Application of Portable Data Recorders in Nursery Management and Research

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A portable data recorder is a specialized electronic device for recording and storing data in the field, then transmitting the data directly to a computer, thus eliminating the time and errors associated with manual data transcription. Use of a data recorder allows errors and completeness to be checked in the field, data to be collected directly from instruments, and turnaround time between collection and completed analysis of data to be kept to a minimum. Considerations for selecting a data recorder to meet individual needs, and some of the drawbacks of these instruments, are discussed. Specific applications in nursery management and research are presented. Tree Planters' Notes 40:3-10; 1989.

A portable data recorder (PDR) is a hand-held, battery-powered, microprocessor-controlled computer terminal *(6)*. PDR's are specialized electronic devices designed to collect and store data in the field or laboratory (in place of data forms), then transmit the data directly to a computer for processing. They differ from laptop computers and hand-held calculators in that they are constructed for outdoor use and their main purpose is to store data, not process it.

As microcomputer use increases in forestry, more resource professionals are turning to automated data processing to increase their productivity. Although computer hardware and software have advanced substantially in recent years, data are still collected and entered into computers by hand in many cases. Doing these two steps manually can be expensive, time-consuming, and prone to error. Alternatively, data can be keyed into a PDR as they are collected and automatically checked for errors and completeness; then the completed data file can be transmitted directly to a computer. Because manual data transcription is eliminated, PDR's can significantly reduce costs, number of errors, and turnaround time. PDR's are becoming the technological link between field measurements and data analysis.

Portable data recorders were first used in supermarkets to expedite taking inventories. In recent years they have found a new home in taking forest inventories because of the volume and diversity of data that are collected, the need for checking for errors during data collection, the cost savings in data transcription, and the reduced time to obtain results *(1, 2, 4, 7, 9)*. Bluhm *(3)* recently reported using a PDR in a nursery seedling inventory. Applications in research have increased in recent years, not only because more efficient data handling is needed, but also because some PDR's can be interfaced to digital and analog instruments to collect data directly.

All these applications have certain characteristics in common:

- A large amount of data needs to be collected and transferred to a computer for summary.
- The costs of manual data entry and verification need to be reduced.
- Errors must be minimized.
- Time between data collection and data processing should be reduced.

In this paper, we will discuss some benefits and drawbacks of using PDR's, list some considerations to help you decide which one to purchase, and present some ways we use PDR's in nursery management and research.

Selecting a Portable Data Recorder

Approximately two dozen devices on the market could qualify as portable data collectors. Specifications for most of

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the dedicated PDR's are reviewed by Cooney *(5,6)*. They differ widely in size, environmental durability, keyboard configuration, operating system, memory capacity, programmability, and communications.

Most are powered by rechargeable batteries and have some form of battery backup and low battery warning, so that the risk of losing data is low. The devices differ greatly in other specifications; users need to determine what configuration they need and select the appropriate device. For example, in forest inventorying, error-checking and completeness-checking routines should be built into the data collection scheme so that complete, error-free data are obtained while the survey crew is on site.

For those applications, a PDR that supports BASIC, a powerful and versatile programming language, is highly recommended. In many other applications that are more straightforward, amounting to filling in the blanks with data, a simple edit mode may suffice for entering data.

Certain PDR's can be interfaced with digital and analog instruments—such as calipers, balances, area meters, porometers, thermometers, and string potentiometers—so that data can be transmitted directly to the data file with the push of a button. In some cases the PDR can be set up to take unattended readings from an instrument at set times. Note, however, that these applications require a custom program to read the device and record the data. All PDR's are equipped with a serial port for RS-232 communications by way of direct cable or a modem to a host computer.

Programmability is desirable for controlling cursor movements, performing mathematical functions, displaying menus and messages, checking for errors, checking for completeness, and accepting data from interfaced instruments. Most devices provide some degree of programmability using either a proprietary language that the user must learn, or BASIC, a more universal language. Although the proprietary languages can be used to provide extensive error-checking and to perform mathematical functions, there are advantages to purchasing a PDR that is programmable in BASIC because the same language can be used for programming on a microcomputer. However, a proprietary language may be more suitable for programming the PDR to accept data from connected instruments.

While building in some programmed error-checking routines and minor manipulations of the data may increase the efficiency of data collection, don't expect the PDR to perform the data summary and analysis. For most applications, it is easier to first transmit the data to a computer, then perform the analyses using existing, more powerful application software. The examples in the applications section will illustrate this point.

We recommend the following approach to selecting a PDR: (a) list all applications where a PDR may be useful; (b) evaluate that list and retain only the applications where a PDR is truly needed to increase efficiency (i.e., large amounts of data, repetitive measurements, need to transmit data to a computer, minimization of errors, and cost savings from eliminating data transcription); (c) make a list of capabilities and features that the PDR must have to meet your needs; (d) compare your list against the tables of specifications provided by Cooney *(5,6)*; and (e) evaluate product information and any available published reports in making your decision. Several companies and agencies have conducted their own evaluations and may be willing to share their information.

You may also wish to evaluate the economics of using a PDR instead of conventional field forms and manual data entry. You can do this by following the procedure outlined by Fins and Rust *(1)*. Assuming that data collection takes the same amount of time by both methods, data transmission and manual entry times can be estimated closely enough to perform the comparative cost estimates without actually using a PDR.

Drawbacks to Using a Portable Data Collector

Some special problems, limitations, and conflicts may be encountered in using a PDR:

- "Computer phobia."
- Limited view of the data file.
- Conflict with existing data collection methods.
- Cabling and communications problems between connected devices.

Many people get computer phobia when they are asked to record numbers electronically rather than writing and storing them physically on a tangible sheet of paper. The task of training personnel to use a PDR should be taken seriously. It is a good idea to develop flow charts and provide practice data for them to learn with before important data are recorded. As a transition, it may be helpful to first write the data on data forms, then enter the data into the PDR.

One limitation of most PDR's is the restricted view of the data file, i.e., only a small portion of the file is seen (and accessible) on the display at one time. It is more difficult for the user to compare current measurements with previous measurements, which are more easily seen on data forms. This is not a problem if you take advantage of the PDR's power by writing a short program to have the PDR display the previous measurement (which must exist in the same file), or you can have it compare the new measurement with the previous measurement, beep if it is smaller, and otherwise enter the data in the file.

A second problem related to the restricted view is keeping track of your location in the file. Because one row in the file is usually the data for one tree, beginning users may skip a tree and get out of sequence with the data file. There are two ways to avoid this problem. One is to print a copy of the data file with lines numbered so that users can keep track of their location by line number, and the other is to program the PDR to display the descriptors (e.g., block, treatment, tree number) pertinent to each measurement being entered.

