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Abstract

These proceedings are a compilation of 20 papers that were presented at the regional meetings of the Intertribal Nursery Council and the forest and conservation nursery associations in the United States in 2009. The **Intertribal Nursery Council Meeting** was held at the Best Western University Inn in Moscow, Idaho, on July 14, 2009. Subject matter for the technical sessions included resource protection, collaborative research efforts, cultural use of native species, and native species programs. The **Joint Meeting of the Western Forest and Conservation Nursery Association and Intermountain Container Seedling Growers' Association** was held at the Best Western University Inn in Moscow, Idaho, on July 15 to 16, 2009, and was hosted by the University of Idaho Pitkin Forest Nursery. Subject matter for the technical sessions included seedling nutrition, pest management, nursery research and new technology, and general nursery topics. Afternoon field trips included tours of the University of Idaho Pitkin Forest Nursery, Decagon Devices in Pullman, Washington, and Washington State University Organic Farm and Composting Facility. The **Northeastern Forest and Conservation Nursery Association** meeting was held at the Amway Grand Plaza Hotel in Grand Rapids, Michigan, on July 20 to 23, 2009, and was hosted by Engel's Nursery Incorporated. Subject matter for the technical sessions included tree improvement programs, nursery culture and management, fumigation updates, and insect and disease management. Field trips included afternoon tours of the Brooks Lodge and Kellogg Forest in Augusta, Michigan, Van's Pines Greenhouses in West Olive, Michigan, and Engel's Nursery in Fennville, Michigan.

Keywords: bareroot nursery, container nursery, nursery practices, fertilization, pesticides, seeds, reforestation, restoration, tree physiology, hardwood species, native species

Papers were edited to a uniform style; however, authors are responsible for content and accuracy.

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Sponsoring Organizations

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Searchable Internet Database—www.rngr.net

The National Nursery Proceedings database includes papers published in the regional nursery proceedings (Western, Intermountain, Northeastern, and Southern) since 1949. The database can be searched by date, author, or keyword and papers are available in portable document format (PDF).

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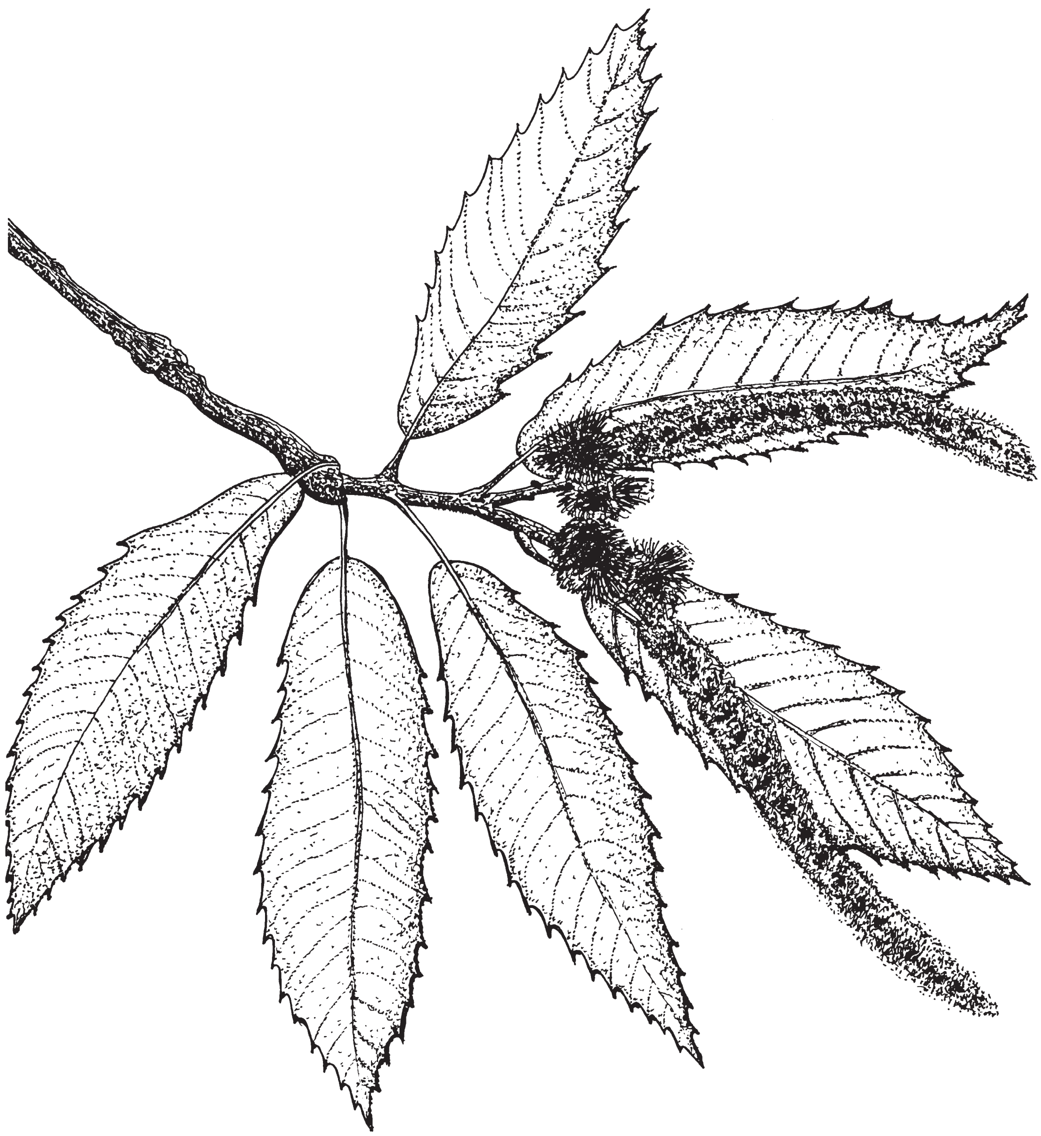
**No papers received; for more information, contact authors at the addresses provided in the list of attendees.

Intertribal Nursery Council Meeting

Moscow, Idaho

July 14, 2009



Intertribal Nursery Council Meeting

American chestnut drawing by Steven Morrison, College of Natural Resources, University of Idaho.

Protecting Black Ash from the Emerald Ash Borer

Les Benedict

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Benedict L. 2010. Protecting black ash from the emerald ash borer. In: Riley LE, Pinto JR, Dumroese RK, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2009. Proc. RMRS-P-62. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station: 1-2. Online: http://www.fs.fed.us/rm/pubs/rmrs_p062.html.

Abstract: Black ash (*Fraxinus nigra*) is an important resource for Tribes in the Northeast and Great Lakes regions of the North American continent. Ash in North America is being threatened with widespread destruction as a result of the introduction of emerald ash borer beetle (*Agrilus planipennis*) in 2002. Measures are being taken to slow the spread of emerald ash borer beetle. Unless proactive measures are taken to secure black ash supplies, however, Native American basket makers stand to lose their only source of materials. One potential action is the establishment of shelter populations of black ash in geographically isolated areas of the country.

Keywords: basketry, medicinal plants, *Fraxinus nigra*

Background

Black ash (*Fraxinus nigra*) is an important non-timber forest product utilized by the Mohawks of Akwesasne in making splint baskets. The tree is also an important medicine plant used by traditional healers to treat a range of maladies. Mohawks prize the black ash because its annual growth rings are easily separated by hitting the bolt with a heavy mallet or back of an axe. After being peeled from the log, the splints are smoothed, split, cut to width, and woven into baskets. Once woven, the black ash splints become dry and sturdy, producing durable products (utility baskets) used for hunting, fishing, and gathering. Mohawk basket makers also produce ornamental baskets that reflect strawberries, corn, and traditional symbols in their weaves. The ornamental baskets interweave "sweet grass" for adornment and aesthetic appeal because the grass is highly fragrant. Black ash baskets are used in traditional ceremonies such as weddings, where the man and woman exchange baskets containing goods symbolizing how they will care for one another and their family. Black ash basketry is also an important subsistence industry for many Mohawks who depend on basket sales for income to purchase food and other necessities.

The introduction of the emerald ash borer beetle (*Agrilus planipennis*) (EAB) from Asia threatens all ash species in North America and Native American black ash basketry. Federal and state agencies have been studying EAB and have developed some hopeful controls, but it continues to spread through the eastern states despite firewood and nursery material quarantines.

While the pest and forest management experts have been studying impacts and evaluating controls, Native Americans are concerned about the long-term prospects for black ash needed to sustain basketry. Discussions have included harvest and long-term storage of black ash materials from existing supplies. Storage options may include debarking and dry storage or submerged storage. The most apparent issue associated with storage options is space and location.

Another option includes establishing and managing plantations of ash as an agri-forestry enterprise. Plantations will minimize costs for pest controls even though they may in fact become a sink for insects such as EAB.

For either option, logistics, costs, and feasibility must be examined. The main point is that while agencies struggle with the expanding EAB infestation and play catch-up in learning about the insect and how best to control it, the future of Mohawk basketry in its present form is doubtful.

Proposal

An appeal was made before the Intertribal Nursery Council to determine the level of interest by Native American participants in establishing shelter populations of black ash as a means of maintaining a supply of trees to be used for basket-making materials. To date, some stands have been established on islands in the St Lawrence River and on Martha's Vineyard, MA for restoration projects. These may serve as models for shelter populations should EAB be prevented from being spread to these places by controlling access to them. There is a report that the Mic Mac people on Prince Edward Island are restoring black ash to the island. This presents an opportunity to maintain black ash for basket-making materials and genetic stock as well.

Opportunities may exist to grow black ash (and also white ash [*Fraxinus americana*]) in the Pacific Northwest regions, such as Oregon and Washington, on commercial scales to produce basket materials for Mohawks. Many questions need to be answered regarding such a proposal, including investment, cost, feasibility, and, most important, the quality of black ash trees produced on the new landscape to which they are introduced.

Summary

The purpose of my presentation was to illuminate the severity of impact due to EAB on Mohawk culture and traditional practices, as well as to highlighting the tremendous economic impact soon to be realized as a result of EAB infestation and spread. While experts work on control of EAB, concerns for having long-term access to black ash supplies need to be addressed. A request was put forth to attendees who may be interested in establishing shelter populations of black ash to supply materials for Mohawk basket makers.

Establishing, Conducting, and Maintaining Mutually Beneficial, Collaborative Research Efforts with Tribes

Justine E James Jr and Daniela J Shebitz

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James JE, Shebitz DJ. 2010. Establishing, conducting, and maintaining mutually beneficial, collaborative research efforts with tribes. In: Riley LE, Pinto JR, Dumroese RK, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2009. Proc. RMRS-P-62. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station: 3-5. Online: http://www.fs.fed.us/rm/pubs/rmrs_p062.html.

Keywords: beargrass, collaborative research, basketry, traditional ecological knowledge

Introduction

No one perspective provides all of the answers to the environmental issues of our time. Humans have created a multitude of problems during the past 150 years or so, not only through continued development and industrialization, but also by suppressing and discontinuing land management techniques that historically enhanced local biodiversity. Through activities such as repetitive burning (with low-severity fire) and selective harvesting and pruning of useful plants, many landscapes were managed in a way that encouraged the growth of culturally important plants and discouraged others from growing in the area. While cultures have changed with time, so too has the landscape.

Fortunately, academics, agency scientists, and policy makers are increasingly seeking traditional ecological knowledge (TEK) as a source of ideas for ecosystem management, restoration, and conservation biology. While many recognize TEK as complementary to western scientific knowledge, its incorporation into scientific research is uncommon. We believe that both traditional and Western scientific worldviews should be integrated into research projects when possible. This is particularly true in cases where the research is being conducted with an area or species that has been, or currently is being, managed or used by indigenous people.

A working relationship between two groups such as an academic institution and a tribal nation requires an enhanced form of communication that emphasizes trust, respect, and shared responsibility. It requires an open and free exchange of information and belief among parties, which leads to a mutual understanding and comprehension. This relationship is essential to a process that results in positive collaboration and informed decision-making.

It is essential for ecologists to not only be concerned about threats to the land, water, plants, and animals that have characterized an area historically, but also for the people that have knowledge that can be used to help address environmental issues. There is an inextricable link between indigenous cultures and the land in which the traditions evolved. As native species of plants and animals and their respective habitats are lost due to factors such as development, suppression of fires, or overharvesting by non-indigenous people, the traditions that relied on these resources are threatened. Our aim has been to unite traditional ecological knowledge with a western scientific perspective to address environmental issues that can benefit not only the plants of concern, but also the cultures that use those species.

Once we unite indigenous and western science perspectives effectively, there is great potential to address environmental concerns such as threatened and endangered species, as well as health concerns such as diseases and diets in today's societies.

How to Start a Collaborative Research Project

When an outside researcher works with Indian tribes, he/she must approach them with an open mind. One must realize that tribes are inundated with requests from various agencies and groups. They often have limited staffing and financial resources, as well as time constraints. Therefore, the tribes must decide which endeavors are the most beneficial for their interests. To initiate the project, a researcher must meet with the appropriate tribal government representatives. This process is greatly facilitated if a member of the tribe advocates for the importance of the project. In addition, it is important for the researcher to allocate ample time to the approval process, because this step can be long-lasting. Often, multiple groups must be approached, with each having their own concerns regarding research in general, and likely a specific project's objectives.

As a scientist, it is helpful to have an ongoing aspect of the project that is not dependent upon human participants. It is beneficial to work on either compiling literature or conducting preliminary exploratory or experimental work while awaiting approval so that progress can still be made during that time. In addition, any background knowledge that you gain regarding the subject area will further benefit your work once you do initiate ethnographic research.

Ideally, work with tribal members will continue throughout the duration of the research projects, for example, having them help in the field, arranging interviews with their friends and family, and reviewing the material before it is prepared for publication.

Beargrass Research as a Case Study

The idea for our research project started because of concerns among the Quinault basketweavers and other Olympic Peninsula tribes regarding the status of a fundamental basketry plant. For the Quinault, an ecological restoration project for beargrass (*Xerophyllum tenax*) would be a very valuable project for future generations of basketweavers. Daniela Shebitz from the University of Washington was contacted by Justine E James Jr, the Cultural Resource Specialist with the Quinault Indian Nation (QIN), due to her interest in both ethnobotany and restoration ecology. Daniela was asked to attend a meeting held with the Olympic Peninsula Intertribal Cultural Advisory Committee (OPICAC) in which many of the members reported a decline in beargrass quantity on traditional gathering sites.

Despite utilitarian and aesthetic benefits of beargrass, limited work has focused on the species, especially on the Olympic Peninsula. In addition, traditional knowledge concerning its past management, and land management in general, is declining among the indigenous people of the area. Therefore, researching past beargrass distribution and management not only enabled us to determine the best way to conserve what remains of its habitat and population in the lower elevations of the Olympic Peninsula, but it also provided an opportunity for people, both native and non-native, to become more aware of the importance and significant influence of past traditional management practices, such as anthropogenic burning.

Initially, there was some resistance to this project. A tribal elder initially rejected the study, stating: "People from the outside just take and take from us and never give anything in return!" She was referring to academics, researchers, and others that conduct studies and research with the reservation tribal members. In order to assuage concerns over data ownership, an agreement was made that stated that all knowledge accumulated from this project was to be shared with the Quinault Indian Nation. Consequently, this stepping stone created the fundamental basis for our working relationship. One party, the University of Washington, is to obtain input regarding interests, concerns, and expectations of another party, the Quinault Indian Nation, and to integrate that input into a decision-making process. Specifically, this referred to the results and conclusions of the beargrass ecological restoration project.

To initiate the project, Daniela had to meet with the appropriate tribal government representatives. Due to the nature of the beargrass project, Daniela and Justine met with, and presented their proposal to, the Department of Natural Resources and the Environmental Protection Division. Daniela was also asked to provide an outline of the project to the QIN Business Committee. This request was made to enable QIN to oversee the project within boundaries of the Quinault Indian Reservation (QIR). The QIN sanctions all research projects within the QIR.

Our research with beargrass began in the summer of 2003 and had ethnographic, historical, ecological, exploratory, ethnobotanical, and experimental components. Ethnographic interviews were conducted with members of the Quinault, Quileute, and Skokomish Tribes to gain an understanding for the pre-European settlement landscape and traditional land management practices, focusing primarily on burning, and the role of beargrass as a basketry plant.

Not only was it essential to gain approval of the QIN to conduct interviews, but it was also required for Daniela, as a researcher affiliated with a university, to gain approval of the Institutional Review Board. This extensive application process includes providing the university with a description of the project, a letter of consent to be signed by each participant, and an example of the questions that would be asked during the interviews.

After approval was granted, the next step was to identify the resource informants or contacts, namely the basketweavers, to assess the condition of the beargrass populations, the threats, history, and traditional knowledge. Many of the basketweavers are elderly, which necessitated traveling to their homes for interviews and discussions. Justine, as the tribal member, attended all of the interviews that Daniela conducted. Together, Justine and Daniela provided copies of the research project and verbally explained it to the participants. In this study, each formal interviewee was paid US$ 30.00 for their time. The interviews were taped, if the participant allowed it to be. Once the interview was transcribed, each participant was given a transcription of the interview. Throughout the course of the study, we revisited elders, informants, and basketweavers for periodic updates. Returning for further conversation enabled them to have time to reflect and for memories to come back to them. Often these recollections are essential to the success of the project.

Both Justine and Daniela searched libraries, archive centers, and tribal and local museums to find documented resources of information regarding beargrass and historic land management in the region. This information was used to formulate a study design for the field activities.

An extensive historical ecology study was conducted to reconstruct the past landscape in order to assist in restoration efforts. For the exploratory study, we researched the ecology and population status of beargrass throughout the Olympic Peninsula. Through the exploratory study and the ethnographic interviews, we determined that beargrass abundance has declined in the low elevations of the Olympic Peninsula. Research indicated that the decline is, in part, due to the loss of open-canopied habitat due to the absence of prescribed burning by Olympic Peninsula tribes during the past 150 years.

Our next step was to determine if we could try to reintroduce anthropogenic burning to enhance beargrass populations. We conducted a series of five experiments (four field and one greenhouse experiment) through which we studied the vegetative and sexual reproductive response of beargrass to fire. Justine assisted in the field studies. Some of the experiments were conducted on the Quinault Reservation, with the assistance of the Quinault Fire Crew, while the rest of the studies were conducted on the Olympic National Forest (ONF) land. We determined that fire does indeed have great potential to increase beargrass vegetative reproduction, seed germination, and seedling establishment.

Because anthropogenically-managed habitats were part of the heritage of the indigenous people in western Washington, the restoration of such habitats in the region offers an opportunity for Tribal Members to gather plants such as beargrass that have declined in quality and/or quantity as their habitat has been lost. Ecologically, the restoration of savannas and anthropogenically-managed wetlands to the Peninsula assists in the return of unique assemblages of plants that have been threatened or lost due to the suppression of natural and anthropogenic fires during the past century.

The most significant implication of this research is to illustrate the importance of incorporating traditional land management techniques when restoring an ecosystem. To work towards this goal, we integrated both TEK and western scientific knowledge to investigate historic fire regimes and the structure of indigenous landscapes, gain an understanding of the ecology of beargrass, and research the influence of fire on beargrass. Through this project, we laid the foundation for, and initiated, a habitat restoration effort on the Peninsula that involves Tribes, the ONF, and the University of Washington so that beargrass can continue to be a fundamental component of the ecology and cultures of the Olympic Peninsula.

Challenges with Collaborative Research

Working with people presents both challenges and rewards that are very different from working with just plants or an ecosystem.

Traditional knowledge is permanently lost when individuals familiar with the past landscape and management practices pass on without sharing their wisdom. This is referred to as the "fading record" problem of attempting to capture what remains of reliable information. Fragmented recollections of elders, coupled with the scarcity of those knowledgeable about the past, limit the ability to understand the historic landscape. Despite this fading record, knowledge of the past is still held by some elders and those who have been taught by their ancestors.

It is often quite difficult to find people to interview without the assistance from a member of the tribe. There is often skepticism initially about the benefits, as was noted in our beargrass study. Additionally, there are inevitably times when the researcher with a scientific background might use phrases or terms that are not understood by the interviewee. Therefore, it is very beneficial to be accompanied by a tribal member.

The approval of the university through the Institutional Review Board (IRB) might be very time–consuming, because the application process can be extensive. It is helpful to have a mentor who can walk the research through all of the procedures associated with the process. With the approval comes the requirement to have letters of consent signed by each participant. The reactions of tribal members upon reading and signing a letter can be quite varied. Some may be thrown off guard a bit and intimidated by the letter, while others might be reassured that the research project is being overseen by the university. However, the IRB is established to protect their rights as individuals and ensure they understand that as a researcher, we can incorporate their knowledge into addressing the issues with which we are concerned. And, as such, it is important for the interviewees to know that if they consent, information that they share may be published.

Conclusion

Ethnographic interviews are arguably one of the most under-utilized tools that can assist in defining the goal of a restoration project. In particular, there is potentially unique TEK regarding the past landscape or status of local plant and animal species. Inviting indigenous people to participate in the development of goals and carrying out the restoration project can have profound ecological and cultural benefits.

No greater reward from research can come than having results that can benefit both people and the environment. From our perspective, the greatest results evolve from establishing, conducting, and maintaining mutually beneficial collaborative research.

For our beargrass work, the project has enriched our lives as we have formed a friendship that will last throughout our lifetime. The research benefitted both the Quinault Indian Nation and the University of Washington, and formed the basis of Daniela's doctoral dissertation. Through dedication and perseverance, we overcame longtime institutionalization from both the academic and tribal realms to create a lasting belief that if you have trust and respect, you can overcome any obstacle for the betterment of all.

The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented within.

An Introduction to the Colorado Plateau Native Plant Initiative

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Padgett W, Olwell P, Lambert S. 2010. An introduction to the Colorado Plateau Native Plant Initiative. In: Riley LE, Pinto JR, Dumroese RK, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2009. Proc. RMRS-P-62. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station: 6-11. Online: http://www.fs.fed.us/rm/pubs/rmrs_p062.html.

Abstract: The Colorado Plateau Ecoregion is occupied by a variety of ecosystems requiring restoration activities following natural and human-caused disturbances. The Colorado Plateau Native Plant Initiative, included in the BLM Native Plant Materials Development Program, was established as a part of the Seeds of Success program. This program is a partnership between USDI Bureau of Land Management, Royal Botanic Gardens (Kew, Richmond, United Kingdom), other federal agencies, and conservation organizations that focus on the collection, conservation, and development of native plant materials for stabilizing, rehabilitating, and restoring lands in the US. Opportunities and challenges for this program have been identified, and the vision, goals, and objectives that address these and more are being incorporated into a 5-year strategy and action plan. Advisory teams and working groups have been identified and their roles outlined in order for the program to reach its goals and objectives for restoring native ecosystems within the Colorado Plateau.

Keywords: ecosystem diversity, native plant materials, native plant seeds, restoration, rehabilitation

Introduction

The Colorado Plateau in the American Southwest is a land of extremes. From elevations near 600 m (2000 ft) at the bottom of the Grand Canyon, to elevations over 3800 m (12,500 ft) at the top of Mount Peal in the LaSal Mountains, the Plateau experiences a wide variety of temperatures and precipitation. Winters are cold, with precipitation from the north and west and significant snow depths at higher elevations. Summers are hot, with intermittent, often intense monsoonal storms that arise from the eastern Pacific, Gulf of California, and Gulf of Mexico. Plant communities of the Colorado Plateau evolved in these environments and are representative of the highly variable and extreme conditions that occur here.

The Colorado Plateau Native Plant Initiative (CPNPI) evolved from the more local program, the Uncompahgre Plateau (UP) Project, whose goal was to improve ecosystem health and function through collaboration with partners and local communities. This program was formally established in 2001 through the development of a Memorandum of Understanding/Cooperative Agreement with western Colorado's Public Lands Partnership, USDI Bureau of Land Management (BLM), Colorado Division of Wildlife, and the USDA Forest Service (USFS). In 2004, Western Area Power Administration and Tri-State Generation and Transmission Association joined the partnership. Representatives from several federal and state agencies, Northern Arizona University, and the UP Project met in 2007 to discuss the need for, and establishment of, the Colorado Plateau Native Plant Initiative. Conceptually, the CPNPI was to be an interagency, multi-state program whose focus would be the identification, development, increased availability, and use of native plant materials for restoration purposes throughout the Colorado Plateau. The Utah State Office of the BLM took the lead in establishing this program.

The Colorado Plateau has been defined in various manners by different agencies and organizations, but all agree that it occupies portions of four states: Arizona, Colorado, Utah, and New Mexico. Figure 1 illustrates the boundary used by the CPNPI, that incorporates ecological characteristics described by the US Environmental Protection Agency, USFS, and The Nature Conservancy.

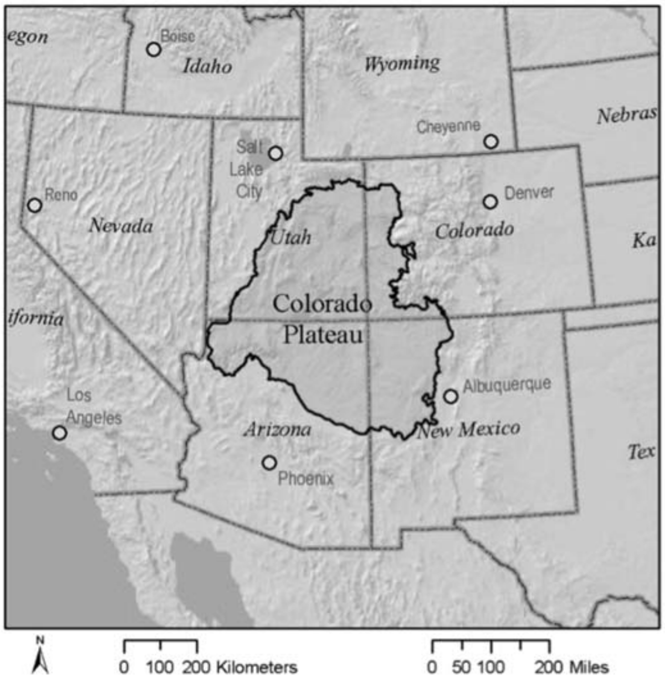

Figure 1. The Colorado Plateau in the Four Corners region of Arizona, Colorado, New Mexico, and Utah.

The CPNPI tiers directly to the national Native Plant Materials Development Program (NPMDP), which was created by Congress in the 2001 Department of Interior and Related Agencies Appropriations Act. In this Act, Congress directed the BLM to lead an interagency effort to develop a long-term program to supply and manage native plant materials for use in stabilization, restoration, and rehabilitation efforts on federal lands. The BLM has established programs for native plant materials development in the Colorado Plateau, Great Basin, and Mojave Desert ecoregions. The Wyoming Basin of southern Wyoming and Permian Basin of western Texas have also been identified as areas for future program development.

Vision and Goals

The CPNPI was conceptually identified, along with the vision, goals, and objectives for this program, by the 2007 Moab Working Group. It was the belief of this group that the synergy of this regional effort would make the best use of limited time and resources and assist all the partners in meeting their goals and objectives. At the 2009 meeting in Salt Lake City, issues and challenges for the CPNPI were identified, and the vision, goals, and objectives were updated as well. These are summarized below and provide the basis for the further development of this program.

Vision

The vision of the Colorado Plateau Native Plant Initiative is a Colorado Plateau that supports healthy and resilient native plant communities now and for future generations. This vision evolved out of initial work done in 2007 by the various state and federal agencies, Northern Arizona University, and the UP Project.

Goals

Long-Term Strategy

Development of a long-term strategy to facilitate the development of an adequate supply and diversity of native plant materials for restoration of landscapes within the Colorado Plateau was identified as Goal 1. In order to meet this goal, we developed a 5-year strategy and action plan, which will be updated annually in order to identify changes in priorities and to establish and maintain the program's annual operating needs. We are in the process of identifying current and future native plant materials needs, and target species have been identified for the Colorado Plateau for this purpose. Existing research and demonstration facilities are being evaluated regarding their ability to meet our needs.

Methodologies and Technologies

Identification of existing methodologies and technologies and future work with partners to develop and test new methodologies and technologies to ensure successful establishment and persistence of native plant materials was identified as Goal 2. The program is working with the Southwest Biological Science Center of the US Geological Survey (USGS), the research branch for the BLM, to provide an overview, synthesis, and assessment of existing and current research relevant to development of native plant materials for the Colorado Plateau. This will include topics such as: 1) plant life history; 2) seed transfer zones; 3) common garden studies; 4) seed germination and establishment data; as well as a broad variety of other topics. USGS will work in coordination with the CPNPI coordinator to develop a long-term strategy for conducting a cooperative research program specifically framed by the goals and objectives identified in the CPNPI Five-Year Strategy and Action Plan. USGS will begin research on genetic variability of priority restoration species identified by the BLM using plant materials collected through the Seeds of Success program.

Other objectives include the identification of adaptable prescriptions for different ecoregions, land types, and species. The variation among ecological sections within the Colorado Plateau Ecoregion is described below. Adaptable management prescriptions will be developed over time as different needs are identified for restoration and rehabilitation efforts. To ensure adequate evaluation of native plant materials for use in restoration, we are developing a species screening guide to assist in the determination of the feasibility of using any given germplasm for release.

Communication with Public and Private Entities

Goal 3 was to communicate with public and private entities (producer and consumer) to build demand and share information regarding the development and use of native plant materials. Communication is instrumental to the development of any native plant materials development program. Through workshops, symposia, publications, and the internet, CPNPI has made this one of its highest goals to meet in the near future. Links to the program are being developed and will be available on the BLM Utah State Office web page (URL: http://www.blm.gov/ut/st/en/prog/more.html). The program is also working with partners to establish demonstration gardens. The University of Utah Entrada Field Station, northwest of Moab, UT, is being considered as a location for both demonstration gardens and common garden studies because of its location, available study sites, and facilities. Locations of all demonstration areas will be identified on the above-mentioned web site. The web site will also provide information for growers and other users about the status of species in development. Success stories will be highlighted and links will be made with other agency web pages.

Opportunities and Challenges

Various opportunities and challenges were identified that the newly-established CPNPI will be able to address and meet. Opportunities for the program include: 1) increasing the availability of native plant materials; 2) development of new technologies for the use of native plant materials; 3) improving the cost-effectiveness of using these materials; 4) updating restoration paradigms and guidelines; 5) meeting the needs for fire restoration and rehabilitation; and 6) providing outreach and education regarding the program.

Challenges include: 1) improving coordination among the various partners; 2) meeting the needs for the restoration of a diverse range of ecosystems within the Colorado Plateau; 3) improving the means for which commercial seeds can be collected; 4) providing assistance for agencies through the development of contracts and agreements for increasing native plant materials; and 5) developing realistic and effective long-term program planning to keep the program moving forward.

Opportunities

Increasing Availability of Native Plant Materials

Because of the amount and kinds of disturbances that have occurred and are occurring on the Colorado Plateau, and because of the desire to restore these ecosystems to a more resilient state, the demand for native plant materials has increased significantly over the past several years. Nationally, the BLM purchases a tremendous amount of seeds for revegetation purposes, mostly for fire rehabilitation. Figure 2 is based on data from consolidated seed purchases between 1996 and 2008 for wildfire restoration activities. In 1999, a year with many large fires, the BLM bought more than 2.9 million kg (6.5 million lb) of seeds, nearly 70% being non-native. The availability of native seeds was limited at that time and it was clear that efforts were needed to increase the supply of native plant materials for future uses.

In 2007, the BLM purchased more than 1.8 million kg (4 million lb) of native seeds, but demand fluctuates annually with variations in wildfire incidents. In 2008, total seeds purchased by the BLM decreased from approximately 3.4 million kg (7.4 million lb) to 0.7 million kg (1.5 million lb) because fewer acres burned. This illustrates the challenges faced by the native seed industry to meet changing needs by federal agencies as a result of the variation in acres burned from year to year. In order for federal agencies to stabilize these markets, they are challenged to identify resource restoration needs far beyond those of wildfire restoration. In addition to identifying needs for using native plant materials for wildlife habitat improvement and rangeland restoration, perhaps the expanded use of seed storage facilities during years with lower demand for wildfire restoration will assist in stabilizing the native seed market over time.

Seeds can be made available in two unique manners. The first is through wildland seed collection, which is simply the collection of native seeds from wildland settings. This may not be practical or economical for some species given annual seed production, access, or a variety of other reasons. Consequently, it will be necessary to increase the amount of some native materials through agricultural practice, for example, seeding and growing native species as a crop from which seeds are harvested. We need many native "workhorse" species, especially those that are most commonly used and needed in large quantities for revegetation projects, to be available at reasonable prices. For this to happen, they need to be produced in such a manner.

Warehouse capacity needs to increase, and the warehouse in Nephi, UT is nearly doubling in size. This will improve our ability to purchase and store select workhorse species in order to help stabilize the commercial development and price of these seeds. This increase in capacity will also increase our ability to store wildland seed collections. In years where the need for seeds is lower, they would be stored in the appropriate environment for use in later years when demand is higher.

Technology Development

A current problem is the general lack of native seeds available in the types and/or amounts required for restoration needs. As seeds become available, and as new species are developed, the need is tremendous for: 1) understanding the best methods for producing seeds; 2) applying seeds in restoration efforts; and 3) understanding how, where, and when to plant. A scientific approach is desired to address these issues in order to make our restoration efforts have the greatest potential for success. Therefore, the development of such technology is an important aspect of this program.

Improving Cost Effectiveness

The economics of a native plant materials program is multi-faceted. Costs are associated with the production of native materials, with the use of native materials, and with developing a stable market for native materials. Methods for producing and applying native seeds on the ground must be affordable in order for any native seed program to succeed. The cost-effectiveness of using native seeds in restoration efforts is a must. While the use of native plant materials may always be more expensive than using exotic species, the goals of restoration require that native materials be available. We not only must work with our seed producers to build the supply of native materials that meet our demands at an affordable cost, but also create a stable market for

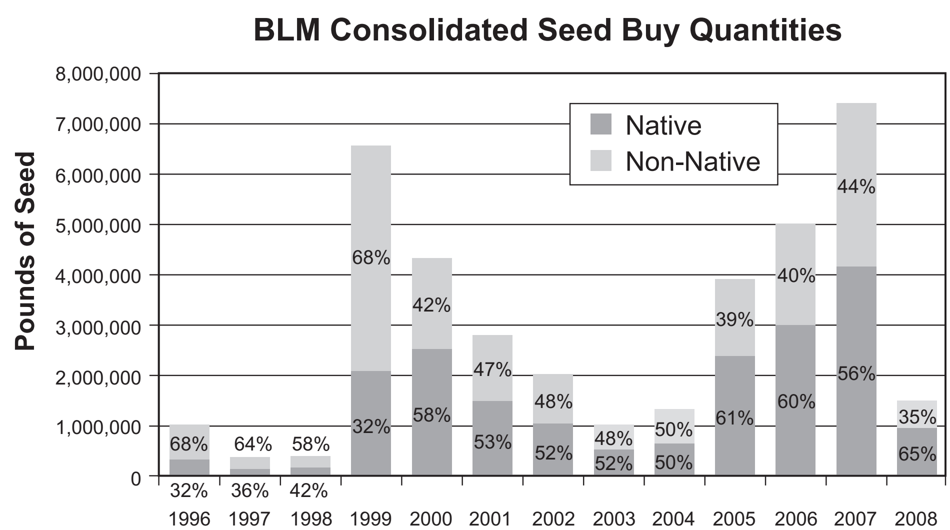

Figure 2. BLM consolidated quantities of native and non-native seeds bought between 1996 and 2007.

those materials in order to keep the producers in business. Our financial resources have been, and will always be, a limiting factor as long as the cost of restoring ecosystems remains high, but in order to build an affordable source of native plant materials, we must work closely with industry in order to understand their business needs. We must understand how we can help them help us achieve our goals and objectives for ecosystem restoration.

Updating Restoration Paradigms and Guidelines

It is important that, as a program, we work together to build restoration paradigms and guidelines that not only work to meet a variety of goals and objectives on the ground, but are also cost-effective. We can identify what does and what does not work and create a process for eliminating the use of methods with a poor track record of success. At the same time, we can promote the use of those methods that have a good record of success.

Meeting Needs for Fire Restoration and Rehabilitation

The largest use of native seeds has been for restoration of burned sites. This is likely to continue into the future, so it is important that we develop sufficient materials to meet those needs, and develop a process whereby information regarding the best materials for use in emergency restoration activities and in the restoration of any given site is easily available.

Providing Outreach and Education

More outreach and education materials (including web sites and hardcopy information) for use both within agencies and with seed producers and other private and public organizations are needed. These outreach and education materials would focus on conservation, sustainability, restoration, and research issues related to the development and use of native plant materials. They would also act as a means to showcase the successes associated with the use of native plant materials in restoration efforts. They would be used to: 1) increase awareness of the importance of ecosystem restoration; 2) enhance knowledge and skills associated with ecosystem restoration; 3) identify potential knowledge gaps and any efforts underway or planned to fill those gaps; and 4) provide recommendations for achieving restoration goals.

Challenges

Improved Coordination

Coordination within and between the various activities associated with native plant research and increase efforts in the Colorado Plateau ecoregion must improve. The CPNPI will focus on steps that will provide the most benefit to the agency, program cooperators, and partners through better coordination. In addition, the CPNPI will be actively involved in reducing any duplication of effort regarding research and development of native plant materials through increased outreach efforts. Coordination between CPNPI and adjacent ecoregional programs—the BLM Great Basin Restoration Initiative and Mojave Desert Native Plant Initiative, and the USFS Great Basin Native Plant Selection and Increase Project—will emphasize efforts to conduct research on species that occur across their boundaries.

Commercial Seed Collection

A permitting process must be established for seed collection that: 1) is simple to implement; 2) allows for monitoring where seeds are being collected; and 3) monitors the amount of seeds being collected from each site. It is critical that we allow for the collection of native seeds in a sustainable manner. It may be necessary for each agency and/or land owner to determine where, when, and how often seeds can be collected from any given area in order to avoid a detrimental effect on the native plant communities. Within federal agencies, however, the permitting process should be as consistent as possible. With the capabilities supplied through the use of GIS, it is possible to identify geographic areas where seeds may be available on some sort of a rotational basis, much like rest-rotational grazing, so that any given area is not over-collected. A regional database available to all permitting agents in the Colorado Plateau would be beneficial for such tracking as well as for assuring compliance with protocols as they are developed.

Contracts and Agreements

Contracts and agreements are a critical aspect of this program, and their development and use needs to be managed and available to agency personnel in order to meet goals and objectives of all aspects of the program. Developing a protocol to assist in the creation of contracts and agreements will assist the program in its growth. Through consolidated contracts and agreements processes, we can help maximize the cost effectiveness of available funding, a critical aspect of all program components.

Long-Term Planning

It is important to create a vision of what the Colorado Plateau Native Plant Initiative is and how to meet its goals and objectives. A 5-year strategy and action plan is being developed and is meant to be updated annually in order to incorporate any changes in priorities and to evaluate actual accomplishments versus those planned. The program will be adaptive in order to respond to changing budgets and updated or newly defined program needs and goals.

Ecosystem Diversity

Because the Colorado Plateau extends from the Uinta Basin in the north to the Painted Desert and Navajo Canyonlands in the south, and elevations range from near 600 m (2000 ft) at the bottom of the Grand Canyon to near 3650 m (12,000 ft) in the LaSal Mountains and San Francisco Peaks, there is a wide range of vegetation cover types. This diversity, as well as current levels of energy development and associated

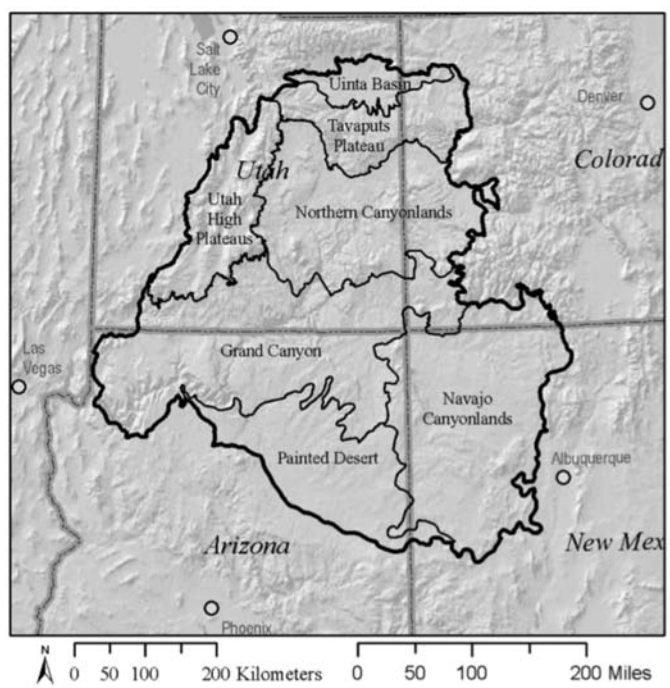

Figure 3. Ecological Sections within the Colorado Plateau.

Table1. Common Land Cover Types within each Ecological Section of the Colorado Plateau Ecoregion (see Figure 3).

Code	Land Cover Type	Utah High Plateaus	Tavaputs Plateau	Northern Canyon-lands	Uinta Basin	Grand Canyon	Painted Desert	Navajo Canyon-lands
S023	Rocky Mountain Aspen Forest and Woodland	D	D	D				
S032	Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest	L	L					
S042	Intermountain Basins Aspen-Mixed Conifer Forest and Woodland	L	L			L		
S036	Southern Rocky Mountain Ponderosa Pine Woodland	L		L		D		D
S046	Rocky Mountain Gambel Oak-Mixed Montane Shrubland	D	L	L				
S039	Colorado Plateau Pinyon-Juniper Woodland	D	D	D	D	D	D	D
S052	Colorado Plateau Pinyon-Juniper Shrubland	D	D	D	D	D		
S075	Intermountain Basins Juniper Savanna					D	D	
S054	Intermountain Basins Big Sagebrush Shrubland	D	D	D	D	D	L	L
S071	Intermountain Basins Montane Sagebrush Steppe	D	D	L				
S056	Colorado Plateau Mixed Low Sagebrush Shrubland	L	L		L			
S065	Intermountain Basins Mixed Salt Desert Scrub			D	D	D	D	D
S096	Intermountain Basins Greasewood Flat			L	L	L	L	L
S045	Intermountain Basins Mat Saltbush Shrubland			D		L		
S079	Intermountain Basins Semi-Desert Shrub-Steppe	D	L	L	L	D	D	D
S090	Intermountain Basins Semi-Desert Grassland			L		L	D	D
S059	Colorado Plateau Blackbrush-Mormon-tea Shrubland			D		D	L	
S136	Southern Colorado Plateau Sand Shrubland			L		D	L	
D04	Invasive Southwest Riparian Woodland and Shrubland	L	L	L	L	L	L	L
S093	Rocky Mountain Lower Montane Riparian Woodland and Shrubland	L	L	L	L	L	L	L
S092	Rocky Mountain Subalpine-Montane Riparian Woodland	D	L	L				
S091	Rocky Mountain Subalpine-Montane Riparian Shrubland	L	L	L				

D = Dominant Cover Type within the Ecological Section.
L = May be locally abundant, but is not a dominant component within the entire Ecological Section.

road construction, drought, fire, invasive species, and historical overgrazing throughout the Colorado Plateau, creates a need for the development of a wide variety of native plant materials. Figure 3 illustrates the ecological sections described by McNab and others (2007) within the Colorado Plateau. Each section is characterized by slight to great differences in climate, geology, soils, and vegetation.

