valuable research tool in achieving biological control of soil-borne plant pathogens.

BIOLOGICAL CONTROL OF PLANT PATHOGENS IN CONTAINER MEDIA

The environment, host plant, and pathogen are not mutually exclusive. These three elements interact to result in plant disease. The host and pathogen are reciprocal biological environmental elements and also influence and are influenced by the physical environment. Cultural methods of managing plant disease are primarily directed toward manipulating the physical environment. The host plant, pathogen, and other biotic elements are the focus of biological control. The objective of biological control is not necessarily to eliminate disease, but to reduce it to a tolerable level.

Genetic Variability of Plants

Genetic resistance, tolerance, and susceptibility to pathogens are of fundamental importance in natural and manipulated biological control schemes. A basic difference exists in the genetic nature of wildland plants and domesticated plants. This is the native, relatively unaltered genetic variability of wildland plants. While this characteristic presents formidable problems for standardized cultural procedures, it is a virtue in providing disease resistance that must be rigidly protected. Variability is a basic factor in the survival and evolution of plant species. It must be protected at each step in the manipulation of native plants to be used for revegetation or range and wildlife habitat improvement. Methods used at each step must be studied carefully for impact on variability--from seed base selection, seed collection, seed cleaning, seed storage, pregermination treatment, and germination culture to seedling culture and plant establishment whether it be direct seeding or planting bare-root or containerized stock. Use of narrow line, vegetatively produced planting stock in wildland revegetation projects should he seriously questioned.

Cultural predisposition of container-grown plants to various pathogens is a two-fold problem in disease prevention. There could be loss from disease in containerized plant production or the potential for loss extended in time. If, for example, 50 percent of a native plant population is susceptible to a root rot when soil environment tends toward the anaerobic, one might predict predisposition to certain pathogens when container-grown plants are overwatered. The surviving population could then have a narrowed range of variability with which to confront their environment when outplanted.

To take advantage of naturally existing biological control systems now functioning in the wildlands of the West, it is important, in fact imperative, than an extreme effort is made to return revegetation plants (via containerized stock, bare-root, or seed) in near their native genetic state. Systematic seed collection methods need to be developed toward maximizing the preservation of the genetic amplitude of plant populations of interest. The plague of achieving disease resistance in agricultural plants has been the loss of native gene pools through the plant selection, improvement, and breeding sequence of domestication. Through history, plant pathologists and plant breeders have searched for lost genes by returning to native populations. Must the native wildland moot venture repeat the costly mistake of losing native variability?

Managing Biological Control

Biological control of soil-borne disease problems centers on manipulating antagonists and certain physical factors in the growing medium of container plants. Antagonistic activity occurs by parasitism, predation, competition for nutrients, and inhibitions from metabolic products of another organism (Baker and Cook 1974). Disease development may be suppressed in certain soils even though both pathogen and susceptible host are present (Baker and Cook 1974; Liu and Baker 1980). Both biological and nonbiological factors are involved in these suppressive soils. Biological control and the nature of suppressive soil are at the forefront of current research on controlling soil-borne diseases of greenhouse and container-grown plants (Henis and others 1979; Chet and Baker 1980; Scher and Baker 1980).

With the aerated-steam treatment method already mentioned, certain pathogens, but not all pathogens, can be selectively eliminated from soil. The common spore-forming bacterium Bacillus subtilis Cohn emend Praznowski is retained and proliferates, producing rather specific antibiotics that are antagonistic to reinvasion by strains of Rhizoctonia solani Kuhn, a common pathogen of container plants (Baker and others 1967; Olsen and Baker 1968). The degree of specificity characteristic of this bacterium limits broad application. Strains of the ectomycorrhizal fungus Laccria accata (Scop.:Fr.) Berk. & Br. protect Douglas fir (Pseudotsuga menziesii [Mirb.] Franco) against Fusarium oxysporum Schlect. emend Snyd. & Hans., which induces a root rot of seedlings (Sylvia and Sinclair 1983). The disease is suppressed in soil-free systems but not in heat-treated soil. Seedling root growth, however, is also suppressed by cell-free metabolites of the fungus. Various soil-free formulations containing composted hardwood bark used as a growing medium are suppressive to Ph tophthora cimmamomi Rands, Rhizoctonia solani, and Fusarium oxysproum, respectively root rot, damping-off, and wilt inducers (Hoitink and others 1977; Nelson and Hoitink 1983; Chef and others 1983). A dual mechanism has been suggested, attributed to antagonistic fungi (for example, Trichoderma harzianum Rifai) and heat-stable chemical inhibitors. Modification of soil factors such as pH and moisture levels can induce suppressiveness in a conducive soil. Parasitism of Rhizoctonia by Trichoderma is enhanced with these modifications.