Use of a PDR may not be compatible with established plot measurement methods. For example, some crews like to have one person record data while two others measure trees in adjacent rows. This does not work out very well with a PDR, because it cannot easily switch back and forth in the data file. The same is true for measuring adjacent rows in opposite directions, unless either the plot or the data file is arranged that way. When using a PDR, it is easiest to enter data in the sequence they occur in the data file. If more than one person is taking measurements, they should leapfrog and provide the data in the file sequence.

Cabling and communications between connected devices are common obstacles when any peripheral device is connected to a computer or PDR. Cabling from a PDR to a microcomputer is usually not a problem because the manufacturer often has a serial cable available. Communications between a PDR and a computer is best done with a communications program.

Establishing communication is a matter of setting up matching protocol (baud rate, parity, duplex, data bits, stop bits, etc.) between the two devices. The PDR manual will usually give some helpful advice on this, but there is no one solution because computers differ widely. The same situation arises when a PDR is cabled to an instrument to collect data. In some cases, e.g., digital calipers, the device, cable, and programming may be available from the PDR manufacturer. In other cases, you purchase the peripheral device with its optional serial port, and the cabling and communications to the PDR are up to you.

Specific Applications of Portable Data Recorders

In this section we will present two applications of the Polycorder (Omnidata International, Logan, UT) in nursery management and research. Published applications of other PDR's include Hewlett-Packard model 71 *(3)*, Husky Hunter *(2, 4)*, Husky Special Performance *(9)*, Oregon Digital Serial Plus II 7100 *(1)*, and Datamyte 1003 *(8)*.

Nursery application. The USDA Forest Service Reforestation Improvement Program *(9)* involves repetitive measurement of several seedling variables (seedling growth, morphology, root growth potential, cold hardiness, stress test, plant moisture stress, and field plot measurements) at 11 nurseries. The same variables are repeatedly measured using the same sampling scheme, so the basic data forms will be used over and over. To facilitate data collection, summarization, file organization, and archiving, a systematic approach was developed that utilizes the Polycorder to record the data and transmit it to a microcomputer. Figure 1 shows how the data will be processed.

The Polycorder requires a format file for each data file that will be created. The format file designs the data form. The data file is the actual form, which is

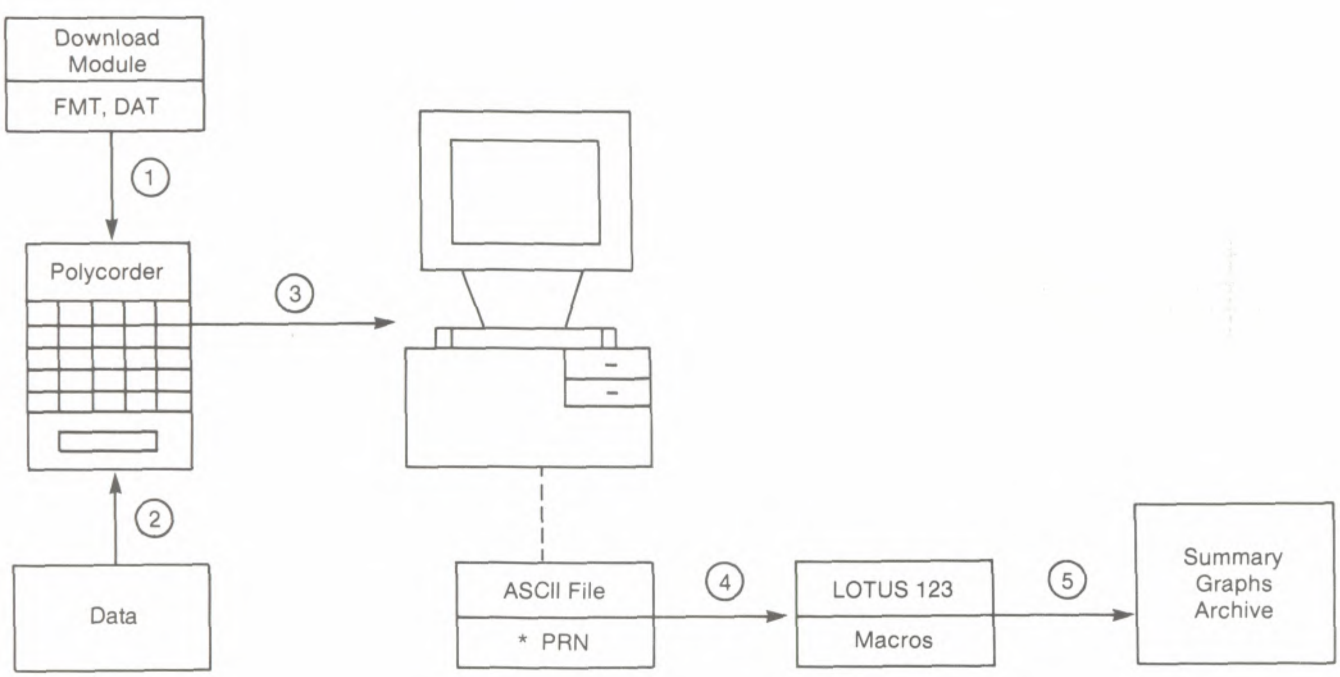

Figure 1—*Flow chart for data processing with portable data recorder.*

blank until data are entered. Format and data files may be keyed into the Polycorder, loaded from a download module **(1)**, or downloaded from a computer. The next step is to key the data into the data file **(2)**. This can be done in edit mode or in program mode, but the latter requires writing a short Polycode program to control cursor movements and must be matched to the number of columns receiving data. Once the data file is complete, the data are transmitted to the computer **(3)** using direct cabling between serial ports on each device. A communications program, Crosstalk, is used to capture the data and create an ASCII file with a .PRN extension. The ASCII data file is then imported into a preformatted Lotus 123 worksheet **(4)** where the data are summari zed, graphs are created, and archiving is done **(5)** by running specialized macros (preassembled lists of commands) on the worksheet.