Table 1 shows the distribution of some of the most common Land Cover Types (LCTs) described by the Southwest Regional GAP Analysis Project (NGAP 2004) within the ecological sections of the Colorado Plateau Ecoregion. Similar LCTs have been grouped in this table by growth form and by similarity in dominant species including: 1) Aspen and Conifer Forests and Woodlands; 2) Oak Woodlands; 3) Juniper and Pinyon Woodlands, Shrublands, and Savannahs; 4) Sagebrush Shrublands; 5) Salt Desert Shrublands; 6) Semi-Desert Shrublands and Grasslands; and 7) Riparian Shrublands and Woodlands. They are arranged, as much as possible, by similarities in distribution as well.

In general, the Colorado Plateau Pinyon-Juniper Woodland LCT is dominant throughout the Colorado Plateau Ecoregion, while Pinyon-Juniper Shrublands and Savannas occur only in portions of the Ecoregion. The Intermountain Basins Big Sagebrush Shrublands LCT occurs throughout the Ecoregion, but is not a dominant type in the Painted Desert or Navajo Canyonlands Sections. The Intermountain Basins Semi-Desert Shrub-Steppe LCT also occurs throughout the Ecoregion, but is less dominant in the Uinta Basin, Tavaputs Plateau, and Northern Canyonlands Sections. The Intermountain Basins Mixed Salt Desert Scrub and Greasewood Flat LCTs are dominant types throughout the Ecoregion, except at the higher elevations (Tavaputs and Utah High Plateaus Sections).

The Ponderosa Pine LCT is common in the Grand Canyon and Navajo Canyonlands Sections and on higher elevations within the Northern Canyonlands Sections (especially the Abajo Range); they are only minor components, or not present elsewhere in the Ecoregion. The Rocky Mountain Aspen Forest and Woodland and Intermountain Basins Aspen-Mixed Conifer Forest and Woodland LCTs are common only in the Tavaputs and Utah High Plateaus Sections and in higer elevations in the Northern Canyonlands and Grand Canyon Ecological Sections.

Riparian ecosystems occur throughout the Ecoregion and, as is typical of these systems, are relatively minor components with extremely high value for wildlife habitat, water quality, and hydrologic control. Gaskin and Schaal (2002) noted that eight to twelve species of *Tamarix* (Tamarisk/Salt Cedar) were brought into the United States in the 1800s for shade and erosion control. These authors described the invasion of *Tamarix* as second only to that of purple loosestrife (*Lythrum salicaria*). Today, it is estimated that nearly 600,000 ha (1.5 million ac) of riparian and wetland ecosystems have been invaded by these species and that they are expanding by nearly 18,000 ha (45,000 ac) annually. Its high seed output and ability to reproduce vegetatively have made it difficult to control.

Conclusions

For this program to be successful, it will take an organization that includes members from a wide variety of agencies as well as private organizations. The core team includes the program coordinator, national plant materials development program lead, national native seed coordinator, and state botanists from each of the four states included in the Colorado Plateau. Additionally, advisory teams (that provide advice and direction related to their specific needs regarding the development and use of native plant materials) and working groups (that complete projects associated with the program) will be needed. Each advisory team and working group will work independently as well as collaboratively with each other in order to achieve objectives and meet goals for this program.

Three advisory teams have been identified based on projected needs and include: 1) Natural Resource Needs; 2) Research and Development; and 3) Intertribal Council.

The Natural Resource Advisory Team will provide direction related to the ecological resource needs associated with native plant materials. Examples of advice and direction this team might provide on the use of native plant materials are: 1) to maintain or improve the biodiversity of a project area; 2) to maintain or improve watershed health; and/or 3) to define the roles they play in response to climate change issues.

The Research and Development Advisory Team will focus primarily on the identification of research needs related to native plant materials. This would include ecological characteristics (for example, seed transfer zones), restoration techniques (for example, appropriate equipment, seeding rates and depths, and so on), as well as social and economic factors associated with ecosystem restoration.

Native Americans have depended on native plant materials for food, medicines, basketmaking, dyes, and so on, and it is important to maintain those species within the landscapes of the Colorado Plateau. The Intertribal Council Advisory Team will provide guidance to the core team regarding traditional uses of, and tribal needs for, native plant materials throughout the ecoregion.

The following working groups have been identified based on the goals and objectives outlined above. These include: 1) Grants and Agreements; 2) Seed Certification and Increase; 3) Seed Industry Liaisons; 4) Outreach and Education; and 5) Web Development and Maintenance.

The Grants and Agreements Working Group would provide direction to the Core Team regarding contracts, grants, and agreements already in place for various aspects of the CPNPI Program. In addition, this group would work closely with agency staff to develop future contracts and agreements following appropriate protocols.

The Seed Certification and Increase Working Group would act as liaisons with the Arizona, Utah, and New Mexico Crop Improvement Associations and the Colorado Seed Growers Association for the certification of native plant materials. They would then work with members of the private seed industry to provide them with sources of foundation seeds for producing registered and certified seeds for use in restoration efforts on the Colorado Plateau.

The Seed Industry Liaison Working Group would act as direct contacts with members of the seed industry. Focus would be on developing a strong native seed industry within the Colorado Plateau Ecoregion. This group would be responsible for providing the most up-to-date information regarding the need for native seed materials and availability of seeds for production within the Colorado Plateau.

The Outreach and Education Working Group would be responsible for developing materials for agency personnel as well as a variety of state and private organizations. These materials would focus on conservation, sustainability, restoration, and research issues related to the development and use of native plant materials.

Web page development, management, and maintenance are critical components of this program. The Web Development and Maintenance Working Group would be responsible for developing and maintaining the CPNPI web page. This web page would not only provide the most up-to-date information regarding the CPNPI program, but would also provide links to other programs as well. It would provide current information regarding seed availability and restoration techniques for field managers, as well as information to assist the private seed industry in the needs for native seed materials.

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Green Gold: The Potential and Pitfalls for North American Medicinal Plants in the US Botanical Supplements Industry

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Botanical Supplements Industry in the US

Complementary and alternative medicine (CAM) has become an implicit part of a lifestyle industry in the United States. The World Health Organization (WHO) reports that at least 41% of the population in the US has used CAM at least once in their lives (WHO 2002). Globalization, an influx of various immigrant cultures, and growing wariness of western allopathic medicine have contributed to a growing CAM industry in the US (Brevoort 1996). CAM in the US consists of a hybrid eclectic mix of several cultural and traditional healing systems from around the globe. Large cities with immigrant populations, such as New York City and San Fransico, offer access to Botanicas and Asian medicine pharmacies. The mainstream population has, however, adopted only some parts of these forms of healing as part of their wellness lifestyle, for example, yoga as a form of exercise and acupuncture for some ailments. Herbal medication is also an aspect of the global healing cultures that has become commercially popular. Consumers are becoming increasingly curious about medicinal plants and often think that their consumption has only negligible side effects.

Herbal or botanical dietary and nutraceutical supplements, phyto-pharmaceuticals, and beauty products constitute a large and integral part of the US CAM industry. They constitute a large commercial sector that has steadily been gathering pace. The internal botanical supplements industry in the US is estimated at US$ 1 to 2 billion (Brevoort 1996). Botanical supplements and many other phyto-therapeutic products are commonly available as over-the-counter products at pharmacies and health food stores, even to suburban and rural populations. Their preparations are found as pills, powders, oils, tinctures, lotions, and teas, and are regulated by the US Food and Drug Administration (FDA) and the Dietary Supplement Health and Education Act of 1994 (DSHEA). A large proportion of the US botanical supplements industry derives its herbal preparations from traditional Chinese medicine and Ayurveda. Latin American and European botanical medicines are also represented.

A large part of the botanical supplements industry relies on raw plant material from outside of the US. A survey conducted on the labels of herbal medicine products found in three natural food stores in rural northern New York (Table 1) indicated that only 30% of the raw material used for manufacturing the botanical supplements was from species found in North America. The remainder was sourced from other parts of the world, for example, weight loss supplements from the African plant *Hoodia gordonii*, various European Bach's flower remedies, and the Asian-based *Gingko biloba* extracts. The US is among the top ten importers of bulk dry herbs in the world (Brevoort 1996). A crude survey of the top 100 suppliers of raw bulk material, using the Internet search engine Google™, indicated that only one fourth of the suppliers were companies located in the US. Many of the suppliers located in the US imported their raw material from Asian, South American, and African countries. Collection and semi-processing of herbal raw material is a large-scale industry in these countries. The exporters and suppliers of herbal raw materials often represent the top links of stakeholder chains that ultimately extend to small-scale wildcrafters and growers in other countries.

Despite the fact that the sale of herbal raw material for botanical supplements is a lucrative business, not many North American plant species are grown or harvested for this industry. Only a few North American species, for example, goldenseal (*Hydrastis canadensis*) and purple coneflowers (*Echinacea* spp.), are found on market shelves. There is a rich heritage of information on the use of North American species that are used in healing (Moerman 1998). The knowledge of medicinal use of these indigenous plants has been severely eroded (Fenton 1941), and their presence in the US botanical supplements industry is negligible. Nevertheless, there is an interest in harvesting and cultivating many of these plants for commerce (Miller 1988; Cech 2002). Indigenous North American medicinal plants present growers and horticulturists with a large untapped potential. Cultivation of medicinal herbs can provide many local growers with an opportunity for income generation. Growing native plants avoids the ecological repercussions of introducing invasives to North American ecosystems. Moreover, cultivation of herbs can meet the market demand without overharvesting wild populations.

Table 1. Product label survey to assess the regional source of botanical materials in supplements found at three natural food stores in rural northern New York.

Country of Origin	Percentage of Botanical Materials
Albania	1
Australia	1
Bosnia	1
Brazil	1
Bulgaria	3
Canada	3
Chile	3
China	8
Egypt	4
Europe	15
France	1
Hungary	1
India	6
Indonesia	3
Japan	1
Mexico	1
Paraguay	1
Peru	1
Poland	3
Romania	1
South Africa	1
South America	1
Sri Lanka	1
Thailand	1
Turkey	1
United States	28
Vietnam	1

East Meets West: Eastern Medicine and Western Plants

The geological history of North America and temperate Asia has resulted in several congeneric species. About two thirds of the North American taxa have Asian relatives, and overlap in the phytochemistry of many of these Asian and North American congeneric species is significant (Li 2002a). It is plausible to examine the usefulness of North American species for some of the Asian phyto-pharmaceuticals. However, this concept does require additional research. The use of North American species in Chinese medicine is not a novel idea. American ginseng (*Panax quiquifolium*), a Native American medicinal species, has been used as a substitute for its overharvested Asian congener *Panax ginseng*, a popular adaptogen in traditional Chinese medicine since the early 20th century. At one point, American ginseng was threatened with over harvest to meet its export demand. It was listed in the Convention for International Trade in Endangered Species (CITES) and its global trade was regulated. Currently, the US Fish and Wildlife Service (USFWS) monitors harvest of North American ginseng by requiring wildcrafters to buy permits for harvesting the species. At the same time, horticulturists have been able to determine optimal conditions for cultivating the species (Anderson and others 2002; Cech 2002; Hsu 2002; Li 2002b), thus subverting the pressure from wild populations. The demand for North American ginseng can be met sustainably through cultivation of the species.

Sometimes, North American species might offer better quality of raw material as compared to their Asian counterparts. For example, sweetflag (*Acorus calamus*) is a medicinal and aromatic wetland species that is ubiquitously distributed through Asia, North America, and Europe. Historically, the plant might have been spread by humans along trade and hunting trails. Its rhizome is currently of ethno-pharmaceutical relevance to several cultures and is used on a commercial scale in the global perfume industry (Motley 1994). The plant is harvested for commercial purposes in South Asia. It is often cultivated from its rhizome on abandoned paddy fields where the soils are marginal and nutrient poor, making it a very low input crop. In North America, however, the species is considered a weed. Because North American varieties of the species have less B-asarone (a carcinogenic compound of concern) as compared to the Asian varieties, sweetflag could be a valuable, albeit untapped, resource in the US.

Even though American species can provide many of the phytochemicals found in Asian species (Li 2002a), they remain unexplored as sources of these chemicals. For example, American goldthread (*Coptis trifolia*) is a forgotten Iroquois medicinal found in the forests of northern New York, and is closely related to the commercially popular goldenseal (from midwestern North America) and Chinese goldthread (*Coptis chinensis*). Although American goldthread cannot act as a complete substitute of either of the two commercially popular species, it does contain two of the major alkaloids (that is, coptisine and berberine) found in the latter species (Kamath and others 2009). As pharmacologists try to hone in on the silver bullets or phyto-chemicals that display efficacy in healing, North American plants could be a potential source for those found in their Asian congeners.

Quality Control and Effort

It is important to understand the growing conditions and requirements of many medicinal plants (Cech 2002). Often, medicinal plants might require very little effort to culture. Sweetflag, for example, requires very little care and can be planted on marginal lands. Preliminary observations on goldenseal cultivated on tilled and untilled soil in Ohio indicated no significant difference in biomass sequestered by

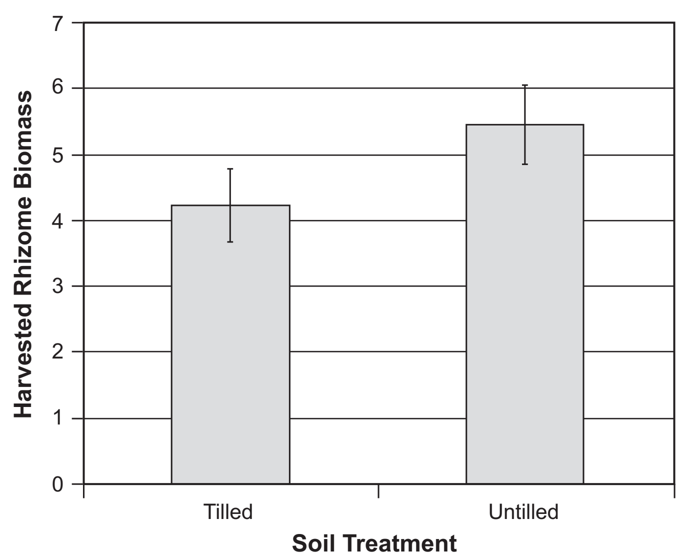

Figure 1. Preliminary observations on goldenseal (*Coptis* spp.) cultivated on tilled and untilled soil in Ohio.

the plant rhizomes (Figure 1), suggesting that tilling might not be necessary for growing the plant. Medicinal plants such as bloodroot (*Sanguinaria canadensis*) that are gaining commercial importance are found nurtured and transplanted in many backyard gardens in northern New York. Herbalists and conservation groups such as the United Plant Savers, a US-based plant conservation organization, encourages the propagation of medicinal plants in all kinds of areas, including kitchen gardens, backyards, restoration projects, understorey of private woodlands, agroforests, and the margins of agricultural lands (Gladstar and Hirsch 2000).

Microenvironment is an important facet when harvesting or cultivating medicinal plants. Strategic cultivation can enhance the quality of the plant part being harvested. For example, pilot greenhouse studies at St Lawrence University (Canton, NY) indicate that high light conditions can induce the production of greater amounts of the alkaloid berberine in goldenseal rhizomes (Figure 2). Understanding the optimal conditions for growth can increase quality and yield of a medicinal plant.

Many North American medicinal plants can be propagated from rhizomes (often referred to by growers as bareroot) as well as seeds. Seed germination and seedling survival can be tricky and uncertain for many medicinal plants. In addition, a long time to maturity can be a limitation when trying to get a crop for economic turnover in a short period of time. Growing plants from rhizome stock is often advantageous because it allows selection and propagation of hardy and better quality genotypes. Rhizomes also require less time to establish and grow as compared to seeds and seedlings.

Potential and Pitfalls

Although North American medicinal plants offer great potential as cash crops, growers have to face some challenges. First, there is a need to popularize botanical medicine that utilizes North American medicinal species. This, however, needs to be done carefully without infringing on the intellectual property rights of Native American groups. Second, small scale growers need to establish marketing links, either directly with companies that produce botanical supplements and ancillary products, or with bulk, large-scale suppliers that deal with this industry. Third, it is important to understand the ecology of these medicinal species and create preemptive sustainable management strategies. Fourth, it is important that optimal growing conditions that yield greater biomass as well as better quality of the plant parts are better understood. Fifth, growers need to gauge North American species as substitutes for other exotic plants. Sixth, growers need to be in tune as new markets and products emerge, for example, North American species that could be sources of phytochemicals for the pharmaceutical industry. If managed well, North American medicinals have the potential to be "green gold" as a commercially viable investment and enterprise for the small-scale grower and farmer.

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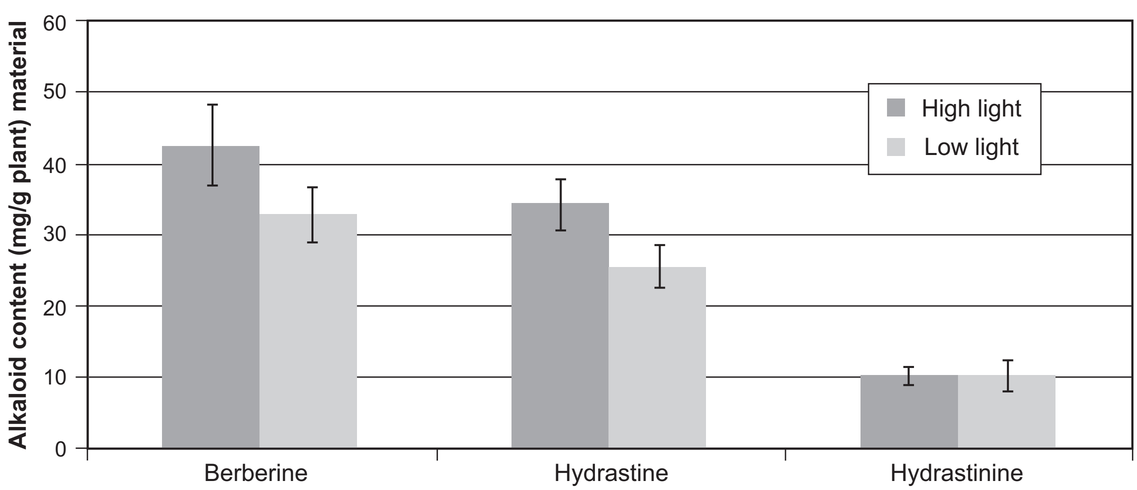

Figure 2. Berberine (an alkaloid) content of goldenseal rhizomes grown under low and high light conditions in the Johnson Hall of Science greenhouse facility, St Lawrence University, Canton, NY.

The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented within.

When Smokey Says "No": Fire-less Methods for Growing Plants Adapted to Cultural Fire Regimes

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Abstract: Two culturally-significant plants (sweetgrass [*Anthoxanthum nitens*] and beargrass [*Xerophyllum tenax*]) are used as case studies for investigating methods of restoring plant populations that are adapted to indigenous burning practices without using fire. Reports from tribal members that the plants of interest were declining in traditional gathering areas provided the impetus for research with both species. In both situations, reintroducing large-scale repetitive burning was not feasible. Field studies of planting with cover crops and manually clearing competing shrubs and herbaceous plants are examined, as well as a greenhouse study evaluating the effect of smoke-water on seed germination. All three experiments yielded significant results when compared to a control. These findings indicate that when reintroducing fire is not feasible, treatments are available that, in some cases, may increase the reproduction and growth of target species.

Keywords: smoke-water, germination, sweetgrass, *Anthoxanthum nitens*, beargrass, *Xerophyllum tenax*

Introduction

Before European settlement of North America, fire regimes were a function of natural events and anthropogenic burning prescribed by Native Americans (Pyne 1982; Boyd 1999). Through the use of burning, indigenous people created and maintained diverse and productive ecosystems that provided resources essential for subsistence (Storm 2004). Fire was used to manipulate the landscape, species distribution, and composition of different habitats (Kimmerer and Lake 2001; Anderson 2002; Wray and Anderson 2003; Storm and Shebitz 2006).

Fire plays an important role in shaping plant communities by influencing patterns of recruitment, thus maintaining native species composition and richness (Pendergrass and others 1999). Without fire, fire-adapted communities change dramatically (Boyd 1999; Peterson and Reich 2001; Copeland and others 2002). Due to the suppression of natural and anthropogenic fire throughout the past two centuries (Boyd 1999; Turner 1999), fires that do occur are much more infrequent, but more intense and greater in extent, than those of pre-settlement North America (Quintana-Ascencio and others 2003). The modification of fire regimes in many prairie, savanna, and open woodland systems has led to an increase in abundance of woody vegetation and declines in native herbaceous understory and prairie species (Wrobleski and Kauffman 2003), and often favors the recruitment of exotics with more tolerant life histories than the natives (Prieur-Richard and Lavorel 2000). Pyne (1982) states: "[t]he role of fire in sustaining these landscapes is incontestable; when broadcast burning was suppressed as a result of European settlement, the land spontaneously reverted to forest."

Plant species and communities that were historically exposed to recurrent fire have become dependent on fire for seedbed preparation, seed germination, early growth of seedlings, and maintenance. Some species and communities are so dependent on fires that, without them, they are becoming rare and endangered (Biswell 1999; Boyd 1999). Fire suppression as an independent factor is the principal threat to 4.1% of the endangered plants in the US; when considered with its effect on additional factors such as invasive species recruitment, its threat dramatically increases (Kaye and others 2001). In fact, The Nature Conservancy has identified altered fire regimes as one of the top five threats facing biodiversity in the US (TNC 2001).

With increased urbanization, budgetary constraints, and local policy restricting prescribed burning, reintroducing fire as a restoration tool is not always feasible. This paper presents alternatives to burning when returning to frequent, low-severity fires is not possible. During the course of 8 years (1999-2007), a series of experiments was conducted in the field and in the greenhouse to examine the most effective means to grow two plant species that are adapted to cultural burning without necessarily reintroducing fire. Two field methods (clearing competition and planting cover crops) and one greenhouse method (smoke-water) are included in this paper. The two species in this research are both basketry plants for indigenous cultures in their respective areas: sweetgrass (*Anthoxanthum nitens*, also known as *Hierochloe odorata*), as used by the Haudenosaunee

(Iroquois Confederacy) of New York, and beargrass (*Xerophyllum tenax*) as used by the Quinault and Skokomish of Washington.

Reports from tribal members that the plants of interest were declining in traditional gathering areas provided the impetus for research with both species (Shebitz 2005). Ethnographic research with both species revealed two possible causes of their decline in traditional gathering sites—unsustainable harvesting practices and the suppression of both natural and prescribed burning over the past century (Shebitz 2005). While the research presented in this paper has been published separately elsewhere (Shebitz 2005; Shebitz and Kimmerer 2005; Shebitz and others 2009a; Shebitz and others 2009b), the use of the various research methods to replace the need to burn is presented together here for the first time.

Species of Interest

Sweetgrass

Sweetgrass (Figure 1) is a perennial grass (Poaceae) native to North America that plays an important role in the lives of indigenous people who reside throughout its range. The plant of interest in this work is one of 23 species throughout the world that have the common name "sweetgrass." The rhizomes of sweetgrass are numerous and slender and are its primary means of reproduction (Small and Catling 1999; Greene 2000). It occurs in a variety of habitats, including moist meadows and swales, along stream banks, at the edges of forests, in forest openings, in wet meadows, low prairies, salt marshes, bogs, lakeshores, and along roadsides and railroad tracks (Walsh 1994; Lynch and Lupfer 1995). Sweetgrass is a mid-successional species, typically found among other grasses, and requires partial to full sunlight. The species is often found in areas that have little competition from taller plants, and in areas that have been disturbed, for example, by fire (Lynch and Lupfer 1995).

Although sweetgrass is most frequently used as a ceremonial smudge and incense (Kavasch and Barr 1999; Shebitz and Kimmerer 2004), it is predominantly used among the Haudenosaunee in basketry (Benedict 1983). While sweetgrass itself was not typically a target for burning, some of the fields from which it was traditionally gathered by Haudenosaunee were burned for hay until the mid 1900s (Shebitz 2005).

Beargrass

Beargrass (Figure 2) is closely related to lilies and is a member of the Melanthiacae family. It is harvested by tribes ranging from northern California along the Pacific Coast to the Olympic Peninsula and southeastern British Columbia. Tribes such as the Modoc on the Modoc Plateau, the Yurok in northern Coast Ranges, the Maidu in the northern Sierra Nevada, and the Shasta in the Cascades gather young, fresh beargrass leaves to provide the soft background or decorative overlay material in twined baskets (Anderson 2005). A weaver may use up to 2000 beargrass leaves to complete a design in a large basket (Rentz 2003). Preferred leaves grow under semi-shade "…where it became long but not brittle" (Nordquist and Nordquist 1983), and where there is enough sunlight for it to flower (Peter and Shebitz 2006). The anatomical structure of beargrass leaves makes it useful in basket making. Weaving requires materials to be narrow, flexible, and have tensile strength. The reduction in sclerified tissue in the

Figure 1. Sweetgrass growing in a fen in Taborton, NY. (Photo by Daniela Shebitz).

Figure 2. Beargrass in bloom in a bog on the Quinault Reservation, Olympic Peninsula of Washington. (Photo by Daniela Shebitz).

leaves and resulting pliability after a fire therefore yields improved basketry material (Rentz 2003).

Low-severity burns have long been used by Native Americans to enhance the growth of beargrass and provide basketry material (Hunter 1988; LaLande and Pullen 1999; Rentz 2003; Shebitz 2005). In addition to Olympic Peninsula tribes such as the Skokomish and Quinault, the Yurok Karuk, Hupa, Chilula, Upland Takelma, and others burned beargrass periodically and then harvested leaves from the burned clumps 1 to 3 years later (LaLande and Pullen 1999; Rentz 2003; Anderson 2005). Historically, burns were low-severity, slow-moving surface fires that burned old beargrass growth and up to 95% of living foliage (Hunter 1988; Rentz 2003).

Methods

Field Experiment: Sweetgrass

Cover crops are generally selected for their annual life cycles and characteristics of effective weed suppression and enhanced growth. In this study, hairy vetch (*Vicia villosa*) was selected for use. It is a nitrogen fixer that has been shown to enhance grass growth in legume-grass bicultures and is not persistent once introduced (Ranells and Wagger 1997; Batte and others 1998; Brandsaeter and others 2000). Because many of the pioneer species that become established following a fire are nitrogen-fixing species (Agee 1993), the nitrogen that vetch contributes can resemble changes in soil chemistry following a fire.

At a Mohawk farm named Kanatsiohareke, in Canajoharie, NY, a field experiment was designed to determine if sweetgrass could be reintroduced successfully and to evaluate the effect of competitors on its growth and reproduction in garden-sized plots. Sweetgrass was grown: 1) in unweeded plots that contained existing old-field vegetation; 2) in manually weeded plots; 3) in combination with hairy vetch to assess the use of a nitrogen-fixing cover crop in alleviating competition following disturbance; and 4) with an annual rye grass (*Lolium multiflorum*), a cover crop that does not fix nitrogen. The experiment was replicated at the LaFayette Experiment Station near Syracuse, NY. This work was published by Shebitz and Kimmerer (2005).

Sweetgrass from nursery stock was transplanted into five replicate plots of each of the four treatments, for a total of 20 plots at both LaFayette and Kanatsiohareke. Transplants were standardized to consist of a maximum of three culms and two rhizomes, with a maximum length of 15 cm (5.9 in). Experimental plots were 2.25 m^2 (24 ft^2) in area, and were separated by 1 m (3.3 ft). Transplants were installed in seven rows of seven in each plot, with 18 cm (7 in) between plants. Transplants were tagged to monitor growth and survival. Plots were tilled in May 2000 prior to planting sweetgrass, with the exception of the treatment with existing old-field vegetation. The seeds of hairy vetch were mixed with water and a pea/vetch inoculant by the name of Nitragin® (EMD Crop BioScience, Brookfield, WI) prior to their dispersal to promote maximum nitrogen fixation ability. The vetch was sown at a heavy density and was later thinned to 490 plants per plot. Weeding of the sweetgrass monoculture treatment occurred weekly through 15 September 2000. The treatments were not watered throughout the course of the experiment.

Sweetgrass tiller density in each plot was recorded monthly in July, August, and September 2000. At the end of the field season, survival and growth of the sweetgrass were measured, and sweetgrass above-ground dry biomass, number of tillers per plot, survival percentage, and height were calculated. Height was determined from the measurement of five randomly selected sweetgrass blades in each of the 20 plots. The numbered markers that were initially planted with each plug allowed us to determine survival percentage of original sweetgrass transplants. Biomass was sampled from a 0.25 m^2 (2.7 ft^2) quadrat placed in a random location within each plot. Sweetgrass within the quadrat was cut at ground level and dried at 26.7 °C (80 °F) for one week prior to weighing. Sweetgrass height and density was measured in May of the following year to assess growth one year after planting. No additional treatment (weeding or cover crop sowing) was applied during the second growing season.

Field Experiment: Beargrass

The growth and vegetative reproduction of early- and mid-successional species are often limited by competition with neighboring shrubs and herbaceous species. The abundance of beargrass in mid- to late-successional communities is limited due to increased competition and resultant shade (Peter and Shebitz 2006; Shebitz and others 2008).

On the Olympic Peninsula of Washington, beargrass grows from sea level up to the subalpine zone in the USDA Forest Service Olympic National Forest and USDI National Park Service Olympic National Park. The Peninsula's Native American basketmakers rely primarily on the lower elevation beargrass for their basketry since it is generally close to the reservations and easily accessible. Many of the harvesting sites were historically burned, but have now undergone succession, resulting in a more forested habitat with a dense shrub understory.

A field experiment examined the effects of manually-clearing competing shrubs and forbs on beargrass vegetative reproduction compared to low-severity fire and a control. We installed a field experiment to an existing beargrass population within a Douglas-fir (*Pseudotsuga menziesii*) savanna habitat restoration area of the Olympic National Forest, close to the Skokomish Reservation. We installed six replicates of burned and manually-cleared competition treatments as well as a control. Each replicate contained three 8 by 8 m (26 by 26 ft) plots for the two treatments and the control (1.5 m [5 ft] buffer on each side), with 1 to 10 m (3.3 to 33 ft) between replicate plots (Figure 3).

Treatments were applied in September 2004 by the Olympic National Forest fire crew. Fires were low-severity and left most beargrass meristems visible following the burns. In plots that were manually

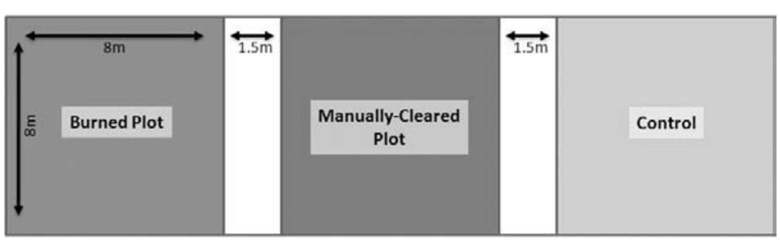

Figure 3. Example of a replicate block established in the Olympic National Forest site with the two treatments and a control. The order of the treatments was random within each block. (1 m = 3.3 ft)

cleared of vegetation, chainsaws, machetes, and weed whackers were used to clear all aboveground vegetation and coarse woody debris from the plots. Beargrass leaves were also cut, but the meristematic region was intentionally left intact to replicate the effects of a burn.

We took measurements in each of 25 contiguous 1 m^2 (11 ft^2) quadrats within each plot prior to treatment. Data collected before treatments and 1 year following the treatments included measurements of beargrass density, cover percentage of all species, and the number of beargrass inflorescences. We randomly selected five beargrass plants in each plot for additional measurements of length of the five longest leaves, height to the highest leaf, widest diameter of foliar crown material (W1), and the diameter perpendicular to this (W2). We marked these five plants in each plot with an aluminum nail hammered into the ground at each of their bases. Each nail was spray-painted one of five colors so that the beargrass could be relocated and remeasured following treatment application.

Greenhouse Experiment: Beargrass Seeds

Smoke is the most striking chemical cue generated by fire. Chemical signals of smoke may not only influence seeds during fires and in the immediate post-fire environment, but can travel far and last for considerable periods after fire. Smoke particles can adhere to plant surfaces, persist in the soil, and be adsorbed to soil particles (Van Staden and others 2000). Egerton-Warburton (1998) demonstrated that the ability of smoke to adhere to soil and plant surfaces plays a role in germination by changing the morphology of some seeds and causing an intense chemical scarification of the seed surface. Fire cues may also deactivate compounds in the soil or the seed coat that inhibit germination (Keeley and Nitzberg 1984). There are two basic methods for exposing seeds to smoke, or the chemicals derived from smoke, that are thought to promote germination. The first is to expose seeds directly to smoke and the other is to indirectly expose seeds to the particulates of smoke through the use of water infused with smoke. The work presented in this paper examines the affect of smoke-water on beargrass seed germination and was originally published in Shebitz and others (2009a).

Without smoke-water, low elevation beargrass requires a 24-hour soak in water followed by a minimum of 8 to 12 weeks of cold, moist stratification (Smart and Minore 1977; Shebitz and others 2009a). A greenhouse study was designed to determine if smoke-water can be used to enhance germination rates of low elevation beargrass and decrease the length of cold stratification.

Mature beargrass seeds were harvested from 20 inflorescences in August 2004 in a bog laurel/Labrador tea/beargrass/sphagnum (*Kalmia microphylla/Ledum groenlandicum/Xerophyllum tenax/Sphagnum* spp.) wetland of the Quinault that is believed to have been historically managed through anthropogenic burning (Shebitz 2005; Shebitz and others 2009b). Seeds were counted, divided into packets of 50, and stored in the Miller Seed Vault at the Center for Urban Horticulture, University of Washington (Seattle, WA) at 15 °C (59 °F) and 20% relative humidity until needed.

Half of the seeds used in this experiment were exposed to smoke-infused water, and the others were exposed to water as the control. The smoke-infused water used in this experiment was created from species associated with the vegetative communities at the Quinault site: salal (*Gaultheria shallon*), sword fern (*Polystichum munitum*), western redcedar (*Thuja plicata*), and beargrass. A charcoal grill was used to make the smoke-infused water. Charcoal was burned on half of the base of the grill and freshly collected vegetation was placed directly above it on the upper grill surface. A pan of water was on the opposite side of the upper grill surface. The grill was covered for 2 hours as the coals burned the vegetation and smoke infused the water in the pan. The water did not reach the boiling point. Once the smoke-infused water cooled, 200 ml (6.8 oz) were poured into glass containers and 50 beargrass seeds were added to each container. An air pump and stone were then used to circulate the water (with seeds added) for 24 hours. The control treatment involved beargrass seeds added to tap water and electrically circulated for 24 hours.

After the seeds were exposed to the pre-treatment, they were sown in nursery flats measuring 53.3 by 26.7 cm (21 by 10.5 in). These flats were prepared by adding a seeding mix (Terra-Lite Redi-Earth; Scotts-Sierra Horticultural Products Company, Marysville, OH), and were divided into eight quadrats measuring 13.3 by 13.3 cm (5.2 by 5.2 in) using a plastic-lined barrier between the smoke-water and control treatments to discourage leaching between treatment soils. The smoke-infused water and tap water were added to the flats with the beargrass seeds, and the flats were watered and covered with plastic before being placed in cold stratification or the greenhouse.

The seeds underwent cold stratification for one of six time periods: 0, 8, 10, 12, 14, or 16 weeks. The flats testing the effects of smoke-water and water with 0 weeks in cold stratification were placed directly in a greenhouse at 26 °C (79 °F). Those undergoing cold stratification for a designated period of time were stored in a chamber at 5 °C (41 °F) and then moved into the greenhouse. Each treatment was replicated four times with 50 beargrass seeds per replicate. Therefore, a total of 12 treatments were used, with four replicates (200 seeds) each.

Data Analysis

Field Experiments: Sweetgrass and Beargrass

The effects of treatments on the performance of both sweetgrass and beargrass was compared with analysis of variance (ANOVA) using SAS® software (SAS Institute Incorporated, Cary, NC). Tukey's method of grouping was utilized to distinguish between significantly different treatments. For sweetgrass, changes in growth and survival were analyzed by treatment for both Kanatsiohareke and LaFayette independently.

Greenhouse Experiment: Beargrass Seeds

The objectives of this study were to determine if seeds being exposed to smoke-water resulted in increased germination rates and/or influenced seed response to increased length of cold stratification. The germination rates of seeds from the two sites were significantly different ($P<0.001$), so the data for each of the two restoration sites were analyzed separately. A two-way analysis of variance (ANOVA) incorporating the treatment and length of cold stratification was performed using SAS® software (SAS Institute Incorporated, Cary, NC). Statistical significance throughout this paper is defined with $\alpha = 0.05$.

Results

Field Experiment: Sweetgrass

Sweetgrass survival was statistically greatest in the hairy vetch plots and the manually-weeded plots at both Kanatsiohareke and LaFayette (Figure 4). After one growing season, the plots in Kanatsiohareke with hairy vetch (HV) as a cover crop, or those plots that were weeded (SG), yielded significantly greater sweetgrass biomass ($P<0.0001$) and height ($P=0.0011$) than that of other treatments. The plots sown with annual ryegrass (AR) or left unweeded (VEG), however, had a significantly lower number of sweetgrass tillers and resulting biomass.

Sweetgrass population within a treatment plot increased by as much as four times the original amount during the first growing season and

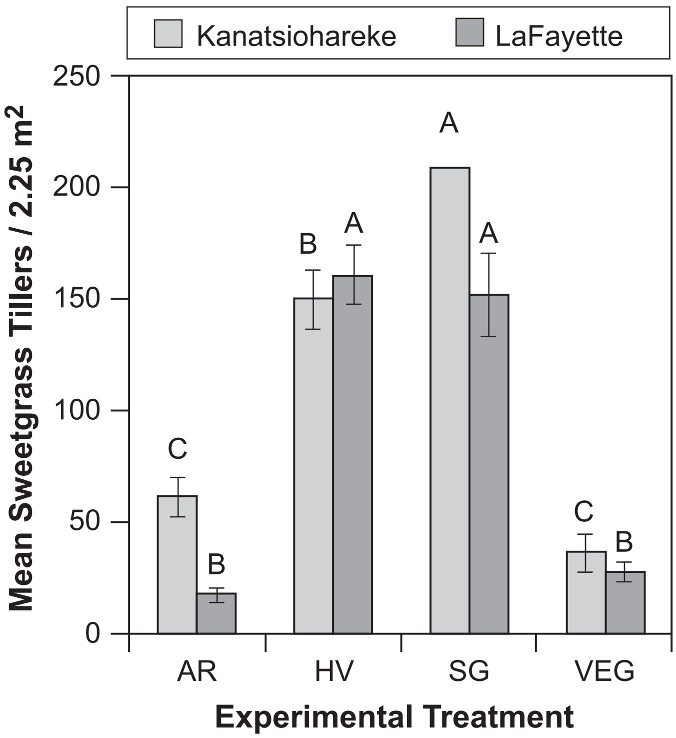

Figure 4. Mean number of sweetgrass tillers per 2.25 m^2 (24 ft^2) plot by treatment in Kanatsiohareke and LaFayette after one growing season; AR = annual ryegrass; HV = hairy vetch; SG = weeded competition; VEG = control with no weeding. Standard error bars are shown. (Figure previously published in Shebitz and Kimmerer 2005).

by as much as 20 times the original amount after one year (Table 1). The significant difference in the height of sweetgrass that was found in plots sown with hairy vetch during the first growing season, however, did not last through the following season. Sweetgrass tiller density continued to increase even after weeding ceased in the plots in which competition was manually controlled. The ability to have increased sweetgrass reproduction and growth, even after weeding ended in SG plots, or after the cover crops were no longer present in HV plots, was an important finding for those individuals interested in growing sweetgrass in garden-sized plots.

Table 1. Sweetgrass growth means for Kanatsiohareke and LaFayette experiment sites after one year (Tukey's method of grouping at α=0.05); SG= weeded competition plots; VEG=vegetated plots; HV=hairy vetch plots; AR=annual rye plots.

Site	Treatment	Tillers/ 2.25 m^2*	Average height (cm)**
Kanatsiohareke	SG	481.6 ^{a}	26.2 ^{a}
	VEG	27.8 ^{c}	36.2 ^{a}
	HV	353.2 ^{ab}	39.0 ^{a}
	AR	150.6 ^{bc}	28.2 ^{a}
LaFayette"	SG	642.2 ^{b}	38.4 ^{a}
	VEG	26.8 ^{c}	33.6 ^{a}
	HV	993.0 ^{a}	40.4 ^{a}
	AR	14.0 ^{c}	19.2 ^{b}

Means with the same letter within the same column are not significantly different. Value is significant at α=0.05.
*2.25 m^2 = 24 ft^2
** 1 cm = 0.4 in

Field Experiment: Beargrass

One year after treatments of clearing competition manually and through burning were applied, the number of beargrass shoots was significantly higher in manually cleared plots than in the control. The mean number of beargrass shoots increased by 18 cm (7 in) the burn plots and 23 cm (9 in) the control, as compared to a mean increase of 99 cm (39 in) the manually cleared plots (P=0.01). The cover percentage of beargrass, however, was significantly lower in cleared (P=0.02) and burn plots (P=0.01) when compared to control plots. Shrub cover was significantly reduced in both burn (P<0.001) and cleared plots (P=0.01) compared to control plots, whereas the cover percentage of all forbs was significantly higher in burn plots than in reference plots (P=0.08) (Table 2).

All 90 beargrass individuals measured in 2004 (five in each of the 18 plots) were alive during the 2005 field season, regardless of treatment (Table 2). Beargrass exposed to low-severity burns had a significantly lower leaf length (P=0.03), shorter height (P=0.02), and smaller crown area (P=0.04) than individuals in control plots. Measurements of beargrass in the plots where vegetation was manually cleared, however, were not significantly different than those in control plots. The flowering rate was significantly lower in cleared plots than

Table 2. Comparison of changes from pre-treatment data to 1-year post-treatment data following installation of the 2004 field experiment on beargrass growth on the Olympic National Forest.

	Burn		Clear		Control		
Variable	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	*P*-value
Leaf Length (cm)*	-11.53	4.97	-9.59	4.87	-3.93	6.16	**0.050**
Height (cm)*	-7.90	4.21	-4.87	2.70	-0.37	6.37	**0.030**
# Inflorescence	0.67	1.21	3.50	1.38	4.17	2.99	**0.020**
# Shoots	7.17	6.67	39.17	26.65	9.17	15.13	**0.010**
% Cover	-5.59	3.25	-5.54	3.25	-1.28	1.67	**0.010**
% Forb Cover	-2.69	2.73	-7.84	3.20	-7.65	5.25	0.060
% Graminoid Cover	-1.11	1.87	-0.71	4.09	-3.93	6.82	0.450
% Shrub Cover	-34.38	16.08	-25.78	6.55	-5.38	7.74	**0.001**

P-value compares the changes in the variables between burn, cleared, and reference plots. Significant *P*-values are in **bold** (α=0.05).
*1 cm = 0.4 in

in control plots (*P*=0.05), but the number of beargrass flowers was not significantly different between burn and reference plots (*P*=0.80)

Greenhouse Experiment: Beargrass Seeds

The earliest germination occurred after 10 weeks in cold stratification. The greatest germination rates for the Quinault seeds (41%) occurred after being soaked in smoke-water and then undergoing 14 weeks of cold stratification. The smoke-water treatment generally resulted in greater seed germination regardless of length of cold stratification (*P*=0.017) (Figure 5).