Container growing media containing native soils have the advantage of a more diverse, complex microbiota than soilless artificial media. With complexity comes stability and a greater chance of biological control without modifications based on extensive research. With introduction of specific antagonistic fungi into sterile or soilless media to suppress specific pathogens there remains the risk of contamination and introduction of a second pathogen not influenced by the existing antagonists. In addition, the medium environment must be adapted to the selected antagonist. The potential for developing biological control with container-grown wildland plant diseases must exist. Existing natural systems must be studied. Disease inducing organisms and specific antagonists need to be identified.

One must conclude that no single disease control method is a complete answer, and so we hear terms like integrated control or a holistic approach--the battle goes on. Regardless and undoubtedly, sanitation and good housekeeping will continue to be in order.

PUBLICATIONS CITED

Baker, K. F. Development and production of pathogen-free seed of three ornamental plants. Plant Dis. Rep. Suppl. 238: 68-71; 1956.

Baker, K. F. ed. The U.C. system for producing healthy container grown plants. Manual 23. Berkeley, CA: University of California, Calif. Agr. Fxp. Sta.; 1957. 332 p.

Baker, K. F. Control of root-rot diseases; section 5, the pathogenesis of root degeneration. In: Toronto: University of Toronto Press; Recent Advances in Botany 1: 486-490; 1961.

Baker, K. F. Principles of heat treatment of soil and planting material. J. Austr. Inst. Agric. Sci. 28: 118-126; 1962a.

Baker, K. F. Thermotherapy of planting material. Phytopathology. 52: 1244-1255; 1962h.

Baker, K. F. Disease-free plants. In: Symposium, a look into the future; 1965 October 26 and 27. Dedication of the Kenneth Post Laboratories, New York State Flower Growers, Inc., and Cornell University; The Kenneth Post Foundation; 1965. 9 p.

Baker, K. F. Aerated-steam treatment of seed for disease control. port. Res. 9: 59-73; 1969.

Baker, K. F. Seed pathology. In: Kozlowski, T. T., ed. Seed biology. Vol. 2. New York: Academic Press; 1972: 317-416.

Baker, K. F.; Cook R. J. Biological control of plant pathogens. San Francisco, CA: W. H. Freeman Co.; 1974. 433 p.

Baker, K. F.; Flentje, N. T.; Olsen, C. M.; Stretton, H. M. Effect of antagonists on growth and survival of *Rhizoctonia solani* in soil. Phytopathology. 57: 591-597; 1967.

Baker, K. F.; Smith, S. H. Dynamics of seed transmission of plant pathogens. Annu. Rev. Phytopathol. 4: 311-334; 1966.

Chef, D. C.; Hoitink, H. A. .1.; Madden, 1,. V. Effects of organic components in container media on suppression of Fusaritim wilt of chrysanthemum and flax. Phytopathology. 73: 279-281; 1983.

Chet, I.; Baker, R. Induction of suppressiveness to *Rhizoctonia solani* in soil. Phytopathology. 70: 994-998; 1980.

Cook, R. .1.; Papendrick, R. I. Soil water potential as a factor in the ecology of *Fusarium roseum* f. sp. *cerealis* "Culmorum". Plant and Soil. 32: 131-145; 1970.

Elton, C. S. The ecology of invasions by animals and plants. New York: John Wiley and Sons; 1958. 181 p.

Harman, G. E. Mechanisms of seed infection and pathogensis. In: Symposium on deterioration mechanisms in seed; 73d annual meeting of the American Phvtopathological Society; 1981 August 3; New Orleans, LA. Phytopathology. 73: 326-329; 1983.

Henis, Y.; Chaffer, A.; Baker, R. Factors affecting suppressiveness to *Rhizoctonia solani* in soil. Phytopathology. 69: 1164; 1979.

Hoitink, H. A. J.; VanDoren, D. M.; Schmitthenner, A. F. Suppression of *Phytophthora cinnamomi* in a composted hardwood bark potting medium. Phytopathology. 67: 561-565; 1977.

Liu, S.; Baker, R. Mechanism of biological control in soil suppressive to *Rhizoctonia solani.* Phytopathology. 70: 404-412; 1980.

Nelson, F. B., Hoitink, H. A. J. The role or microorganisms in the suppression of *Rhizoctonia solani* in container media amended with composted hardwood hark. Phytopathology. 73: 274-278; 1983.

Olsen, C. M.; Baker, K. F. Selective heat treatment of soil, and its effect on the inhibition of *Rhizoctonia solani* by *Bacillus subtilis.* Phytopathology. 58: 79-87; 1968.

Scher, F. M.; Baker, R. Mechanism of biological control in a Fusarium-suppressive soil. Phytopathology. 70: 412-417; 1980.

Sylvia, D. M.; Sinclair, W. A. Suppressive influence of *Laccaria laccata* on *Fusarium oxyporum* and on Douglas-fir seedlings. Phytopathology. 73: 384-389; 1983.

In: Murphy, Patrick M., compiler. The challenge of producing native plants for the Intermountain area: proceedings: Intermountain Nurseryman's Association 1983 conference; 1983 August 8-11; Las Vegas, NV. General Technical Report INT-168. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 96 p.