This scheme offers many conveniences as a result of the repetitive nature of the application: (a) because the same data files are used over and over, they may be stored in a download module (or the computer) and loaded into the Polycorder whenever they are needed; (b) after the data are offloaded to a computer, they may be erased from the Polycorder file, retain-

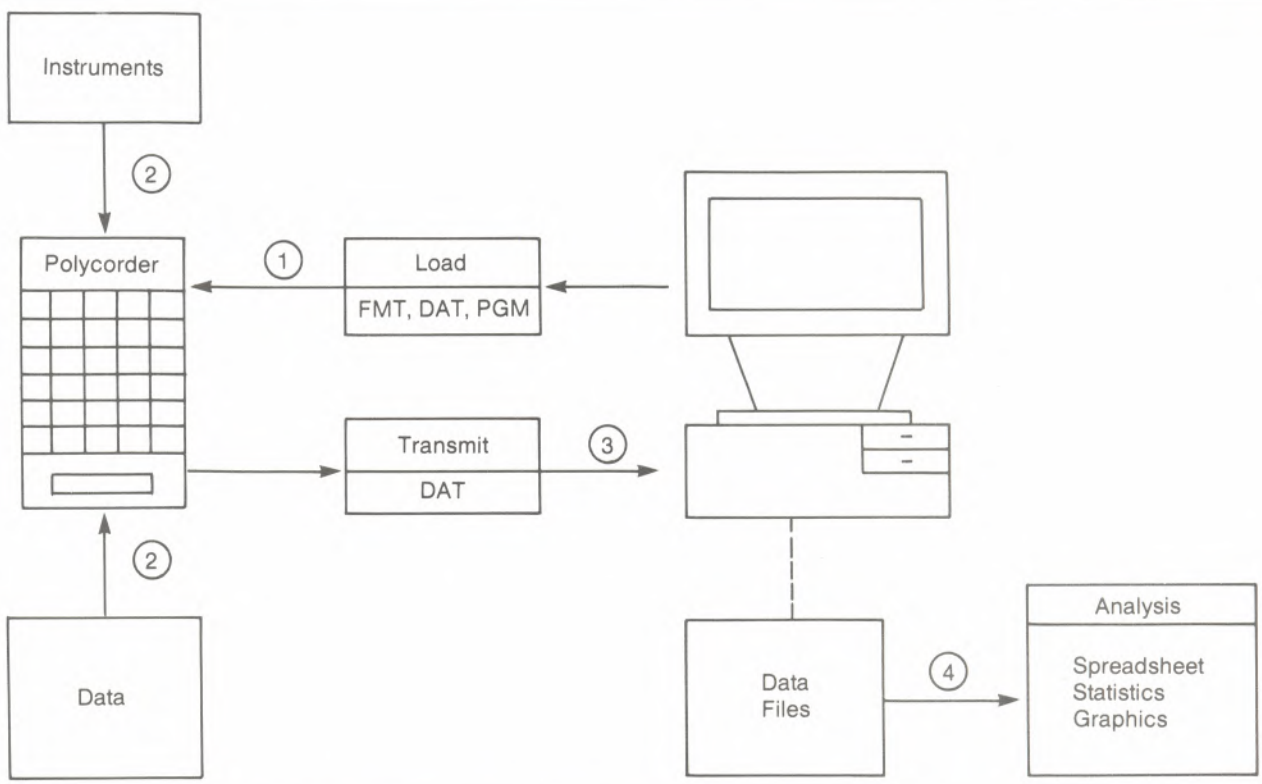

Figure 2—*Typical scheme for collecting and processing research data with a portable data recorder.*

ing the blank data file in the Polycorder for reuse; and (c) automated data processing is optimized, thus the data can be transmitted to a computer and summarized in minutes.

Research application. The above approach works well for situations with repeatedly measured variables in which the same data forms are consistently used. However, that is often not the case in research. Each study typically has one or more unique data files; the data files will usually be more complex, e.g., containing several columns of descriptors for block, treatments (in random order), and seedling number. There may be a need to append additional columns onto the original file for annual measurements. Some types of data may be transmitted to the PDR via a serial port from a digital balance, calipers, area meter, porometer, or other device. The following diagram (fig. 2) shows a typical data collection and processing scheme in research applications of PDR's.

The format and empty data files are more easily created on a computer, stored as ASCII files, then downloaded directly to the Polycorder (**1**). The format file can be written with EDLIN or any word processor that will output an ASCII file. The data file containing the descriptors (block, treatment, tree number, etc.) in the desired sequence can be "constructed" using Lotus 123 or can be created directly with certain statistical programs such as Minitab. The ASCII format and data files are downloaded to the Polycorder using a communications program. This step can be expedited by using a communications program that has versatile command and script file capabilities (fig. 3).

Data are entered into the PDR through the keyboard (**2**) or by direct transmission from instruments (**2**). Direct transmission of data from instruments is very fast, but requires that a Polycode program be written to accept, manipulate, and file the transmitted data. For example, we weigh dried plant samples without removing them from the bags. Paper bags of the same size are surprisingly consistent in weight. We dry a group of empty bags along with our plant samples, determine an average empty bag weight, then enter that value into a Polycode program.

```
GO LOCAL
CLEAR
ASK Type L for Load, T for Transmit, E for Edit, or Q for Quit
JUMP DO-@
LABEL DO-Q
QUIT
LABEL DO-L
SCREEN D
CLEAR
LWAIT CHAR " "          ; insert mating call character sent by PDR, if used
SEND
RWIND
LABEL DO-T
SCREEN D
CLEAR
CA
WHEN " " ALARM NOW      ; insert end of file character sent by PDR
WAIT STRING " "         ; insert end of file character sent by PDR
CA —
RWIND
LABEL DO-E
RUN
```

Figure 3—*A Crosstalk script file (*.XTS) for transferring files between a portable data recorder and a microcomputer. The script file loads automatically when it is given the same prefix as the command file (*.XTK). The communication protocols used in the command file must match those of the portable data recorder.*

The program subsets the measured weight from an alphanumeric string transmitted by the balance, subtracts the average empty bag weight, records the tissue dry weight in the data file, performs cursor movements, and provides file location prompts. This technique works well for samples that have a dry weight greater than 1 g; the experimental error is no greater than that introduced by removing the plant samples from the bags to weigh them.

The completed data file is transmitted back to the computer **(3)** by a communications program. File redirection programs such as Dpath and File Facility are handy for organization purposes because they allow you to store data files in separate subdirectories on a hard disk, rather than storing them all in the same subdirectory with the communications program. The final step of the scheme shows the data files being imported into various spreadsheet, statistical, or graphics programs for analysis **(4).**

Discussion

Portable data recorders have the potential to increase efficiency of data collection in a variety of applications. However, they are not for everyone. Converting to a different method requires an investment in new equipment and time—time to evaluate the actual need for the device, to learn how to use it, to develop a system to apply it, and to train personnel to use it properly. Thus, there will be a start-up period before a net increase in efficiency is realized. You should be reasonably certain that using a PDR is justified before you make a commitment. Use of a PDR (and a computer for that matter) may well help you reach a higher level of technology, efficiency, and productivity. However, that is only achieved through learning, commitment, and adaptability.

In research applications, we find that using PDR's allows us to take more data than would otherwise be possible with available personnel. This is especially true when instruments are interfaced with a PDR. One person can take several times more data in a single day, with good precision and less fatigue. Most technicians are enthusiastic about using data collectors because of the savings in time, and they feel a sense of accomplishment for mastering the use of a sophisticated electronic tool. Because data entry and verification are eliminated, the technicians are relieved of those tasks, and the computer is freed for other uses.