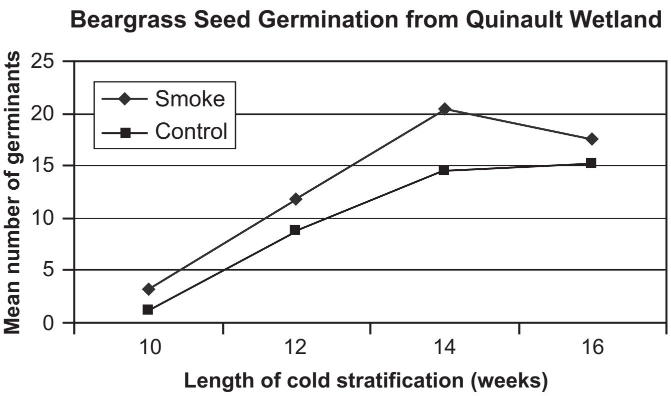

Figure 5. The mean number of beargrass seeds that germinated after exposure to smoke or the control for 10, 12, 14, or 16 weeks in cold stratification.

Discussion

Many plant resources were historically managed through indigenous management techniques such as burning, pruning, or harvesting. With changes in management over time, the plants themselves may decline in both abundance and quality. Simultaneously, as the resources diminish, the traditions that rely on them may become threatened (Shebitz 2005). The studies presented took place on opposite coasts of North America and differed in regards to the Native American cultures, the plant species, and sites involved. The continuation of traditions such as basketry is dependent upon the availability of culturally significant resources. The restoration projects presented were designed to not only restore basketry plants to their native habitat, but also to enable cultural traditions associated with those plants to continue (Shebitz 2005).

The high rates of sweetgrass growth and survival in the plots with vetch found in this research may be the result of both the weed suppression and the nitrogen-fixing capability of the legumes. In addition, the partial shade established by the presence of the hairy vetch might have contributed to the increased sweetgrass height. The increased height and abundance of sweetgrass in the plots with hairy vetch contributes to its value as basketry material. The effects of hairy vetch on sweetgrass height and the minimal effort that is required to maintain plots with the cover crop suggest that basketmakers can benefit from planting sweetgrass with hairy vetch. It is essential to note, however, that hairy vetch is not native to North America and, while used in this study, is not suggested for use in restoration projects that aim to enhance the population of native plant communities.

For beargrass, it was found that manually clearing areas of vegetation and coarse woody debris may result in an increase in beargrass shoot number after only 1 year (Shebitz and others 2009b), and that exposing seeds to smoke-water before undergoing cold stratification may increase germination rates (Shebitz and others 2009a). It is essential to note, however, that for each research study presented in this paper, attempts were made to replicate the experiments at different sites and from different sources of beargrass seeds. Not all were effective at generating a significant response. The success of such methods, therefore, is not always guaranteed and it may require multiple trials to yield desired responses.

When reintroducing fire to a restoration project is not feasible, it is still possible to encourage the growth of those plant species that are fire-adapted. One must understand, however, that just as habitats that had experienced repetitive cultural burning would have been exposed to a recurrent disturbance, fire-adapted plants, and the areas to which they are reintroduced, would have to be frequently maintained. This commitment of time and energy is often not a problem if the species of concern is still used by tribal members. In fact, the community involvement in activities such as weeding and collecting seeds can play a vital role in not only maintaining healthy populations of the plants, but also in reinforcing ecological knowledge and traditions associated with those species.

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Joint Meeting of the Western Forest and Conservation Nursery Association and Intermountain Container Seedling Growers' Association

Moscow, Idaho

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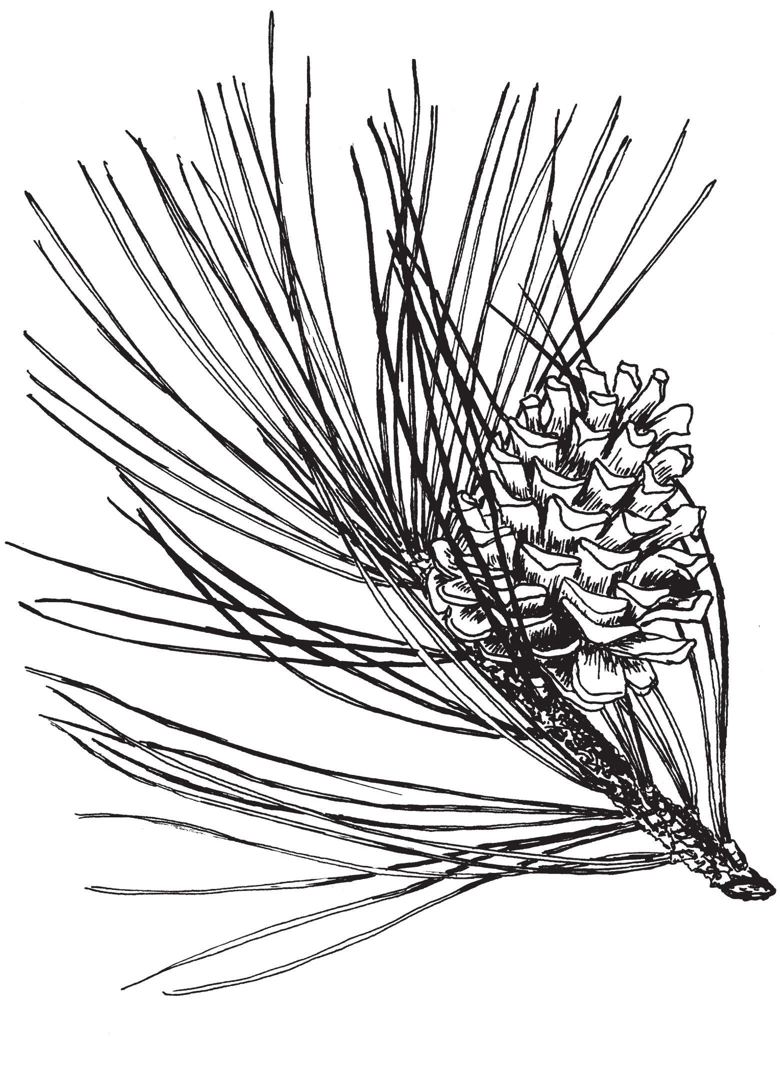

Joint Meeting of the Western Forest and Conservation Nursery Association and Intermountain Container Seedling Growers' Association

Ponderosa pine drawing by Lorraine Ashland, College of Natural Resources, University of Idaho.

Influence of Mineral Nutrition on Susceptibility and Recovery of Planted Seedlings to Ungulate Browse

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Burney OT, Jacobs DF. 2010. Influence of mineral nutrition on susceptibility and recovery of planted seedlings to ungulate browse. In: Riley LE, Pinto JR, Dumroese RK, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2009. Proc. RMRS-P-62. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station: 25-29. Online: http://www.fs.fed.us/rm/ pubs/rmrs_p062.html.

Abstract: Efforts to minimize animal damage during reforestation in the Oregon Coast Range have had little success. Enhancing plant mineral nutrition via application of controlled-release fertilization at the time of planting may provide some relief from ungulate browse pressure due to increased height growth, but associated impacts on susceptibility of fertilized plants to browse is unknown. This study is broken into two components, a field study and a simulated browse study. The field study examines the response (in terms of growth and browse) of Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and western redcedar (*Thuja plicata*) to controlled-release fertilization at time of outplanting at a continuum of four fertilizer application rates (0, 20, 40, and 60 g [0, 0.7, 1.4, 2.1 oz]). The simulated browse study uses the same fertilizer treatment regime and includes three simulated browse treatments: 1) 75% terminal shoot reduction; 2) 50% reduction; and 3) no reduction (control). For the field study, browse intensity was site- and species-specific. Few patterns were observed between browse preference and fertilization. Overall, relative height growth was optimized at the middle fertilizer rates (20 to 40 g [0.7 to 1.4 oz]) for all species. Results from the simulated browse study confirm the findings from the field study that fertilization is providing significant height growth gains for non-browsed seedlings and significant recovery for those seedlings that were mechanically browsed.

Keywords: reforestation, animal damage, ungulate browse, fertilization, terpenes, *Pseudotsuga menziesii, Tsuga heterophylla, Thuja plicata*

Introduction

Animal damage can have a severe negative impact on reforestation success and may cause reduced seedling vigor during early plantation development (Black 1994; Nolte and Dykzeul 2000; Nolte 2003). Impact of damage to plantations varies according to local ungulate population size, migratory patterns, tree species, seedling size, presence of alternative forage, weather, slash, topography, and habitat interspersion (Nyberg 1990).

The Oregon Department of Forestry (ODF) has experienced severe problems with reforestation efforts associated with damage from deer and elk browsing. For instance, in the winter of 2003, more than 25% of areas planted by ODF were subsequently interplanted or completely replanted as a result of animal damage (Powell 2003). Thus, animal damage can clearly impede the regeneration phase and may have severe economic and ecological consequences to Pacific Northwest forestry.

A variety of silvicultural options exist to limit damage caused by animals during the regeneration phase in forest management. However, the expense associated with many of these options (for example, fencing, vexar tubing) limits their practical application in operational reforestation (Nolte and others 1990; Nolte 1999, 2003). Chemical repellents applied to terminal buds are labor-intensive and produce varied, but often ineffective, results (Nolte 1999; Nolte and Wagner 2000; Wagner and Nolte 2001). An alternative means that may prove more cost effective is to promote rapid seedling growth to free-to-grow status (that is, above the browse line) as quickly as possible.

The purpose of this study is to assess the response of Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and western redcedar (*Thuja plicata*) to manipulation of plant nutrient content via controlled-release fertilization at time of outplanting at four fertilizer application rates (0, 20, 40, and 60 g [0, 0.7, 1.4, 2.1 oz]). Seedlings will be consistently monitored over a 5-year period for growth, foliar nutrient and terpene levels, and susceptibility and recovery from animal browse. Simultaneously, a simulated browsing study will be conducted to help verify animal browsing treatment responses observed in the primary field trials using the same fertilizer regime. Relationships between browse susceptibility, recovery, and fertilization treatments will be thoroughly quantified. Additionally, the effect of fertilizer treatments and browsing intensity on production of plant terpenes will be examined. This information may be used to determine how variation in plant nutrition affects production of chemical plant herbivory defenses and will simultaneously yield practical, useable scientific results regarding the efficacy of silvicultural treatments that may help reduce damage and costs associated with animal browsing during the reforestation process.

In this paper, we describe this ongoing project and report some preliminary results. We expect that more detailed reports will be published in the future.

Materials and Methods

Field Browse Study

Four sites were chosen for the field browse study, covering a range of the northwestern Oregon Coast Range physiographic province. These study sites (Bale Bound, Post Canyon, Yellow Bus, and Zig Zag) were installed on forest land managed by the Oregon Department of Forestry, Tillamook District. The different sites represent a range of site conditions (that is, slope, aspect, soils).

A total of 960 seedlings were planted for each species (Douglas-fir, western hemlock, western redcedar) for all four sites on 5 to 8 February 2006. Hampton Tree Farms (Salem, OR) provided Douglas-fir plugs grown in Styroblock® 515 containers (250 ml [15.3 in^3]) from IFA Nurseries, Incorporated (Canby, OR). ODF provided western hemlock and western redcedar plugs grown in Styroblock® 615 containers (336 ml [20.5 in^3]) from Pacific Regeneration Technologies, Incorporated (Hubbard, OR).

For each species, there are four fertilizer treatments in a complete randomized block design. The fertilizer treatments consist of Osmocote Exact® Lo-Start 15N:9P_2O_5:10K_2O plus minors controlled-release fertilizer (CRF) applied at four different application rates (0, 20, 40, and 60 g [0, 0.7, 1.4, 2.1 oz]) per seedling). Fertilizer was applied with a planting tool on the uphill side of the tree 5 cm (2 in) from the stem and at a depth of 5 cm (2 in) (Figure 1). There are four fertilizer treatments and four replications per species per site. This equates to 15 seedlings per treatment per rep per species per site. Species will be analyzed separately.

Prior to planting, a sub-sample of five seedlings from each species was destructively sampled to evaluate initial nutrient concentration levels and terpene levels to establish a baseline. Field measurements will be conducted twice per year, at the beginning (October) and end (May) of the primary winter browsing period. At each sampling, seedlings will be evaluated for survival and degree of browse damage (lateral and terminal shoot assessment). Evidence of foliar chlorosis, which may be indicative of nutrient stress, will also be noted. At each October sampling, seedlings will be measured for shoot height and root-collar diameter. Additionally, foliage samples will be collected from every seedling and pooled by species/block/treatment to evaluate foliar levels of both nutrients and terpenes.

Figure 1. Pottiputki planting tool used to deliver controlled-release fertilizer 5 cm (2 in) uphill of the seedling and 5 cm (2 in) below the soil surface.

Simulated Browse Study

A single site was selected in the southern region of the Tillamook District (ODF) where a total of 648 seedlings were planted for each species (Douglas-fir, western hemlock, western redcedar) in January 2007. Prior to planting, the site was prepared with an aerial herbicide application and intensive slash removal. Following these prescriptions, the site was fenced around its perimeter and trapped for mountain beaver (Figure 2). Western redcedar, Douglas-fir, and western hemlock seedlings were planted in January 2007. ODF provided the following plug stock from PRT: Douglas-fir and western hemlock plugs grown in Styroblock® 615 containers (336 ml [20.5 in^3]), and western redcedar grown in Styroblock® 512 containers (220 ml [13.4 in^3]).

Figure 2. Simulated browse study site with all large slash and residual live trees removed. A 2.4 m (8 ft) fence was constructed around the perimeter of the site, which extended 30.5 cm (12 in) into the soil. The first 0.6 m (2 ft) from the base of the fence was covered in chicken-wire to exclude rodents.

The simulated browse study is a complete randomized block design examining the three separate species. There are four fertilizer treatments and three browse treatments for a total of 12 treatment combinations. With three reps and 18 seedlings per rep, there are a total of 648 seedlings per species. Species will be analyzed separately. The fertilizer treatments are the same as the field study, consisting of four different application rates (0, 20, 40, and 60 g [0, 0.7, 1.4, 2.1 oz] per seedling). At the time of planting, the simulated elk browse treatments were applied as follows: 1) no browse (control); 2) clip main stem with a 50% reduction; 3) clip main stem with 75% reduction (Figure 3).

Survival, growth, and browse damage (if it occurs) of seedlings within this experiment will be measured once a year (~October) using the same protocol as the field study. Foliage samples will also be collected from every seedling and pooled by species/block/treatment to evaluate foliar levels of both nutrients and terpenes.

Figure 3. Clipping of the simulated browse treatment was performed by first measuring the pre-clipped height and then determining the 50% or 75% clipping height. All foliage was grabbed from the base and pulled up to the calculated height to be clipped.

Summary

Field Browse Study

For the field study, browse intensity was site- and species-specific. Differences in site may be a function of ungulate herd dynamics, which includes the number of individuals and their range of movement. Browse differences by species may be a function of plant chemical defenses in the form of terpene production.

Western Redcedar

Measurements after one growing season revealed high levels of browse across all sites and fertilizer treatments (Figure 4). Browse intensity (measured as the percentage of seedlings browsed) after the first growing season differed only by site. Seedlings at Bale Bound and Zig Zag had less than 70% browse, whereas Post Canyon and Yellow Bus had nearly 100% browse. By the end of the third growing season, browse intensity was approximately 100% for all sites and fertilizer treatment levels.

Figure 4. Typical browse intensity and severity of western redcedar after three growing seasons. Half of the field sites resulted in negative relative height growth.

Trends were observed with fertilizer response; the 40 g (1.4 oz) treatment appeared to have greater mean relative height growth ([current ht - initial ht] / initial ht) compared to the other fertilizer rates, including the control. Repeated browse and severity of browse interfered greatly with fertilizer response.

Mean relative height growth was used to describe not only height growth but also browse severity. After three growing seasons, western redcedar was the only species with negative relative height growth (occurring only at Post Canyon and Zig Zag). Interestingly, even in the presence of browse after three seasons, positive relative height growth was observed at Bale Bound and Yellow Bus, suggesting browse was not as severe. This may be a function of both site conditions and ungulate herd population dynamics.

Douglas-fir

Browse intensity also varied greatly for Douglas-fir between sites for all measurement periods, though was far less than that of western redcedar and western hemlock. Mortality was extremely high at Bale Bound due to site conditions (unrelated to browse) and thus was dropped from the analysis. After the first growing season, browse differed only by site; the average browse percentage was less than 10% for Yellow Bus and Zig Zag and greater than 50% for Post Canyon. By the third growing season, there were only slight increases in browse intensity at all three sites, mostly in the form of lateral damage (Figure 5).

Figure 5. Impacts from browse on Douglas-fir was far less severe than the other species. After the third growing season, most browse occurred as damage to the lateral branches.

Mean relative height growth at the end of the first growing season was below 50% for all sites and fertilizer treatments. Post Canyon, having high browse pressure, revealed negative growth rates after the first season. By the third measurement period, all sites and treatment levels had positive mean relative height growth in which some trees had already grown beyond the browse height range (Figure 6).

With the addition of fertilizer, regardless of rate, general trends in relative height growth gains were observed compared to the control (no fertilizer) for seedlings at all sites. A possible toxicity effect was observed under the 60 g (2.1 oz) fertilizer rate; all sites showed a declining trend in relative height growth compared to the 20 and 40 g (0.7 and 1.4 oz) rates.

Western Hemlock

Soil conditions at the Zig Zag site were extremely harsh due to buried slash, resulting in almost 100% mortality. For this reason,

Figure 6. Outstanding height growth of Douglas-fir with minimal to no browse at the Zig Zag site after three growing seasons.

Figure 7. Extreme browse damage of western hemlock after three growing seasons.

Zig Zag was removed from the analysis. Similar to western redcedar and Douglas-fir, western hemlock browse intensity varied greatly between sites, ranging between 10% and 75% after the first growing season. By the third season, browse intensity nearly doubled for each site (Figure 7). No trends were observed between browse intensity and fertilizer rate.

At the end of the first growing season, mean relative height for all sites and treatment levels was below 50%. There were no negative growth rates after this first season, suggesting browse was not as severe as was observed with western redcedar and Douglas-fir. Substantial relative height growth was observed at the end of the third growing season at both Post Canyon and Yellow Bus; growth rates exceeded 150% for all treatment levels. A combination of heavy browse pressure and site conditions at Bale Bound may have contributed to lower growth rates (range of 50% to 100%) compared to the other sites. At the end of the third growing season, the 20 g (0.7 oz) fertilizer treatment appeared to outperform all other fertilizer levels, including the control. This trend was similar to that observed with western redcedar and Douglas-fir in that the middle fertilizer levels (20 to 40 g [0.7 to 1.4 oz]) provided height growth gains up to 8.5 times that of the control.

Simulated Browse Study

After two growing seasons, the simulated browse study revealed positive relative growth response under all fertilizer and browse treatments. This differs from the field study, which has shown, and continues to show, negative growth for some species and some sites. This negative growth in the field is a function of repeated browse.

Western Redcedar

Second growing season results for mean relative height growth were similar to those found one year after planting. Fertilization, regardless of rate, showed gains in relative height growth relative to the control. Trends suggest that greater gains were achieved at the higher fertilizer rates (40 and 60 g [1.4 and 2.1 oz]). As anticipated, simulated browse treatments resulted in significant differences in mean relative height growth. The gains from fertilization and lack of interaction between treatments suggest that fertilization is aiding in recovery from browse.

Douglas-fir

Fertilization appeared to also aid in the recovery from browse after the second growing season of Douglas-fir seedlings. The greatest gains in relative height growth were observed under the 20 g (0.7 oz) treatment. These gains were more evident under the 75% reduction level. Beyond the 20 g (0.7 oz) rate, there was a decreasing trend toward the 60 g (2.1 oz) rate, suggesting potential toxicity effects.

Western Hemlock

Compared to the control fertilizer treatment (0 g), there was a steady increase in mean relative height growth with increasing fertilizer rate. Height growth was maximized at the 60 g (2.1 oz) rate, which differed from the findings in the field study. Again, there were obvious differences between the simulated browse treatment levels.

Terpene Analysis

Currently, terpene analyses have only been performed on baseline seedlings (prior to treatment application) due to the complexity of the methodology/preparation and the time consuming process of gas chromatography-mass spectrometry (GC-MS). Future reports will have a strong focus on terpene responses to browse and fertilization.

Conclusions

Results from both studies suggest that fertilization is providing significant gains in terms of both growth and recovery. Examining the influence of browse and plant mineral nutrition on the production of plant chemical defense (terpenes) is a part of this study and will contribute to better understand those specific factors driving browse susceptibility and recovery.

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Detection and Control of *Fusarium oxysporum* and *Cylindrocarpon destructans* in Forest Nursery Soils

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Abstract: *Fusarium oxysporum* and *Cylindrocarpon destructans* cause root disease that leads to significant crop losses in forest nurseries when not treated. Treatment currently relies on methyl bromide fumigation to eradicate soil pathogens. New environmental protection laws, however, are phasing out methyl bromide. Alternative chemical treatments are being tested, as well as biological fumigants such as seed meals and cover crops of *Brassica* spp. In this study, several different *Brassica*-based biofumigation treatments are being tested at Washington Department of Natural Resources Webster Forest Nursery in Olympia, WA. Fungal populations are being traced using molecular techniques such as PCR-ELISA and Real Time PCR. Use of molecular techniques to quantify the fungal pathogens should increase pathogen detection sensitivity and accuracy over the traditional dilution plating method.

Keywords: *Fusarium commune*, *Brassica* spp., seed meals, biofumigation, PCR-ELISA, Real Time PCR

Introduction

Conifer seedling production is plagued by soilborne fungal pathogens. The costs of chemical controls, both monetary and environmental, are rising, and seedling producers are finding new interest in alternative methods for disease control. In order to quickly and accurately assess both pathogen pressure in soils and the effectiveness of alternative treatments, new methods of detection and quantification are needed.

Biofumigation with *Brassica* spp. and other mustard species has been successful in some production systems (Larkin and Griffin 2006). Green manures of *Brassica* spp. are used by both organic and conventional potato growers in Central Washington to control scab. Brassicaceous seed meal and green manure soil amendments release glucosinolates, including volatile methyl isothiocyanate (sold commercially as MiTC). The glucosinolates released by *Brassica* spp. have been shown to be fungitoxic (Fan and others 2008). As with most biological treatments, timing and application method are critical to success. Methods used in one system are not directly transferable to another system. If timing and application rates can be determined, Brassica biofumigants show promise in reducing soil populations of fungal pathogens on conifer roots.

In conifer seedling production, the major pathogens include *Fusarium commune*, *Cylindrocarpon destructans*, and *Pythium ultimum*. Quantification of *Fusarium* spp. pathogens has been only marginally successful because traditional plating methods cannot separate pathogenic *Fusarium commune* from non-pathogenic *Fusarium oxysporum*. In order to accurately quantify the soil pathogen load before and after traditional or alternative treatment, molecular methods are being developed. Real Time PCR protocols (Schroeder 2008) are also being developed for pathogen quantification.

Methods

Greenhouse

Three brassicaceous seed meals, *Brassica juncea*, *Sinapus alba*, and *B. carinata*, and green manures of *B. juncea* and *S. alba* were used in a greenhouse trial to assess application rate and timing for biofumigation in nursery soil at Washington Department of Natural Resources Webster Forest Nursery (Olympia, WA). Potting mixes were made using 10% contaminated soil, perlite, vermiculite, and the biofumigant. Two rates of seed meals were tested for each species, that is, 2.2 tonne/ha and 4.4 tonne/ha (1 ton/ac and 2 ton/ac). Potting mixes were incubated in semi-sealed plastic bags to simulate tarping for 1 week or 4 weeks before one-year old Douglas-fir (*Pseudotsuga menziesii*) seedlings were planted into the mixes. Plantings were done in parallel at both Washington State University (Pullman, WA) and Webster Nursery. Trees were assessed for height and stem diameter at 5 weeks and 12 weeks, and destructively sampled at 12 weeks to assess root and shoot growth as well as root pathogen populations. Root pathogen populations were assessed by the standard plating method (James 2008). Samples were saved to be assessed using PCR-ELISA and Real Time PCR (RT-PCR).

Field

Field scale trials of the most promising greenhouse treatments used four replications of *B. juncea*, *B. carinata* and *S. alba* seed meals, a methyl bromide-fumigated control, and an untreated control in a randomized complete block design in 1.2 x 9 m (4 x 30 ft) beds. Trees were assessed for height, caliper, root and shoot mass, and root pathogen populations at 6 and 12 weeks, and will be assessed again at harvest.

Pathogen Detection

Isolates of *Fusarium* species from seedling roots were used to generate sequence from the ITS1 region of the genome. Both *F. commune* and *F. oxysporum* were found, with high homology to samples sequenced from other conifer nurseries (Stewart and others 2006). Sequence alignments provided 4 regions suitable for PCR-ELISA probes.

Table 1. Treatment codes.

Treatment code	Treatment
Ctl	Control
AutoClv	Autoclaved
BcSM1t	*Brassica carinata* at 1 ton/ac
BcSM2t	*Brassica carinata* at 2 ton/ac
BjSM2t	*Brassica juncea* at 2 ton/ac
SaSM2t	*Sinapus alba* at 2 ton/ac

1 ton/ac = 2.2 tonne/ha

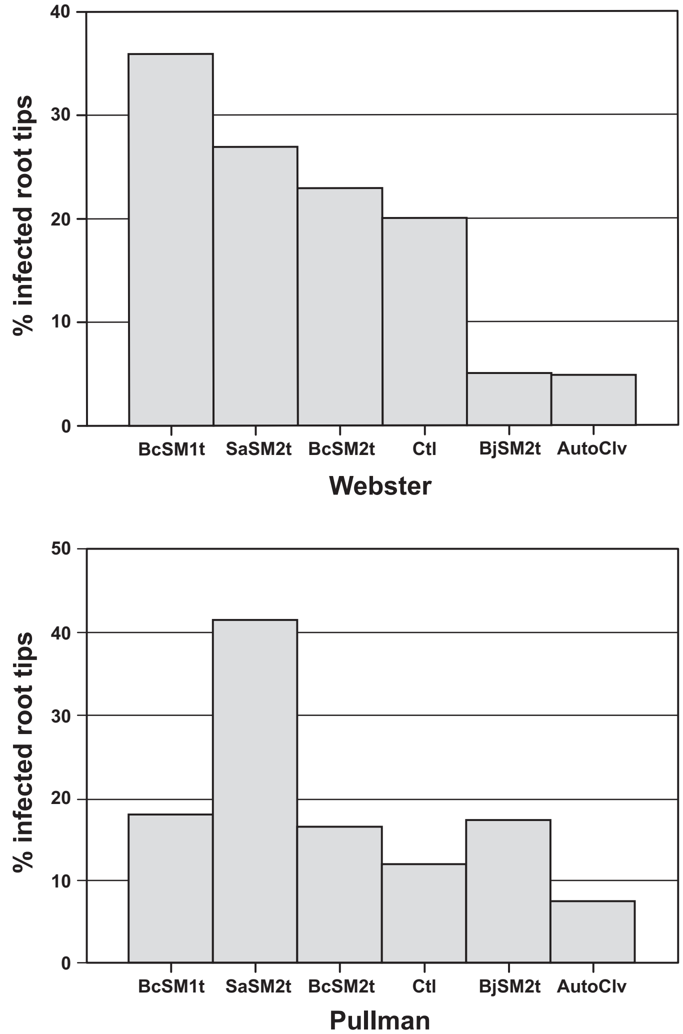

Figure 1. Visual root infection scores after 12 weeks in potting mixes amended with brassicaceous seed meal.

Results

Greenhouse

In the greenhouse trial, differences in visual scoring of root infection were found between the brassicaceous seed meal treatments and the untreated control potting mix (Figure 1). Differences were also observed in the pathogen population counts (Figures 2 and 3). In general, *S. alba* increased root pathogens, while *B. juncea* reduced pathogen populations. *Trichoderma* spp., a beneficial fungus, was also found to be elevated by the seed meal treatments, with *B. juncea* being the most effective at increasing Trichoderma populations. Only *S. alba* significantly reduced tree height relative to the control (Figure 4).

Field

Field trials are still in progress.

Pathogen Detection

Testing of the four probes yielded two probes with strong, specific binding properties needed for detection and discrimination of *F. commune*. Testing of the PCR-ELISA protocol is currently underway.

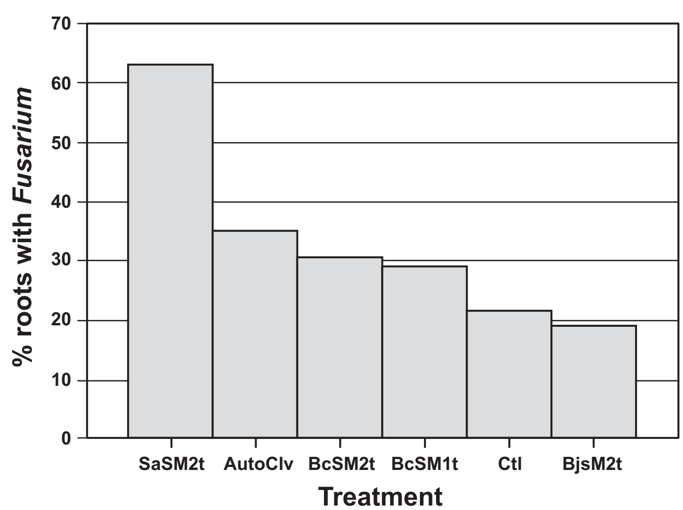

Figure 2. *Fusarium* spp. counts on seedling roots after 12 weeks of growth. No significant differences were observed for location; data presented are combined counts from Washington State University and Washington Department of Natural Resources Webster Nursery.

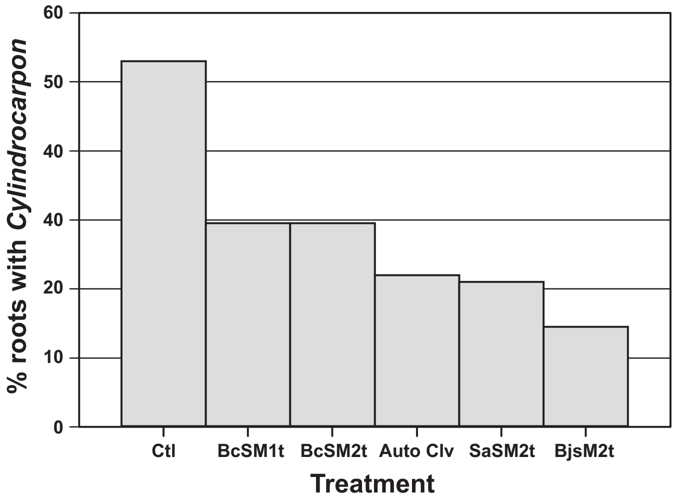

Figure 3. *Cylindrocarpon* spp. counts on seedling roots after 12 weeks of growth. No significant differences were observed for location; data presented are combined counts from Washington State University and Washington Department of Natural Resources Webster Nursery.

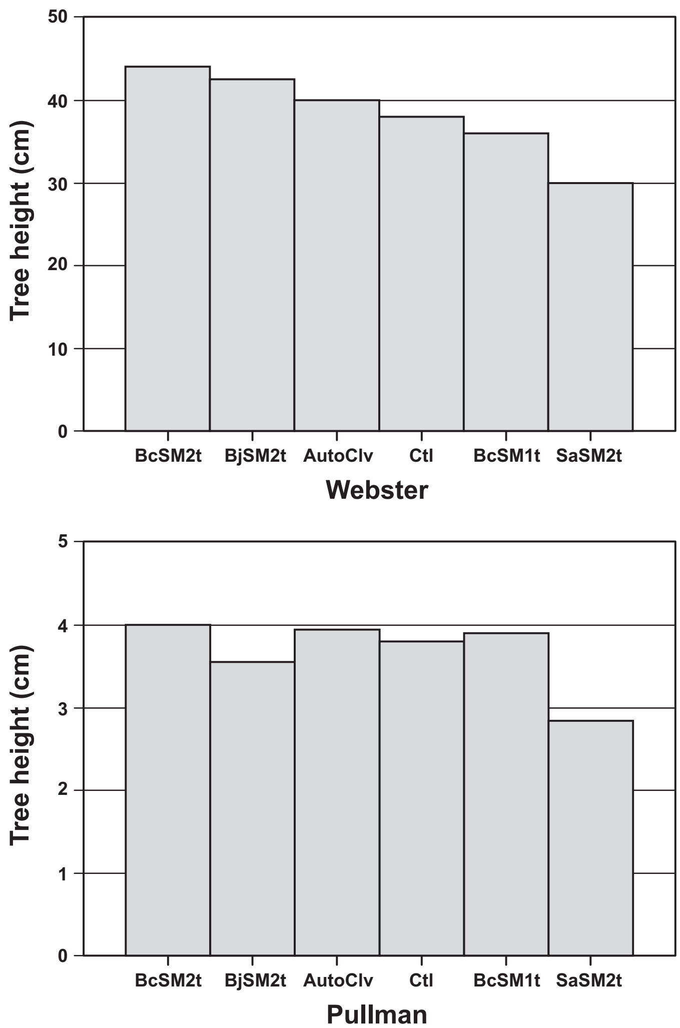

Figure 4. Tree height measurements after 5 weeks of growth in potting mixes amended with brassicaceous seed meal.

Experimental parameters to maximize detection of F. commune, as well as calibrations to make the reactions semi-quantitative, are currently being developed.

Discussion

From the greenhouse trial, several potential field scale treatments were determined. Field trials are currently running. *B. juncea* and *B. carinata* (available commercially) appeared to reduce *Fusarium* spp. populations and increase *Trichoderma* spp. populations. Molecular probes have been developed for *F. commune*, and PCR-ELISA methods (Grimm and Geisen 1998) can now be used to discriminate between *F. commune* and *F. oxysporum*. The next step will allow detection of *F. commune* in soils. With the recent advances in molecular methods to quantify *F. commune*, the major soil pathogen in this system, the greenhouse trial samples will yield even more data on the effectiveness of brassicaceous seed meal treatments. Data from the field will also be valuable in determining whether biofumigation will provide adequate pathogen control for Webster Nursery.

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Protocols for Sagebrush Seed Processing and Seedling Production at the Lucky Peak Nursery

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Abstract: This paper presents the production protocols currently practiced at the USDA Forest Service Lucky Peak Nursery (Boise, ID) for seed processing and bareroot and container seedling production for three subspecies of big sagebrush (*Artemisia tridentata*).

Keywords: *Artemisia tridentata*, seed fabric, production protocols, Wintersteiger combine, retractable-roof greenhouse, sagebrush

Introduction

Public lands in the Great Basin are experiencing uncharacteristically severe wildfires. For example, the Murphy Fire in southern Idaho in 2007 burned 243,000 ha (600,000 ac) of native rangeland. This fire resulted in a significant loss of habitat for the wildlife that rely on native vegetation for their survival (that is, mule deer [*Odocoileus hemionus*], elk [*Cervus canadensis*], sagegrouse [*Centrocercus urophasianus*]). Public land management agencies chartered to manage those affected lands and/or wildlife are committed to re-establishing native vegetation.

Since 1960, the USDA Forest Service Lucky Peak Nursery (LPN), located in Boise, ID, has processed native dryland shrub seeds and produced native dryland shrubs for public land management agencies. Production is dependent upon clients' needs. It is not uncommon for LPN to annually process several thousand pounds of seeds, and produce more than 1,000,000 one-year old dryland shrub seedlings.

Because big sagebrush is a dryland shrub of particular importance in restoration efforts, this paper will focus on the production protocols currently practiced at LPN for the following subspecies of big sagebrush: basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*), mountain big sagebrush (*A. tridentata* ssp. *vaseyana*) and Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*.). This paper is divided into three parts: seed processing, bareroot seedling production, and container seedling production. Seed collection methods are beyond the scope of this paper.

Seed Processing

Initial Drying

Wildland collections are made soon after the seeds are ripe (November), and generally continue until all seeds have fallen from the plants (usually December). The collected material is delivered to LPN for processing. All material must be thoroughly dried prior to processing. The collected material (which could contain leaves, twigs, stems, snow) is placed in shallow layers on conifer seed drying racks. A 1.5-mil polypropylene fabric (DeWitt N-Sulate™, DeWitt Company, Sikeston, MO) is placed on the bottom of each rack prior to filling with collected material to prevent seeds from falling through the screen mesh. The individual racks are stacked in such a manner to allow for airflow, which facilitates drying. The stacks of drying racks remain in the seed drying room at 24 °C (75 °F) until such time as we can begin processing the seeds. The time interval from "racking" to processing can vary from a few days to a few weeks. The longer duration of drying appears to have no detrimental effect on viability. All seed testing (purity, germination, and so on) is conducted at the Idaho State Seed Laboratory (Boise, ID).

Manual Seed Extraction

Once the seed material is sufficiently dried, it is run over a Hance Model 36 Scalper (Hance Corporation, Westerville, OH) (top screen of 14; bottom screen of 1/16). Workers position themselves on either side of the machine and hand-rub the material as it cascades down the inclined screen. This rubbing separates the seeds from the stem and screens out the coarse material, achieving a purity of 12%. This level of purity is suitable for aerial seeding by our clients. While this is an effective method, it is very time-consuming. An M2B Clipper (Seedburo Company, Chicago, IL) or similar machine could be substituted for the Hance Scalper.

Mechanical Seed Extraction

Debearders and hammermills are machines typically used to separate the seeds from the stem. In 2008, however, LPN effectively used a Wintersteiger small plot combine (Wintersteiger, Incorporated, Salt Lake City, UT) to mechanically perform this operation. This combine was set up as a stationary seed plant, with its built-in hammermill and scalper. With the front reel disengaged, one worker systematically fed the conveyor system. Another worker positioned at the rear of machine ensured adequate seed processing. This mechanical method was extremely effective in processing seeds. The target purity of 12% was achieved with some adjustments to the combine. Table 1 shows the settings for the Wintersteiger combine.

Table 1. Wintersteiger small plot combine settings for processing sagebrush seeds at Lucky Peak Nursery.

Concave	Blower	Drum Speed	Screen Incline	Screen Opening
00	Low to medium	High	Flat	3rd to 4th notch

Comparisons

Table 2 compares manual versus mechanical extraction results. Using the Wintersteiger combine, we were able to process a larger quantity of material in a shorter period of time while achieving the same test results. This was significant, as it allowed us to meet our clients' time-critical project deadlines.

Table 2. Comparison of manual versus mechanical processing methods for sagebrush seeds at Lucky Peak Nursery.

Process	Raw Weight in kg (lbs)	Processed Weight in kg (lbs)	Work Days	Purity	TZ
Manual	30 (65)	26 (58)	1	12	93
Mechanical	932 (2054)	830 (1830)	5	12	93
Total	962 (2119)	856 (1888)	6		

Mechanical Separation

Seeds processed to this point are suitable for aerial seeding. It is not suitable, however, for nursery seedling production; further processing is required. The MTDC dry dewinger was developed by the USDA Forest Service Missoula Technology Development Center for processing conifer seeds. With its variable speed drive, gum rubber-lined drum, and interior flapper, it will separate the sagebrush seeds from the capsules (feeder setting at 4; drum speed at 7.5). The vacuum attachment removes fine debris as it exits the machine. This debris often contains viable seeds, and is retained for further processing.

Air Separation

A Westrup Air Separator (McKenna Engineering Equipment Company, Incorporated, Fairfield, CA) performs the final processing step, separating the filled seeds from fine trash and empty seeds. At this point, the end product is virtually pure seeds and ready to be used for seedling production. Table 3 provides a calendar of events of seed ripening, with some processing results we could reasonably expect from the three subspecies of sagebrush of interest to LPN.

Seed Storage

Once the sagebrush seeds are processed to the level of purity possible with our machines, and once the moisture content has reached 10% or less, they are packaged in plastic resealable bags (minimum 4-mil thickness; preferably 6-mil) for long-term freezer storage at -12 °C (10 °F). There appears to be some evidence that sagebrush seeds will remain viable for some period under those conditions, based on the information presented in the Table 4. These seeds were collected, processed, and freezer-stored in 1999, and then re-tested in 2009. Additional research on this subject is being conducted jointly between the USDA Forest Service National Seed Laboratory (Dry Branch, GA) and the Rocky Mountain Research Station.

Table 4. Viability of one sagebrush seedlot stored for 10 years at Lucky Peak Nursery.

Seedlot	Year	Viability (TZ %)
BS61990005	1999	60
BS61990005	2009	59

Bareroot Sagebrush Seedling Production

Seed Preparation

No stratification is necessary prior to sowing. Sowing is usually scheduled in mid-May.

Seed test results are used when calculating the seed need (germination, seeds/lb, purity). The volume of seeds needed is based upon the industry standard sowing calculation formula. We use a target sowing density of 1800 to 2000 seeds/m^2 (160 to 180 seeds/ft^2). We assume a large percentage of viable seeds will not germinate and develop due the critical timing of irrigation water during the germination phase.

Pure sagebrush seeds are mixed with ground alfalfa meal (1:1 v:v) to increase weight and decrease static electricity. This allows the seed mix to flow through the seeder drop tubes without incident. Alfalfa meal has been used operationally at LPN since 1998, and has proven to be far superior to rice hulls as a seed mix in all our native grass, forb, and shrub seedings. A pinch of orange dust is added to each mix to increase visibility during and following seeding.

Sowing

Seeding is done with an Oyjörd seeder (JE Love Company, Garfield, WA) with the "Small Lot Device." Seeding consists of eight rows per 122-cm (48-in) wide seedbed. Once the total estimated bed length is determined for a seedlot, a gear setting (determining the revolution of the "pan") is identified on the calibration chart that will provide a whole number when it is divided into the total length. This

Table 3. Sagebrush seed maturation calendar and processing results from Lucky Peak Nursery.

Flowering Date	Ripening Date	Pre-Ripe Color	Ripe Color	Kg Pure Seeds/100 kg Collected (lb/100 lb)	Seeds/kg (Seeds/lb)	Bareroot Seedlings/kg Seeds (seedlings/lb seeds)	Container Seedlings/kg Seeds (seedlings/lb seeds)
July to September	November	Light Brown	Black	8.8 (4)	4,400,000 (2,000,000)	220,000 (100,000)	220,000 (100,000)

quotient is then used to divide the total seed volume of the seedlot. The end result virtually ensures the correct amount of seeds will be dispensed over the correct distance.

The seeds are covered by a 0.6-cm (0.25-in) sand layer following seeding. Ample irrigation is provided immediately after seeding and throughout the development of the plants. Germination should be expected within 7 days.