In summary, PDR's are a cost-effective alternative to conventional data sheets for data collection and manual entry of data into a computer. Data collection time is about the same with a PDR, but the need for manually entering data into a computer and verifying them is eliminated. Other benefits are the opportunity to perform error-checking in the field, interface with instruments, and obtain faster turnaround of completed data analyses. In general, if a PDR is used frequently, the labor savings will pay for the device in 1 to 2 years.

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Changes in the Rate of Return Caused by Increased Cost of Red Pine Nursery Stock in Wisconsin

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The rate of return was compared between six costs of red pine (Pinus resinosa Ait.) *2 + 0 seedlings and three rotation lengths. An increase of $100 per thousand seedlings causes the real rate of return before taxes to drop almost 1% for a 40-year rotation and more than 0.5% for a 95-year rotation.* Tree Planters' Notes 40(1):11-14: 1989.

Trees produced by the State-operated nurseries in Wisconsin are sold for the cost of producing the trees with no additional margin added for profit, risk, insurance, or other charges normally added by private tree nurseries. Low-cost trees offer an economic incentive to encourage reforestation projects. As with any investment made where, capital resources are committed for the long term, such as real estate or business ventures, the initial capital cost of the investment influences the potential earning power and income produced for the investor.

This condition also holds true for investments in growing timber. A small change in the initial cost of establishing a pine plantation, for example, can have important impacts on the economic attractiveness of this investment as well as force adjustments to the forest management practices planned for this plantation. The size of these impacts depends on many factors.

This paper examines the economic impacts to an investment in a red pine *(Pinus resinosa* Ait.) plantation in Wisconsin that result from an increase in the cost of planting stock. This impact would be comparable to a situation where tree costs were held constant but other initial establishment costs were increased a similar amount. For simplicity, only red pine is considered here, but similar trends would occur with other species.

In Wisconsin, nursery trees for reforestation are grown by three State-owned nurseries, as well as by several forest products companies and many private tree nurseries. Both public and private forest landowners purchase trees from the State nurseries for reforestation. In 1987, the State-owned nurseries sold 19.1 million trees and shrubs. Orders for red pine seedlings accounted for 11.6 million of this total.

Analysis of the Investment

There are several investment criteria that can be used to evaluate the effect of changes in the price of planting stock on a forest investment. Probably one of the easiest criteria to understand is the rate *of return on investment,* also called the *internal rate of return.* Simply stated, the rate of return is the annual percentage rate at which an investment grows towards the income it eventually generates. All income earned by this investment is measured against all costs, and an annual rate of return is calculated for the term. Most people understand the concept of rate of return, because many other forms of investments, such as passbook savings, money market funds, and IRA accounts, are measured or expressed as a percentage rate. Rate of return also allows easier comparisons between forest investments with different rotation lengths or against other non-forestry-related investments.

WORTH (a forest investment analysis program written for IBM PC's, XT's, AT's, and other compatible computers) was used to calculate the rate of return for the options considered in this analysis *(2)*. All values were calculated and listed as before income taxes, both Federal and State. All costs, yields, and incomes for this analysis were made on a per-acre basis.

This analysis examines a typical red pine investment for Wisconsin. A private or industrial landowner elects to establish a red pine plantation on a site with an estimated site index of 65 (50 years). The prescribed planting spacing is 6 by 8 feet, or approximately 900 trees/acre. This example assumes that the land has been entered under Wisconsin's Managed Forest Law, which offers property tax relief to forest landowners enrolled in the program. Over the enrollment period of 25 or 50 years, the landowner must follow a mandatory management plan, pay a 5% severance tax on the value of stumpage cut, and pay an annual property tax currently set at $0.74/acre.

The following investment schedule was used in our analysis:

- Site preparation costs = $75.00/acre.
- 2 + 0 planting stock (900 trees/acre at $36.00/thousand) = $32.40/acre.
- Hand planting or machine planting charge = $40.00/acre.
- Control of brush competition (fifth year) = $50.00/acre.
- Annual administrative costs =$1.00/acre/year.
- Annual Managed Forest Law taxes = $0.74/acre/year.

Three different rotation lengths are considered here: 40 years, 60 years, and 95 years. The shorter lengths are included because some landowners are considering shorter rotations than generally prescribed. Yields for these different rotation lengths are listed in table 1.

Table 1—*Estimated volume yields for a Wisconsin red pine plantation with a site index of 65 for rotation lengths of 40, 60, and 95 years*

Stand age (yr)	40-yr rotation cords	40-yr rotation thousand bd ft	60-yr rotation cords	60-yr rotation thousand bd ft	95-yr rotation cords	95-yr rotation thousand bd ft
30	11.0	—	11.0	—	11.0	—
40	25.0	.25	8.0	—	8.0	—
50			8.0	—	8.0	—
60			2.5	12.5	1.5	3.0
70					1.5	3.0
80					—	3.0
90					2.0	18.0

Yields are based on a site index 65 with an initial survival of 800 trees/acre. At the first thinning (age 30) trees in every other row are harvested. All later harvests are selective thinnings, leaving 100 ft^2/acre of basal area except for the last cutting, when all merchantable timber is harvested.

TWIGS (the woodsman's ideal growth projection system) was used to project future yields. Stand information from a 22--year-old red pine plantation on the Washburn County Forest in Wisconsin was used as the basis for this TWIGS projection *(3)*. TWIGS 3.0 is a distance-independent, individual tree growth model designed for use on personal computers. Stands can be grown under selected management options to project stand conditions in the future.

Future revenues from harvests are estimated using the following stumpage values: $12.00/cord for first thinnings, $16.00/cord for second and later thinnings, and $52.00/thousand board feet for all sawtimber. The effects of inflation on stumpage prices were ignored, because discounting back to the present would cancel out future increases caused by inflation. A 5% yield tax against all income from stumpage reduced income received by the landowner participating in MFL program.

As of 1988, the cost per thousand trees for 2 + 0 red pine purchased from the State of Wisconsin for reforestation is $36.00 per thousand for bulk orders. Five higher prices, $50, $100, $136, $150, and $200 per thousand were tested to show the impact on the rate of return if higher prices were charged for planting stock.

This analysis focuses on the change in the rate of return before income taxes to landowners assuming they do not alter any other factor in management of their plantations. Other options not examined here that offer logical choices for landowners to recapture income lost to higher tree costs include raising the minimum acceptable stumpage prices to achieve the same rate of return as before the increased tree cost. Landowners could also elect to plant fewer trees per acre, plant improved or hybrid stock, reduce other site preparation costs, change harvest schedules, or alter other practices to offset the higher cost of planting stock.

Table 2 shows the estimated rates of return for the three rotation lengths and six tree costs. Under the assumptions used here and using 1988 tree prices, forest landowners can expect to earn between 2.09% and 2.94% real rate of return, depending on the rotation period they chose. As the cost for trees increases, the rate of return drops. Under a 40-year rotation, an increase of $100 per thousand seedlings in costs reduces the rate of return by almost 1% (0.96%). The same increase causes the rate of return for a 60-year rotation to drop 0.73% and for a 95-year rotation to decrease 0.58%. Even small increases in the cost for planting stock cause important changes in the rate of return earned by an investment in a red pine plantation (fig. 1).

The final impacts of these changes depend on the intentions and size of investment made by each landowner. For a small landowner, a change of 0.5% to 1.0% may not have much impact because personal satisfaction or other goals may

Table 2—*Real rate of return on investment for a Wisconsin red pine plantation with a site index of 65 before income taxes for rotation lengths of 40, 60, and 95 years (rates do not include inflation)*

Cost of 2 + 0 seedlings per thousand	Real rate of return (%)		
	40-yr rotation	60-yr rotation	95-yr rotation
$ 36	2.09	2.90	2.94
$ 50	1.93	2.78	2.84
$100	1.44	2.40	2.54
$136	1.13	2.17	2.36
$150	1.03	2.09	2.30
$200	0.67	1.83	2.09

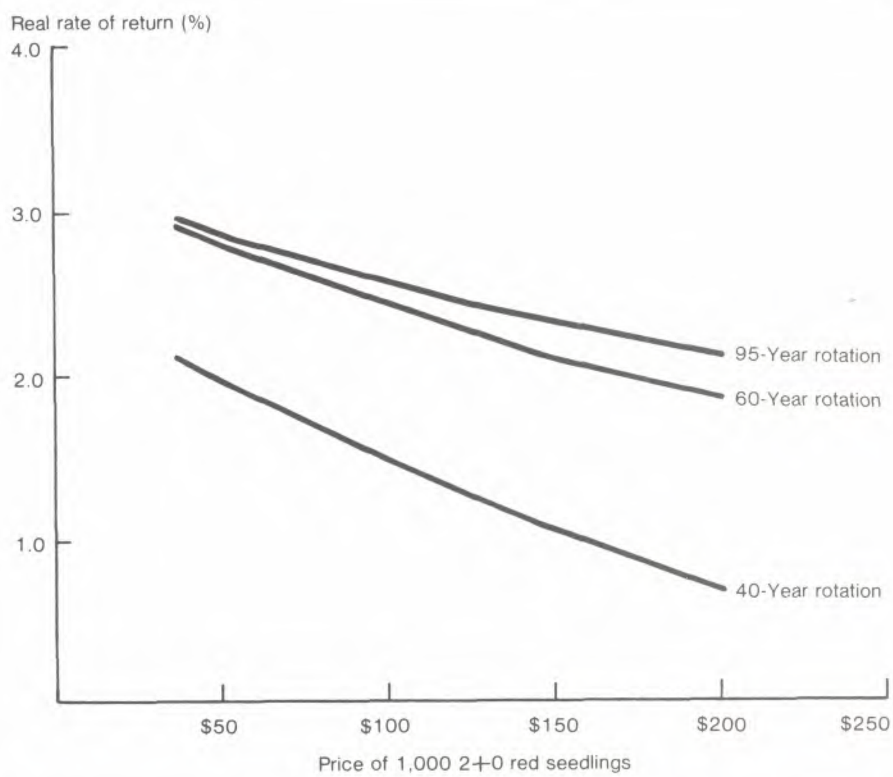

Figure 1—*Real rate of return on investment in a Wisconsin red pine plantation before income taxes.*

offset increased costs. But for other landowners, particularly large industrial or public landowners, where investment capital is borrowed or in short supply, or many acres are involved, a change as small as 0.1% may force changes to the investment or management schedules.

All rates of return shown here represent real rates that do not include any inflation or risk. In recent years, inflation has fluctuated between 2 to 4% annually. A simple way to compare these real rates of return to currently known markets rates is to add the inflation rate to the calculated rate of return. For example, a calculated real rate of return of 2.5% would be comparable to a market rate of 4.5 to 6.5%, which currently reflects rates available to investors in money market funds. These rates may not be acceptable rates for some investors in forest land, particularly the forest products industry, where higher rates can be earned with lower risk. Several reforestation tax incentives (Public Law 96-451; 1980), cost-sharing programs, and other incentives such as the Conservation Reserve Program may help some investors realize a higher rate of return after taxes than shown here.

Conclusion

The price of red pine planting stock influences the real rate of return earned by this investment. Establishment and planting costs occur 20 to 30 years before any income is earned from thinnings. Therefore, any increase in the price of planting stock without compensating increases in faster growth or added volume and no reduction in other establishment costs causes the real rate of return to drop.

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Susceptibility of Pacific Northwest Conifers to Phytophthora Root Rot

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Seedlings of 11 conifer species were inoculated with 5 species of Phytophthora—P. cactorum *(Lebert & Cohn) J. Schroet.,* P. cryptogea *Pethybr. & Lafferty,* P. drechsleri *Tucker,* P. megasperma *Drechsler, and* P. pseudotsugae *Hamm & E.M. Hansen—to determine susceptibility to phytophthora root rot. Pine, cedar, larch, and spruce species showed tolerance to the disease whereas some true fir and hemlock species were quite susceptible. Other species showed intermediate susceptibility. Management of phytophthora root rot is discussed, utilizing this information on relative susceptibility of various conifers grown in the Pacific Northwest.* Tree Planters' Notes 40(1):15-18; 1989.

Phytophthora species cause varying amounts of damage on bareroot conifer seedlings in the Pacific Northwest. Many conifer species are susceptible to *Phytophthora (4, 5, 7).* Although infection and mortality of seedlings is usually confined to nurseries, stock quality and survival of infected seedlings after outplanting may also be adversely affected *(6).*

Damage in nurseries is most severe in fields with heavy soil or topography that favors water accumulation. Although phytophthora root rot can be effectively controlled with fungicides *(2)*, an integrated control program is recommended *(1)* to ease the selection pressure on the fungi that results in development of resistant strains. One aspect of an integrated program involves planting tolerant tree species in *Phytophthora-infested* nursery soils.

Previous work *(4, 7)* showed western redcedar *(Thuja plicata* Donn ex D. Don) to be immune to infection by *Phytophthora* species; white fir *(Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.), sugar pine *(Pinus lambertiana* Dougl.) and ponderosa pine *(Pinus ponderosa* Dougl. ex Laws.) to be tolerant; and Douglas-fir *(Psuedotsuga menziesii* (Mirb.) Franco), western hemlock *(Tsuga heterophylla* (Raf.) Sarg.), noble fir *(A. procera* Rehd.), Pacific silver fir (*A. amabilis* Dougl. ex Forbes), and California red fir *(A. magnifica* A. Murr.) to be susceptible.