Production

Ample irrigation is applied to the sagebrush during the summer. The sagebrush receives 112 kg/ha (100 lb/ac) N (as urea) in two equal applications during the growing season. In mid-September, the sagebrush seedlings are root-wrenched at a depth of 25 cm (10 in) to slow height growth and to enhance the development of a fibrous root system. In many cases, the plants are also topcut to a uniform height with a tractor-mounted topcutter.

Harvest and Storage

Typically, we will harvest and process all seedlings in the fall. The maximum value for plant moisture stress (PMS) for sagebrush is -0.8 MPa (-8 bars). Molding can be a severe issue with sagebrush storage, so we ensure the foliage remains dry. No additional water is sprayed on the seedlings; seedling roots are not washed. Processed seedlings are packaged horizontally in waxed boxes without bags/liners, and freezer-stored at -2 °C (28 °F) for up to 5 months.

Container Sagebrush Seedling Production

Seed Preparation

No stratification is necessary prior to sowing. Sowing is usually scheduled in early-May.

Seed test results are conducted prior to calculating the seed need (germination, seeds/lb, purity). As pure seeds are sown into the cells, no mix is added. The number of seeds/cell is a function of seed test results, and can vary from three to seven seeds/cell.

Sowing

All container sagebrush seedlings are grown in a Cravo® retractable-roof greenhouse (Cravo Equipment Limited, Brantford, ON Canada). Because the roof and sides can open, molding issues on the foliage are minimized.

All containers are steam-sterilized at 71 °C (160 °F) prior to being filled. This is a very effective method in controlling diseases, as well as being a very efficient and safe operation. The minimum container size we use is the Styroblock® 112/106 (103 cm^3 [6.3 in^3]). The soil mix is a 75:25 peat:vermiculite mix. The seeds are mechanically sown with a Bouldin & Lawson® Precision Needle Seeder (Bouldin & Lawson, LLC, McMinnville, TN). Following sowing, a 14-g (0.5-oz) polypropylene fabric mulch (DeWitt Seed Guard™, DeWitt Company, Sikeston, MO) is laid over the top of the containers to keep the seeds moist during the germination phase (Schmal and others 2007). The fabric has been used operationally since 2003; it ensures adequate moisture will be maintained and helps moderate soil temperatures. The fabric will increase the soil temperature by 2.5 °C (5 °F) during the evening, and decrease it by 2.5 °C (5 °F) during the heat of the day. This greatly aids in uniform and rapid germination. The fabric will be removed when germination is greater than 90% and stored for future use.

Production

Because sagebrush seedlings will grow rapidly when provided ample irrigation, we limit the amount of water and fertilizer the plants receive. It is our intention to manage the shoot growth in such a way that a well-balanced plant is produced at the end of the rotation. Too much shoot growth on the plants will adversely effect diameter growth and greatly increase the risk of mold. We use a fertilizer mix of $4N{:}25P_2O_5{:}35K_2O$ at a rate of 40 ppm N.

Harvest and Storage

We will typically harvest and process all seedlings in the fall. Molding can be a severe issue with sagebrush storage, so we ensure the foliage remains dry. Processed seedlings are packaged vertically in small plastic bags (10 seedlings/bag) in cardboard boxes with plastic liners and freezer-stored at -2 °C (28 °F) for up to 5 months.

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Strategies and Challenges for Nursery Production: Perspectives on Where We're Going and Where We've Been

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Haase DL. 2010. Strategies and challenges for nursery production: perspectives on where we're going and where we've been. In: Riley LE, Pinto JR, Dumroese RK, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2009. Proc. RMRS-P-62. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station: 36-42. Online:http://www.fs.fed.us/rm/pubs/rmrs_p062.html.

Abstract: During the past century, seedling production has changed in accordance with technology and new knowledge. Many strategies have been developed to address challenges associated with pests, environmental conditions, and customer demands. Although the underlying concepts for growing seedlings have remained relatively constant, technological advances have enabled nurseries to improve stock quality significantly. As we move further into the 21st century, nurseries continue to face new challenges and develop new strategies with regard to pest management regulations, personnel shortages, demand for conservation species, economic hardships, and climate change.

Keywords: reforestation, native plants, nursery history, plant production

Introduction

During the past century, the world's land base has been subject to urban expansion, poor management practices, and increasing pressure to provide resources for a growing population. As a result, seedling production has become a fundamental tool for addressing reforestation, restoration, and conservation needs. Nursery practices for seedling production have evolved considerably over the past several decades in accordance with technological advances, increased understanding of seedling physiology and development, and changing customer demands (Dumroese and others 2005). Following is a broad overview of the past, present, and future strategies and challenges associated with several key areas within the nursery production process.

Growing Techniques

Considerable research into plant physiology and nursery culturing has led to a much greater understanding of seedling responses to environmental conditions, nursery treatments, and growing regimes over the past several decades (Rose and others 1990). For example, early nurseries had limited understanding about soil physical and chemical properties, as well as limited resources to improve them. Experimental trials resulted in guidelines and recommendations for amending soils to achieve maximal growth under specific soil conditions. Additionally, the manufacture of chemical fertilizers and other products, as well as the ability to transport materials over greater distances, have given growers more options for optimizing soil/media properties for seedling development.

Knowledge has also increased on the topic of seed preparation. Early nurseries often broadcast seeds onto seedbeds and then covered with a canvas tarp to allow the seeds to stratify in the soil (Figure 1). This could result in variable seed density and non-uniform germination. Much research into seed physiology has led to increased seed purity and viability, as well as stratification and sowing techniques for uniform crop production.

In addition to our better understanding of seedlings and the growing environment, technological advances in nursery equipment have greatly enabled nurseries to produce large volumes of high quality stock. Just about everything in early nurseries had to be done by horsepower and manpower, resulting in many hours of tedious labor to produce a seedling crop (Toumey 1916; Jones 1925; Olson 1930; Fleege 1995). For instance, transplanting seedlings was achieved by use of a transplant bar in which seedlings were aligned between two wooden boards and then, with a person on either end, the plants were suspended over a planting trench and transplanted (Figure 2a). This process was time-consuming and could result in desiccation of exposed seedling roots. Later, machines were developed to mechanically transplant individual seedling rows (Figure 2b); nowadays, multiple rows can be transplanted at once (Figure 2c). Lifting was also labor intensive and was accomplished slowly via horse and human labor (Figure 3). Today, there are custom machines for most nursery processes, from sowing to harvest, although smaller nurseries still rely on manual labor for many tasks. Additionally, most nurseries, small or large, must carry out much of their weed control via hand weeding.

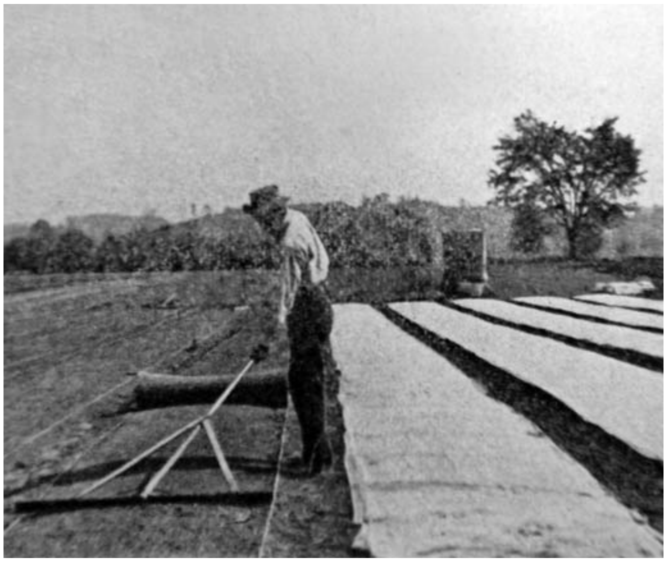

Figure 1. Covering seedbeds with burlap or cheesecloth following broadcast sowing was common practice in early bareroot nurseries to protect seeds from wind, sun, invasion of weed seeds, and predation from birds and rodents (Toumey 1916).

The basic concepts regarding density, fertility, irrigation, pruning, grading, storage, handling, and other seedling production practices have always been considered in nursery management. Whether it is 1909 or 2009, the underlying driving force is based on the Target Seedling Concept: "Targeting specific physiological and morphological characteristics that can be quantitatively linked to outplanting success" (Rose and others 1990). Seedling culturing is continually being fine-tuned to adapt to current needs and optimize seedling quality. Because nursery production is expanding more and more to encompass a larger variety of species, there is an accompanying need to develop and refine culturing techniques for many nontraditional native species.

Species

Until the past few decades, nursery production was primarily focused on commercial species for forest regeneration or horticultural cultivars for urban landscaping and gardens. Many indigenous plants were considered unwanted weed species, and control measures were developed to eradicate them, thereby reducing their competitive effect on desirable timber species. The rise of the environmental movement in the late 20th century, the explosion of invasive nonnative plants over the past century, and increased land degradation has led to much attention being directed toward propagation and restoration of native plants (Haase and Rose 2001).

Figure 2. Technology for transplanting has evolved over time from the labor-intensive manual tranplanting using boards (A) (Savenac nursery photo archives), to mechanical planting of individual rows (B) (Savenac nursery photo archives), to modern transplanting in multiple rows (C).

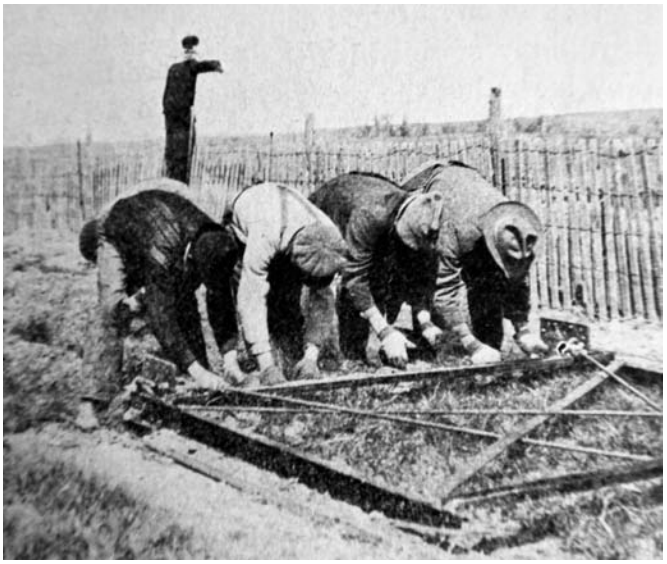

Figure 3. The Smith Tree Lifter consisted of a steel blade mounted in a slanted position on an iron frame. It was drawn over the bed using horse power and followed by a labor crew who removed the plants (Toumey 1916).

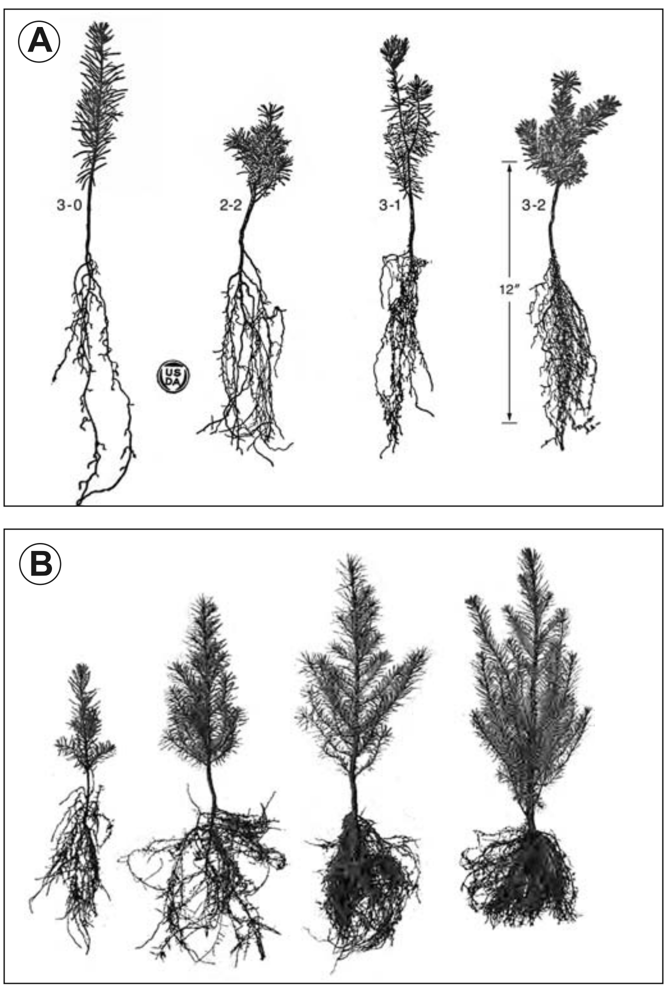

Figure 4. It could take 3 to 5 years to produce bareroot stock for outplanting in the early 20th century (A) (Douglas-fir seedlings, Korstian 1925); modern growing technology has resulted in production of quality bareroot seedlings in much less time (B) (left to right: 1+0, 1+1, 2+0, and plug+1 Douglas-fir, Rose and Haase 2006).

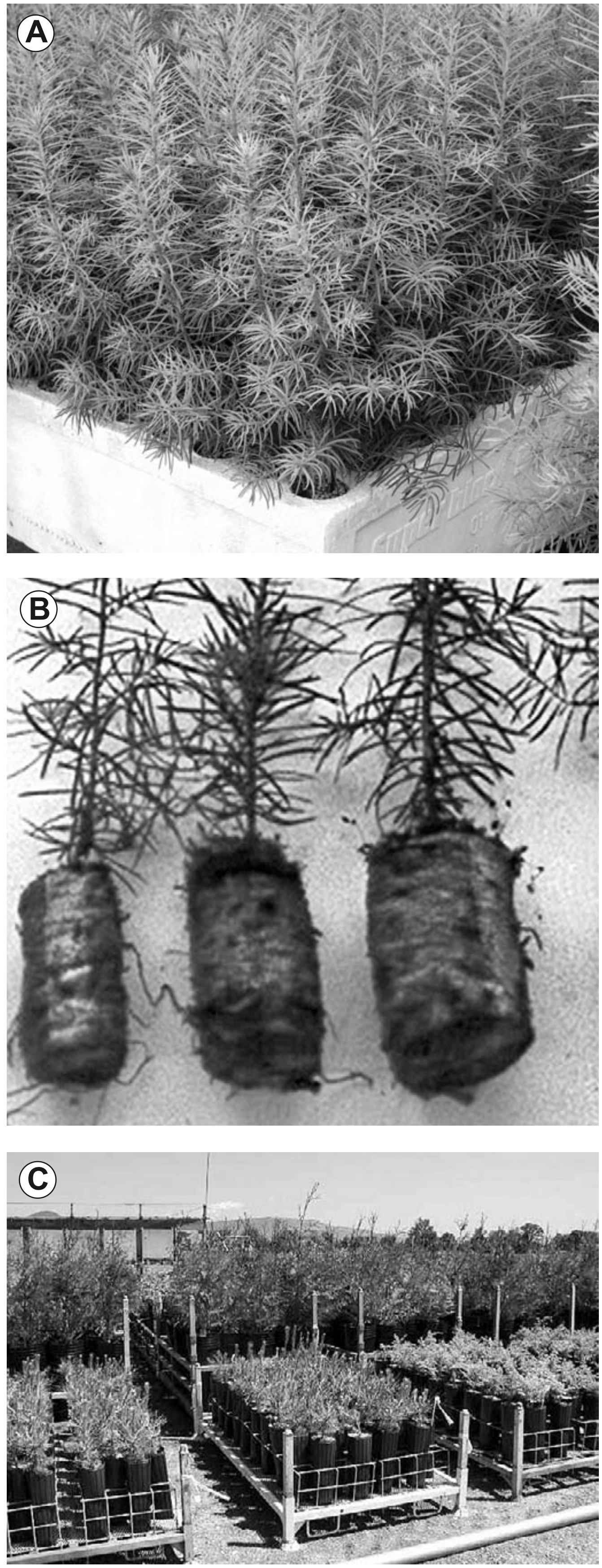

Figure 5. Many container growers in the US use Styroblock® containers (A). In addition, many other stocktypes are available, such as Jiffy® plugs (B) and large containers for restoration projects (C).

Shrubs and forbs provide erosion control, competitive exclusion of nonnative plants, and wildlife habitat. In addition, mixed plantings are important to avoid potential monoculture issues, such as was found in the 1990s with the onset of the Swiss needle cast epidemic (caused by the ascomycete fungus *Phaeocryptopus gaeumannii*) in the western United States (Hansen and others 2000).

Stocktypes

A century ago, it took 3 to 5 years to produce a bareroot seedling of adequate size and vigor for outplanting (Tillotson 1917; Korstian and Baker 1925; Show 1930) (Figure 4a). As growing practices improved, nursery growers modified stock specifications accordingly. Today, the same size (or better) can be produced in one or two growing seasons (Rose and Haase 2006) (Figure 4b). The 2+0 bareroot seedling was the standard stocktype for many years, but has been largely replaced by larger and better performing 1+1 and plug+1 transplant stocktypes.

The increase in automated processes and the transportation of peat over greater distances has also resulted in a significant proportion of plants now being grown as greenhouse container stock. In the past 25 years, container seedling specifications have changed considerably. In the forestry sector, container seedlings have gone from a typical 82- to 131-cm^3 (5- to 8-in^3) plug for outplanting to a 246- to 328-cm^3 (15- to 20-in^3) plug in the past 20 years. While most container growers in the US are using Styroblock® containers (Beaver Plastics, Acheson, AB Canada) for production (Figure 5a), many other container types have been developed to accommodate a wide range of seedling sizes and outplanting objectives (Figure 5b).

Genetics

Early seed collection for conifer species was accomplished primarily by raiding squirrel caches (Figure 6). In addition, few records were kept regarding the geographic location and elevation of the seed source. Variability in growth patterns and outplanting performance opened the door for the field of forest genetics and a wider understanding of species adaptation to ecotypes. Today, seeds are collected within specific seed or breeding zones (Figure 7) and elevation bands to ensure that seedlings are best adapted to their designated outplanting site (Randall and Berrang 2002). Many seed orchards have been established that produce billions of seeds from parent plants of commercially valuable tree species with desirable growth and form traits. Furthermore, nursery culturing regimes have been developed to best simulate the natural seasonal climate for given ecotypes within a species. These culturing techniques are still being developed to address various issues with genetically selected seedlots. In conifer species, seeds from orchards can result in rapidly growing seedlings exhibiting "speed wobble" (stem sinuosity) as well as stem splits that are vulnerable to infection if disease is present. In addition, growers have difficulty getting these fast-growing seedlings to cease growth and harden off in a timely manner.

Figure 6. Early seed collection was accomplished by gathering cones from squirrel caches (Toumey 1916).

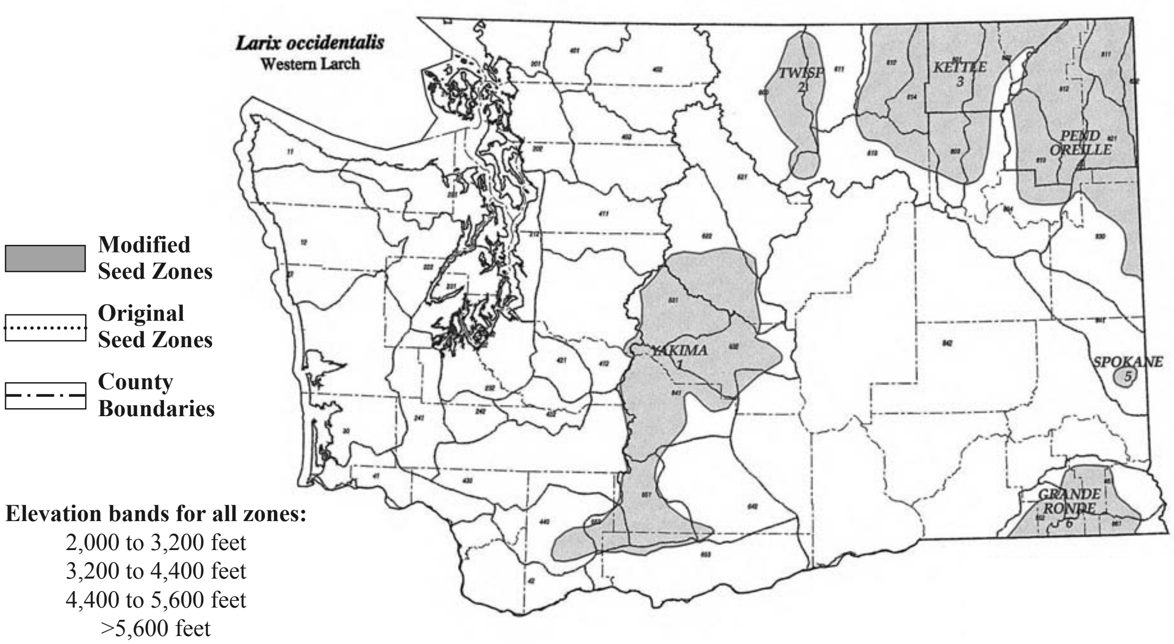

Figure 7. Seed zone maps, combined with elevational bands, are used for many tree species to determine appropriate geographic planting areas for seedlings. This is an example of a map for western larch (*Larix occidentalis*) in the state of Washington (Randall and Berrang 2002).

An understanding of genetics is lacking for most of the native species grown in nurseries for conservation and environmental restoration (Johnson and others 2004). There is still a need to develop a better understanding of the maximum distance many plant species can be established from the location of the original seed source (when seed production or sources are inadequate at a desired planting area), as well as how much growth can be gained by selection of seeds from parent plants with desirable traits. Additionally, climate change is likely to result in corresponding changes to plant geographic ranges (Gitay and others 2002) that will demand continued evaluation and development of seed zones and genetic families.

Products

As nursery practices have evolved over the past several decades, so too have the products that are manufactured to support seedling production. Specialized chemicals, fertilizers, equipment, tools, and supplies have been developed to improve seedling quality and to facilitate daily growing operations. Every year, new products abound for the nursery industry. There are root dips, foliar sprays, media amendments, technological gadgets, biological agents, and a wide range of others. Because most major nursery issues have already been addressed, many new products are based on some new twist of an old idea. These products are usually accompanied by a glossy flier and a slick company representative who promises a host of benefits that will cure just about any nursery ailment imaginable. While some products do have promise, too few are scientifically tested to statistically confirm the manufacturer's assertions. While many products are crucial to nursery processes, it's important for new products to undergo rigorous scrutiny to determine if they are a cost-effective and useful addition to seedling production.

Pest Management

Early seedling nurseries were often susceptible to decimation by disease or insects, or were overrun with weed species. This could result in huge annual crop losses. As these pests were studied more closely and various pesticides were developed in the mid 1900s, more and more control measures were available. In the chemical heyday, there was a toxic treatment for just about everything. However, as the US Environmental Protection Agency (EPA) revises and reviews its regulations based on national and international policies, more and more chemical treatments have been banned or heavily regulated to protect people, animals, and the environment. Most recently, soil fumigants that are commonly used in bareroot nurseries have been subject to Re-registration Eligibility Decisions (REDs) and will have greater restrictions for their use in the near future. Fortunately, most nurseries rely on an Integrated Pest Management (IPM) program that includes biological and cultural treatments in addition to chemical use. This reduces the need for chemical applications to some extent, although a complete loss of chemical options would be devastating to most nurseries. The past few decades have seen many private, academic, and governmental projects to evaluate potential pest control treatments in seedling nurseries and other agricultural crops. These projects are aimed towards providing alternative treatments in response to chemical regulations, thereby avoiding pest resistance to existing treatments.

Seedling Quality

Stock quality standards were once very forgiving (Figure 8). If it was alive and free of visible defects, then it was a quality plant worthy of outplanting. With limitations in technology and vulnerability to nursery pests, growers could lose half or more of their crop in a season. The surviving stock was therefore subject to minimal scrutiny before being sent to the field for outplanting. Over time, standards were developed for minimal size specifications. Shoot height and stem diameter are still the main criteria used today (Mexal and Landis 1990; Jacobs and others 2005), although the minimum acceptable sizes for these parameters have increased greatly. Acceptable size categories from just 25 years ago would be considered culls under today's customer expectations. It's important to also pay attention to morphological parameters beyond the traditional shoot height and stem diameter. While these are very important measures, many other seedling morphological and physiological attributes contribute to overall plant quality, such as root mass, fertility, cold hardiness, xylem water potential, and shoot to root ratio (Haase 2008).

Figure 8. Monitoring seedling height of 2+0 Engelmann spruce seedlings in 1932 (Savenac Nursery photo archives).

One of the challenges for the future is to continue gaining an understanding of physiological quality in response to culturing practices, customer needs, and climate change. In addition, demand is always present to develop better, quicker tests for determining that quality. For example, seedling mortality is sometimes not visible following a stress event; it would be useful to refine testing procedures for early detection of plants that are damaged or killed. As with all other components of nursery production, expansion of the knowledge to include non-traditional native species is also an area deserving of further attention.

Outplanting Practices

By necessity, nursery practices must evolve along with outplanting practices. Research programs and technological advances have resulted in significant changes to outplanting techniques and treatments (Figure 9). As with any business, the end-user dictates the specifications for the product. As a result, nurseries must adjust their growing practices to accommodate their client's planting season, site environment, species needs, and requests for specific plant morphological/physiological conditions.

Too often, seedling growth in the nursery and its subsequent outplanting and establishment are treated as distinct, independent phases. Communication between the nursery and outplanting personnel is critical and contributes to ensuring the vigor and longevity of seedlings destined for specific outplanting sites.

Figure 9. A snapshot of 75 years of forest regeneration with nursery-grown seedlings: tree planters in 1930 (A) and 2005 (B).

People

People who work in nurseries generally love their jobs and stay in them for many years. Most consider it a very rewarding career and enjoy working with young plants destined for reforestation or conservation plantings. Early nursery managers were passionate about their crops as well. They were pioneers in an early effort to replant many thousands of acres of deforested land.

Currently, the nursery workforce is aging, with a paucity of "new blood" to fill critical positions as they become vacant. Even with unemployment rates climbing, professional nursery jobs can be difficult to fill. Young people rarely have nursery work as their career goal. This is especially true in the forestry sector in which college students are only introduced to seedling production during one term of reforestation silviculture and seldom go on to pursue a nursery position. A career as a professional grower or nursery manager is often not on their radar or is not quite as alluring as positions in ecology, climate change, or field forestry. Nonetheless, nursery careers are every bit as professional, rewarding, and vital as those in other disciplines.

Economy

During the past 100 years, the nursery industry has grown substantially. In the latter half of the 20th century, production rose to 1.5 billion seedlings annually. In recent years, the economy has had a significant impact on nursery production. As timber prices fall, logging declines, funding for conservation projects decreases, and orders for nursery plants have waned.

Seedlings are always in demand regardless of the ups and downs in the economy. Although new construction and production of wood- and plant-based products has declined during the current economic downturn, the growing consumer population continues to need fiber resources such as printer paper, toilet paper, food packaging, housing, furniture, and other products which require harvesting and reforestation of the nation's forests. Additionally, forest fires are a growing problem in the country and most necessitate replanting seedlings in order to establish new forests to provide long-term resources for wildlife, recreation, timber, and other uses within a reasonable timeframe. This is essential in areas where competing brush species become rapidly established following wildfire and can subsequently prevent growth of tree species for several decades.

Furthermore, awareness and concern regarding the environment is rising. The media and the public have placed a growing emphasis on the importance of being "green" in order to protect and improve the environment to mitigate climate change and conserve resources for future generations. As such, we now see unprecedented attention directed toward employing trees as carbon sinks and using woody and herbaceous native plant species to restore degraded lands. Seedling production will never cease to be important on this planet.

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Equilibrium Relative Humidity as a Tool to Monitor Seed Moisture

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Karrfalt RP. 2010. Equilibrium relative humidity as a tool to monitor seed moisture. In: Riley LE, Pinto JR, Dumroese RK, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2009. Proc. RMRS-P-62. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station: 43-45. Online: http://www.fs.fed.us/rm/pubs/rmrs_p062.html.

Keywords: hygrometer, seed storage, seed testing

Introduction

The importance of seed moisture in maintaining high seed viability is well known. The seed storage chapters in the Tropical Tree Seed Manual (Hong and Ellis 2003) and the Woody Plant Seed Manual (Bonner 2008a) give a detailed discussion and many references on this point. Working with seeds in an operational setting requires a test of seed moisture status. It is necessary to know if the seeds are high in moisture or if they are dry enough to store without losing germination. Seed moisture testing was originally done by drying seeds for about 16 hours in a hot oven to drive off the water in the seeds. The moisture content was then determined indirectly by weight loss. For example, if there is a 1 g weight decrease after drying 10 g of seeds, the moisture content is assumed to be 10%. The test is destructive because the high temperature required to drive off the moisture will kill seeds.

Seed moisture content determined by the oven method can be related to readings taken by an electronic moisture meter. Charts can be made that allow a meter reading to be converted to moisture content. This is a quick, non-destructive test, but requires development of charts for every species. In addition, the seeds must be clean and of high viability.

A quick, non-destructive, and simple method of testing the moisture status of seeds is now available that combines the best features of oven tests and moisture meters. This method is equilibrium relative humidity or ERH. Baldet (2007) and Baldet and others (2009) have used this technique with tree seeds. This paper will give some practical description of how the test works and how to use it based on experience at the USDA Forest Service National Seed Laboratory.

What Is ERH?

A moist seed placed in dry air will lose moisture to the air. This is the principle that allows the drying of seeds. A dry seed placed in humid air will absorb moisture from the air. This is the reason it is necessary to store seeds in a dry storage room or to seal them in moisture proof containers. When the seeds no longer lose water to the air or absorb water from the air they are in equilibrium with the air. The relative humidity of the air at that point is then the equilibrium relative humidity, or ERH, for the seeds. If the air is humid, seeds will have a high ERH (Figure 1); if the air is dry, seeds will have a low ERH (Figure 2).

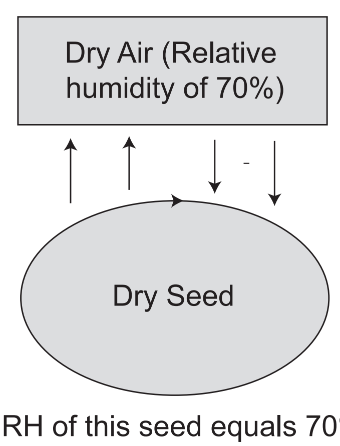

Figure 1. Seeds equilibrated in humid air will have a high ERH and contain a high amount of moisture.

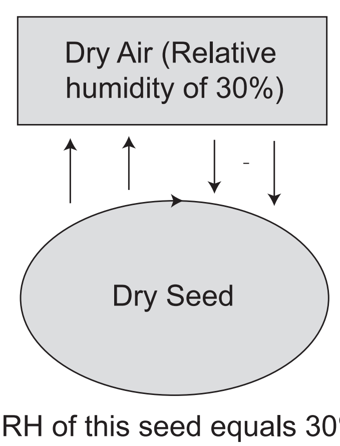

Figure 2. Seeds equilibrated in dry air will have a low ERH and contain a small amount of moisture.

How Is ERH Measured?

ERH is measured with any reliable hygrometer, an instrument to measure relative humidity of the air, for which the sensor can be isolated in a closed area with an appropriate amount of seeds. A reliable hygrometer would be one that is known to give true readings. Most manufacturers supply salt solutions that are used to calibrate the hygrometer in the field to be sure it is giving true readings. For more accuracy, the solutions can be traced back to official standards and come with a certificate verifying their accuracy. Specialized hygrometers, called water activity meters, are more expensive but offer some advantage to working with small samples of seeds because they have a small chamber in which to place seeds. Water activity is actually a more complicated measurement than ERH, but as long as the seeds and the meter are at the same temperature, ERH and water activity are the same. An example of a water activity meter is shown in Figure 3. Water activity meters have some automated features that are helpful in taking the reading and work somewhat easier with smaller seeds or larger individual seeds. The hygrometer gives readings that are identical to those from the water activity meter.

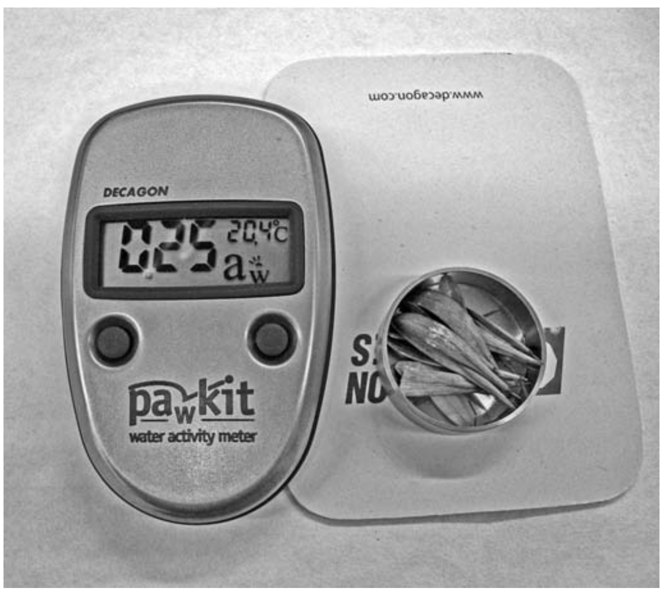

Figure 3. A water activity meter made by Decagon Devices Incorporated (Pullman, WA).

To measure ERH with an inexpensive hygrometer, it is necessary to improvise a test chamber. If there are many seeds, they can be placed in a container such as the plastic box shown in Figure 4. The whole meter is placed in the container with the seeds. It is important that the probe does not touch the seeds or the container. If it does touch the container, a small static electricity charge can upset the hygrometer reading. A second approach is to take a small tube or discarded drink bottle to make a chamber (Figure 5). When using a tube or bottle, use a small strip of plastic foam to seal the probe in the neck of the tube or bottle. This keeps outside air from entering the test chamber. To use a drink bottle for the test chamber, squarely cut off the bottom. The bottom is then inverted and a cap used to seal the end of the test chamber.

How Is ERH Used?

Most temperate zone seeds are stored dry. They would be ready for storage when they have an ERH of 30% to 40%. Figure 6 shows how ERH changes as the moisture content of the seeds increases. Between 3% and 6% moisture content, the ERH increases sharply; between 6% and 10% moisture content, ERH increases slowly; and from 10% to

Figure 4. Measuring the ERH of sagebrush seeds by placing the hygrometer (Rotronic Instruments USA, Huntington, NY) entirely inside a plastic box containing the seeds.

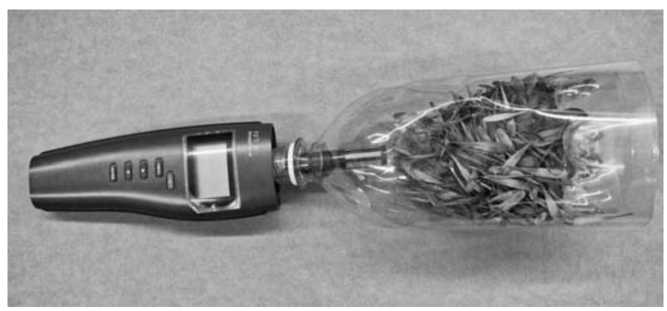

Figure 5. A 2-L (0.5-gal) plastic drink bottle converted to a chamber to measure ERH with a hygrometer.

full saturation, the ERH again increases sharply. Relating ERH to moisture content is important from the standpoint that most existing seed storage research has been done using the moisture content principle. Research has shown that green (Fraxinus pennsylvanica) and European ash (F. excelsior) seeds at 8% moisture content would store for 7 years without losing viability (Bonner 2008b). Our chart shows that 30% ERH equates to a moisture content below 8%. The general rule of storing seeds at 30% ERH is, therefore, a good practice. For example, Wyoming big sagebrush (Artemisia tridentata var. wyomingensis), stored in sealed poly or foil laminate bags, maintained viability for an extended period if first dried to an ERH of 30% or 40% (Karrfalt and Vankus 2009) (Figure 7).

Seeds that must be kept moist to maintain viability would require the ERH to be high. Samples of northern red oak (*Quercus rubra*) were tested for ERH as they were dried. An ERH of 80% equated to a moisture content below 25%, that is, the minimum moisture content needed for seeds to remain viable (Figure 8).

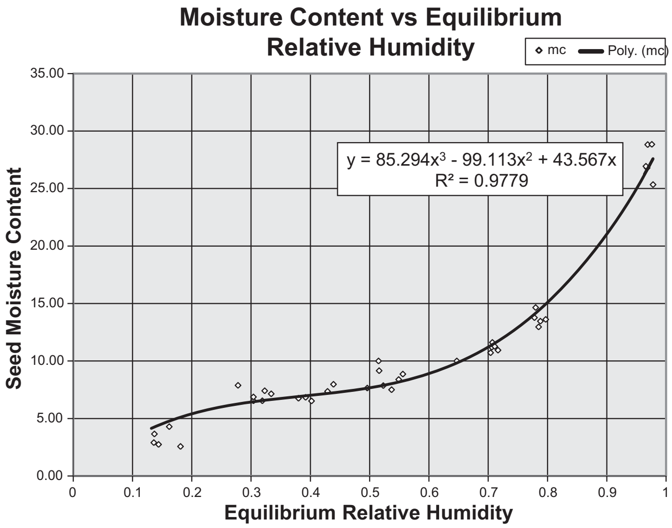

Figure 6. ERH of green ash (*Fraxinus pennsylvanica*) plotted against moisture content.

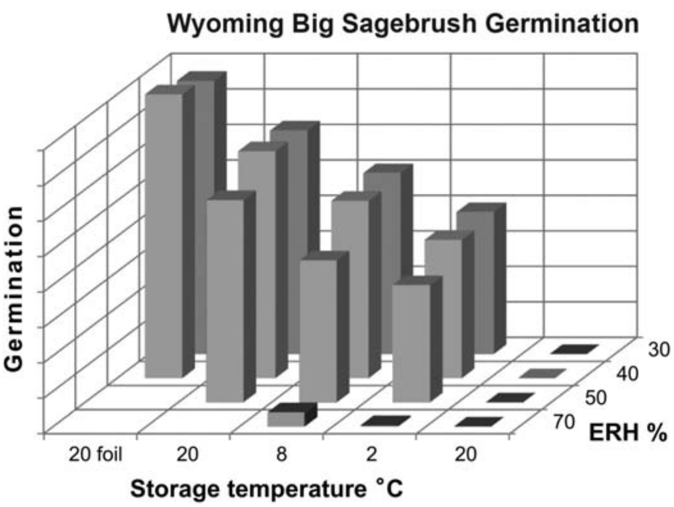

Figure 7. Germination of Wyoming big sagebrush (*Artemisia tridentata* var. *wyomingensis*) stored at different ERH and storage temperatures.

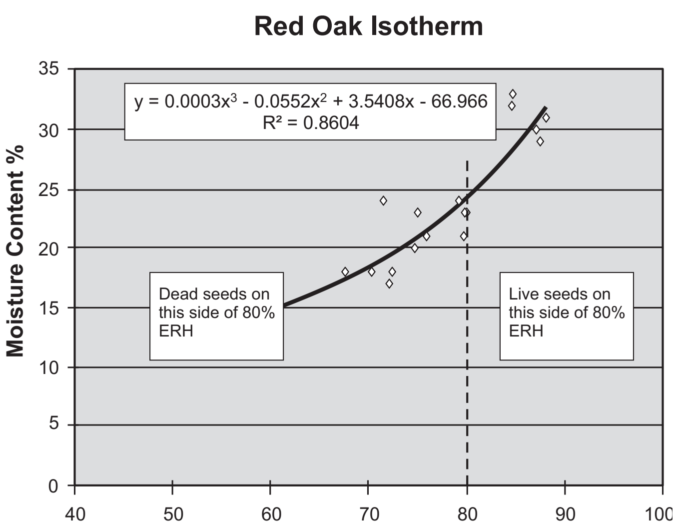

Figure 8. ERH of northern red oak (*Quercus rubra*) plotted against moisture content.

Conclusion

ERH is a very simple and accurate method for monitoring seed moisture. It has the following benefits:

- It can be used on any seed lot regardless of viability, purity, stage of extraction, or species. Seeds of grasses, forbs, shrubs, and trees can all be tested with ERH. Most research to date suggests that 30% ERH will be a good target for storing seeds.
- No conversion charts are needed. Therefore, any species can be tested.
- Traceable standards are available for calibrating the hygrometer, providing excellent ways to maintain high quality control for very accurate measurements.
- The test is non-destructive. Valuable seeds or very small lots can be tested directly with no loss of material.
- ERH is a fast test; results are obtained in a few minutes.
- The test is very easy to use.
- Equipment costs are relative low, between US$ 200 to 2500. A proper set of equipment for oven moisture testing would be twice as expensive.

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Effect of Organic Amendments on Douglas-Fir Transplants Grown in Fumigated Versus Non-Fumigated Soil

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Khadduri N. 2010. Effect of organic amendments on Douglas-fir transplants grown in fumigated versus non-fumigated soil. In: Riley LE, Pinto JR, Dumroese RK, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2009. Proc. RMRS-P-62. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station: 46-50. Online: http://www.fs.fed.us/rm/pubs/rmrs_p062.html.

Abstract: We transplanted one-year old Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) seedlings into compost-amended soil that had either been spring-fumigated with a methyl bromide/chloropicrin combination or left unfumigated. Seedling nutrient, pathology, morphology, and packout measurements were significantly better for those transplanted into fumigated rather than non-fumigated soil, regardless of compost treatment. Among seedlings transplanted into non-fumigated soil, those grown in the biosolid and bark-based composts had the highest average number of packable seedlings.

Keywords: seedlings, root disease, methyl bromide, compost, pest management

Introduction

Many bareroot forest nurseries have traditionally relied on the injection and tarping of the soil fumigant methyl bromide as an integral part of their pest management programs. Methyl bromide was listed as a Class 1 ozone depleting substance in 1991, and was officially phased out in 2005 under the Montreal Protocol (MBTOC 2006). Some agricultural sectors, such as bareroot forest nurseries, including the Washington Department of Natural Resources Webster Nursery, continue to use methyl bromide under limited quarantine pre-shipment or critical use exemptions (Haase 2009). Meanwhile, registered fumigants that serve as potential alternatives to methyl bromide have recently come under stricter regulation based on the potential for human inhalation exposure (EPA 2009). In 2008, we conducted a pilot trial of composts to determine disease suppression as part of a larger research effort to identify chemical and non-chemical alternatives to methyl bromide.

Forest nurseries have traditionally used organic amendments to maintain or improve soil physical and chemical parameters (Rose and others 1995; Davis and others 2006). Incorporating organic amendments has also been shown to stimulate functional groups of bacteria, fungi, and other soil organisms that, in turn, suppress soil pathogens in crops such as snap peas and corn (Stone and others 2004). Modes of fungal pathogen suppression include direct antagonism, competitive exclusion, and induced systemic resistance (Hoitink and Fahy 1986).