Several important western conifers have not yet been tested. A more complete knowledge of the relative susceptibility of the majority of conifer species grown in Pacific Northwest nurseries to *Phytophthora* would give nursery managers a greater selection of tolerant tree species for problem areas in their nurseries. In this paper, we compare the susceptibility of 11 conifer species (including 9 that had not been tested previously) to the more common species of *Phytophthora* found in bareroot nurseries in the Pacific Northwest.

Methods

One-year-old bareroot seedlings of the following species were tested: mountain hemlock *(Tsuga mertensiana* (Bong.) Carr.), incense cedar *(Libocedrus decurrens* Torr.), east-side Douglas-fir,* west-side Douglas-fir,* Sitka spruce *(Picea sitchensis* (Bong.) Carr.), Engelmann spruce (*P. engelmannii* Parry ex. Engelm.), ponderosa pine, lodgepole pine *(Pinus contorta* Dougl. ex Loud.), western white pine (*P. monticola,* Dougl. ex D. Don), western larch *(Larix occidentalis* Nutt.), grand fir *(Abies grandis* (Dougl. ex D. Don) Lindl.), and California red fir. Douglas-fir, ponderosa pine, and California red fir had been previously tested *(4)* and were used as reference points to allow for comparisons with previous studies.

Each seedling was transplanted into a mixture of cornmeal sand (CMS) inoculum and soil *(4)*. The five most commonly isolated species of *Phytophthora* were

The authors thank Ellen Michaels Goheen for assistance with the seedling inoculations and the Wind River and J. Herbert Stone Nurseries for the seedlings used in this study.

**East-side* and *west-side* refer to seed sources originating on the east and west sides of the Cascade Mountains.

used: *P. cactorum* (Lebert & Cohn) J. Schroet., *P. cryptogea* Pethybr. & Lafferty, *P. drechsleri* Tucker, *P. megasperma* Drechsler Group 2 *(3)* and P. *pseudotsugae* Hamm & E.M. Hansen. All were originally isolated from conifers grown in Pacific Northwest nurseries or seed orchards. Inoculum for each *Phytophthora* species was a mixture of 3 isolates, each of which was inoculated and incubated separately in CMS and then mixed together with steamed soil in a 1:16 ratio. The inoculum-soil mix was then added to 450-ml plastic seedling containers (Dee-pots) when seedlings were planted.

Each combination of fungus species and host was replicated 10 times. For controls, 10 seedlings of each tree species were transplanted into soil mixed with uninoculated CMS. Potted seedlings were placed on a greenhouse bench and watered to saturation daily. Seedlings inoculated with the same *Phytophthora* species were blocked together and a buffer space between groups was made to avoid cross-contamination. Containers were arranged randomly within each *Phytophthora* species group.

Seedlings were observed daily for development of aboveground symptoms of *Phytophthora* infection including chlorosis, wilting, and mortality. Dead or dying seedlings were removed, and isolations from symptomatic root tissue were attempted at 3- to 5-day intervals according to described methods *(4)* . Root symptoms include reddish-brown discoloration of cambium and missing or rotted fine roots. The occurrence and identity of resulting *Phytophthora* colonies were recorded.

After 10 weeks, all remaining nonsymptomatic seedlings were carefully removed from containers. Roots were washed and then rated according to the severity of disease on a scale of 0 to 4: 0 = 0 to 10% of root system killed, 1 = 11 to 25%, 2 = 26 to 50%, 3 = 51 to 75% and 4 = 76 to 100%. Seedlings killed during the study period were given a rating of 5. Isolations were made from a total of 5 seedlings from each host—fungus combination, including the prior isolations from killed seedlings.

Results and Discussion

Mortality. Table 1 lists the percentage of seedlings killed for each *Phytophthora* species pooled over all tested hosts. The percentage of seedlings from which the inoculated species was recovered also is shown (percent reisolation). Isolates of *P. cryptogea, P. cactorum,* and *P. pseudotsugae* caused the highest overall mortality; isolates of *P. megasperma* the least. *P. cryptogea* was the most frequently reisolated. Only one uninoculated control seedling died (California red fir); *P. pseudotsugae* was isolated from this seedling.

Table 1—*Mortality and reisolation of each of 5 species of* Phytophthora *on 11 conifer hosts*

	% killed	% reisolated*
Control†	0.8	1.5
P. megasperma Group 2	3.3	18.3
P. dreschleri	5.0	16.7
P. pseudotsugae	11.3	19.5
P. cryptogea	12.5	65.0
P. cactorum	14.2	34.4

*Percent of seedlings from which inoculated *Phytophthora* was reisolated.
†Non-inoculated sterile CMS mixed with soil for control seedlings.

Table 2 lists the percentage of killed seedlings for each host species pooled over all five *Phytophthora* species and the percentage of seedlings from which

Table 2—*Mortality and reisolation of* Phytopthora *spp. for each of 11 inoculated conifer species*

	% killed	% reisolated*
Ponderosa pine	0.0	4.0
Lodgepole pine	0.0	8.0
Western larch	0.0	55.0
Western white pine	2.0	29.2
West-side Douglas-fir	6.0	12.5
Incense cedar	6.0	20.0
Sitka spruce	6.0	20.0
Engelmann spruce	12.5	50.0
East-side Douglas-fir	14.0	46.2
Grand fir	17.5	35.0
California red fir	22.0	56.0
Mountain hemlock	27.5	57.1

*Percent of seedlings from which inoculated *Phytophthora* was reisolated.

inoculated *Phytophthora* was recovered. Mountain hemlock and California red fir suffered the highest mortality. No mortality occurred in lodgepole and ponderosa pine and western larch. Other host species showed intermediate mortality. Over twice as many Douglas-fir seedlings from the east-side seed source were killed compared to those of west-side origin. Generally, the highest reisolation rates were obtained from seedlings species showing the highest mortality.

Root Rot. Table 3 lists the average root rot rating for each host—fungus combination. The amount of root rot was greatest in California red fir and least in lodgepole and ponderosa pine. Mountain hemlock and Douglas-fir showed relatively severe root rot, with average root rot ratings greater than 1 (over 25% of root system killed). Western larch, Engelmann and Sitka spruce, incense cedar, grand fir, and the pines all showed relatively low amounts of root rot, with average root rot ratings of less than 1. East-side and west-side Douglas-fir showed similar amounts of root rot overall even though percent mortality was different (table 2). A more extensive study is needed to determine if differences in susceptibility between Douglas-fir seed sources are significant.

Phytophthora cryptogea and *P. cactorum* were the most aggressive of the 5 *Phytophthora* species tested. They caused the most mortality and the most severe root rot. *Phytophthora megasperma* Group 2 and *P. drechsleri* were the least pathogenic. *P. pseudotsugae* was intermediate. Similar results were obtained by others *(4, 7)*.