Several trials in conifer forest nurseries have specifically examined the use of organic amendments to suppress soil pathogens. In direct comparisons with a methyl bromide control, Stevens (1996) reported incorporation of 1.3 cm (0.5 in) yardwaste compost resulted in poor pre-plant control of root rots caused by *Fusarium* spp. and *Pythium* spp., and inferior seedling density and morphology in a 1+0 Douglas-fir (*Pseudotsuga menziesii*) crop. Elevated nitrogen (N) levels in the compost were implicated in disease outbreaks. Hildebrand and others (2004) found that incorporation of aged sawdust (with delayed N application) benefited conifer seedlings over mature composts in USDA Forest Service nursery trials. Although pre-plant soil pathology did not correlate well with resulting favorable seedling morphology, they commented that slowly decomposing organic soil amendments, such as sawdust, may tend to favor the growth of competitive soil saprobes to the detriment of soil pathogens that use simple organic substrates. In a southern forest nursery, Barnard and others (1997) similarly found that higher carbon to nitrogen (C:N) ratio materials, like composted pine bark, resulted in better disease suppression and superior packout morphology in comparison to lower C:N compost materials. However, still other forest nursery studies have documented suppression of conifer root pathogens (such as *Cylindrocladium* spp.) through application of low C:N materials like human sewage composted with sawdust (biosolids) and mushroom compost (Hunter and others 1997).

Materials and Methods

Organic Amendments

With the assistance of experts in the field, we identified four reproducible, scalable, high-quality organic amendments that are made within a reasonable distance from the nursery. These organic amendments covered some of the range of materials previously used in forest nursery trials:

1) *woody*—primarily made from woody landscape debris;
2) *bark*—Douglas-fir bark material (0.6-cm [0.25-in] screen);
3) *yard/food*—made from municipal yard, food, and food-soiled paper waste;
4) *biosolid*—a processed sewage sludge composted with 3 parts Douglas-fir sawdust.

All amendments were raised to pile temperatures of at least 71 °C (160 °F) at least three times and turned in a minimum 45-day process. Selected nutrient and compost quality results, conducted by a certified compost testing lab (Soiltest, Moses Lake, WA), are listed in Table 1. All amendments passed a CO_2 evolution test, and Solvita® tests (Earthcare Limited, Coventry, UK) revealed that the amendments were only slowly decomposing prior to incorporation. Only the yard/food and biosolid composts passed a maturity test (cucumber seed germination test).

Fumigation and Organic Amendment Application

The trial field had a Yelm sandy loam with 3.4% organic matter and was cover-cropped in winter wheat for 2 years, then left bare fallow the year prior to the trial. Fumigation took place 13 April 2008, and consisted of a “spring mix” of 80% methyl bromide and 20% chloropicrin at a rate of 336 kg/ha (300 lb/ac) fumigant applied. We incorporated each of the compost types 3 weeks later, and included a no-compost control. There were four replications of each compost treatment in fumigated and non-fumigated soil in a split-plot design, with fumigation as the whole plot and compost treatment as the split plot (Figure 1). Plot sizes were 9 m (30 ft) long by 1 bed width (1.2 m [4 ft]). Compost applications were applied at a rate of 44 dry tonnes/ha (20 tons/ac) by weight (180 to 189 m^3/ha [95 to 100 yd^3/ac] by volume, equivalent to a surface application of approximately 2-cm [0.75-in] depth). Composts were incorporated into the soil to a depth of 18 cm (7 in). One-year old Douglas-fir seedlings (1+0 bareroot) were then transplanted during the next several days into the amended soils and cultured according to operational practices for the 1+1 stocktype. Operational practices include regular supplemental nitrogen applications in addition to preplant soil fertilization.

Prior to incorporation, the compost amendments used in our trial were assayed by Dr Robert James (USDA Forest Service, retired, now with Plant Disease Consulting Northwest, Vancouver, WA) to check that we were not introducing pathogens that pose significant risk to Douglas-fir seedlings into the nursery. *Fusarium* spp. and *Cylindrocarpon* spp. were not detected, and *Pythium* spp. were detected at very low levels in the woody amendment.

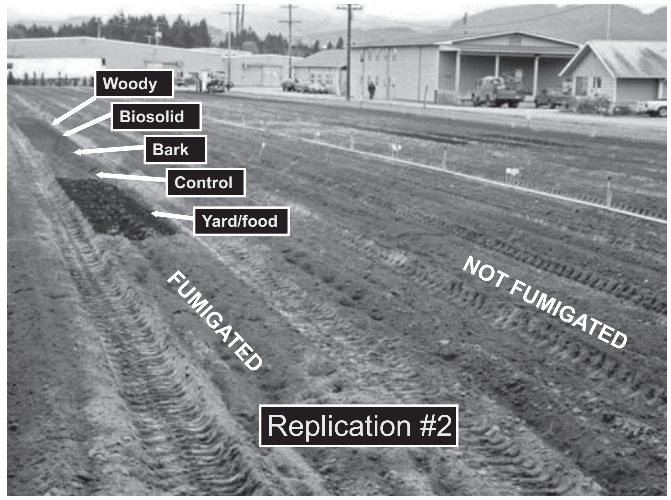

Figure 1. Trial layout. There were four replications of each compost treatment in fumigated and unfumigated soil.

Assessments

Foliar nutrient concentration (Soiltest, Moses Lake, WA, with needle weights taken at Webster Nursery for content calculations) and root pathology measurements (Plant Disease Consulting Northwest, Vancouver, WA) were taken monthly from May through September 2008, and at final harvest (February 2009). Height, stem diameter, root volume, shoot volume, and packable seedling counts were also taken at harvest. Weed evaluations were abandoned due to an uncharacteristic lack of pressure. Outplant evaluation of packable seedlings at two forest sites in southwest Washington, as well as at a nursery garden plot, is ongoing and will be reported on later. We used SAS® software (SAS Institute Incorporated, Cary, NC) for analysis of variance (ANOVA) to identify statistical differences among treatments.

Results

Root fungal analysis revealed significantly lower levels of *Fusarium* spp. (Figure 2A) and *Cylindrocarpon* spp. (Figure 2B), and higher levels of beneficial *Trichoderma* spp. (Figure 2C) from seedlings across all compost treatments in fumigated plots from June onwards. Late September trends of lower *Fusarium* spp. and significantly higher *Trichoderma* spp. levels for the bark compost compared to other composts in unfumigated soils disappeared by the last sampling in February 2009. Due to high variability, the late-season downward trend in *Cylindrocarpon* spp. in the unfumigated woody compost was not significantly different from other amendments in unfumigated soils.

At the late June and late July sampling dates, foliar N concentration was significantly higher for seedlings grown in fumigated soils (Figure 3). Foliar N content (concentration x weight of 100 dried needles) was also significantly higher for seedlings in fumigated plots from June onwards (data not shown). Foliar N did not vary significantly among compost types.

Table 1. Compost amendment descriptions.

Compost type	C:N	pH	EC (mmhos/cm)	Total %N	EPA 503 metals	CO_2 evolution	Bioassay maturity
Woody	34	7.4	0.21	1.10	Pass	Stable	Immature
Bark	132	3.9	0.24	0.37	Pass	Stable	Immature
Yard/Food	18	8.1	0.77	1.67	Pass	Stable	Mature
Biosolid	21	6.8	1.24	1.84	Pass	Stable	Mature

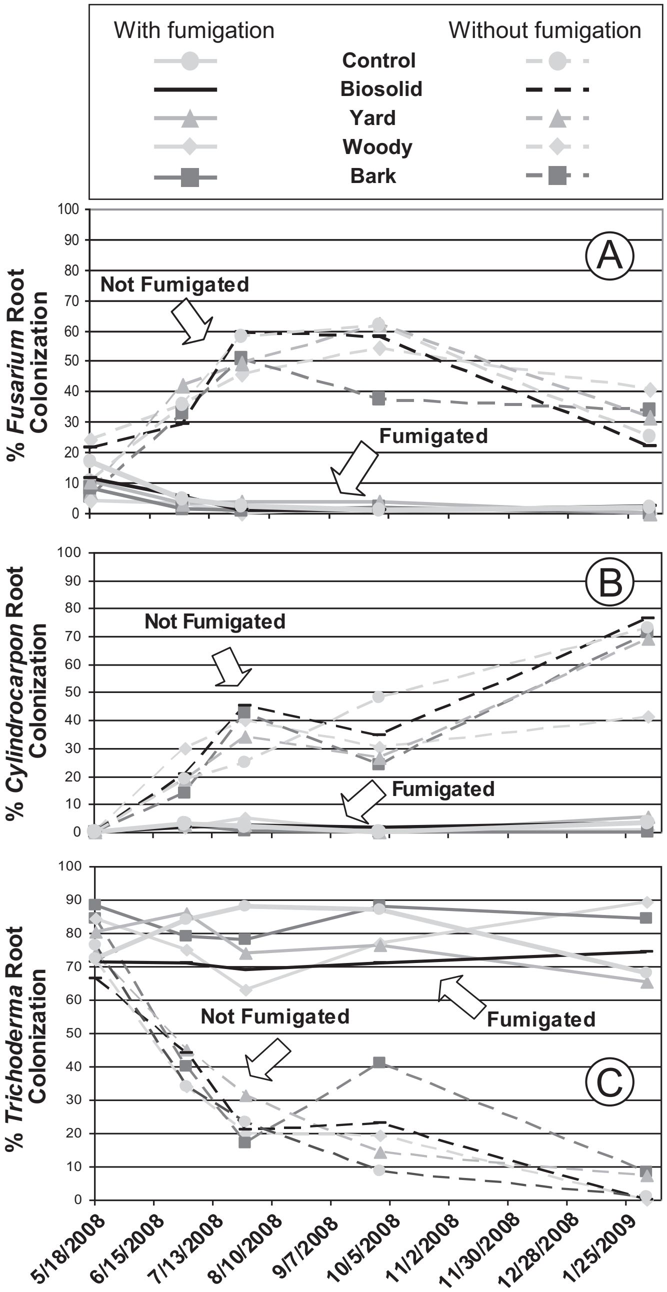

Figure 2. Root fungal analysis revealed significantly lower levels of *Fusarium* spp. (A) and *Cylindrocarpon* spp. (B) and higher levels of beneficial *Trichoderma* spp. (C) from seedlings across all compost treatments in fumigated plots from June onwards.

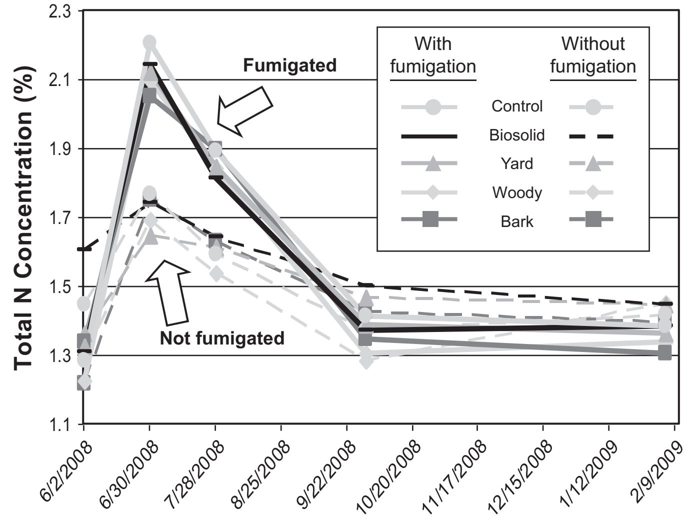

Figure 3. Foliar N concentration levels for compost treatments in fumigated versus non-fumigated plots. At the late June and late July sampling dates, foliar N concentration levels were significantly higher for seedlings grown in fumigated soils.

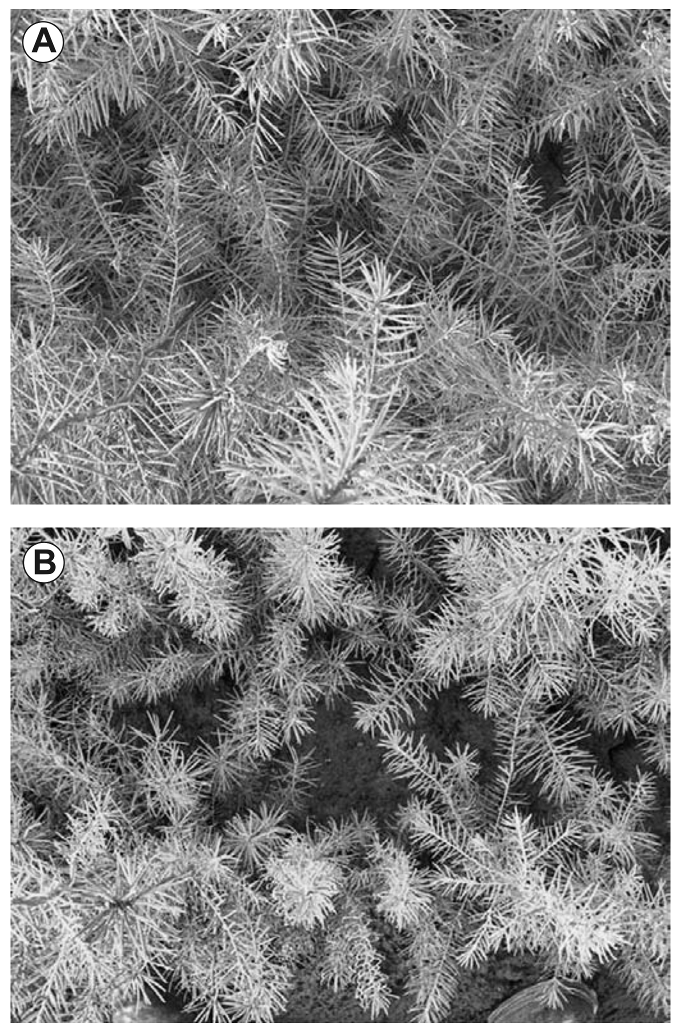

Figure 4. End of season fumigated control plot (A). End of season unfumigated control plot (B). Note terminal stunting, relatively short needle length, and poor lateral branch development.

End-of-season morphology yielded significantly larger height, stem diameter, and shoot volumes for seedlings grown in fumigated versus unfumigated plots, regardless of compost treatment. Root volumes were not significantly different (Table 2). Figures 4a and 4b show dramatic aboveground morphology differences between selected fumigated and unfumigated control plots. Packout averages based on minimum 5-mm stem diameter and 25-cm (10-in) height standards averaged 95.2% across all treatments in fumigated soils versus 83.3% for all seedlings in unfumigated soils (Figure 5). Among seedlings transplanted into unfumigated soil, those grown in the biosolid and bark-based composts had the highest average packable seedlings, though were not significantly different from the unfumigated control. However, only the fumigated biosolid treatment had a significantly

Table 2. Height, stem diameter, shoot volume, and root volume at end of season (February 2009). Averages within a column and followed by the same letter are not significantly different (*P* = 0.05).

Whole plot	Split plot	Height (cm)*	Stem diameter (mm)	Shoot volume (cc)*	Root volume (cc)*
Fumigated soil	Woody	48.6a	6.9a	58a	19a
	Bark	47.9a	6.9a	56a	19a
	Yard/food	50.5a	7.1a	60a	19a
	Biosolid	49.2a	7.1a	60a	19a
	Control	48.9a	7.2a	61a	19a
Unfumigated	Woody	38.8b	5.8b	35b	16a
	Bark	40.9b	6.2b	43b	17a
	Yard/food	39.1b	5.9b	38b	17a
	Biosolid	41.0b	6.3b	38b	17a
	Control	41.3b	6.3b	37b	16a

*1 cm = 0.4 in; 1 cc = 0.06 in^3

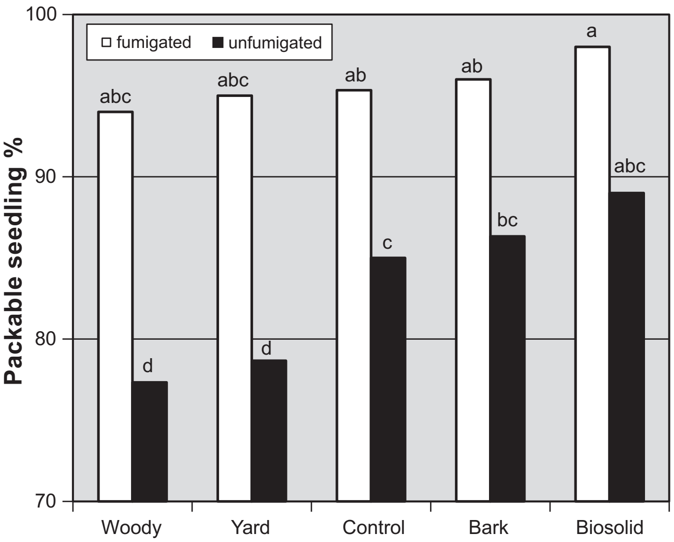

Figure 5. Packout averages based on minimum 5-mm stem diameter and 25-cm (10-in) height standards averaged 95.2% across all treatments in fumigated soils versus 83.3% for all seedlings in unfumigated soils. Means followed by the same letter are not significantly different. Among seedlings transplanted into unfumigated soil, those grown in the biosolid and bark-based composts had the highest average packable seedlings, though were not significantly different from the unfumigated control. However, only the fumigated biosolid treatment had a significantly higher packout than the unfumigated bark treatment. The unfumigated biosolid treatment was not significantly different in packout tally than any of the fumigated treatments.

higher packout than the unfumigated bark treatment. The unfumigated biosolid treatment was not significantly different in packout tally than any of the fumigated treatments.

Discussion

The overriding pathology and nutrition treatment effects clearly were due to fumigation and not to compost treatment. Expected nitrogen tie-up in seedlings from higher C:N materials did not take place. Pairing the nutrient and pathology data, seedlings grown in all of the non-fumigated treatments may have struggled to take up nitrogen at the peak of the growing season due to root systems weakened by root rot fungi. Hamm and others (1990) note that even minor disease of fine feeder roots may limit nutrient uptake in Douglas-fir and other conifer seedlings.

Fumigated plots, regardless of subsequent compost treatment, were associated with season-long high populations of *Trichoderma* spp., some of which are known to be beneficial to Douglas-fir. Rapid post-fumigation colonization by *Trichoderma* spp. and other beneficial fungi and bacteria may be, in part, responsible for the positive growth response associated with fumigation (James 2003).

The timing of compost application preceded transplanting by only 1 to 6 days. Typically, organic amendments are incorporated several weeks or months prior to transplanting or sowing of a crop (Rose and others 1995). Darby (2003) correlates increased microbial activity from organic amendment incorporation over time with increasing disease suppression in a study involving corn root rot in Oregon. A follow-up timing trial of compost incorporation is warranted. Nonetheless, the short turnaround in this trial was expected to show favorable results for the higher C:N treatments because these types of amendments have shown optimal disease suppression in the first 3 months following incorporation (Stone and others 2004).

The high packout of the unfumigated bark, particularly biosolid treatments, is balanced by the fact that even these packable seedlings remain inferior in size and with higher pathogen loads than seedlings from fumigated plots. Outplanting performance of these trees is being tracked and will be reported elsewhere. At the very least, this trial quantified the dramatic increase in root disease and subsequent decrease in seedling size and packout that occurs when soil fumigation is eliminated from our current production system. Although weed pressure was uncharacteristically low in this study, methyl bromide is perhaps valued as much for its herbicidal properties as for its fungicidal properties in Pacific Northwest nurseries, where it was first introduced as an herbicide (Landis and Campbell 1989). In a 2009 trial at our nursery, weed biomass and weed timing measurements are significantly higher in non-fumigated versus fumigated plots (Khadduri 2009).

A number of changes to cultural practices will most likely need to be made to deal with root rot pathogens that affect Douglas-fir seedlings in the absence of fumigation (Linderman and others 1994). Our nursery will evaluate combined treatments from this and other pilot trials in the coming years (for example, high-glucosinolate seed meal biofumigation of a previously fallow field combined with an organic amendment incorporation). The several years or rotations it may take to build up disease-suppressive soils (Bailey and Lazarovits 2003), combined with the necessity of avoiding crop falldowns in the interim to meet economic demands, remain a fundamental challenge.

Chemical alternatives trialed at the nursery include fumigants tested under lower-permeability plastics. These plastics trap fumigants in soil very effectively and allow for reduced rates of active ingredient. Combined with ongoing herbicide and fungicide trials, these chemical alternatives represent the best short-term solution to the loss of methyl bromide fumigation at this time.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented within.

Sulfometuron Methyl: Its Use in Forestry and Potential Phytotoxicity

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Abstract: Planting site preparation is a common practice used to enhance seedling establishment success. Site preparations include herbicide, fire, and mechanical methods. Studies designed to explore the use of herbicides as site preparation and release tools are common, and herbicides have shown their use in forestry to be logistically, economically, and ecologically advantageous. Herbicides that pose little threat to animal health or off-site contamination are desirable for forest management. Sulfometuron and related herbicides have been identified as effective vegetation suppressants with little collateral environmental impact. However, most research involving site preparation with sulfometuron has tested for efficacy and environmental safety alone, without addressing potential herbicide influence on growth of desirable species. Because the growth of seedlings is often a primary concern in forestry herbicide use, growth suppression is undesirable. Some research recognizing the potential for sulfometuron to damage tree seedlings has been conducted, but most emphasis lies with eastern US hardwoods and southeastern US softwoods that show species-specific tolerance levels. Little study has been conducted to explore the effects of sulfometuron on important species of the northwestern US, despite its use there. The few experiments conducted in the west have focused only on a few species. Widespread and important species such as western white pine (*Pinus monticola*), western larch (*Larix occidentalis*), and interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) have received little or no study with sulfometuron, despite their value and current use in intensively-managed forests; ideally the information presented in this paper will serve as a basis for new research to fill this information gap. The deficit of knowledge concerning potential detrimental effects of sulfometuron on these species calls for further research to establish best-use practices for individual species and site factors.

Keywords: sulfometuron, phytotoxic, seedling, site preparation, nursery

Introduction

Actions taken to prepare a forest planting site can aid in seedling establishment and success. These practices are aimed at reducing risk to planted or natural regeneration and promoting rapid forest establishment, growth, and productivity by reducing competition for resources.

Today, herbicides are frequently more appropriate than mechanical methods or fire for intensive-management forestry site preparation and release treatments. While unintentional ecological impact is a risk, herbicides have the advantage of relatively low cost, low soil disturbance, functionality in areas with difficult access, and improved control of re-sprouting species (Otchere-Boateng and Herring 1990).

Given the variable effects of individual species and herbicide combinations, there is great value in focusing study on one particular site-preparation herbicide (Seifert and Woeste 2002). The herbicide sulfometuron-methyl (methyl 2-[[[[(4,6-dimethyl-2-pyrimidinyl) amino]-carbonyl]amino]sulfonyl]benzoate), known by the trade names, Oust® and Oust® XP (hereafter referred to as sulfometuron), is a member of an increasingly popular family of herbicides available for forestry use (Russell and others 2002). Sulfometuron is used to chemically control herbaceous competition in the establishment and maintenance of forest plantations in the southeastern, eastern, and northwestern US (Anderson and Dulka 1985). Studies correlating sulfometuron to tree seedling damage and mortality, however, are rare, and this area invites further analysis.

Sulfonylurea Herbicides

Sulfonylureas are generally broad-spectrum herbicides first commercialized in 1981 (DuPont 2002). They function by inhibiting the plant growth enzyme acetolactate synthase (ALS) (Obrigawitch and others 1998). ALS participates in the biosynthesis of the branched-chain amino acids valine, leucine, and isoleucine, which are essential to normal, healthy cell division and growth (Blair and Martin 1988). Root meristem tissues are especially affected by disruption of the ALS enzyme function (Brown 1990). These root meristem cells eventually senesce and, without any viable growing points, the entire plant succumbs (Russell and others 2002).

Because all plants use the ALS enzyme for cell division and maturation, sulfonylureas rank low for plant species/group selectivity (Russell and others 2002). As with other sulfonylureas, ALS inhibition is the essential mode of action for sulfometuron, and while growth inhibition is fast (less than 3 hours in typical applications), target plant death is slow, often exceeding 4 weeks (Blair and Martin 1988). Sulfometuron is even less selective than most sulfonylureas (Russell and others 2002), and this fact means it can be used effectively as both a pre- and post-emergent herbicide (DuPont 2007).

Apart from their ability to target most weed species, sulfonylureas have several desirable characteristics separating them from other herbicide families. Due to the high specific activity of the ALS inhibitor, sulfonylureas such as sulfometuron can be used at very low application rates. Rates for field applications are generally over 100 times lower than those for older, conventional herbicides (Obrigawitch and others 1998). These low application rates translate to decreased chemical volumes and logistic expense, and the feasibility of effectively and economically treating large land areas. Besides low application rates, sulfonylureas have the advantage of a long application window, that is, whenever target plants are actively growing (Russell and others 2002) However, the advantage gained by this long application window is offset by the nonselective nature of the herbicide. Sulfometuron selectivity can often only be obtained by applying the herbicide when crop species are made less susceptible by dormancy and strong establishment (Cox 2002).

Environmental Fate

While sulfometuron has minimal impact on human health and aquatic fauna (Michael 2003; Michael and others 2006), it does persist in, and to a small extent travel through, the spray site environment. Its persistence in the environment is dependent upon a number of site-specific factors (Green and Strek 2001; Russell and others 2002). Once sulfometuron has been applied to a site, it will follow one of several fates. Ideally, it will be taken up into target plant tissues where it will be translocated to root and shoot meristems. It could also potentially be degraded on exposed surfaces, end up in surface water channels, or be adsorbed into the soil surface. As a class, sulfonylureas are essentially non-volatile (Russell and others 2002).

If sulfometuron molecules are unable to penetrate plant surfaces and be taken up into tissues, photolysis (degradation via ultraviolet sunlight) is probable. DuPont (2007) reports that most exposed Oust® not taken up by target vegetation is chemically destroyed by sunlight. Several other research efforts have confirmed this claim (Harvey and others 1985; EXTOXNET 1994; Green and Strek 2001; Michael and others 2006). The photolysis half-life for sulfometuron is reportedly 1 to 3 days (Harvey and others 1985). Photolyzed sulfometuron poses little further threat to the ecosystem because resulting compounds are herbicidally inert and ecologically harmless (Russell and others 2002). If sulfometuron is not photolytically destroyed, it may diffuse or percolate into surface runoff. Michael (2003) and Michael and others (2006) reported that off-site movement of sulfometuron occurred only after significant storm flow events and at no time were aquatic sulfometuron concentrations high enough to be detrimental to local aquatic invertebrates. The outcomes of these studies and others indicate that while most sulfometuron remains within the treatment site, it is capable of moving into aquatic systems and could thereby be moved off-site, although little or no damage is done to those systems because most residues are quickly photolytically or hydrolytically degraded.

Sulfometuron in the Soil

Apart from those portions which are taken into plant tissues or lost to photolysis, the majority of sulfometuron on treated sites is integrated into the soil. For pre-emergent herbicide activity, soil integration is desirable. Any herbicide not taken up by underground plant tissues is eventually degraded hydrolytically or metabolically. Because it does have potential for lasting soil activity, however, much study has been done to assess the fate of sulfometuron incorporated into treated soil.

Once in the soil, sulfonylureas degrade through both abiotic and biotic processes (Russell and others 2002). Soil microbe populations metabolize sulfometuron into its inert components. While this metabolizing action removes the chemical from the soil at a continuing rate, the speed of this process is dependent on factors affecting soil microbial activity and populations (Michael and others 2006). No study has yet been done to determine the percentage of herbicide degraded metabolically, but it can be inferred that, depending on application rate, a significant amount of residue is broken down in this fashion, especially in basic soils. The remainder is degraded through abiotic processes.

As in aqueous systems, abiotic breakdown of sulfometuron in the soil is the primarily result of chemical hydrolysis (Michael and Neary 1993). The speed of this process is directly influenced by the chemical and material composition of the soil, as well as moisture content and temperature. Drier soils prolong residue presence, as do high soil pH and low temperature values (Russell and others 2002; Michael and others 2006). As a family, sulfonylureas are weakly acidic, and that results in some chemical properties, such as solubility and susceptibility to hydrolysis, being pH dependent. The rate of sulfometuron soil hydrolysis is described as being slowest under conditions of neutral or alkaline pH, while acidic conditions are particularly effective in promoting degradation by destabilizing chemical bonds (Russell and others 2002). Harvey and others (1985) analyzed the hydrolysis of the active ingredient under various pH conditions and found that at pH 5.0, the half-life of sulfometuron was approximately 14 days. Conversely, measurements taken 30 days after treatment for pH 7.0 and 9.0 in another study showed 87% and 91% of the active chemical remaining, respectively (Anderson and Dulka 1985). Because of this apparently wide-ranging variation in the longevity of active residue in the soil due to pH-dependent hydrolysis, implications for treating neutral or alkaline forest soils are great. While pH is reportedly the most influential factor in determining sulfometuron persistence, other soil properties, such as composition, also affect hydrolysis and movement (Russell and others 2002). Soils with a high percentage of organic material tend to adsorb sulfometuron at a greater rate than mineral or sandy soils. It has also been suggested that soil pH values below the pH (5.2) of the herbicide greatly increase its hydrophobicity, contributing to its affinity for soil carbon molecules (Oliveira and others 2001). Once bound into a soil carbon complex, sulfometuron is essentially inert and will be degraded via one of the pathways already described.

Temperature is also influential in determining the rate of sulfometuron degradation. Although no studies have correlated soil temperature to residue persistence, DuPont (2007) suggests that lower temperatures slow the degradation process. This is primarily due to decreased biotic and hydrolytic activity. A combination of all biotic, climatic, and soil factors determine the rate at which sulfometuron degrades and the duration of the chemical in the soil.

Because of the high specific activity, sulfometuron is one of the longest persisting sulfonylurea herbicides. While figures for residue soil half-life vary, most authors suggest values between 10 to 35 days depending on soil, vegetation, and climate conditions (Harvey and others 1985; EXTOXNET 1994; Trubey and others 1998; Cox 2002; DuPont 2007). In their area-specific review of sulfometuron soil persistence, however, Anderson and Dulka (1985) report that the chemical was detectable in soils up to 12 months after application in eastern US states; in west coast states, conditions allowed persistence up to 18 months; and in the Rocky Mountain states, up to 2 years.

As with most sulfonylureas, sulfometuron has little potential to move off-site and cause serious ecological damage. However, due to its solubility at pH values common in forest soils and its ability to persist for considerable periods under differing soil and climate conditions, sulfometuron has the potential to remain on site and active, continuing to influence the growth of local flora for a wide range of time. This ability to remain active in the soil, coupled with its other weed control characteristics, has made it a common instrument in the practice and research of forest site preparation and management.

Research that strictly concerns the value of sulfometuron for various sites and forest associations is very rare; work comparing it to other herbicides or site treatments is more abundant. Most work, however, focus almost entirely on species native to eastern US forests, especially southeastern plantation species such as loblolly pine (*Pinus taeda*). In a study by Blazier and Clason (2006), two plots initially treated with sulfometuron showed high stand volume and mortality levels, despite the fact that other factors (namely unequal stand densities among plots) affected growth and survival. The researchers suggested the lasting results of herbicide treatment and the initial mortality of weaker individuals accounted for long-term growth advantages by increasing available site moisture and nutrition. In these studies, sulfometuron reportedly performed well and with lasting results.

Studies involving loblolly pine imply or agree that the species is particularly resistant to sulfonylureas (Yeiser and others 2004; Blazier and Clason 2006). Unfortunately, the case is not always true for other eastern species, especially some valuable hardwoods. A study by Ezell (2002) compared the effectiveness of 12 forestry herbicide mixtures, several of which contained sulfometuron. Pre-planting vegetation control was the desired result, so grass and broadleaf herbaceous species, as well as native woody species including loblolly pine, were treated with herbicide mixtures. Overall control with sulfometuron was reported to be very good, especially with respect to longevity. Because of its ability to remain on site and active in the soil, plots treated with sulfometuron regularly exhibited suppression up to 12 months after treatment. When contrasting species survival rates, loblolly pine had higher survival rates than all hardwoods in sulfometuron-treated plots. In one treatment, loblolly pine increased substantially, whereas several oaks (*Quercus* spp.) were completely eliminated by sulfometuron mixtures.

Seifert and Woest (2002) compared four herbicides (one being sulfometuron) and their effects on the growth of outplanted seedlings of nine species of eastern hardwoods and eastern white pine (*Pinus strobus*). Reportedly, seedling performance varied significantly according to species and herbicide mixture. No single treatment ranked above others for all species tested, and while most seedlings showed growth benefits from herbicidal control of competing vegetation, seedlings of a given species grew better under some treatments than others. They found that at least one of the herbicides/combinations resulted in less volume than the control for seven of the ten species examined, indicating that some treatments may have suppressed aboveground growth of tree seedlings as well as weeds. For eastern white pine, sulfometuron resulted in less seedling volume than other herbicides, despite providing better vegetation suppression. Although vegetation control with sulfometuron may be useful in forest site preparation and release, species-specific crop injury is a factor to be considered, especially with some eastern hardwood species.

Rose and Ketchum (2003) addressed the influence of weed control on coastal Douglas-fir growing in the northwest US using Oust®. More recently, Roberts and others (2005) reported on the effects of harvest residue and competing vegetation on soil characteristics and coastal Douglas-fir seedling growth. Again, Oust® was used as a site-preparation and release herbicide for the purpose of establishing weed-control plots as part of a larger experiment. The results of both studies reiterated the value of controlling competing vegetation for the purpose of making growth resources available to crop seedlings, but did not specifically target the effects of sulfometuron as an objective.

Studies investigating the use and effects of sulfometuron in the east contribute valuable information to species-specific sulfometuron susceptibility, as well as the value of sulfometuron, sulfonylureas, and herbicides in general in forest site preparation, plantation establishment, and maintenance. However, transferring the implications of those studies to western forest practices has limited value, and research correlating sulfometuron and western forests is insufficient. In addition these research efforts provide little information about direct interaction between sulfometuron and important timber species. Apart from coastal Douglas-fir, little or no work has been done with other important western timber species, despite the current use of sulfometuron in their management and culture.

Phytotoxicity in Western US Forest Species

The idea that eastern hardwood species are more susceptible to herbicide injury than more tolerant conifers (Seifert and Woeste 2002) has resulted in the use of site treatment herbicides in plantings of relatively un-studied western conifers. A review by Obrigawitch and others (1998) provided information across the spectrum of sulfonylureas and potential non-target species, but very few studies focus directly on phytotoxicity to western timber species. One of the most recent and significant of these was conducted by Burney and Jacobs (2009) who analyzed sulfometuron phytotoxicity in their study of field-planted coastal Douglas-fir, western hemlock (Tsuga heterophylla), and western redcedar (Thuja plicata). While root growth reductions in treated seedlings were seen the first year after planting, they had recovered to control levels after the second year. However, the authors suggest that soil and climate conditions on their study sites were conducive to residue breakdown; that given the reductions in root growth, seedling survival and establishment may be compromised in a commercial scale situation; and that growth setback may eliminate any vegetation control benefits.

Cole and Newton (1989) reported on height growth and weed suppression in Christmas tree plantations. Sulfometuron at several rates ranging from 0.05 to 0.21 kg ai/ha (0.04 to 0.19 lb/ac) was applied to Douglas-fir, grand fir (*Abies grandis*) and noble fir (*Abies procera*) pre- and post-bud break. Vegetation suppression was reportedly equally effective for sulfometuron and two other herbicides being tested (atrazine and hexazinone), but levels of injury differed significantly between herbicide, treatment rates, and application timing. Indications of injury included needle chlorosis, height growth reduction, and diminished overall appearance. Noble fir showed no significant foliar damage from any treatment, although the highest rate of sulfometuron did slow growth significantly. Similarly, grand fir was apparently uninjured by all treatments and rates. One-year Douglas-fir, however, showed significant injury under all treatment regimes, as evidenced by needle chlorosis and stunting. For older Douglas-fir trees (≥3 years), injury was less apparent, and only cosmetic damage was reported as significant for trees in that age class. Post-bud break treatments in Douglas-fir resulted in more damage than pre-bud break treatments. Overall, sulfometuron treatments resulted in the worst growth of Douglas-fir compared to the other herbicides considered.

In 2002, the Agricultural Products division of DuPont published an addition to the generic Oust® label (DuPont 2002). This special, local-needs label outlined directions and general use information for low spray volume conifer release and site treatment applications in the state of

Washington. This new literature provided general directions for the treatment of important western timber species, but most are lumped together without regard for individual species tolerance levels. According to the label, western timber species, except western redcedar, should be treated with 0.11 to 0.21 kg ai/ha (0.10 to 0.19 lb/ac). This is in spite of the fact that some variations in tolerance between these species have already been established. Lower applications (0.11 to 0.16 kg ai/ha [0.10 to 0.14 lb/ac]) to western redcedar are suggested due to the susceptibility of this species to injury (DuPont 2002). This publication indicates the lack of information on species-specific sulfometuron tolerance levels for western timber species, and is indicative of the degree to which Oust® is being used in western forestry applications.

Nursery Seedling Phytotoxicity Trials

Given the importance of herbicides such as sulfometuron in intensive forest management in the inland northwest of the US, and the inherent tradeoff between control of competing vegetation and phytotoxic damage to crop seedlings (Wagner and others 2007), a more complete understanding of seedling-herbicide interaction is needed to refine use practices and insure timely seedling establishment. In an effort to address this knowledge deficit, two nursery trials using seedlings in large containers were conducted to assess the effects of sulfometuron and two important soil variables controlling residue persistence. These trials were designed to control for all sulfometuron-degrading variables except substrate pH and moisture, and to address these study objectives: 1) determine the effect of substrate pH on herbicide phytotoxicity relative to herbicide application rate; 2) determine the effect of substrate moisture on herbicide phytotoxicity relative to herbicide application rate; and 3) assess the relative sensitivities of three important conifers native to the US inland northwest to different levels of sulfometuron. We hypothesized that higher concentrations of herbicide would result in decreases in measurable growth parameters, and that higher substrate moisture and lower substrate pH would moderate phytotoxicity by hastening residue breakdown.

Experimental Design, Data Collection, and Analysis

This study consisted of two experiments, both conducted at the University of Idaho Center for Forest Nursery and Seedling Research, Pitkin Forest Nursery (Moscow, ID). Both experiments were set up in a completely randomized design to test sulfometuron concentration and one of two soil parameters as causal variables, with growth and physiological responses as dependent variables. Prior to planting, 7.7-L (2-gal) pots (TPOT3; Stuewe and Sons, Incorporated, Tangent, OR) were filled with commercial potting mix, treated with various concentrations of Oust®, and aged for 10 days to allow photolytic elimination of exposed soil-surface residues (Harvey and others 1985). Dormant 1+0 western larch, interior Douglas-fir, and western white pine seedlings, grown in Styroblock™ 415C containers (130 cm^3 [7.9 in^3]; Beaver Plastics, Acheson, Alberta), were used in this study.

The first experiment (Trial #1) was designed to determine the influence of various soil moisture levels on sulfometuron phytotoxicity relative to herbicide concentration under controlled conditions. Six rates of sulfometuron (0.0, 0.026, 0.053, 0.105, 0.158, and 0.210 kg ai/ha [0.0, 0.023, 0.047, 0.094, 0.141, 0.188 lb ai/ac]) were applied to pots filled with medium in April 2008. Seedlings were planted individually in pots in May 2008, and grown under one of three randomly assigned moisture regimes: medium drydown to 25%, 21.5%, or 16% volumetric water content prior to irrigation, with n = 8 seedlings per treatment per species. Seedlings were grown without fertilizer in a greenhouse at the Pitkin Forest Nursery until September 2008. During this time medium moisture conditions were monitored using a Field Scout® TDR 300 soil moisture meter (Spectrum Technologies, Southlake, TX) and hand watered to field capacity when needed.

The second experiment (Trial #2) was similar in design to the first, with medium pH level replacing moisture as a treatment. Three levels of sulfometuron (0.0, 0.079, and 0.158 kg ai/ha [0.0, 0.071, and 0.141 lb ai/ac]) and four pH levels (5.0, 5.5, 6.0, and 6.5) were used, with n = 8 seedlings per species per treatment. Medium pH levels were chosen based on native soil pH values in the inland northwest (McDaniel and Wilson 2007). Medium pH was adjusted prior to treatment and planting and subsequently maintained, using irrigation water adjusted with phosphoric acid (H_3PO_4) and hydrated lime ($Ca(OH)_2$). The pH was set and monitored using an IQ 150 pH meter (Spectrum® Technologies, Southlake, TX). Seedlings were planted in July 2008, grown outside, and hand irrigated when volumetric water content neared 25%. Seedlings were removed for final measurement after 35 growing days (August 2008).

Prior to planting, all seedlings were root-washed and initial measurements of growth variables were taken. Root-washing and root volume measurements were conducted using the water displacement method (Burdett 1979). Initial root-collar diameter (RCD) and height were also measured. Final measurements were taken after the onset of dormancy in October 2008 for Trial #1 seedlings. Final measurements of seedlings in Trial #2 were taken in August 2008. These included RCD, height, root volume after root washing (Burdett 1979), and treatment-caused mortality. Measurements of net photosynthesis, transpiration, and stomatal conductance to water vapor were taken for seedlings in Trial #1 using a portable photosynthesis system (Li-6400, Li-Cor® Biosciences, Lincoln, NE). These leaf function variables were measured in July 2008. Sample needles were harvested and dried, and leaf areas calculated using a leaf area meter (Li-3100, Li-Cor® Biosciences, Lincoln, NE). Leaf area measurements were used to correct leaf function measurements for individual sample leaf areas.

Statistical analyses were performed using SAS® software (SAS Institute Incorporated, Cary, NC). Data normality and homogeneity of variance were assessed and determined to be normal and homogeneous, and no transformations were conducted. Correlations between dependent variables and sulfometuron concentration/media moisture regime, and sulfometuron concentration/media pH were conducted using a two-factor ANOVA for each species in each trial. When the F-test for a given dependant variable was significant at $P \leq 0.05$, Tukey's HSD test was used to separate means. Regression analyses were performed to determine relationships between sulfometuron concentration and significantly affected response variables.

Results

Trial #1

None of the growth parameters measured was significantly affected by medium moisture for any of the three species. Treatment-caused mortality was minimal (< 7% for each species), and mortality differences were not statistically significant for any treatments. Only sulfometuron had a significant influence on seedling growth in Trial #1. Western larch height ($P < 0.0001$), RCD ($P < 0.0001$), and root growth ($P < 0.0001$) were strongly inversely correlated with sulfometuron treatment concentration (Figures 1a, 1b, 1c). Douglas-fir height growth differences ($P = 0.0085$) were detected between seedlings treated with 0.0 or 0.053 kg ai/ha (0.0 and 0.047 lb ai/ac) and seedlings treated with 0.210 kg ai/ha (0.188 lb ai/ac) (Figure 2a). Although not significant, Douglas-fir diameter growth tended to decrease with increased sulfometuron concentration (Figure 2b). The two highest levels of sulfometuron (0.158 and 0.210 kg ai/ha [0.141 and 0.188 lb ai/ac]) were different from control seedlings for root volume change ($P = 0.0002$) (Figure 2c). Mean western white pine seedling height

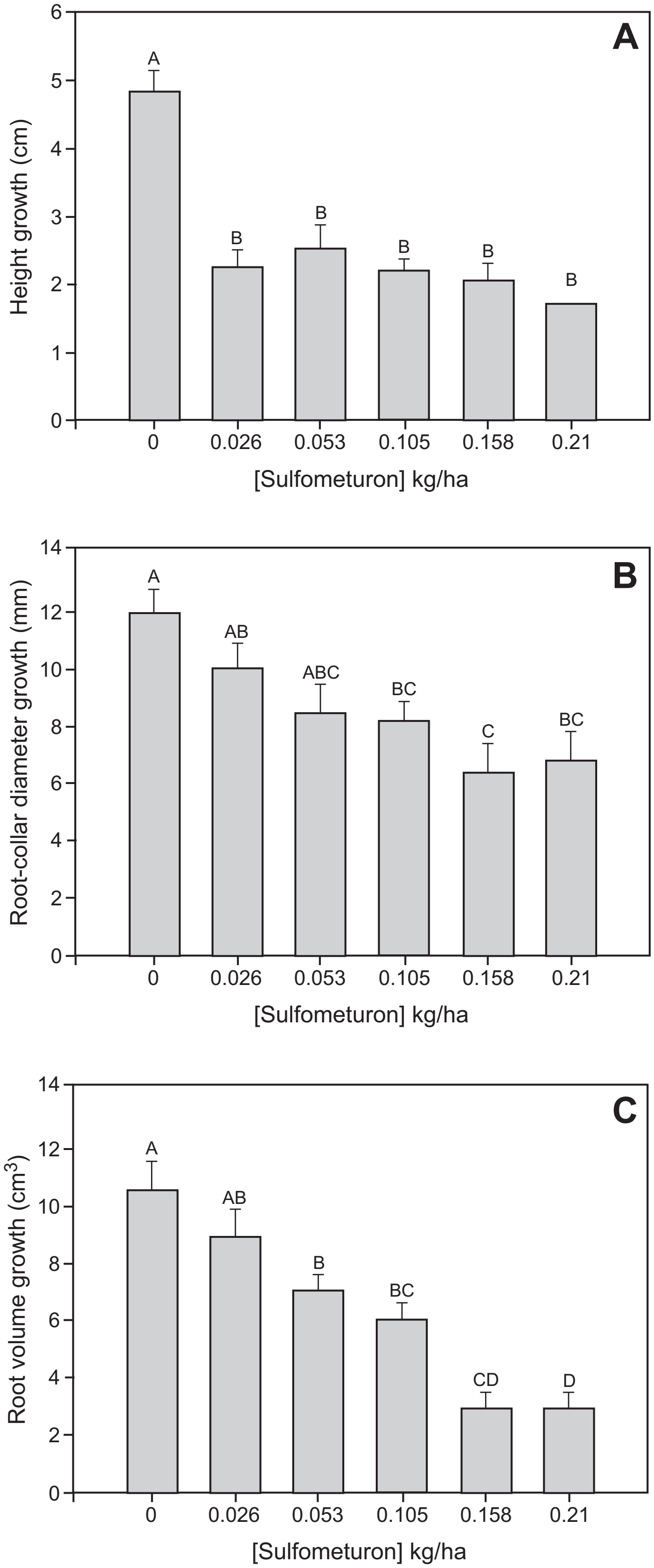

Figure 1. Western larch height growth (A), root-collar diameter growth (B) and root volume growth (C) were inversely correlated with sulfometuron treatment concentration ($P < 0.0001$).

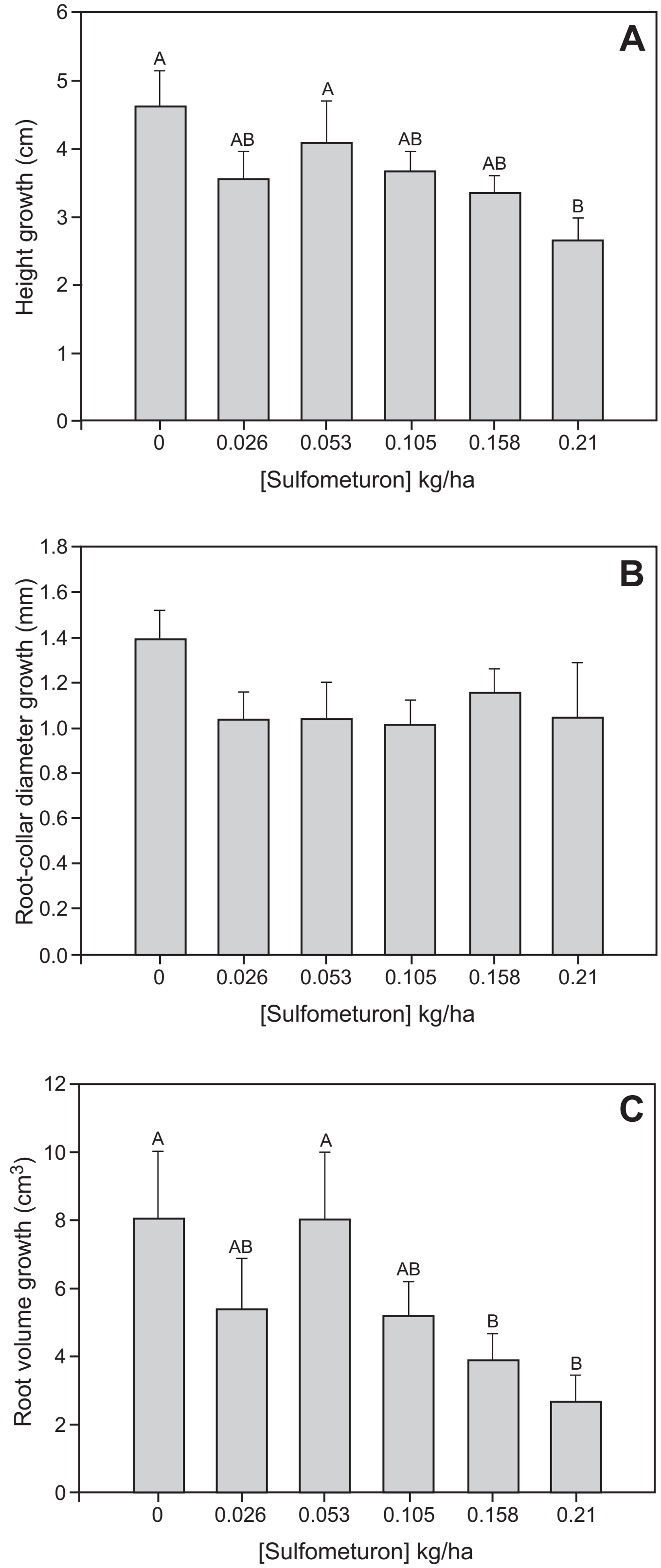

Figure 2. Douglas-fir height growth differences (A) were significant between seedlings treated with 0.0 or 0.053 kg ai/ha (0.0 and 0.047 lb ai/ac) and seedlings treated with 0.210 kg ai/ha (0.188 lb ai/ac). Douglas-fir root-collar diameter growth (B), although not significantly different, tended to decrease with increased sulfometuron concentration. Root volume change in control Douglas-fir seedlings (C) differed from the two highest levels of sulfometuron.

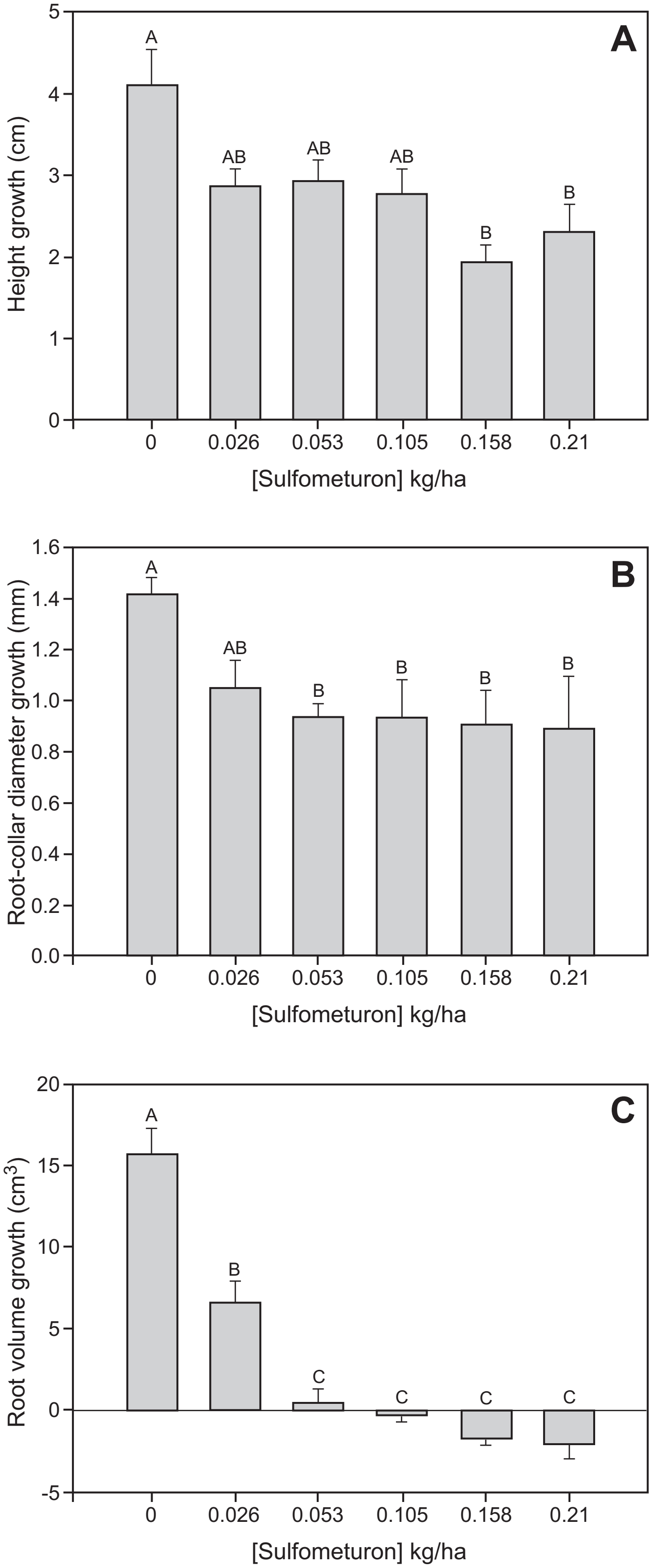

Figure 3. Mean western white pine seedling height growth (A) was significantly less than untreated controls for the two highest levels of sulfometuron only. (B) Western white pine diameter growth (B) differed significantly between controls and the four highest sulfometuron treatment levels. All sulfometuron treatments reduced root volume growth (C) in western white pine.

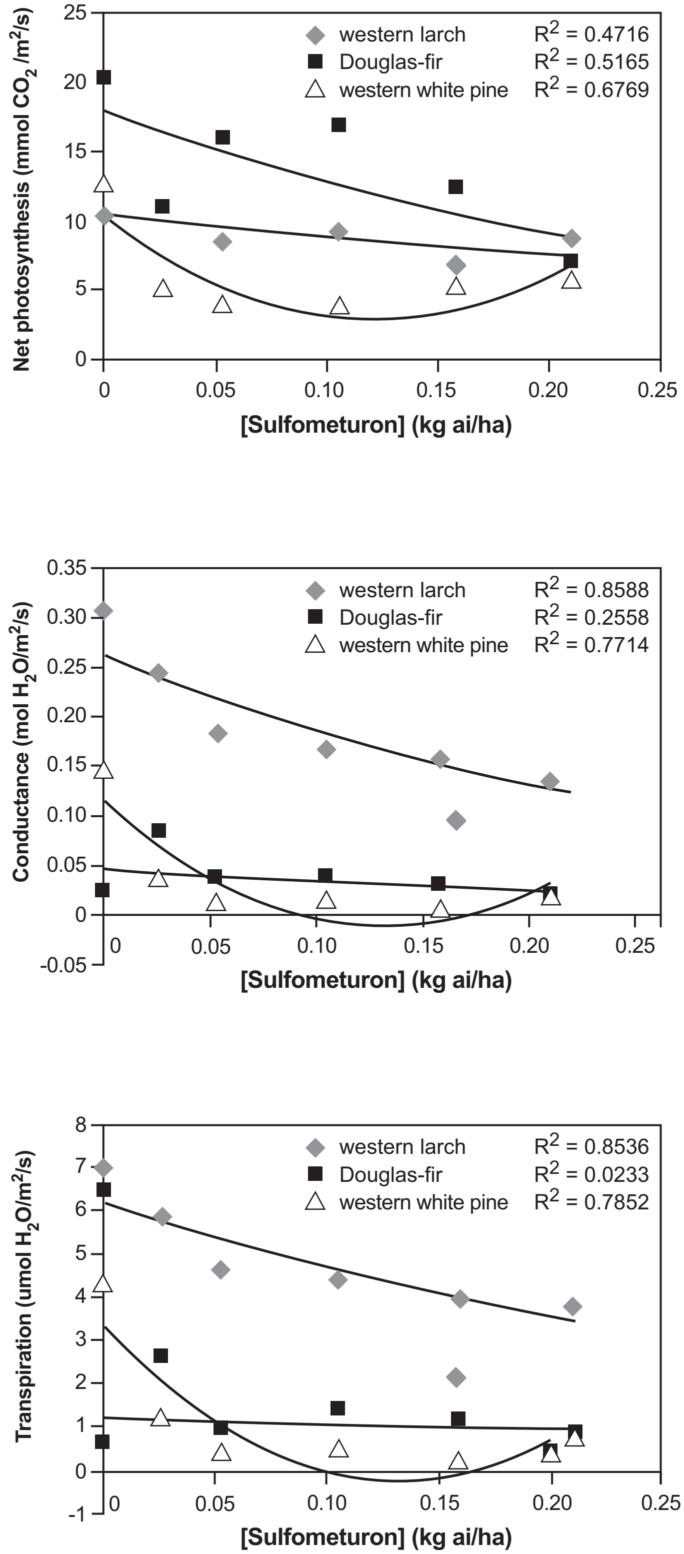

Figure 4. While no significant differences for *A* were apparent for western larch, *gs* and *E* were higher for controls than most herbicide-treated groups. Analyses of Douglas-fir seedlings resulted in no significant differences between treatments. Control western white pine seedlings showed significantly higher *A*, *gs*, and *E* compared to treated seedlings. For *gs* and *E*, all sulfometuron treated groups were significantly lower than the control.

growth was significantly less than untreated controls for the two highest levels of sulfometuron (0.158 and 0.210 kg ai/ha [0.141 and 0.188 lb ai/ac]) only (P = 0.0016) (Figure 3a). For diameter growth, however, the four highest sulfometuron treatment levels differed significantly from controls (P = 0.0008); and for root volume change, all sulfometuron treatments reduced growth (P < 0.0001) (Figures 3b and 3c).

Physiological results were similar to the morphological measurement data. Medium moisture had no effect on the variables of interest: net photosynthesis rate (A), stomatal conductance to water vapor (gs), and transpiration rate (E). Sulfometuron concentration was the only significant treatment variable, and no main-effects interactions were observed. While no significant differences for A were apparent for western larch, gs (P = 0.0002) and E (P = 0.0004) were higher for controls than most herbicide-treated groups (Figure 4). Analyses of Douglas-fir seedlings resulted in no significant differences between treatments. Control western white pine seedlings showed significantly higher A (P = 0.0141), gs (P < 0.0001), and E (P < 0.0001) compared to treated seedlings. For gs and E, all sulfometuron treated groups were significantly lower than the control (Figure 4).

Trial #2

Only sulfometuron concentration was significant in differences in seedling performance for all species. Medium pH did not significantly affect any growth parameter for any species; neither were there any significant main-effects interactions. Treatment-caused mortality was low for all species (< 10%), and not significantly different for any treatments of any species. Larch height growth was significantly affected by sulfometuron (P < 0.0001), with both treated groups differing from the untreated control. Similarly, the influence of herbicide on RCD (P = 0.0148) and root volume (P < 0.0001) was significant. Although only the highest treatment level differed from control means for RCD, root volume was strongly affected, with both treated groups differing from the control. Effects on Douglas-fir seedlings were less apparent, although at least one treatment group differed significantly from the control for height (P = 0.0208), diameter (P = 0.0335), and root volume (P < 0.0001). Control western white pine had significantly more height (P = 0.0378) and RCD (P = 0.0416) growth than seedlings in the highest sulfometuron treatment group. Root volume was again affected (P < 0.0001), and means for both treatment groups differed significantly from the control.

Discussion

Higher medium moisture levels were anticipated to moderate phytotoxic effects of sulfometuron by accelerating hydrolytic residue breakdown (Michael and others 2006). This was not significantly apparent. No effect was seen for any growth variable or for any species tested, and this is indicative of the influence of media moisture and pH relative to sulfometuron application concentration in this trial. Brown (1990) found that soil moisture-dependent sulfonylurea residue breakdown was not strictly a result of hydrolysis, but of a complex interaction of soil moisture, microbial community and activity, temperature, and soil composition. It may be that in non-sterile, native soil, residue breakdown via these intertwined mechanisms reduces sulfometuron phytotoxicity levels beyond what was seen in this trial. These variables were intentionally controlled, however, and any main effects from medium moisture or pH alone were not significant at this timescale.

It should be qualified that for both variables, differences in residue phytotoxicity according to substrate pH and moisture regime may become apparent at longer time periods or under field conditions. The abbreviated nature of this study, which allowed for photolytic degradation of surface residues but restricted the pre-planting period to less than 4 weeks, necessitated exposing seedlings to relatively fresh soil residues. As seen by Burney and Jacobs (2009), site preparation treatments using sulfometuron significantly decreased root growth of seedlings planted several months after treatment. Although seedling recovery was seen in their study, it was partly attributed to favorable breakdown conditions. Compared to the US Inland Northwest, where winters are colder and the climate dryer, the coastal soils and climate in their study may shorten residue persistence timescales by increasing microbial activity and hydrolytic breakdown (Anderson and Dulka 1985). Even so, it is unknown whether such timescales would be compatible with typical commercial operations in the US Pacific Northwest (PNW), much less the US Inland Northwest (INW).

For all response variables addressed in this study, herbicide concentration was the only significant causal variable. Although species were impacted differently, increased levels of herbicide generally coincided with significant decreases in growth and physiological function. In a plantation scenario, restricted conductance and transpiration would jeopardize seedling survival during times of moisture stress, especially in hot, dry summers typical of the INW. Reduced root egress would also increase seedling susceptibility to being removed by ungulate browsing (Burney and Jacobs 2009). Similarly, a restriction in height growth reflects a potential loss of height gain in field situations. Because one purpose of vegetation control is to allow crop seedlings to swiftly overtop competing vegetation, suppression of height growth is counterproductive.

The results of this study suggest that these species vary in degree of vulnerability to phytotoxic damage by sulfometuron. Height growth of untreated western larch controls was 55% greater than sulfometuron treated seedlings. Seedlings in the 0.105 to 0.210 kg ai/ha (0.094 to 0.188 lb ai/ac) label-suggested treatment range showed 40% less diameter growth and 62% less root volume than controls, and reductions in gs and E values of 50% and 43%, respectively. For Douglas-fir, control groups had 31% more height growth, 22% more diameter growth, and 51% more root volume than seedlings in the Oust® treatment groups. Western white pine control groups averaged 43% more height growth and 35% more diameter growth than treated seedlings. Pine root volume in the control groups increased 109% over treated seedlings. As seen in Figure 3a, white pine root volume approached zero net growth near 0.075 kg ai/ha (0.069 lb ai/ac) and atrophy of the existing root mass was evident at concentrations higher than 0.105 kg ai/ha (0.094 lb ai/ac). Leaf function measurements were similar, with untreated seedlings averaging 62%, 87%, and 86% greater A, gs, and E, than treated groups, respectively.

Western larch needle and root length, diameter, and vigor were reduced progressively under increasing treatment levels. If such growth setbacks occur in intensively-managed plantations in the INW, establishment success and efficiency could be compromised. Even in the event of eventual seedling recovery, the positive effects of reduced competing vegetation may be negated for this species (Burney and Jacobs 2009). Douglas-fir may possess a degree of tolerance for sulfometuron, although the results of growth and leaf function measurements were variable for this species. Burney and Jacobs (2009) found coastal Douglas-fir to be the most tolerant of three conifers in their study, and Rose and Ketchum (2003) showed that larger coastal Douglas-fir seedlings tolerated treatment best. Because of the apparent interplay of seedling size and herbicide tolerance, interior Douglas-fir may be the most suitable of the three species in this study for use in conjunction with sulfometuron site preparations. Western white pine seedlings in this study showed a very low degree of tolerance for sulfometuron. We conclude that western white pine is very susceptible to sulfometuron, especially when considering root growth and water transport functions. Seifert and Woeste (2002) saw similar results with eastern white pine, and sulfometuron was ranked last out of 17 herbicides for use with eastern white pine. If such growth constraints are seen in field situations, sulfometuron may jeopardize establishment success even at low treatment levels, and negate any positive effect of reduced competition (Burney and Jacobs 2009).

When considering herbicidal site preparation for all tree species, an application rate threshold exists at which point vegetation control benefits are outweighed by seedling phytotoxicity. With sulfometuron, this threshold may be very low or even impractical for western white pine. Using lower sulfometuron treatment levels than recommended by the label may minimize damage to acceptable levels while still providing a suitable degree of vegetation control for all species, but further trials and field studies should be conducted to establish the efficacy and practicality of these rates.

Conclusion

Contrary to our predictions for objectives 1 and 2 of this study, we conclude that given the conditions of these trials, sulfometuron residue persistence was not so affected by substrate moisture and pH as to show differences in seedling phytotoxic response. In the timetable of these trials, neither variable was significant in overcoming the strong, negative effect of herbicide residue at any application level. Of the three species tested for relative sensitivity to sulfometuron (objective 3), interior Douglas-fir proved fairly resilient, while western white pine, and western larch to a lesser degree, proved sensitive; physiological and growth parameters, especially root growth, were negatively impacted. As a site preparation herbicide, the prospects of sulfometuron efficacy, longevity, ecological safety, and economics are appealing, but in order for its use to be truly profitable, it must be established through further study that the benefits of site preparation with sulfometuron outweigh the potential for seedling damage and growth loss. If it is to be used, seedling size, treatment and outplanting timing, and application rate are among the critical factors to consider in balancing weed control and crop injury, especially in sensitive crop species, and further study should be done to refine use practices.

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Illustration courtesy of College of Natural Resources, University of Idaho.

Forest Tree Improvement at Michigan State University: Past, Present, and Future

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Bloese P. 2010. Forest tree improvement at Michigan State University: past, present, and future. In: Riley LE, Pinto JR, Dumroese RK, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2009. Proc. RMRS-P-62. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station: 61-63. Online: http://www.fs.fed.us/rm/pubs/rmrs_p062.html.

Abstract: The Department of Forestry at Michigan State University has engaged in forest tree improvement for more than 50 years. This paper presents a brief historical perspective on past research, the status of current projects, and outlines plans for the future.

Keywords: provenance tests, genetics, progeny tests, seed orchards, resistant genotypes

Introduction

Forest tree improvement in the United States began in earnest in the 1950s. At Michigan State University (MSU), the first tree improvement planting (a hybrid chestnut blight resistance trial) was established in 1947. Although only a handful of outplantings were accomplished throughout the 1950s, the program expanded dramatically in the early 1960s. More than 500 outplantings have been established since 1947. These plantations contain(ed) over 5,000+ accessions of 59 hardwood species, and over 10,000+ accessions of 58 conifer species. The preponderance of conifer accessions reflects the fact that conifers are much more widely planted than hardwoods on forest land in Michigan.

The Tree Research Center (TRC) located on the south end of the MSU campus (East Lansing, MI) serves as a base of operations, and the TRC greenhouses and nursery produce virtually all of the planting stock for our forest genetics plantations. Many of our tests are located on several off-campus experimental forests, and the crews at Kellogg Forest (Augusta, MI), the Upper Peninsula Tree Improvement Center (Escanaba, MI), and the TRC provide invaluable help in outplanting, maintaining, and collecting data from these outplantings.

During its long history, the Michigan State Forest Genetics (MSFG) program has worked nearly continuously on a few widely-planted species, such as jack pine (*Pinus banksiana*), red pine (*P. resinosa*), and white spruce (*Picea glauca*). There have, however, been periodic shifts in species emphasis that correspond to changing market demands for planting stock and funding opportunities. These shifts are roughly associated with the tenure of the three successive directors of MSFG research: Jonathan Wright, James Hanover, and Daniel Keathley. To briefly sketch the history of MSFG research, I plan to highlight the accomplishments and primary species of interest to each of these directors. The paper will conclude with a description of plans for future tree improvement work.

Jonathan Wright: 1957 to 1974

Jonathan Wright was one of the proverbial forefathers of tree improvement in the United States. Wright advocated a relatively low cost, less intensive approach to tree improvement that relied heavily on provenance and half-sib progeny testing. This approach contrasted sharply with the more intensive programs in the Southeastern and Northwestern US that placed more emphasis on costlier full-sib progeny testing and grafted seed orchards. The two approaches essentially reflected the forestry markets in which they operated. Operational forestry is much more intense, and the increased cost of more intensive tree improvement programs can quickly be recouped in these large markets. In contrast, Lake States timber and pulp markets are substantially smaller, with fewer acres planted annually, and the resources available for tree improvement are greatly reduced.

During his tenure, Wright was responsible for establishing 140 provenance test plantations. Species tested ranged from regional staples like white spruce, and jack and red pine, to relatively minor native species such as balsam fir (*Abies balsamea*), black cherry (*Prunus serotina*), and black walnut (*Juglans nigra*), to exotics including Scotch pine (*Pinus sylvestris*), Japanese larch (*Larix leptolepsis*), and Norway spruce (*Picea abies*). Many of these provenance tests were cooperative efforts with other universities and the USDA Forest Service (USFS). For many years the USFS organized and partially funded a loose regional cooperative of land grant universities and state agencies in the North Central region. One institution would initiate a test and cooperating institutions would aid in the collection of seeds, plantation establishment, and collection of data. Nearly all of Wright's provenance tests were implemented under this cooperative agreement.

Compared to provenance tests, Wright established markedly fewer half-sib progeny tests (approximately 40). Many of them, however, were very intensive and formed the foundation of future MSFG work with a handful of native species. Notable among these are progeny tests of red, jack, and eastern white pine (*Pinus strobus*). Each of these tests contained from 150 to 300 half-sib families collected from Michigan and Ontario, and provided selections for second generation tree improvement.

Although Wright worked to varying extents with several exotic species, he certainly devoted more effort to Scotch pine than any other exotic. Wright was responsible for establishing over 40 Scotch pine provenance and progeny tests. Wright and his cooperators (establishing 31 test locations spread over eight North Central states) delineated geographic varieties based on growth, foliage color, needle length, and susceptibility to four insect pests. This information aided Christmas tree growers in selecting appropriate seed sources, and made Scotch pine the premier Christmas tree in Michigan for more than two decades.

James Hanover: 1974 to 1992

James Hanover joined the MSU faculty in 1966, 15 years prior to Wright's retirement in 1981. During the mid-1970s, Hanover gradually assumed the reins of the MSFG program. In 1974, Hanover founded the Michigan Cooperative Tree Improvement Program (MICHCOTIP). At its inception, MICHCOTIP had nearly 20 cooperators, including several Michigan nurseries, pulp and paper companies, and the Michigan Department of Natural Resources (MDNR). MICHCOTIP strove to optimize available resources and advance tree improvement in Michigan by drawing a broad group of private and public interests under one organizational umbrella.

MICHCOTIP continued Wright's work on species essential to the state's pulp and timber industry, particularly jack, red, and eastern white pine, and white spruce. Data collected from 1960s progeny tests of all four species were used to thin several plantations for the production of genetically improved seeds. Hanover also began to work more intensively with Douglas-fir (*Pseudotsuga menziesii*) in order to provide seed source recommendations to Michigan Christmas tree growers.

In 1988 and 1989, controlled pollinations were made among selections in a Great Lakes half-sib progeny test of jack pine. In 1994, seedlings from those crosses were planted in a second generation full-sib progeny test and a 9-ha (23-ac) seedling seed orchard at the MDNR State Tree Improvement Center near Brighton, MI.

While he continued work on pulp and timber species, Hanover also began screening a wide variety of species for biomass production. Interest in alternative forms of energy was extremely high during, and immediately following, the gasoline crisis of the 1970s. The US Department of Energy (DOE) was charged with evaluating and developing the potential of various alternative energy sources; one of these sources was woody biomass. At this point in time, potential species were evaluated primarily on the basis of BTU production (a simple function of biomass production, wood density, and moisture content), because all woody fuels were expected to be burned in power plants. Ethanol production, gasification, torrefaction, and other conversion processes under consideration today did not figure prominently in immediate plans to convert wood to energy. In species trials, black locust (*Robinia pseudoacacia*) produced the most BTU/ac in southern Michigan, while poplar and aspen hybrids (*Populus* spp.) performed best in northern Michigan and the Upper Peninsula.

The species trials led to the establishment of an extensive black locust half-sib progeny test containing more than 400 families collected throughout the natural range of the species east of the Mississippi. Field tests of clones selected from the progeny test were also established. Work also continued on hybrid poplar and aspen hybrids with establishment of clonal trials and full-sib progeny tests respectively.

Daniel Keathley: 1992 to Present

By 1990, only the USFS, MDNR, and Christmas tree growers were planting significant acreages in Michigan. Membership in MICHOTIP had dwindled below financially and operationally sustainable levels, and the DOE had virtually ended all of its woody biomass genetics research. In 1992, James Hanover's untimely death led to Daniel Keathley assuming the directorship of MSFG research. Faced with diminished resources, Keathley focused tree improvement research on the needs of its two most prominent constituents: the MDNR and Christmas tree growers.

Work for the MDNR still focused primarily on the same pulp and timber species that the MSFG program had worked with continually for more than 40 years. In 2004 and 2008, two progeny test plantings of white spruce were thinned to produce genetically improved seeds. Progeny test data was used to modify a systematic thinning of the MDNR jack pine seed orchard at Brighton, MI. More than 2600 trees were removed to create growing space for residual trees and increase the level of genetic gain. An aerial view of the one of the thinned blocks is provided in Figure 1. The topping of residual trees is currently underway in order to keep live crowns within reach of cone harvesting equipment.

In 2007, the MDNR requested that the MSFG program cooperate with them and the USFS in evaluating American beech (*Fagus grandifolia*) selections for potential resistance to beech bark disease (BBD). BBD has devastated beech in New England for decades, and was discovered in Michigan in 2000. Uninfected trees have been identified in killing fronts (areas of heavy BBD-induced mortality) in Michigan. The project is managed by Jennifer Koch of the USDA Forest Service Northeastern Forest Experiment Station. MSFG has been producing rootstock and assisting in the propagation of resistant selections via grafting. The goals of the project include quantifying the degree of genetic control over BBD resistance, archiving resistant genotypes via grafting, and creating seed orchards that produce known percentages of resistant progeny.

Other than the USFS and MDNR, no commodity group or agency in Michigan plants more acres of trees annually than Christmas tree growers. By 1992, the national Christmas tree market was becoming increasingly competitive as demand decreased and new states (particularly North Carolina) entered the market. For more than two decades, Scotch pine was the mainstay of the Michigan Christmas tree market. As cultural practices intensified to produce higher quality trees, growers had difficulty finding consistent sources of quality Scotch pine seeds. In cooperation with the Michigan Christmas Tree Association, we made more than 50 phenotypic selections after surveying growers' fields across Lower Michigan. Ramets of these selections were established in two grafted seed orchards in 1995 and 1997. A half-sib progeny test of the orchards established in 2009 will empirically quantify the actual genetic value of the phenotypic selections and guide any future roguings of the orchards.

During the past two decades, Fraser fir (*Abies fraseri*) has gained prominence in Michigan's Christmas tree market, and commands a premium price. Fraser fir, however, is susceptible to root disease caused by *Phytophthora* spp. on wet sites and suffers poor growth and survival on even moderately dry sites. MSFG is grafting Fraser fir scion on various *Abies* spp. rootstock to determine if the rootstock can confer resistance to *Phytophthora* spp. and/or drought to Fraser fir scion growth. This work was spurred by field tests at North Carolina State University that found Fraser fir grafted on to Momi and Nordmann fir (*A. firma* and *A. nordmanniana*) rootstock survived and grew dramatically better than standard Fraser fir planting stock on sites infested with *Phytophthora* spp. Similar success in Michigan could expand the range of sites capable of producing Fraser fir. If the biology of conferring resistance to *Phytophthora* spp. and/or drought is effective, further work will need to be done to determine if the added cost of using grafted planting stock is financially feasible.

Figure 1. Aerial view of a block in the Michigan Department of Natural Resources jack pine (*Pinus banksiana*) seed orchard after thinning.

Current Plans for Future Work

Work will surely continue with the staples of the pulp and timber industry, particularly jack pine, red pine, and white spruce. Trees in the MDNR jack pine orchard at Brighton are currently being topped, and the orchard should remain in production for many years. Selections will eventually be made from the full-sib progeny test that complements the orchard, and a third generation seed orchard and progeny test will be established. Red pine selections have been made in a 44-year old progeny test. Past grafting efforts with red pine have met with limited success, and we may attempt to establish a seedling orchard when we get a decent cone crop.

We will continue our cooperative work with the USFS and MDNR on developing BBD-resistant beech. In 2010, MSFG will design and help establish an orchard of resistant genotypes at the MDNR State Tree Improvement Center. It is expected to take several years of testing and grafting selections to complete the orchard.

Future work for Michigan Christmas tree growers will include roguing the Scotch pine orchards based on data from the progeny test established this year. The progeny test will also provide selections for the eventual establishment of a second generation orchard.

In spring 2010, we plan to start field testing grafts of Fraser fir on various *Abies* spp. rootstocks on dry sites and sites infested with *Phytophthora* spp. The field tests will determine if the rootstock species can confer resistance to *Phytophthora* spp. and/or drought to the Fraser fir scion, and produce a high quality Christmas tree within an acceptable rotation length.

Following a decade long lull, our work with biofuels species will increase as Michigan and the country seek to develop alternative energy sources. Currently, a general consensus on which systems are most efficient and practicable in converting cellulosic feedstocks into energy is lacking. Therefore it is difficult to determine what the ideal characteristics of feedstocks will ultimately be. Recent biofuels field tests in the Lake States are emphasizing poplar and willow (*Salix* spp.) feedstocks. The TRC is providing planting stock for large plot clonal trials in the Upper Peninsula organized by Ray Miller (Upper Peninsula Tree Improvement Center manager). In southern Michigan, our previous work with black locust puts us in a position to develop improved planting stock if black locust proves to be a suitable feedstock. We have already coppiced one replication of a clonal trial to get basic information on coppice yield and management. A wider array of species that have been field tested for their suitability in Michigan biofuels plantings would also be useful. MSFG plans to collect silver maple (*Acer saccharinum*) seeds from Ontario and the Northeastern US in spring 2010. These seeds will provide planting stock for a combined provenance/progeny test to be planted in spring 2011. If growth and wood characteristics of silver maple are suitable for operational biofuels outplantings in Michigan, this test will provide the first step in developing genetically improved planting stock.

MSFG will continue to maintain older genetic plantings, particularly at MSU-owned properties with on-site personnel. Although many of these plantings are now of little use for operational tree improvement, forestry researchers from many different fields have found it extremely useful to have mature trees of known geographic origin in common garden field trials. Researchers working on forest entomology, pathology, basic population genetics, physical wood properties, and climate change models have all made use of MSFG plantings, data, and records. MSFG plantation records, accession information, and nearly 50 years of data are maintained by the author. Anyone wishing information on MSFG plantings should contact the author.

Determining Irrigation Distribution Uniformity and Efficiency for Nurseries

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Fernandez RT. 2010. Determining irrigation distribution uniformity and efficiency for nurseries. In: Riley LE, Pinto JR, Dumroese RK, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2009. Proc. RMRS-P-62. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station: 64-66. Online: http://www.fs.fed.us/rm/pubs/rmrs_p062.html.

Abstract: A simple method for testing the distribution uniformity of overhead irrigation systems is described. The procedure is described step-by-step along with an example. Other uses of distribution uniformity testing are presented, as well as common situations that affect distribution uniformity and how to alleviate them.

Keywords: water management, water conservation

Introduction

Water availability is becoming a critical issue to the ornamental plant industry nationwide, even in regions thought of as water-rich. Competition for water resources, increased legislation, and recent droughts are all increasing the need for ornamental crop producers to manage water more effectively. Additionally, significant losses of fertilizers and other agricultural chemicals, such as pesticides, can occur due to misapplication. Runoff water created by misapplication and over-application can transport these chemicals to containment ponds and/or off-site into groundwater or surface water (Camper and others1994; Briggs and others 1998, 2002; Cabrera 2005). Irrigation water management is a key component in reducing the impact of runoff water on surrounding water resources and in nutrient management in ornamental crop production (Tyler and others 1996; Lea-Cox and others 2001). Improving irrigation efficiency and uniformity will reduce misapplication and over-application, improve plant production, and possibly reduce costs. There are some very simple procedures that any nursery can do to evaluate and improve their irrigation systems.

Determining Overhead Irrigation System Distribution Uniformity

Distribution uniformity (DU) is a term used to express water application uniformity. The higher the DU, the more uniform the water application. A low DU, below 60%, indicates unequal distribution of irrigation water, while a high DU, over 80%, indicates water is applied fairly evenly to all the plants in the irrigation zone. Irrigators should attempt to have DU over 80%, especially for container production where gaps between containers decrease irrigation application efficiency. Field evaluation of DU is simple and should be done annually.

It is important to determine the DU of irrigation systems, because a higher uniformity of water application results in more similar delivery of water to all plants within an irrigation zone. Water use efficiency increases as water application uniformity increases. Low DU of an irrigation system will result in either over-watering of some plants in order to provide sufficient water to others, or under-watering of some plants in order not to over-water others.

Testing DU for overhead irrigation systems is easy to conduct and requires no special equipment. A minimum of 16 rain gauges or 16 straight-sided catch containers and a ruler are the only necessary pieces of equipment. As long as the cans are straight-sided, they can be of different types (width or height). More than 16 gauges/cans may be used, but should be kept to multiples of 4; it will make the math easier. Distribute the gauges/cans evenly throughout the irrigation block to be tested as shown in Figure 1. Place gauges/cans so that they are not all in the same proximity to lateral lines; for example, do not place them all directly in the middle of lateral lines or in line with laterals (Figure 1). In a large irrigation block, test several areas within the irrigation block. As was done for location of gauges/cans, do not locate all test sites in line with each other; rather locate them so different sets of lateral lines are tested. (See example in Figure 2.) Run the irrigation system for at least 1 hour, or for the duration of a normal irrigation cycle. Measure the depth of water in each can and record it. The average application rate for the block is the sum of all the depths divided by 16. For the example using Figure 1 and Table 1, the application rate is 21 mm/hour (0.8 in/hour). To determine the DU, use the lowest quarter of the measurements and calculate the average of those readings. For the example, (5 +5 + 5 + 5) / 4 = 5 mm [(0.2 + 0.2 + 0.2 + 0.2) / 4 = 0.20 in]. DU equals the lowest quarter of the measurements divided by the average application rate times 100, that is, (5 / 21) x 100 = 24%.

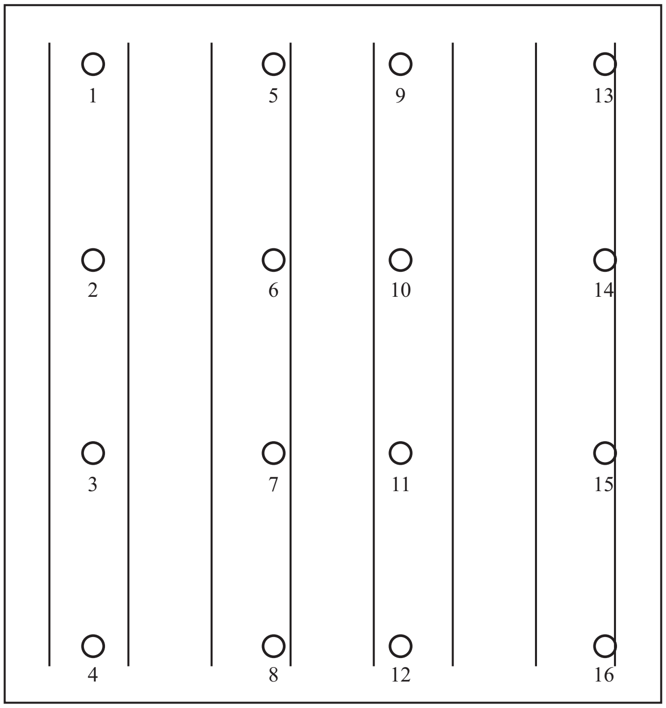

Figure 1. Layout example for rain gauges or catch cans for determining irrigation distribution uniformity in a small (0.4 to 1.2 ha [1 to 3 ac]) irrigation block. Lines denote lateral irrigation lines and circles denote location of rain gauges or catch cans. The numbers below the circles are for identification of the location of the gauges or cans to assist with trouble-shooting.

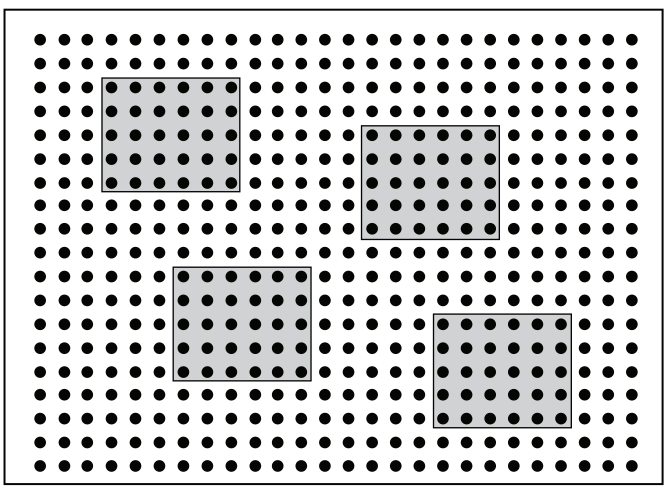

Figure 2. Layout example for determining distribution uniformity (DU) within a large irrigation block (greater than 1.2 ha [3 ac]). Black circles denote irrigation heads. The small squares denote suggested areas to measure to determine DU. DU tests should be conducted in each area using 16 rain gauges or catch cans to better determine DU of the large block.

It is useful to know the location of gauges/catch cans to assist in troubleshooting. In the example, the DU was very low, 24%. The 4 lowest measurements were gauges 5 to 8, all along the same lateral line. This may indicate a problem with that lateral, perhaps a crack in the line or something clogging the lateral. Examine the line for problems, fix any found, and rerun the test. It is also useful to record the time the irrigation system was run; this will allow determination of the application rate. In the example, the system was run for 1 hour and 15 minutes (1.25 hours). The application rate is the average of all gauges/catch cans divided by the run time, 21 mm/1.25 hour = 17 mm/hour (0.8 in /1.25 hours = 0.7 in/hour).

Table 1. Example of catch can water levels corresponding to the catch can layout shown in Figure 1.