Conclusions

Based on results from this and previous tests *(4, 7)* and field observations, tested hosts and their relative susceptibility to *Phytophthora* species found in nurseries in the Pacific Northwest can be listed as follows:

Highly tolerant
- western redcedar
- lodgepole pine
- ponderosa pine
- western larch

Tolerant
- incense cedar
- Sitka spruce
- Engelmann spruce
- western white pine
- sugar pine

Table 3—*Average root rot ratings for 11 conifer species from the Pacific Northwest inoculated with species of* Phytophthora

Seedling species	Control	*P. megasperma*	*P. drechsleri*	*P. pseudotsugae*	*P. cactorum*	*P. cryptogea*	Ave.
Lodgepole pine	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0
Ponderosa pine	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0
Western larch	0.0 a	0.0 a	0.0 a	—	0.2 a	0.4 a	0.12
Western white pine	0.1 a	0.0 a	0.1 a	0.3 a	0.8 a	0.3 a	0.27
Sitka spruce	0.0 a	0.0 a	0.0 a	0.0 a	1.5 a	0.9 ab	0.40
Engelmann spruce	0.0 a	0.1 a	0.1 a	0.0 a	1.5 ab	2.1 b	0.63
Incense cedar	0.8 ab	1.0 ab	0.6 ab	0.0 a	0.2 ab	1.9 b	0.75
Grand fir	0.5 a	1.2 a	0.8 a	—	0.0 a	2.1 a	0.92
West-side Douglas-fir	0.0 a	0.6 ab	1.4 abc	2.6 c	2.2 c	2.0 bc	1.47
Mountain hemlock	0.0 a	0.5 ab	2.3 c	—	1.9 bc	4.0 d	1.74
East-side Douglas-fir	0.3 a	0.9 a	0.6	4.3 b	3.1 b	1.8 a	1.83
California red fir	1.8 ab	1.9 ab	0.5 a	3.5 b	3.0 b	3.6 b	2.38
Mean root rot rating	0.29	0.52	0.58	1.19	1.46	1.59	

Root rot ratings: 0 = 0 to 10%, 1 = 11 to 25%, 2 = 26 to 50%, 3 = 51 to 75%, and 4 = 76 to 100% root rot. Ratings in each horizontal row followed by the same letter do not differ significantly according to Duncan's new multiple range test ($P < 0.05$).

Susceptible
white fir
grand fir
Pacific silver fir
Douglas-fir

Highly susceptible
mountain hemlock
western hemlock
noble fir
California red fir

Recommendations

Knowledge of relative susceptibility of hosts and pathogenicity of various *Phytophthora* species should be useful to northwest nursery managers when they plan sowing and transplanting locations. Highly susceptible species should never be placed in disease-conducive areas. Tolerant or susceptible species, if placed in disease-conducive areas, should be given cultural or chemical treatments to reduce the likelihood or severity of disease. Highly tolerant species can be put in disease-conducive areas with relatively little risk.

Some caution should be exercised, though, when predicting field outcome from greenhouse results. Changes in the pathogen population characteristics, the existence of different, more aggressive isolates in nursery fields than those used in greenhouse tests, or ideal field environments may result in severe disease in hosts previously thought tolerant. An integrated control program, incorporating both cultural and chemical practices, is recommended *(1)*. Such a program would include

1. Proper soil management, ensuring adequate drainage through and over the soil.
2. Irrigation practices that avoid constantly saturated soils.
3. Removal of chronic wet areas from production.
4. Use of tolerant tree species in diseased or disease-conducive areas.
5. Good sanitation practices to insure that diseased seedlings or soil do not contaminate disease-free areas.
6. Pre-sowing fumigation, if economically, socially, and environmentally feasible.
7. Fungicide applications for high-risk seedlings (very susceptible seedlings and seedlings planted in diseased areas or disease-conducive areas).

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"Fall Mosaic" of Loblolly Pine in a Forest Tree Nursery

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*A mosaic pattern of yellow and green seedlings has been observed in loblolly pine (*Pinus taeda *L.) seedbeds in the fall at several forest nurseries in the southern United States. Seedlings in green areas appear to be associated with mycorrhizal symbionts. Sampling at one nursery in Alabama confirmed a strong relationship between* Pisolithus tinctorius *(Pers.) Coker & Couch and green seedlings. It is hypothesized that stressing seedlings by undercutting can result in differential seedling response according to the degree of mycorrhizal infection.* Tree Planters' Notes 40(1): 19-22; 1989.

A mosaic pattern of yellow and green seedlings has been observed in the fall in forest nurseries in the southern United States. The term *fall mosaic* has been coined to describe this phenomenon. In October 1983, fall mosaic was observed in one area of the Robert Mitchell Nursery near Camden, AL. The green and yellow areas were delineated, and soil and seedlings were sampled in an effort to document the problem.

The authors thank Dr. Donald H. Marx, director, USDA Forest Service, Forestry Science Laboratory, Institute for Mycorrhizal Research and Development, Athens, GA, for assessing roots for mycorrhizae.

Materials and Methods

Study area. The study area consisted of four adjacent beds in compartment 9 of the Robert Mitchell Nursery. The sandy loam soil was not fumigated and was sown with loblolly pine seed (Livingston Parish) on April 27, 1983. Prior to seedbed preparation, 50 kg/ha of nitrogen was applied to the soil with an EZEE Flow spreader. Weeds were controlled with herbicides, and fusiform rust (*Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme* Burdsall and Snow) was controlled with a systemic fungicide. Final density on the beds was approximately 280 seedlings/m^2.

On July 7, 34 kg/ha of nitrogen was applied to the seedlings with a Gandy spreader. On August 9, three beds (adjacent to an irrigation sprinkler line) were undercut (fig. 1). The fourth bed (next to a nursery road) was not undercut because seedling growth was not as advanced as in beds closer to the irrigation line. Approximately 1.25 cm of irrigation water was applied on the same day following undercutting and 1.4 cm of rain fell during the next 2 days. Several days after undercutting, the lateral roots were pruned.

According to soil tensiometer readings, soil moisture was lowest 26 days after the August undercutting (a reading of 54 kPa on September 4 was the highest recorded from July 20 to November 14). On September 21, all four beds were undercut and were irrigated with approximately 1.25 cm of water. Soil and seedlings in the study area were sampled in October.

Sampling procedures. In each of the four beds, two plots (30 m long) were established. The plots were mapped according to seedling color (fig. 1). Fruiting bodies of *Pisolithus tinctorius* (Pt) were counted and their positions noted on the map. In plots that were undercut in August, samples of seedlings and of soil were collected from areas exhibiting green seedlings and from areas exhibiting yellow seedlings. No yellowing was present in the plots not undercut in August; therefore, only green seedlings and soil samples from these areas were collected. One-hundred and twenty seedlings were sampled from each plot: 60 were used for morphological measurements and 60 for assessing mycorrhizal development.