Catch can number	Height of water in catch can in mm (in)
1	28 (1.1)
2	25 (1.0)
3	23 (0.9)
4	23 (0.9)
5	5 (0.2)
6	5 (0.2)
7	5 (0.2)
8	5 (0.2)
9	25 (1.0)
10	28 (1.1)
11	22 (0.9)
12	24 (1.0)
13	29 (1.2)
14	33 (1.3)
15	23 (0.9)
16	28 (1.1)
Average all catch cans	21 (0.8)
Average lowest quarter catch cans	5 (0.2)
DU (Avg lowest ¼ / avg all) x 100	24 %
System run time	1 hour 15 minutes (1.25 hours)
Application rate (avg all cans/system run time)	17 mm/hour (0.7 in/hour)

Several factors can cause a poor DU, some of which are easy fixes and others that are more difficult. The easier fixes are:

1) Inadequate irrigation system operating pressure for the nozzles being used. Sprinkler heads come with pressure specifications regarding pattern and distribution, usually a fairly large range. If the pump is supplying too much or too little pressure, the nozzles will not perform properly. Adjusting the delivery pressure at the pump will solve this problem. If the pump pressure has to be high to supply other irrigation blocks, in-line pressure reducers can be used and are inexpensive. If the pump pressure cannot be increased further, the irrigation block is too large and can be split into smaller blocks.
2) Improper selection of nozzles. Instead of adjusting the pump pressure, different nozzles can be selected with pressure specifications that fit what the pump delivers. Also, all nozzles within a block should ideally be from the same manufacturer with the same distribution patterns (that is, the same model).
3) Changes in system components over time. Nozzles wear out; pumps become less efficient; pressure regulators fail. Proper maintenance is essential and components should be serviced or replaced when they no longer meet specifications. Nozzles are the easiest

and least expensive to replace, and will change more rapidly than other system components. Use a drill bit of the same size as the nozzle opening to check for nozzle wear. The bit should fit snuggly in the nozzles. As nozzles wear, the fit will become poor and the nozzles should be replaced. Nozzles can become clogged by mineral deposits. If the bit can no longer be placed in the nozzle orifice, then the orifice should be cleaned.

4) Clogged nozzles. In addition to mineral deposits, nozzles get clogged with a variety of objects from stones to insects. Usually you can easily see what is clogging the nozzles, and it is easy to remove the item with a wire or by taking the nozzle off and cleaning it.
5) In-line filters. Some of the smaller overhead nozzles have filters just before the nozzle. These need to be cleaned regularly.
6) Wind. Irrigation systems should be designed with regard to prevailing winds. Increasing the amount of head-to-head overlap can increase DU for established systems that were not properly designed for prevailing winds.
7) Improper selection of pipe diameters. This is the most expensive mistake to remedy. Replacing above-ground pipe is relatively inexpensive, but replacing buried pipe is costly. In some cases, minor changes in system design can solve the problem.

Summary

Testing DU is the first step in improving the overall efficiency of irrigation systems. Determining DU can not only improve irrigation efficiency, but can assure adequate irrigation is reaching all plants in an irrigation zone, assist with trouble-shooting, and determine actual irrigation application rate within irrigation zones. Spacing, timing, duration, rate, and several other factors also need to be considered when trying to improve irrigation efficiency, but DU is one of the most important factors and easiest to determine.

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An Overview of Forestry in the Farm Bill and Natural Resources Conservation Service Forestry Resources

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Keywords: incentives program, wetlands reserve program, conservation reserve program

Introduction

Since 1935, the Natural Resources Conservation Service (NRCS) (originally the Soil Conservation Service) has provided leadership in a partnership effort to help America's private landowners and managers conserve their soil, water, and other natural resources. NRCS employees provide technical assistance based on sound science and suited to a customer's specific needs. NRCS provides financial assistance for many conservation activities. Participation in our programs is voluntary.

The Food, Conservation, and Energy Act of 2008 (also known as the Farm Bill) provides guidance and funding for several financial assistance programs with forestry components. The following is an overview of a few select programs administered through NRCS and our partners that affect forest landowners, managers, and industry.

Environmental Quality Incentives Program

The Environmental Quality Incentives Program (EQIP) provides a voluntary conservation program for farmers and ranchers that promotes agricultural production and environmental quality as compatible national goals. US$ 7.3 billion has been authorized for 5 years for EQIP. Forest land, including land where trees could be planted, is an eligible land type for this program. The legislative rule does require a forest management plan to be developed prior to applying for EQIP funds to do on-the-ground implementation. Eligible plans include Forest Stewardship Plans and NRCS Forest Management Plans developed by a certified Technical Service Provider.

Wildlife Habitat Incentives Program

The Wildlife Habitat Incentives Program (WHIP) is a voluntary program that reimburses landowners for a portion of their eligible costs for enhancing wildlife habitat on private lands. In return for the cost-share, landowners agree to manage their contract acreage primarily for wildlife according to a plan based on landowners' intentions and identified resource concerns for the life of the contract. Funding for WHIP is authorized at US$ 4.25 million for 5 years. WHIP funding is determined based on five specific priorities as follows:

- Threatened and Endangered Species (T&E). T&E projects positively address a habitat need for a state or federal T&E species, or at-risk species as found on the "Michigan at-risk Indicator Species List."
- Rare Habitats. These projects target the restoration of a remnant or degraded High-Priority Habitat as found in the "Michigan WHIP Priority Habitat List." Participants qualifying under this category and the previous category can receive highest funding priority and can receive a higher payment rate.
- Aquatic Buffers. Aquatic buffers include grasses, trees, and shrubs along streams, wetlands, and other water bodies.
- Grassland Habitats. Grassland habitats include grasslands, prairies, savannas, and barrens.
- Forestland Habitats. Planting of trees and shrubs beneficial to wildlife to reduce habitat fragmentation or improve existing forest stands are included in the forestland habitat priority.

Wetlands Reserve Program

The Wetlands Reserve Program (WRP) provides assistance to restore and protect wetlands through permanent or 30-year easements, 30-year contracts (Tribal lands only), and restoration cost-share agreements. Eligible lands include floodplain forests, as well as certain upland areas adjacent to wetland project areas. The legislative rules allow for up to 310,000 new hectares (766,000 acres) to be enrolled through 2012. For more information, visit the Internet site provided in Table 1.

Conservation Reserve Program

The Conservation Reserve Program (CRP) is a voluntary program for agricultural landowners administered through the Farm Services Agency (FSA) with technical assistance provided by NRCS. Through CRP, you can receive annual rental payments and cost-share assistance to establish long-term, resource-conserving covers on eligible farmland. The Commodity Credit Corporation (CCC) makes annual rental payments based on the agriculture rental value of the land, and it provides cost-share assistance for up to 50% of the participant's costs in establishing approved conservation practices. Participants enroll in CRP contracts for 10 to 15 years. Three sign-up options are available under the CRP umbrella:

- CRP General Sign-up. Producers can offer land for CRP general sign-up enrollment only during designated sign-up periods. A new sign-up is anticipated in the next year; the last sign-up was in 2004. The general sign-up allows for whole field enrollment, and traditionally results in a significant increase in the number of trees planted on private land.
- CRP Continuous Sign-up. Environmentally desirable land devoted to certain conservation practices may be enrolled at any time under CRP continuous sign-up. Certain eligibility requirements still apply, but offers are not subject to competitive bidding.
- Conservation Reserve Enhancement Program (CREP). The CREP is a voluntary land retirement program that helps agricultural producers protect environmentally sensitive land, decrease erosion, restore wildlife habitat, and safeguard ground and surface water. CREP is available in targeted areas only.

Biomass Crop Assistance Program

The Biomass Crop Assistance Program (BCAP) is administered by FSA. It provides financial assistance to producers or entities that deliver eligible biomass material to designated biomass conversion facilities for use as heat, power, bio-based products, or biofuels. BCAP has two purposes:

Provide assistance for the establishment and production of crops for conversion to bioenergy in specific project areas. Information on this portion of BCAP is not yet published; it is anticipated by spring 2010.

Assist with collection, harvest, storage, and transportation (CHST) of eligible materials. This portion of the program should be available in late 2009.

For more information on BCAP and the 2008 Farm Bill, visit the Internet site provided in Table 1.

Technical References

Electronic Field Office Technical Guide

NRCS Electronic Field Office Technical Guides (eFOTG) are the primary scientific references for NRCS. They contain technical information about the conservation of soil, water, air, and related plant and animal resources, and are organized into five sections: Section I, General Reference; Section II, Soil and Site Information; Section III, Conservation Management Systems; Section IV, Practice Standards and Specifications; and Section V, Conservation Effects. The eFOTG can be accessed at URL: http://www.nrcs.usda.gov/technical/efotg/. Follow the map links. Forestry and nursery professionals might have particular interest in the Conservation Tree and Shrub Group list in Section II, which helps land managers make better decisions about which tree and shrub species to plant on a particular soil. For a wealth of forestry reference material, visit the Internet site provided in Table 1.

Web Soil Survey

The Web Soil Survey (WSS) is an on-line publically available tool that allows one to identify a specific area of interest on an interactive map and generate custom soil surveys for that property containing user-selected soil data. See Table 1 for the Internet address. WSS is the official repository of soils information, allowing NRCS to constantly update and add to the soils information available.

Plant Materials Program

The NRCS Plant Materials Program selects conservation plants and develops innovative planting technology to solve the nation's most important resource concerns. The Program includes a network of 27 Plant Materials Centers (PMCs) and associated Plant Materials Specialists serving all 50 states and territories. To date, the program has released more than 600 conservation plants, most being grown by commercial growers. For more than 70 years, PMCs and Specialists have provide essential and effective plant solutions for critical habitats, environmental concerns, management practices, and key farm and ranch programs. For more information on the Plant Materials Program, visit the Internet site provided in Table 1.

PLANTS Database

The PLANTS Database provides standardized information about the vascular plants, mosses, liverworts, hornworts, and lichens of the US and its territories. It includes names, plant symbols, checklists, distributional data, species abstracts, characteristics, images, crop information, automated tools, onward Web links, and references. See Table 1 for the Internet address.

Table 1. NRCS programs and Internet sites.

NRCS Programs	Internet Sites
Wetlands Reserve Program	http://www.mi.nrcs.usda.gov/programs/
Biomass Crop Assistance Program	http://www.fsa.usda.gov/energy
2008 Farm Bill	http://www.nrcs.usda.gov/programs/farmbill/2008/index.html
Forestry Reference Material	http://www.mi.nrcs.usda.gov/technical/forestry.html
Web Soil Survey	http://websoilsurvey.nrcs.usda.gov/app/
Plant Materials Program	http://plant-materials.nrcs.usda.gov/
PLANTS Database	http://plants.usda.gov/
NRCS Home Page	http://www.nrcs.usda.gov

The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented within.

Effects of Pine Sawdust, Hardwood Sawdust, and Peat on Bareroot Soil Properties

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Koll P, Jurgensen MF, Dumroese RK. 2010. Effects of pine sawdust, hardwood sawdust, and peat on bareroot soil properties. In: Riley LE, Pinto JR, Dumroese RK, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2009. Proc. RMRS-P-62. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station: 69-73. Online:http://www.fs.fed.us/rm/pubs/rmrs_p062.html.

Abstract: We investigated the effects of three organic amendments on soil properties and seedling growth at the USDA Forest Service JW Toumey Nursery in Watersmeet, MI. Pine sawdust (red pine, *Pinus resinosa*), hardwood sawdust (maple [*Acer* spp.] and aspen [*Populus* spp.]), and peat were individually incorporated into a loamy sand nursery soil in August 2006, and soil properties were sampled periodically for the next 14 months. Red, jack (*Pinus banksiana*), and white pine (*Pinus strobus*) were sown into test plots in June 2007 and sampled for growth responses at the end of the growing season. We hypothesized that pine sawdust and peat could be used as satisfactory soil amendments to improve soil conditions and reduce costs when compared to hardwood sawdust in bareroot nursery soils.

The addition of peat and pine sawdust increased soil organic matter above control soil conditions after 14 months. Hardwood sawdust-amended soils did not differ from control soils after the same time period. High nitrogen (N) concentrations in peat increased total soil N over the other treatments. We are currently analyzing seedling growth data; our preliminary observations suggest that addition of peat as a soil amendment enhanced soil properties, but no amendments increased 1-year seedling growth over control soils.

Keywords: soil amendments, bareroot nursery, organic matter, soil fertility

Introduction

Organic amendments are commonly used to improve bareroot nursery soil conditions for increased seedling growth. Few studies, however, have compared the effects of organic amendments on soil conditions, and even fewer have compared subsequent effects on seedling growth. Declining availability and increased cost of conventional soil amendments, such as sawdust, have prompted a search for alternate sources of organic matter (OM) (Munson 1983; May and Gilmore 1985). For example, the USDA Forest Service J Herbert Stone Nursery in Central Point, OR explored the use of yard wastes as a soil amendment due to the rising cost of sawdust and the necessary supplemental N fertilization (Riley and Steinfeld 2005). The USDA Forest Service JW Toumey Nursery, located in northern Michigan, has been using hardwood sawdust of various species as an organic amendment for more than 25 years. This sawdust was readily available from many local sawmills at little or no cost. However, with the closing of several small local mills and the demand from wood pellet companies for wood residues, sawdust prices have increased significantly (Holland 2008). In 2008, 20 tonnes (22 tons), or approximately 50 to 61 m^3 (65 to 80 yd^3) of hardwood sawdust delivered to Toumey Nursery cost nearly US$ 1350, as compared to US$ 300 in 2005 (Makuck 2008). The nursery uses around 765 m^3 (1000 yd^3) of sawdust each year. This recent increase in the cost of hardwood sawdust will increase growing costs by an estimated US$ 16,900 annually (Moilenen 2008).

Pine sawdust is much more abundant locally and lower in cost. Many bareroot nurseries have used pine sawdust with success; Toumey Nursery, however, has not used it in the past due to its generally higher carbon to nitrogen ratio (C:N) and lower pH (Williams and Hanks 1976; Follett and others 1981; Rose and others 1995). Peat has also not been used as a soil amendment at Toumey Nursery, although the nursery is uniquely located where peat can be acquired locally at a minimal cost. In the 1940s, large amounts of peat were mined from bogs to the east of the nursery, and have remained untouched in piles since then. Nursery personnel, however, were worried about the impact of acidic peat on soil pH. This study examined the effects of using hardwood sawdust, pine sawdust, and peat as organic amendments on: 1) soil physical and chemical properties; and 2) the growth response of three bareroot species commonly grown at Toumey Nursery—jack pine (*Pinus banksiana*), red pine (*P. resinosa*), and white pine (*P. strobus*).

Materials and Methods

Study Site

The study was conducted on the USDA Forest Service JW Toumey Nursery in Watersmeet, MI (T45N R39W Sec. 27 [46.2719 N, 89.1709 W]). The nursery soil is a Pence-Vilas loamy sand (NRCS 2008), and has supported rigorous seedling cultivation for more than 70 years. Production consists largely of conifer species, such as jack, red, and white pine seedlings; however, many other conifer and hardwood species are also grown. Most seedlings are grown on a 4-year rotation, consisting of three growing seasons and 1 year for soil organic amendments and soil fumigation. Jack pine is grown on a 3-year cycle. Hardwood sawdust has been used as the primary organic amendment for the past 25 years.

Organic Amendments

Three organic amendment treatments, pine sawdust, hardwood sawdust, peat, and a non-amended control were used in this study. Specific information on the source of the hardwood sawdust was not obtainable, but nursery personnel indicated that mills cutting sugar maple (*Acer saccharum*), red maple (*A. rubrum*), quaking aspen (*Populus tremuloides*), and big-toothed aspen (*P. grandidentata*) were the likely sources. Pine sawdust, composed solely of red pine, was supplied by Triple L Lumber, a small mill in Marengo, WI. Peat was mined from a bog on the nursery property, piled, and aged about 60 years. Each amendment was analyzed by the USDA Forest Service Rocky Mountain Research Station Laboratory (Moscow, ID) for carbon (C) and nitrogen (N). Toumey Nursery normally adds a 2.5-cm (1-in) deep layer of hardwood sawdust to each bed 1 year before seeds are sown (every 3 to 4 years). Using a series of 0.3-m^2 (3-ft^2) collection boxes in fields outside the study area, the hardwood sawdust application rate, in concert with its C analysis, was converted to total C applied. Once the C content of hardwood sawdust, as applied, was determined, the quantities of pine sawdust and peat needed to add similar amounts of C were calculated and applied accordingly. All applications were checked in the field using the same collection boxes to determine the applied amounts, and a second application was used to refine applications. All three amendments were added to each plot on 3 August 2006 (Table 1).

Table 1. Carbon and nitrogen application rates in organic amendments added to bareroot nursery beds at Toumey Nursery in August 2006. All values in kg/ha.

	Conifer Sawdust	Hardwood Sawdust	Peat
	kg/ha Carbon*		
Application Rate	17126	15166	15572
% of Desired	110%	97%	100%
Actual Nitrogen Rate	26.2	53.6	584.9

* 1 kg/ha = 0.89 lb/ac

Results and Discussion

Organic Matter and Carbon

Peat was the most effective organic amendment for increasing soil organic matter (SOM) (Figure 1). Adding peat to the nursery soil increased the SOM by 27% over the control after 14 months. Munson (1983) also reported an increase in SOM of 40% after 18 months in a Florida nursery with a similar peat application rate. In contrast, 2 years after amending soils with nearly twice as much peat moss as applied in this study, Mexal and Fisher (1987) did not find any significant SOM differences in New Mexico. Mined peat may have lower nutrient concentrations than the commercial peat moss used by Mexal and Fisher, and may have slowed decomposition in this study. Although long-term effects of peat on SOM have yet to be studied in bareroot nursery applications, it has a greater potential to persist than most other forms of OM amendments added to bareroot nursery soils (May and Gilmore 1985).

Application of red pine sawdust raised SOM concentration by 21% over the control after 14 months, which was similar to results reported by Munson (1983). Mexal and Fisher (1987), however, found no significant

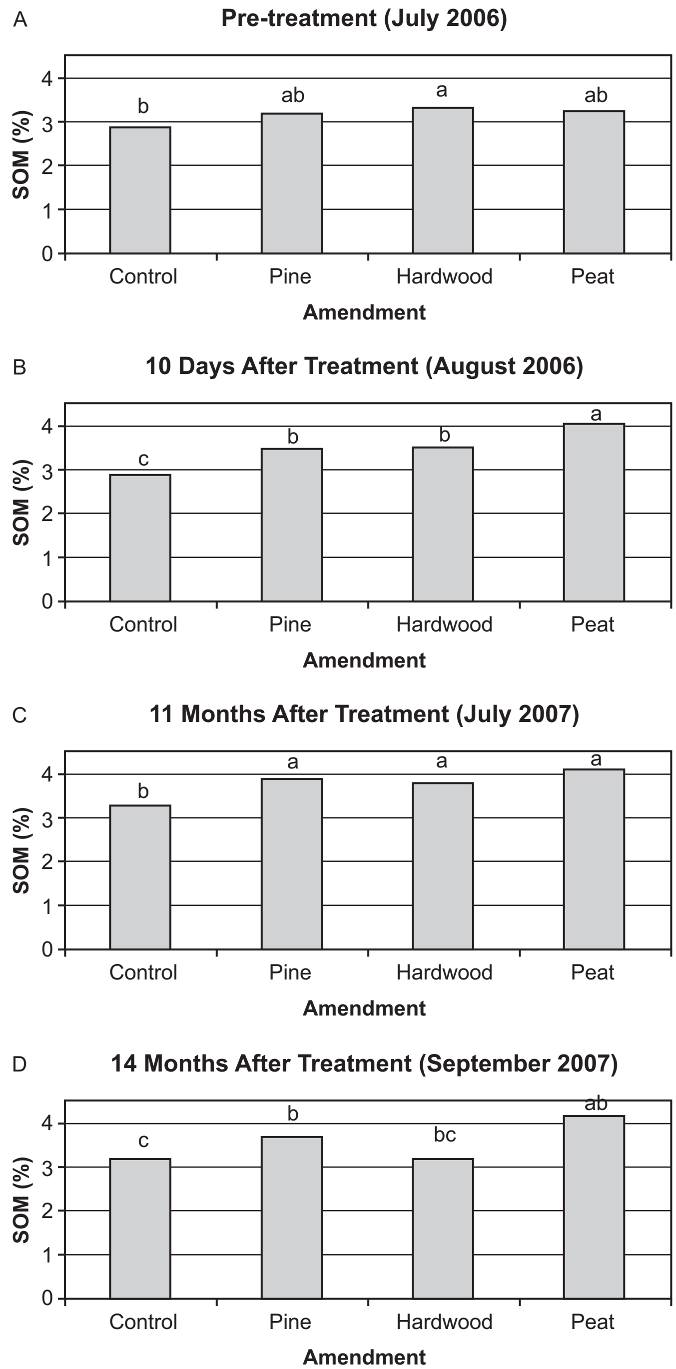

Figure 1. Differences in SOM concentration among control soil and soils amended with red pine sawdust, hardwood sawdust, and peat. (Lowercase letters represent significant differences at $P < 0.05$); A) $P = 0.0346$; B) $P < 0.0001$; C) $P = 0.0003$; and D) $P < 0.0001$.)

difference in SOM 2 years after applying pine sawdust. May and Gilmore (1985) found it took nearly five times as much pine sawdust, applied over a 6-year period, to achieve similar rates of increase in SOM as achieved in this study. Larger increases may have been observed earlier in their study, but sawdust can decompose quickly, and no earlier results were presented. Even though sawdusts have a high C:N, their low lignin concentrations can allow for rapid decomposition (Davey 1984; Mexal and Fisher 1987).

Although Starbuck (1994) reported a 95% increase in SOM after amending soil with hardwood sawdust, the hardwood sawdust used in this study did not increase SOM content. Hardwood sawdust decomposes more rapidly than conifer sawdust due to its lower C:N. The short duration of Starbuck's study may explain the contradictory findings to this study, but further study is needed to support this hypothesis.

Williams and Hanks (1976) and Gulde and others (2007) indicated that soils may have an equilibrium SOM level, or a C saturation point, above which higher values cannot be maintained. This study was conducted on a sandy Pence-Vilas Complex soil, which normally contains between 0.5% and 3% SOM (NRCS 2008). Pre-treatment SOM levels were near 3%, and exceeded 4% in peat-amended soils after 14 months. The minimal response of SOM in these amended soils could be due to a C saturation point, although the actual level of this property in these soils requires further analysis.

Total Soil Nitrogen

Peat-amended soils had higher concentrations of total N than the other treatments (Figure 2). Total N concentrations in soils amended with either hardwood or pine sawdust were not significantly different from the control soils. No other nursery studies were found that investigated the effect of sawdust additions on total soil N. Mexal and Fisher (1987) did find available soil N was rapidly depleted in sawdust-amended plots. Sawdust of any species is not recommended as an OM amendment due to its immobilization of soil N (Allison and Anderson 1951; Davey 1965; Armson and Sandreika 1974; Williams and Hanks 1976; Abd-el-malek and others 1979; Cogger 2005). When low lignin, high C:N sawdust is consumed by soil microbes, available soil N is immobilized, which may result in growth-limiting N deficiencies. This loss of available N can begin as quickly as 40 days after application of sawdust with high C:N, or may take up to 160 days from sawdust with lower C:N. These N deficiencies can persist from 1 to 4 years or longer with high rates of sawdust application (Roberts and Stephenson 1948; Allison 1973). Consequently, large quantities of additional N are necessary with sawdust to offset this immobilization. Allison and Clover (1959) recommend adding N to sawdust until the N concentrations reach 0.75% to 1%. Although 141 kg/ha (126 lb/ac) of N (as $21N:0P_2O_5:0K_2O$) was added to the OM amendments in this study as part of the nursery routine fertilization program, amendment N concentrations (amendment + fertilizer) did not reach the recommended concentration of Allison and Clover (1959) (pine sawdust 0.4%, hardwood sawdust 0.6%, and peat 1.0%). Even using that conservative recommendation, the N fertilization rate used in this study was likely not high enough to offset N immobilization by sawdust.

Soil pH

Soil pH decreased significantly in all treatments from a maximum of 5.3 to a minimum of 4.6 over the study duration. These values are still within the acceptable range for jack, red, or white pine growth. Follett and others (1981) and May and Gilmore (1984) also reported slight, but not specified, reductions in soil pH after addition of sawdust and peat. In contrast, Mexal and Fisher (1987) found no significant change in soil acidity, and speculated this was due to high levels of calcium carbonate buffering the pH of their study soils.

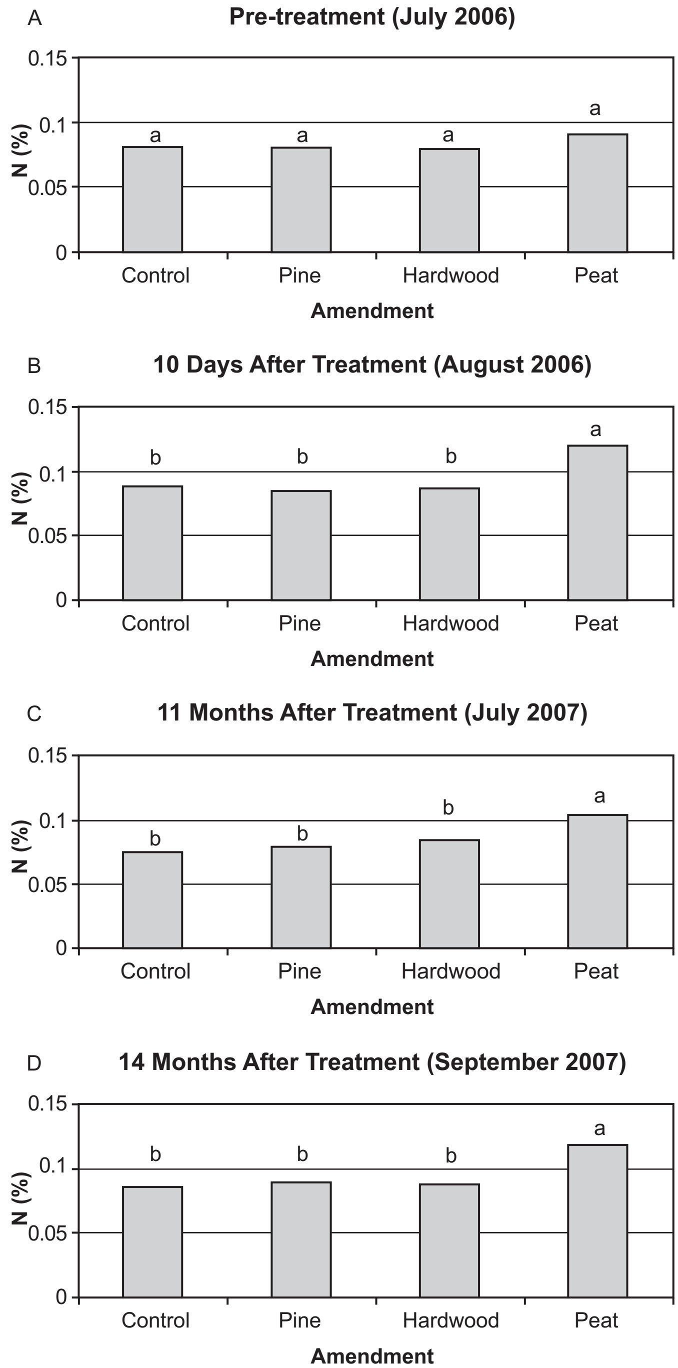

Figure 2. Differences in total soil N concentration among control soil and soils amended with red pine sawdust, hardwood sawdust, and peat. (Lowercase letters represent significant differences at $P < 0.05$); A) $P = 0.274$; B) $P < 0.0001$; C) $P < 0.0001$; and D) $P < 0.0001$.)

Matric Potential and Available Water

It is often stated that high levels of OM in nursery soil will increase soil water-holding potential (Bollen 1969; Allison 1973; Rose and others 1995; Christopher 1996; Jacobs and others 2003; Cogger 2005; Riley and Steinfeld 2005). The results of this study indicated that addition of peat increased soil matric potential and available water after 14 months, but not with either red pine or hardwood sawdust (Figure 3). No other studies were found reporting specific results of the effects of soil amendments on matric potential or available water.

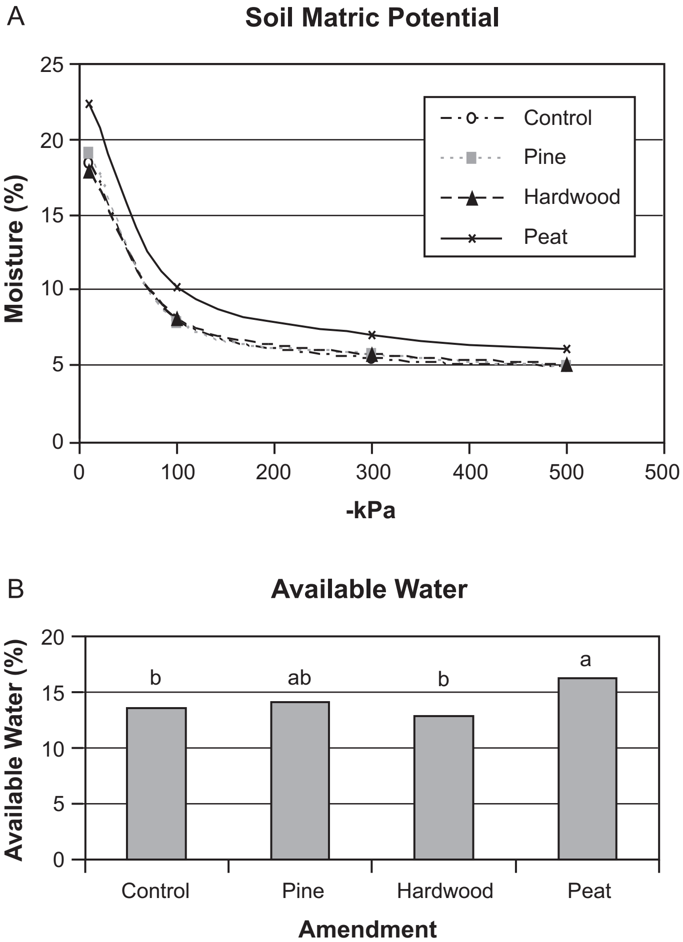

Figure 3: Matric potential (A) and available water (B) 14 months after amending soil with nothing (control), pine sawdust, hardwood sawdust, and peat. (Lowercase letters represent significant differences at $P < 0.05$); A) -10 kPa, $P = 0.006$; -100 kPa, $P = 0.002$; -300 kPa, $P = 0.01$; and -500 kPa, $P = 0.004$; and B) $P = 0.01$.)

Seedling Response: Preliminary Observations

We are in the process of analyzing our seedling data. We noted some differences in growth, and it will be interesting to see if these differences will be significant. Growers may, however, find our preliminary observations interesting. First, even though pine seedlings in this study appeared to grow poorer in soils amended with red pine sawdust and hardwood sawdust as compared to seedlings grown in control soil, sawdust-amended soils contained similar amounts of total soil N as the control, and seedling N concentrations were within normal and acceptable ranges for each species (Armson and Sandreika 1974). The potential immobilization of soil nitrogen by sawdust may be responsible for this difference in growth. Starbuck (1994) found similar reductions in *Forsythia* spp. height growth after the addition of oak sawdust. May and Gilmore (1985) observed, but did not quantify, reduced growth after soil was amended with pine sawdust. In contrast, no growth differences were found when Mexal and Fisher (1987) added conifer sawdust or peat moss to nursery beds where ponderosa pine (*Pinus ponderosa*) seedlings were grown. That study indicated that the depletion of soil available N in sawdust-amended plots may have reduced seedling growth, but the results were not significant. As discussed earlier, addition of sawdust lowers the amount of available soil N, which can reduce seedling growth. In future studies of this nature, available soil N data should be collected.

Seedlings grown in soils amended with peat appeared to grow taller with larger stem diameters than those grown in soils amended with either hardwood or pine sawdust. This could be because the peat amendment added large quantities of N to the soil. Similarly, the low C:N and high lignin content of peat does not create available soil N deficiencies from immobilization as can occur with sawdust treatments. As seedling N demand increases with age, it is expected that seedlings in the peat-amended soil will outperform those in the non-amended soil, as suggested in other studies (for example, Bollen 1969; Allison 1973; Armson and Sandreika 1974; Riley and Steinfeld 2005). Jacobs and others (2003) reported an increase in Douglas-fir (*Pseudotsuga menziesii*) seedling height and stem diameter over control seedlings when applying peat supplemented with pumice, perlite, vermiculite, and coconut fiber. The nutrient concentration of such a peat mixture may have been beneficial to seedling growth. Mexal and Fisher (1987) found no significant growth differences between ponderosa pine seedlings grown in soils amended with peat moss, sawdust, and the control. Again, this result may be related to the higher nutrient content and quicker decomposition rate of commercial peat moss.

Conclusions

The results of this 14-month study at the USDA Forest Service JW Toumey Nursery on the effects of three organic amendments on soil properties and conifer seedling response showed that the addition of peat and pine sawdust increased SOM above an untreated control soil. The addition of hardwood sawdust did not, however, result in any change in SOM concentration. Total soil N concentration, matric potential, and available water-holding capacity increased in the peat-amended soil, but not in soils where sawdust was added. Other chemical and physical properties were generally similar across the three organic-amended and control soils after 14 months. Seedlings appeared to grow tallest and have the largest stem diameter, and obtained the greatest biomass in soil amended with peat as compared to either sawdust treatment. Seedlings grown in the control soil were, however, as large as seedlings grown with peat additions, which may be a reflection on the low available N requirements of 1+0 seedlings or the lack of N immobilization.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented within.

The Forests of Michigan — From Ice to Axe to Growth

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Leefers LA. 2010. The forests of Michigan—from ice to axe to growth. In: Riley LE, Pinto JR, Dumroese RK, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2009. Proc. RMRS-P-62. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station: 74-76. Online: http://www.fs.fed.us/rm/pubs/rmrs_p062.html.

Abstract: Michigan's forests have evolved considerably during the past 4500 years. Post-glacial expansion of forests provided extensive, versatile resources for indigenous peoples. Eventually, these resources were exploited by immigrants to Michigan from Europe and the eastern US. Today, the forests are recovering and growing via natural regeneration and tree plantings, with many current uses and challenges.

Keywords: Michigan history, public nurseries, forest exploitation, forest fires

Introduction

Michigan's forests provide important ecological, economic, and social benefits. They inspire strong ties through past and present cultures—everything from practical uses to artistic expressions flow from the forests. The purpose of this paper is to describe selected dimensions of Michigan's forest history and to present some directions for the future of the forests.

In the mid-1990s, Drs Donald Dickmann and Larry Leefers designed a new course at Michigan State University (East Lansing, MI). That course was entitled *Forestry 101—Michigan's Forests*. The intent was to attract students from outside of the College of Agriculture and Natural Resources so they would have a greater knowledge of forests and their evolution. The course has fulfilled this role by educating 60 to 70 students each spring from many majors across the university. From the onset, it was clear that a textbook would be useful; a book covering the breadth of course topics simply did not exist. So, after several years of research and writing, *The Forests of Michigan* (Dickmann and Leefers 2003) was published (reprinted in 2007). This paper reflects many topics covered in the book: glaciation and species migration; indigenous peoples and their uses of the forests; early European and American settlement; use of General Land Office records to construct maps of circa 1800 forests; the plunder of the pineries; horrific fires of the late 1800s and early 1900s; and how Michigan's policies began addressing these problems.

Overview of Michigan's Forest History

The Great Lakes region, including Michigan, was covered with ice and snow during the latter part of the Pleistocene Epoch. The Wisconsin Ice Age began approximately 70,000 years before present (YBP), and the Great Wisconsin Glacier began to retreat 17,000 to 19,000 YBP (Hupy and Yansa 2009). As the glaciers receded, species migrated into the region from refugia to the south. By 4500 to 3500 YBP, most of the forests we have today had arrived, though the distribution was different (Dickmann and Leefers 2003). This slow race to the north will continue as the atmosphere warms.

Paleo-Indians likely followed the flora and fauna migration into the region. Over a long period of time, the Paleo-Indian populations waned and eventually indigenous people, especially the Odawa (Ottawa), Ojibwe (Chippewa), and Bodewademi (Potawatomi), migrated into the region. These indigenous peoples made extensive use of forest resources—from the construction of birch-bark canoes to the cooking of maple sugar. Extensive knowledge of trees was passed on orally over many generations, including much knowledge about the use of trees for medicinal purposes.

European and American explorers and settlers brought dramatic changes to the land that would become Michigan (from the Ojibwe word "meicigama" meaning "great water," which refers to the Great Lakes). The French focused on the fur trade, but they were eventually supplanted by the British, and later the Americans, who had a greater interest in land and its bounty. Europeans also brought new diseases, and indigenous lives and many aspects of culture were lost as epidemics swept across the region.

Another great force was unleashed by the Continental Congress when it passed the Land Ordinance of 1785 and the Northwest Ordinance of 1787. Combined, these new laws fueled the desires of settlers by providing a means for establishing legal descriptions of land in the "Northwest" (Ohio, Indiana, Michigan, Illinois, Wisconsin, and part of Minnesota) and a mechanism for statehood (Williams 1989). In the end, their main desire was to own land, so a series of treaties between the United States and various tribes led to acquisition of most lands and resources in the state. This paved the way for the land sales to come. The Land Ordinance allowed the General Land Office to survey Michigan's lands and establish townships (9.7 km x 9.7 km [6 mi x 6 mi]) and sections (1.6 km x 1.6 km [1 mi x 1 mi]). The effort started in Michigan in 1816 and ended in 1866. The surveyors' records, which included extensive information on tree species and sizes, have been interpreted to provide maps of the circa 1800s forests in Michigan (Albert and Comer 2009). These maps provide a foundation for comparing the extent and composition of today's forests with those of the past.

In addition to land grants for railroads, schools, and other purposes, the US Congress passed the Homestead Act in 1862. This legislation allowed settlers to acquire 65 ha (160 ac) of land if they resided on it for 5 years and built a 12 x 14 house with a shingle roof and two windows. Some shenanigans took place because there was no unit of measurement on the dimensions…inches worked as well as feet! This policy and later revisions helped move more land into private hands, and the stage was set for the plunder of Michigan's pineries.

The white pine (*Pinus strobus*) logging era began in the 1840s and lasted until early in the 20th century. A New Englander, upon arriving in heavily forested northern Michigan, was quoted as saying, "We'll never cut all this pine until Hell freezes over" (as quoted in Wells 1978). Michigan had extensive timber resources and little enforcement of the rule of law. As a result, there was ample fraud and thievery to illegally exploit the timber resources; we see similar events in contemporary times in several developing countries. New technologies also contributed to the demise of the forests, that is, Michigan double-bit axes, crosscut saws with rakers, Silas Overpack's big wheels, and narrow-gauge railroads. These all contributed to the movement of the pines from the woods to the rivers to the mills. The hardwoods soon followed, with mills located in the forests and lumber transported via railroad to markets. In total, over 472 million m^3 (200 billion bd ft) of softwood and hardwood lumber was cut (approximately one billion trees) by the time the carnage was completed (Dickmann and Leefers 2003).

The aftermath of the logging had two intertwined components—the agrarian settlement of the north and forest fires. Farmers poured into northern Michigan with hopes of a prosperous agricultural future. For many, this dream became a nightmare. "A Farmer for Every Forty" was a nice slogan (Schmaltz 1983). Grueling work was required to convert the logged-over lands into farmsteads, but the sandy soils were not productive. A major tool for land clearing was fire; fire and smoke were common on the landscape. In time, weather conditions deteriorated to create disastrous fires. For example, innumerable land-clearing fires during a droughty period in October 1871 were fanned by strong winds from a low-moisture, high-pressure front (Haines and Sando 1969). These conditions were instrumental in the disastrous Chicago Fire, Pestigo Fire, and Great Michigan Fire. The latter covered approximately 1 million ha (2.5 million ac). Many other fires followed in coming decades (Dickmann 2009).

Forest exploitation, extensive fires, and failed farming all marked the close of the 19th century. At the turn of the 20th century, three forestry challenges needed to be addressed in northern Michigan: what to do about the "lands nobody wanted," how to control wildfires, and how to reforest the denuded lands. Forestry leaders such as Dr William James Beal at Michigan Agricultural College (MAC) agitated for forestry laws and actions. The Department of Forestry at MAC was established in 1902 to train foresters that would be needed to address the "forestry problem." It is the oldest, continuous undergraduate forestry program in the US.

Carl Schenck, renowned forester and founder of the Biltmore School of Forestry, noted that, "The State claims 3,000,000 acres of so-called tax homesteads, which are held for sale to ignorant immigrants" (Schenck 1904). Indeed, farmers failed many times in their efforts on dry sandy plains and hills, and subsequently abandoned their farms. These farms would come back to state ownership and were then sold to speculators or other farmers. Failure would come again, and the cycle would repeat itself. Eventually, the state adopted policies to establish the first state forests, and more productive lands were left in private hands. Over the 20th century, the state forest system eventually grew to 1.5 million ha (3.8 million ac) in size. National forests and other public lands expanded as well. The "lands nobody wanted" became the public lands everybody wanted.

Fire control was greatly aided in the 1930s by the creation of Civilian Conservation Corps (CCC) camps throughout northern Michigan. For the first time, there was an army of men ready to attack fires and various forestry projects when needed. In the mid-1940s, Smokey Bear made his fire prevention debut. In time, fire control mostly gained the upper hand through the efforts of public forestry agencies and local fire departments, but fire remains a concern for those living in the northwoods.

As with fire control, the CCC played a major role reforesting Michigan. Many pine plantations were established during the 1930s and in subsequent years. Initially, the focus was on reforestation and soil protection. During the CCC era, 485 million trees were planted in Michigan by enrollees (Dickmann and Leefers 2003). In time, timber products began flowing from these stands.

Several public nurseries were essential in reforestation efforts. Most produced jack pine (*Pinus banksiana*) and red pine (*P. resinosa*) seedlings along with white pines and various hardwoods. The first federal nursery in Michigan, and the second one nationally, was at Higgins Lake (Dumroese and others 2005). It operated from 1903 to 1965 and produced up to 20 million seedlings per year during the 1930s. Today, remnants of the nursery are on display at the CCC Museum at North Higgins Lake State Park. Three major nurseries were established during the Great Depression—the James W Toumey Nursery at Watersmeet, the Thomas B Wyman Nursery at Manistique, and the AK Chittenden Nursery at Wellston.

Toumey was named after a Yale forestry professor and dean. Established in 1935, it supplied 6 million seedlings per year at its peak. It still annually supplies national forests in the Lake States with seedlings (Anonymous 1985).

Wyman was named after a pioneering Upper Peninsula field forester and educator. In 1936, 3 years after its establishment, it was the largest nursery in the US, with 15 million seedlings produced per year. The nursery was closed during most of World War II and was transferred to the Michigan Department of Natural Resources in 1950. It continues to supply their needs for seedlings, mostly jack and red pine (Botti 1992).

Chittenden was named for the long-time chair of the Department of Forestry at MAC. It operated until 1973 and had a capacity of 18 million seedlings per year. It was established in the spring of 1934, and jack pine seedlings produced in the first year were used to plant 1950 ha (4825 ac) in the fall of 1934 (Watts 1938). In 1935, there were 120 million trees in the ground, "a tree for every person in the country…" On a humorous note, an overturned bathtub sat next to stacks of lumber during initial construction, leading some suppliers to mistakenly think that a children's nursery was being built. As a result, some mail was sent to "Nurse Ryman" (Rindt 1958).

Several other nurseries came and went during the period that Chittenden operated. These included the Hardwood Nursery at Wolverine and the Southern Michigan Nursery at Brighton. Michigan Agricultural College (now Michigan State University) also operated several nurseries, as did some Soil Conservation Districts (Botti 1992).

Though nurseries played a significant role in the reforesting of Michigan, natural regeneration was even more important. Today, Michigan's forests are increasing in area and volume (Leefers 2009). On public lands, multiple-use is still the overriding management philosophy; timber, recreation, wildlife, water, and so on are all important.

Family forests are more oriented towards aesthetic and recreational uses, and investor-owned lands focus on timber. The future of Michigan's forests will be determined by what has evolved during the 20th century and the trends we are now facing.

Forests of the Future

Dumroese and others (2005) described four nursery eras. The first was "Restoration Response" from the 1900s to 1930s. Soil stabilization and watershed protection were of special interest; Higgins Lake Nursery fit this model. The second was "Conservation and Jobs Creation," running from the 1930s to the 1950s. Most public nurseries in Michigan were established for this purpose. The third era was "Responding to the Public's Demand for Timber" from the 1950s to the 1990s. Most Michigan nurseries fulfilled this goal, but began curtailing operations as the focus on timber diminished. Finally, we entered the "Return to Restoration" in the 1990s. Now the focus is on endangered species, ecosystems, and related concerns, and the nurseries produce seedlings for these purposes.

Several other trends will also affect Michigan's future forests. These include concerns for sustainability, the role of communities in forest resource management, fragmentation and parcelization, global warming, the development of carbon markets, bioenergy, international trade, and insect and diseases. Foresters and the nursery industry will be affected by these forces.

On a recent trip to Indonesia, I saw a banner near the Jakarta airport. It read "One Man, One Tree." This program encourages the planting of millions of trees across the country. As optimists who plant trees, foresters and nursery people likely agree with the saying, "There are two great times to plant trees: the first was 20 years ago—the second is now." Michigan's forests have made it through ice, axe, and fire. They will make it through the next wave of challenges as well.

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Soil Fumigants — Risk Mitigation Measures for Reregistration

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Abstract: The US Environmental Protection Agency is requiring important new safety measures for soil fumigant pesticides to increase protections for agricultural workers and bystanders, that is, people who live, work, or otherwise spend time near fields that are fumigated. These measures are included in Amended Reregistration Eligibility Decisions for the soil fumigants chloropicrin, dazomet, metam sodium/potassium (including methyl isothiocyanate or MITC), methyl bromide.

Keywords: fumigant management plans, risk mitigation measures, restricted use pesticides

Soil Fumigant Amended Reregistration Eligibility Decisions

In May 2009, after consulting with stakeholders and obtaining extensive public input, the US Environmental Protection Agency (EPA) issued final new safety measures for soil fumigant pesticides to increase protections for agricultural workers and bystanders. Implemented during the next 2 years, these measures will work together to establish a baseline for safe use of the soil fumigants throughout the United States, reducing fumigant exposures and significantly improving safety.

Many of the new safety measures were announced in July 2008 when EPA issued risk management Reregistration Eligibility Decisions (REDs) for soil fumigants. During the past year, the agency took significant public comment on implementation of these measures, including public meetings and visits with many agricultural, farm worker, and public health constituents. In the May 2009 Amended REDs, all measures to reduce risks are still required; some aspects of these measures, however, have been adjusted based on input from stakeholders and on new scientific data that reduce the uncertainties in the Agency's assessments and improved information on certain technological capabilities. These modifications, summarized in Table 1 and discussed in detail in the 2009 Amended REDs, will achieve the same level of protection for people potentially exposed to the fumigants, while resulting in greater compliance and fewer impacts on the benefits of soil fumigant use.

Risk Mitigation Measures for Soil Fumigants

EPA is requiring a suite of complementary mitigation measures to protect handlers, reentry workers, and bystanders from risks resulting from exposure to the soil fumigant pesticides. These measures are designed to work together to address all risks, but focus on the acute human inhalation risks that have been identified in the revised risk assessments for these fumigants.

Most of the measures summarized here apply to all of the soil fumigants (for example, fumigant management plans). However, some measures are specific to individual fumigants (for example, buffer distances).

Table 1. Modifications from 2008 to 2009 Amended Soil Fumigant REDs.

Mitigation	2008 REDs	2009 Amended REDs
Buffers	Buffer zones based on available data	- New chloropicrin data support smaller buffers and increased confidence in safety - New dazomet data support larger buffers
Buffer Credits	Credits allowed based on available data	New data support more credits
Rights-of-Way	Permission from local authorities must be granted if buffers extend onto rights-of-way	Permission from local authorities is only required when sidewalk is present
Buffer Overlap	Buffers may not overlap	Buffers may overlap; separate applications by 12 hours
0.4 km (0.25 mi) Restriction	0.4 km (0.25 mi) restriction around hard-to-evacuate areas including day care centers, nursing homes, prisons	Maintain 0.4 km (0.25 mi) restriction but allow a reduced restricted area of 0.2 km (0.14 mi) for applications with smaller buffers (less than 91 m [300 ft])
Respiratory Protection	Required monitoring devices to trigger additional measures	- Allow sensory irritation properties to trigger additional measures for MITC and chloropicrin - Device required for methyl bromide formulations with <20% chloropicrin
Emergency Response and Preparedness	Neighbors must be provided with information or buffer zones must be monitored every 1 to 2 hours over 48 hours with monitoring devices	- Same basic measures - Monitoring is required only during peak emission times of the day; irritation acceptable trigger for MITC and chloropicrin in lieu of devices; methyl bromide requires devices

Changes in mitigation measures include:

— Buffers
- Size
- Posting
- Restrictions on buffer overlap
- Restrictions to encroachment on adjacent properties
- Sensitive area restriction
- Improved use practices
- Tarp cutting and removal restrictions
- Worker reentry restrictions
- Use site and rate restrictions
- Fumigant handler respirator protections
- Best management practices

To ensure safety and enhance compliance and enforcement, additional requirements include:

— Planning
- Fumigant management plans
- Emergency preparedness and response measures
- First responder outreach
- Notice to state lead agencies
- Community outreach programs

— Training
- Applicators supervising fumigations
- Handler safety materials
- Restricted use classification

Buffer Zones

EPA is requiring fumigant users to establish a buffer zone around treated fields to reduce risks from acute inhalation exposure to bystanders. A buffer zone provides distance between the application site (that is, edge of field) and bystanders, allowing airborne residues to disperse before reaching the bystanders. This buffer will reduce the chances that air concentrations where bystanders are located will cause acute adverse health effects.

EPA has selected buffer distances that will protect bystanders from exposures that could cause adverse effects, but that are not so great as to eliminate benefits of soil fumigant use. The size of the buffer zones is based on the following factors: application rate; field size; application equipment and methods; and emission-control measures (for example, tarps).

Buffer zone distances are scenario-based using applicable site conditions, and will be provided in look-up tables on product labels. EPA is also giving "credits" to encourage users to employ practices that reduce emissions (for example, use of high barrier tarps). Credits will reduce buffer distances. Some credits will also be available for site conditions that reduce emissions (for example, high organic or clay content of soils).

Posting Requirements

For buffer zones to be effective as risk mitigation, bystanders need to be informed about the location and timing of the fumigation to ensure they do not enter areas designated as part of the buffer zone. EPA is requiring that buffer zones be posted at usual points of entry and along likely routes of approach to the buffer unless: 1) a physical barrier prevents access to the buffer; or 2) all of the area within 91 m (300 ft) of the buffer is under the control of the owner/operator.

The signs must include a "do not walk" symbol, fumigant product name, and contact information for the fumigator.

Agricultural Worker Protections

Persons engaged in any of a number of activities that are part of the fumigation process are considered "handlers." Handler activities include operating fumigation equipment, assisting in the application of the fumigant, monitoring fumigant air concentrations, and installing, repairing, perforating, and removing tarps.

Respiratory Protection

Many current labels require handlers to use respirators when air concentrations in the area where they are working reach certain action levels, but do not require monitoring to determine if the action levels have been reached. New labels will require handlers to either stop work or put on respirators if they experience sensory irritation.

Tarp Perforation and Removal

Fumigant gases become trapped under tarps and can be released when the tarp is perforated (that is, cut, punched, poked) and removed (for application methods in which tarps are removed before planting). Handlers perforating and removing tarps may be exposed to air concentrations of concern. To reduce these exposures, the EPA is requiring the following: 1) a minimum interval of 5 days between application and tarp perforation; 2) a minimum interval of 2 hours between perforation and tarp removal; 3) that handlers stop work or use respiratory protection if irritation is detected; and 4) use of mechanical devices (for example, using all-terrain vehicles with cutting implements attached) with few exceptions.

Entry-Restricted Period

Current labels allow worker reentry into fumigated fields 2 to 5 days after applications are complete. There is, however, concern for risks to workers reentering even after 48 hours. Stakeholder comments indicate that reentry for non-handler tasks is generally not needed for several days after the application is complete. EPA is extending the time that agricultural workers (that is, non-handlers) are prohibited from entering the treated area. The entry-prohibited period depends on the method of application, but generally the minimum period for worker reentry will be 5 days or until tarps are perforated and removed.

Applicator and Handler Training Programs

EPA is requiring fumigant registrants to develop and implement training programs for applicators in charge of soil fumigations on proper use and good agricultural practices so these applicators are better prepared to effectively manage fumigant operations. The registrants also must prepare and disseminate training information and materials for fumigant handlers (those working under the supervision of the certified applicator in charge of fumigations). Providing safety information to other fumigant handlers will help them understand and adhere to practices that will protect them from risks of exposure. The training materials must include elements designed to educate workers regarding work practices that can reduce exposure to fumigants, and thereby improve safety for workers and bystanders.

Good Agricultural Practices

Current fumigant labels recommend practices that help reduce off-gassing and improve the safety and effectiveness of applications. The EPA has determined that including certain practices on labels as requirements rather than recommendations will minimize inhalation and other risks from fumigant applications. Several fumigant products already incorporate some of these measures on their labels. Examples of good agricultural practices include proper soil preparation/tilling, ensuring optimal soil moisture and temperature, appropriate use of sealing techniques, equipment calibration, and weather criteria.

Application Method, Practice, and Rate Restrictions

The EPA is restricting certain fumigant application methods and practices for which data are not currently available to determine appropriate protections, or that lead to risks that are otherwise difficult to address. These include certain untarped applications for some fumigants. The agency is also lowering maximum application rates to reflect those rates needed for effective use, thereby reducing the potential for inhalation exposure and risk.

Restricted Use Pesticide Classification

All soil fumigant products containing methyl bromide, 1, 3-dichloropropene, and chloropicrin are currently restricted use pesticides, but many soil fumigant products containing metam sodium/potassium and dazomet are not restricted use pesticides. The EPA has determined that all of the soil fumigants undergoing reregistration meet the criteria for restricted use. Therefore, the agency will reclassify metam sodium/potassium and dazomet as restricted use pesticides.

Site-Specific Fumigant Management Plans

Soil fumigations are complex processes involving specialized equipment to properly apply volatile and toxic pesticides. EPA's risk mitigation allows for site-specific decisions to address the specific conditions where the fumigant is applied. To address this complexity and flexibility, EPA is requiring that fumigant users prepare a written, site-specific fumigant management plan before fumigations begin. Written plans and procedures for safe and effective applications will help prevent accidents and misuse and will capture emergency response plans and steps to take in case an accident occurs.

Fumigation management plans (FMPs) will be a resource for compliance assurance; FMPs will require fumigators to state how they are complying with label requirements. FMPs will help ensure fumigators successfully plan all aspects of a safe fumigation, and will be an important tool for federal, state, tribal, and local officials to verify compliance with labeling.

Elements that must be included in soil FMPs are: general site information; applicator information; application procedures; measurements taken to verify compliance with good application practices; how buffers were determined; worker protection information; procedures for air monitoring; posting procedures; documentation of training of applicators supervising fumigations; procedures for communication among key parties, hazard communication, and record keeping; site-specific response and management activities; emergency plans; procedures for controlling fumigant releases in case of problems during or after the application.

The certified applicator supervising the fumigation must verify, in writing, that the FMP is current and accurate before beginning the fumigation. A post-fumigation summary report describing any deviations that may have occurred from the FMP will also be required within 30 days of the end of the application. The fumigator and the owner/operator of the fumigated field must keep the FMP and post-fumigation summary report for 2 years and make them available upon request to federal, state, tribal, and local enforcement officials.

Emergency Preparedness and Response Requirements

Although buffers and other mitigation will prevent many future incidents, it is likely that some incidents will still occur due to accidents, errors, and/or unforeseen weather conditions. Early detection and appropriate response to accidental chemical releases are effective means of reducing risk. Preparedness for these types of situations is an important part of the suite of measures necessary to avoid risks posed by fumigants.

First Responder Education

EPA is requiring registrants to provide training information to first responders in high fumigant use areas. These measures will ensure that emergency responders are prepared to effectively identify and respond to fumigant exposure incidents.

Site-Specific Response and Management Activities

EPA is requiring site-specific measures in areas where bystanders may be close to fumigant buffer zones. Fumigators may choose either to monitor the buffer perimeter or to provide emergency response information directly to neighbors. If site-specific measures are required, and the fumigator chooses to monitor, the emergency response plan stated in the FMP must be implemented if the persons that are monitoring experience sensory irritation. This monitoring must be done during the full buffer zone time period at times when the greatest potential exists for fumigants to move off-site.

If the fumigator chooses instead to provide emergency response information directly to neighbors, the certified applicator supervising the fumigation, or someone under his/her direct supervision, must ensure that nearby residents and business owners/operators have been provided with the response information at least 1 week prior to fumigant application. The method for distributing information to neighbors must be described in the FMP.

Compliance Assistance and Assurance Measures

Assuring compliance with new label requirements is an important part of the package of mitigation measures. Some states have mechanisms in place to obtain information needed to assist and assure compliance with new fumigant requirements. Therefore, in states that wish to receive this information, fumigators must notify State and Tribal Lead Agencies for pesticide enforcement about applications they plan to conduct. This information will aid those states in planning compliance assurance activities. EPA will work with all the states to amend their cooperative agreements with the Agency to include strategies for assuring compliance with new fumigant labels. States that do not choose to receive notification will need to document in their cooperative agreements their methods of identifying fumigant application periods and locations.

Community Outreach and Education Programs

EPA is requiring fumigant registrants to develop and implement community outreach programs to ensure that information about fumigants and safety is available within communities where soil fumigation occurs. Outreach and information will address the risk of bystander exposure by educating community members about fumigants, buffer zones, how to recognize early signs of fumigant exposure, and how to respond appropriately in case of an incident.

Table 2. Implementation schedule for soil fumigant risk mitigation measures.

Risk Mitigation Measure	Currently	2010	2011
Restricted Use (methyl bromide and chloropicrin only)	◘	●	●
New Good Agricultural Practices		●	●
Rate reductions		●	●
Use site limitations		●	●
New handler protections		●	●
Tarp cutting and removal restrictions		●	●
Extended worker reentry restrictions		●	●
Training information for workers		●	●
Fumigant management plans		○	●
First responder and community outreach		○	●
Applicator training		○	●
Compliance assistance and assurance measures		○	●
Restrictions on applications near sensitive areas			●
Buffer zones around all occupied sites			●
Buffer credits for best practices			●
Buffer posting			●
Buffer overlap prohibitions			●
Emergency preparedness measures			●

◘ = applies to some chemicals ○ = under development ● = adopt completely

Next Steps

Implement Fumigant Mitigation Measures

To achieve new protections, EPA is moving expeditiously to implement the mitigation measures in the soil fumigant Amended REDs. As indicated in the Timeline for Next Steps and Table 2, many mitigation measures will appear on fumigant product labels by the 2010 growing season, and all measures will be implemented no later than 2011. EPA will continue to work closely with stakeholders to ensure that they understand the new requirements and how they will be phased in.

Registration Review

A substantial amount of research is currently underway, or is expected to begin in the near term, to address current data gaps and refine understanding of factors that affect fumigant emissions. Additionally, new technologies to reduce emissions are emerging. EPA plans to move the soil fumigants forward from 2017 to 2013 in Registration Review. This will allow EPA to consider new data and technologies sooner, determine whether the mitigation included in this decision is effectively addressing the risks as EPA believes it will, and to include other soil fumigants that are not part of the current review.

Timeline for Next Steps

Summer 2009: EPA sends letters to fumigant registrants outlining label schedule.
Fall 2009: Registrants submit revised labels to EPA.
2010: EPA reviews and approves new soil fumigant labels before the growing season, implementing most measures (except those related to buffer zones) to achieve improved protections.
2011: EPA implements remaining measures relating to buffer zones to gain full protections.
2013: EPA begins reevaluating all soil fumigants under the Registration Review program.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented within.

Mosaic Stunting in Jack Pine Seedlings in a Northern Michigan Bareroot Nursery

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Abstract: Mosaic, or patchy, stunting of bareroot conifer seedlings is thought to be caused by deficiencies of mycorrhizal fungi following fumigation, resulting in reduced nutrient uptake, particularly phosphorus. Mosaic stunting of jack pine (*Pinus banksiana*) seedlings was observed in 2005 at the USDA Forest Service JW Toumey Nursery in Watersmeet, MI. We initiated a study to determine if either the species of mycorrhizal fungi or the quantity of mycorrhizae were different on stunted and healthy seedlings. In 2006 and 2007, we tested the soil, sampled root tips, and analyzed seedling growth and foliar nutrient concentrations. In 2006, we used DNA sequencing to identify mycorrhizal fungi. Our results showed four main fungal taxa (*Sistotrema brinkmannii*, *Thelephora terrestris*, *Suillus luteus*, and *Laccaria* spp.) were associated with mycorrhizal root tips on stunted and healthy seedlings, and that the number of mycorrhizal root tips was high on both types of seedlings, although we observed variation among stocktypes and years. Despite soils having similar nutrient concentrations, we observed differences in foliar concentrations between stunted and healthy seedlings. Only 1+0 seedlings in 2007, however, showed significant differences. This suggests that reduced root nutrient uptake was a factor in stunting of 1+0 seedlings in 2007, but does not appear to be related to ectomycorrhizal fungi.

Keywords: ectomycorrhizal fungi, foliar nutrients, bareroot, sawdust, organic matter, *Sistotrema brinkmannii*, *Thelephora terrestris*, *Suillus luteus*, *Laccaria* spp.

Mosaic-pattern stunting is identified as random patches of seedlings with reduced top and root-collar diameter growth and chlorosis. Mosaic-pattern stunting has been observed in a variety of tree species in bareroot and container nurseries (Landis 1998). In container nurseries, stunting is most often associated with compacted growing media; in bareroot nurseries, the cause is often more vexing. Stunted bareroot seedlings that lack biotic disease (Tanaka and others 1986; Linderman and others 2007), combined with variation in soils and nursery practices, often make finding a conclusive cause difficult (Landis 1998). In most cases, the problem is thought to be linked to a lack of ectomycorrhizal fungi in the nursery soil caused by soil fumigation (Campagna and White 1969; Trappe and Strand 1969; Henderson and Stone 1970).

Fumigation eliminates ectomycorrhizal fungi (Henderson and Stone 1970; Ridge and Theodorou 1972). Because ectomycorrhizae are important for nutrient uptake in pines (McComb 1938; Trappe and Strand 1969), this lack of a symbiotic association results in poor seedling growth (Henderson and Stone 1970; Croghan and others 1987). Nursery soil is recolonized by ectomycorrhizal fungi in a random pattern. These pockets of mycorrhizae provide better access to nutrients, and seedlings grow better than their non-inoculated cohorts, resulting in random patches of excellent seedling growth interspersed with stunted growth (Landis 1998). Most studies with mosaic stunting have, therefore, focused on ectomycorrhizae levels (Croghan and others 1987; Linderman and others 2007).

In 2005, mosaic stunting was identified in jack pine (*Pinus banksiana*) seedlings at the USDA Forest Service JW Toumey Nursery, located in the Upper Peninsula of Michigan. We investigated potential causes of stunting. We compared mycorrhizal fungi (species and the number of mycorrhizal root tips) and soil nutrients for stunted and healthy seedlings. Our goal was to assist nursery personnel in identifying the cause of stunting in jack pine seedlings, and thereby ameliorate future incidence.

Methods

The USDA Forest Service JW Toumey Nursery is located on the Ottawa National Forest in Watersmeet, MI (46°27' N; 89°17' W). The soil is a fine sandy loam soil of the Pence-Vilas complex (NRCS 2007). The primary stocktypes produced are jack pine, red pine (*Pinus resinosa*), and eastern white pine (*P. strobus*). Mean annual precipitation is 77 cm (30 in) and mean annual air temperature is 4 °C (39 °F) (MCRP 2009).

Soil Sampling and Seedling Measurements

In 2006 and 2007, we selected 10 plots within areas of mosaic stunting of jack pine seedlings. These plots were selected throughout the length of a field, and included 1+0, 2+0, and, in 2006, some 3+0 holdover stock. Each plot had at least 10 stunted seedlings adjacent to healthy seedlings. From each plot, we extracted eight soil cores (four under stunted and four under normal seedlings) to a 15-cm (6-in) soil depth with a 2-cm (0.8-in) diameter soil probe, and sampled 5 stunted and 5 healthy seedlings. Samples were refrigerated at 2 °C (36 °F) until processed.

Soil samples were dried at 105 °C (221 °F), sent to the Rocky Mountain Research Station in Moscow, ID, and analyzed for pH, total carbon (C) and nitrogen (N), available phosphorus (P), and exchangeable potassium (K), calcium (Ca), and magnesium (Mg). Exchangeable K, Ca, and Mg were extracted with pH neutral ammonium acetate and processed on a Perkin Elmer® Atomic Absorption Spectrometer (Model 5100PC). Available P was estimated using the Bray 1 method and analyzed on an OI Analytical Flow Solution® 3000 (College Station, TX); C and N were analyzed on a LECO CN2000 (LECO Corporation, St Joseph, MI). Soil pH was measured in a 1:2 (v:v) soil:deionized water slurry.

Seedlings were carefully rinsed. Root sections for mycorrhizae analysis were removed from seedlings and stored in water at 2 °C (36 °F) less than 24 hours before analysis. We measured seedling height and root-collar diameter. Shoots (needles and stems) and roots of 1+0 seedlings (sampled in September 2007) and needles of 2+0 seedlings (July 2006, July 2007, August 2007) were ground with a Wiley Mill to pass a 40-mesh screen and analyzed for nutrient concentrations at the Penn State Agricultural Analytical Resources Laboratory (University Park, PA). Total N was determined on a Carlo Erba NA1500 Elemental Analyzer (Horneck and Miller 1998). Analysis was done for P, K, Ca, Mg, manganese (Mn), iron (Fe), copper (Cu), boron (B), sodium (Na), and zinc (Zn) after dry ashing at 500 °C (932 °F) (Miller 1998).

Mycorrhizae Quantification, Isolation, and Identification

To quantify mycorrhizae, we excised a 3-cm (1.2-in) section of root from the third and sixth lateral roots of each seedling. Using a dissecting microscope (10x to 40x power), we counted mycorrhizal root tips on each root section and categorized by morphology. Using sterile technique, we then isolated the fungi from mycorrhizal root tips within 24 hours of sampling to improve success rate (Molina and Trappe 1982). A 2% malt (2M) agar medium with additions of antibacterials (100 ppm streptomycin [S] and 100 ppm tetracycline [T]) and 10 ppm of the fungicide benomyl (B) (Benlate®) (2MSTB) was used for isolations and culturing. For root tip isolations, we clipped three 3-cm (1.2-in) sections from the lateral roots of one stunted and one healthy seedling per plot. Excised roots were surface sterilized for 30 seconds with agitation using a 1:10 (v:v) Clorox® solution (5.25% sodium hypochlorite) water solution, and rinsed three times with sterile water (slightly modified from methods of Zak and Bryan 1963). Two mycorrhizal root tips were removed from each 3-cm (1.2-in) root section and plated on Petri dishes. For each sample date, we used approximately 120 total root tip pairs (10 plots x 4 seedlings [two stunted; two healthy] x 3 root sections).

Possible ectomycorrhizal fungi are characterized by slow hyphal growth, presence of clamp connections on hyphae, and distinctive colony characteristics (Zak and Bryan 1963); we transferred cultures with these characteristics to fresh MMN (modified Melin-Norkrans) agar (Marx 1969) for further study. After at least 3 weeks of growth at 26 °C (79 °F), cultures having at least 15 hyphae were organized by "type" based on macro- and micro-morphological characteristics (Hutchison 1991). When characterized, the fungal isolates were actively growing for 3 weeks at 26 °C (79 °F) and a minimum of 15 hyphae per type. In 2006, we identified these types to species using DNA sequencing as described in Potvin (2008).

Statistical Analysis

We used a two-tailed paired-sample t-test to look for differences between stunted and healthy seedlings for each year x stocktype x sample date combination for these variables: 1) seedling morphology (height [n = 50]; RCD [n = 50]); 2) mean foliar nutrient concentrations; 3) mean soil nutrient concentrations from soils beneath sampled seedlings (n = 20); 4) mean numbers of monopodial, bifurcate, dichotomous, coralloid, and pinnate root tips morphologies (2006 seedlings; n =120), and 5) total mycorrhizal root tip counts (2006 seedlings; n = 120). Chi-square

Table 1. Stunted and healthy seedling morphology measurements taken in 2006 and 2007.

		2006			2007	
		3+0	2+0	1+0	2+0	1+0
Height (cm)*	Healthy	19.90	23.15	5.25	17.25	7.40
	Stunted	7.50	7.20	1.55	5.20	1.10
	P value[2]	0.000	0.000	0.000	0.000	0.000
Root Collar Diameter (mm)	Healthy	4.15	3.99	NA[1]	3.35	1.30
	Stunted	2.31	1.79	NA[1]	2.00	0.61
	P value[2]	<0.0001	<0.0001	NA[1]	<0.0001	<0.0001

[1] RCD measurements were not measured on these seedlings as all calipers were <1.0 mm.
[2] Values < 0.05 are statistically different.
* 1 cm = 0.4 in

goodness of fit was used to analyze differences between stunted and healthy seedlings for specific fungal types isolated from root tips of stunted and healthy seedlings in 2006. Tests were considered significant if $P < 0.05$.

Results and Discussion

Seedlings and Soil

Stunting was most prevalent in 1+0 jack pine seedlings in 2007, with widespread growth deficiencies and chlorosis. Stunted seedlings were significantly shorter with significantly less stem diameter (Table 1). Root dry weights of healthy 2+0 seedlings were 189% greater than stunted seedlings in 2007, but were not significantly different in 1+0 seedlings. For shoots, healthy 1+0 and 2+0 had 280% and 267% greater biomass, respectively, than stunted seedlings in 2007.

For both years, we found no significant differences in extractable Ca, K, Mg, total C and N, available P, and pH in the soil below either stunted or healthy seedlings. Concentrations of N, P, K, Mn, and Zn in shoots and roots of stunted 1+0 seedlings sampled in 2007 were 159%, 133%, 27%, and 86%, respectively, lower than in healthy seedlings, while Ca and Mg were 169% and 36% greater in stunted seedlings. In contrast, N and P concentrations in stunted and healthy 2+0 seedlings were not significantly different in 2006 and 2007. Because most researchers suspected a mycorrhizae deficiency, the focus of their work has been on P nutrient contents; lower P values have been observed by others in stunted seedlings (Campagna and White 1969; Trappe and Strand 1969; Croghan and LaMadeleine 1982).

The N, P, and K levels observed in the stunted 1+0 seedlings were consistent with other studies, and just below, or at the low end of, the acceptable range of values for bareroot seedlings (Table 2). Additional soil nutrient analysis, involving available N, may provide further insight into seedling nutrient deficiencies. Applications of foliar $21N{:}0P_2O_5{:}0K_2O$ and $19N{:}19P_2O_5{:}19K_2O$ fertilizers to 2+0 stunted seedlings did result in increased growth when compared to stunted seedlings with no fertilizer. When the heights were compared to control healthy seedlings, however, the seedlings were still not up to grading specs (Koll 2008). Applying fertilizer as a top dressing when stunting first appears could ameliorate growth deficiencies, but this has not been tested at this time. Average soil pH ranged from 4.68 to 4.94. This is acceptable, but not ideal, for soil nutrient conditions. Slightly raising soil pH could also improve nutrient availability and possibly reduce seedling growth deficiencies in jack pine.

Mycorrhizae

Healthy 2+0 and 3+0 seedlings had significantly more mycorrhizal root tips than stunted seedlings, but no significant difference was detected in 1+0 seedlings (Table 3). While 2+0 and 3+0 stunted seedlings had statistically less mycorrhizal root tips, the total numbers were still very high when compared to healthy seedlings, and stunted seedlings did not appear to be deficient in mycorrhizae. In 2007, visual estimates of colonization by mycorrhizal fungi on fresh 1+0 and 2+0 seedling roots indicated no major differences between stunted and healthy seedlings.

We classified seedlings from 2006 into three distinct types of ectomycorrhizal fungi. We compared the DNA sequences with known sequences in the National Center for Biotechnology Information BLAST search and the UNITE database (Kõljalg and others 2005) (see Potvin 2008 for details). Our three distinct types were identified as *Sistotrema brinkmannii* (Bres.) J. Erikss., *Thelephora terrestris* Ehrh., and *Suillus luteus* (L.: Fries) Gray. The fungi we isolated in 2007 had similar growth characteristics in culture as these three types. In 2007, we also identified a fourth type as a *Laccaria* spp. using comparisons with known pure cultures of *Laccaria laccata* ((Scop.) Cooke.).

All but *S. brinkmannii* are mycorrhizal fungi common to conifer nursery systems (Trappe and Strand 1969; Croghan 1984; Richter and Bruhn 1993; Menkis and others 2005). *S. luteus* was the most frequently isolated mycorrhizal fungus in this study, and commonly colonize pine nursery seedlings in their first months of growth (Richter and Bruhn 1993; Dahlberg and Finlay 1999). *T. terrestris* was also detected on almost all seedlings, and is an aggressive colonizer of pine seedling roots in nurseries (Richter and Bruhn 1993; Colpaert 1999). *Laccaria* was isolated from stunted and healthy jack pine seedlings in 2007. *Sistotrema brinkmannii* was also isolated from stunted and healthy jack pine seedlings, and is typically classified as a wood decay fungi (Eriksson and others 1984); a follow-up study that was conducted on this fungus indicated it was neither a true mycorrhizae nor a pathogenic fungus (Potvin and others forthcoming).

None of the four fungal taxa were exclusively found on either the stunted or healthy seedlings. Although we observed some differences

Table 2. Acceptable foliar nutrient ranges for N, P, K, Ca, Mg, Mn and Zn (Youngberg 1985; Powers 1974) and values for healthy and stunted 1+0 seedlings analyzed in 2007. *P* values < 0.05 are statistically different.

	N	P	K	Ca	Mg	Mn	Zn
			----- % -----			----- ppm -----	
Acceptable	1.2 to 2.0	0.1 to 0.2	0.3 to 0.8	0.2 to 0.8	0.1 to 0.15	100 to 5000	10 to 125
Healthy 1+0	2.59	0.28	1.16	0.26	0.14	490	106
Stunted 1+0	1.00	0.12	0.60	0.70	0.19	385	57
***P* value**	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Table 3. Total mycorrhizal root tip counts and average number of mycorrhizal root tips per 1-cm (0.4 in) root section for healthy and stunted 1+0, 2+0, and 3+0 jack pine seedlings in 2006. *P* values < 0.05 are statistically different.

	1+0 Seedlings			2+0 Seedlings			3+0 Seedlings		
	Healthy	Stunted	*P* value	Healthy	Stunted	*P* value	Healthy	Stunted	*P* value
Total mycorrhizal root tip count	1013	955	0.443	2172	1805	0.005	2058	1748	0.032
Average number of mycorrhizae/cm	3.38	3.18	0.443	7.24	6.02	0.005	6.86	5.83	0.032

in the frequency of them on stunted and healthy seedlings, these differences were inconsistent across age groups and years. We hypothesized differences would be present in the types of mycorrhizal fungi and between stunted and healthy seedlings and in the numbers of mycorrhizae on stunted and healthy seedlings. Our results do not support those hypotheses.

Work by Koll (2009) and Koll and others (2010) indicates that mosaic stunting observed at JW Toumey Nursery may reflect problems associated with excessive application of sawdust as a soil amendment.

Summary

It is traditionally thought that mosaic stunting in fumigated bareroot nursery beds occurs through these steps: 1) the biocide eliminates ectomycorrhizal fungi; 2) seedlings lacking ectomycorrhizae have poor nutrient uptake, especially P, and a reduced growth rate; 3) ectomycorrhizal fungi reinvade the nursery soil in a random fashion; 4) colonized seedlings have better growth than nearby non-inoculated seedlings, resulting in islands or pockets of remaining, stunted seedlings. Our results, however, indicate ectomycorrhizal fungi, or their quantities, are not a factor in jack pine seedling stunting at the JW Toumey Nursery, even though severely stunted seedlings were deficient in foliar N, P, and K. It may be that stunting at the nursery is a result of improper application of sawdust as a soil amendment.

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Management of White Grubs in Forest Nurseries

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Abstract: In Michigan, the most important white grub pests of nursery seedlings are European chafer beetle (*Rhizotrogus majalis*) and June beetles (*Phyllophaga* spp.). If damage is observed and white grubs found, beds can be protected from future damage with imidacloprid applied as Discus™ or Marathon® once per year in June or July.

Keywords: white grubs, forest nurseries, pest management

Introduction

Forest nursery seedlings are sometimes damaged by white grubs feeding on the roots. C-shaped white grubs are the larval stage of scarab beetles (Family Scarabaeidae) (Figure 1). In Michigan, most of the damage is caused by either European chafer beetle (*Rhizotrogus majalis*) or June beetle (*Phyllophaga* spp.) grubs (Figures 2 and 3). European chafer is now spread throughout the lower peninsula of Michigan to the latitude of Midland, MI. It has also been found in several locations north of Midland, including Traverse City and Alpena. Because we lack the proper natural enemies to keep populations of European chafer under natural control, it may become abundant in some areas, causing substantial damage. In several nursery fields, blue spruce (*Picea pungens*) and arborvitae shrubs (*Thuja occidentalis*) up to 61 cm (24 in) tall have been so severely damaged that 25% of the shrubs were lost.

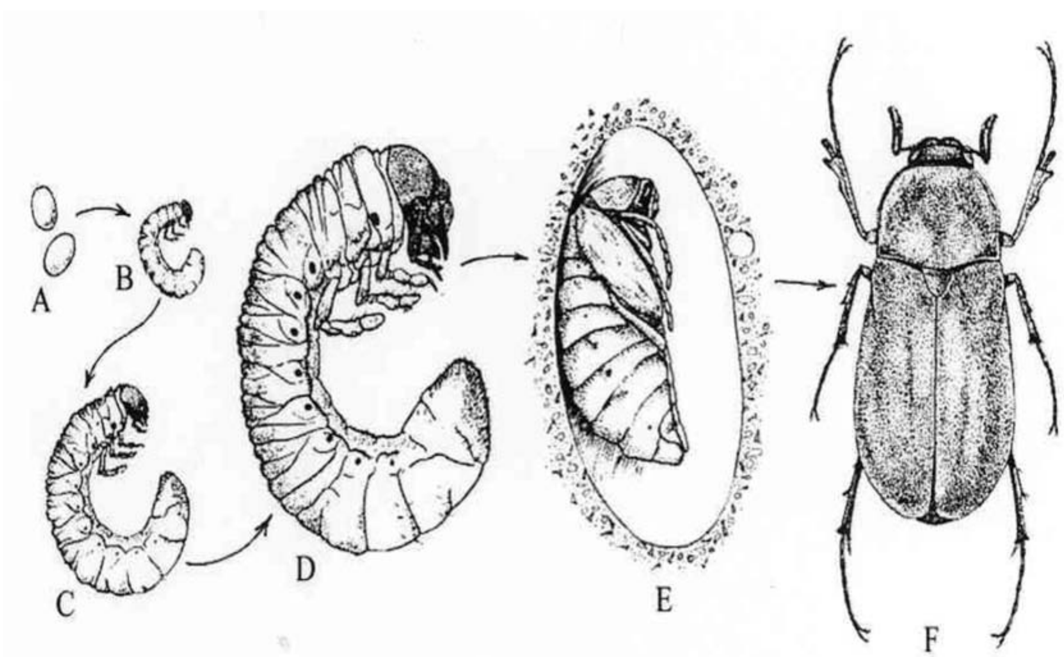


Figure 1. Life cycle of a scarab beetle (Family Scarabaeidae): A) eggs; B) first instar grub; C) second instar grub; D) third instar grub; E) pupa; F) adult scarab beetle.

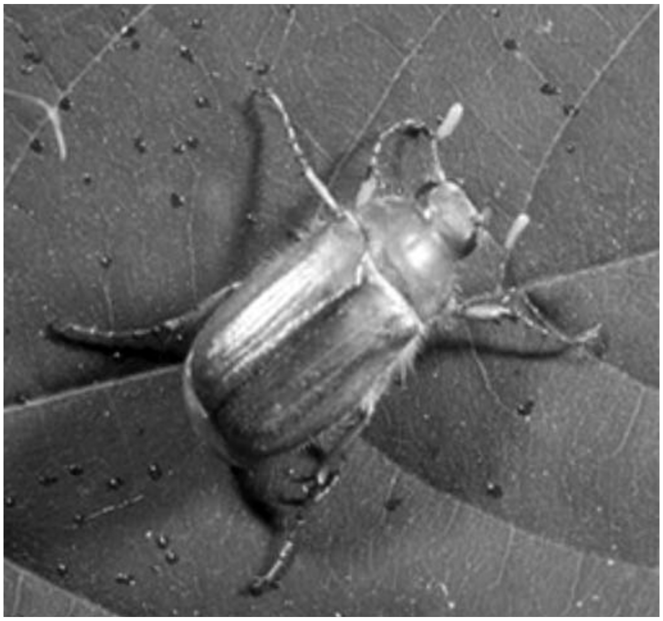


Figure 2. European chafer beetle (*Rhizotrogus majalis*).

Similar damage can be caused by June beetle grubs anywhere in Michigan. The damage caused by June beetle grubs, however, is more sporadic from place to place and year to year because we have natural enemies that keep populations under control.

Management

Forest seedling growers are urged to scout for white grubs by pulling-up seedlings and examining the roots and surrounding soil whenever plants wilt and die. If white grubs are found, the damage can be prevented the next year by applying imidacloprid as Discus™ or Marathon® in June at the labeled rate.

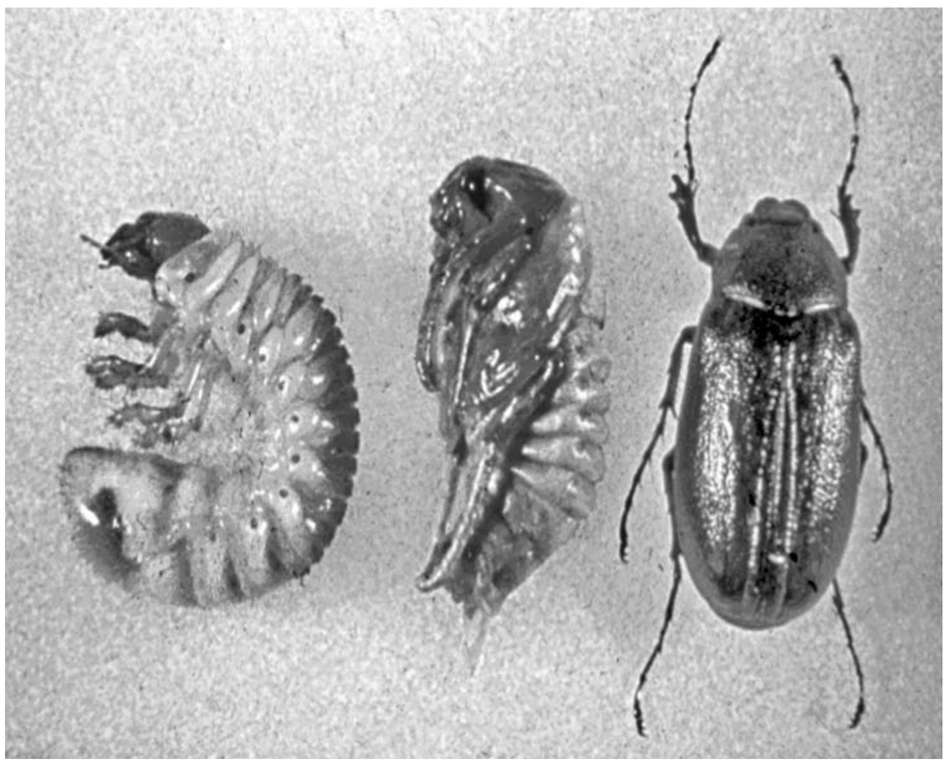
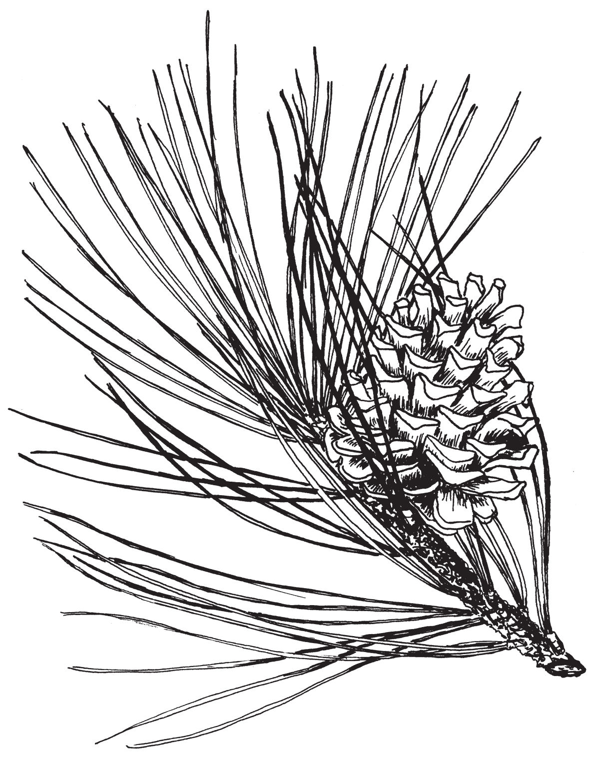


Figure 3. Grub, pupa, and adult June beetle (*Phyllophaga* spp.).

Intertribal Nursery Council Meeting

Joint Meeting of the Western Forest and Conservation Nursery Association and Intermountain Container Seedling Growers' Association

Northeastern Forest and Conservation Nursery Association Meeting



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Ponderosa pine drawing by Lorraine Ashland, College of Natural Resources, University of Idaho.

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Rocky Mountain Research Station

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of the forests and rangelands. Research is designed to meet the needs of the National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals. Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications may be found worldwide.

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