Seedling and soil analyses. Morphological measurements included root-collar diameter, shoot height, shoot weight, and root weight. Seedlings were evaluated for mycorrhizal development at the USDA Forest

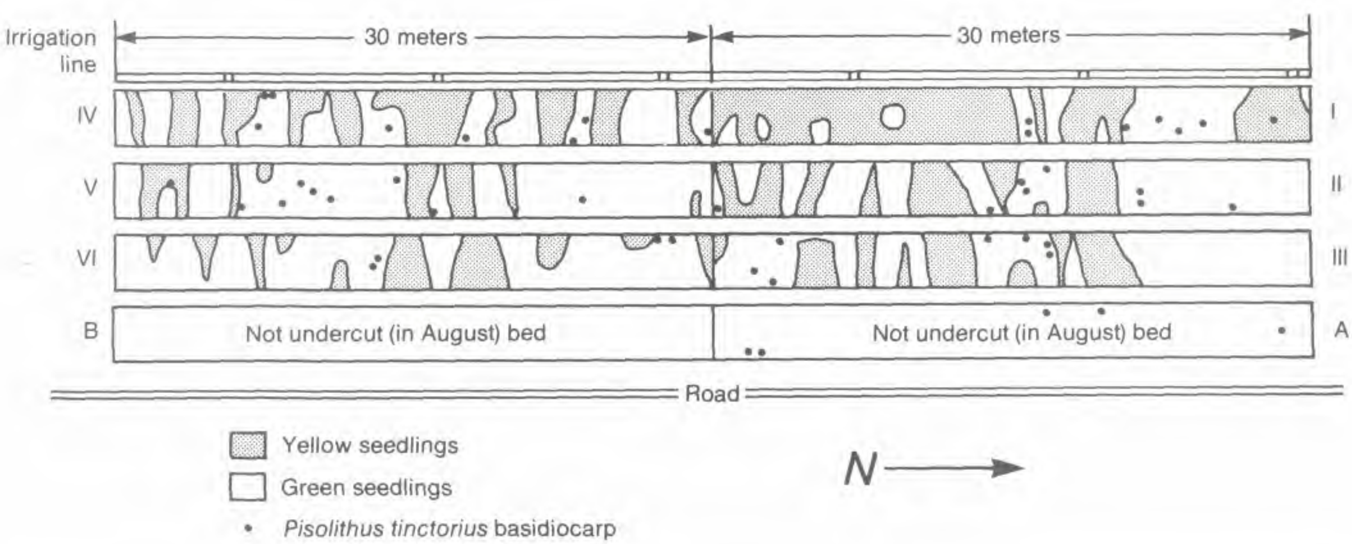

Figure 1—*Map of the fall mosaic study area at the Robert Mitchell Nursery, October 1983.*

Service, Institute of Mycorrhizal Research and Development, Forestry Sciences Laboratory, Athens, GA. In assessing the seedlings, the number of seedlings with Pt and the average percentage of short roots with mycorrhizae were recorded. In addition, the percentage of total mycorrhizae due to Pt was also estimated. Soil samples were sent to A&L Laboratories (Memphis, TN) for analysis of macronutrients and micronutrients, soil acidity, and organic matter.

Statistical analysis. Student's t-test was used to compare soil and seedling characteristics between paired samples from green and yellow areas within plots on beds undercut in August. Statistics were not used to compare seedlings undercut in August with those not undercut in August.

Results

The two plots not undercut in August did not exhibit the fall mosaic pattern and contained a total of only five Pt fruiting bodies. Plots located in undercut beds exhibited clearly defined areas of fall mosaic. Areas exhibiting fall mosaic were determined from the scale map of the study plots. Yellow seedlings occupied an area equal to 37% of the plots that were undercut; the remaining area contained green seedlings. Forty-five fruiting bodies of Pt were counted within the six undercut plots. Of these, 43 were in the green areas and two were in yellow areas.

Seedlings from green areas were heavier and larger in root-collar diameter than those from yellow areas (table 1). Seedlings from the green areas had higher percentages of mycorrhizal roots and these roots contained a higher proportion of Pt (table 1). Soil collected from green areas in undercut plots generally contained fewer extractable cations than did soil from yellow areas (table 2).

Table 1—*Morphology of seedlings from the study area at the Robert Mitchell Nursery in 1983*

Characteristic	Plots undercut in August		Plots not undercut in August
	Yellow area	Green area	
Diameter (mm)	3.3**	3.6	3.3
Height (cm)	23.1	23.8	22.7
Shoot dry weight (g)	1.56**	1.91	1.70
Root dry weight (g)	.49	.55	.50
% of seedlings with Pt	9**	67	35
% of Pt on seedlings with Pt	1**	28	8
% Total mycorrhizae	31**	51	50
Pt index	1**	42	13

**Significantly different from "green area" at 0.01 level of probability.
Pt = *Pisolithus tinctorius* mycorrhizae.

Table 2—*Soil characteristics for areas having green and yellow seedlings in beds undercut in August in study area at the Robert Mitchell Nursery in 1983*

Characteristic	Yellow area	Green area
pH	5.9	5.8
Cation exchange capacity (mEq)	3.5**	3.1
Organic matter (%)	1.4	1.4
Phosphorus (weak Bray) (ppm)	97	81
Potassium (ppm)	108	107
Magnesium (ppm)	55**	43
Calcium (ppm)	404	352
Sodium (ppm)	26	25
Sulfur (SO^4) (ppm)	8*	5
Zinc (ppm)	38	28
Manganese (ppm)	50	46
Iron (ppm)	21	19
Copper (ppm)	1	1
Boron (ppm)	0.7	0.7

*Significantly different from "green area" at 0.05 level of probability.
**Significantly different from "green area" at 0.01 level of probability.

Discussion

We can make no conclusions as to the underlying cause of the fall mosaic phenomenon. Although past experiences have allowed us to observe differences in seedling growth due to pathogens and from irregular irrigation or fertilization patterns, none of these appear to adequately explain the fall mosaic pattern. Although not conclusive, data and observations from this study suggest that fall mosaic may be correlated with differences in mycorrhizal colonization of seedling roots.

It may be that a certain combination of environmental and cultural practices are required before symptoms of fall mosaic are expressed. These circumstances may involve a certain soil condition, a certain distribution of mycorrhizae, use of a certain systemic fungicide, a certain level of soil moisture, undercutting at a certain time, and irrigating at a certain time. If a particular combination of factors is required, then it may be very difficult to reproduce the phenomenon with a planned experiment.

The fact that fall mosaic was observed only in plots that had been undercut in August suggests that this practice may play a role in this phenomenon. However, not all beds undercut in August at this nursery exhibited the fall mosaic pattern. It is believed that internal drainage of the study area was greater than the remainder of the nursery, and thus moisture stress resulting from undercutting may have been greater at this location. One hypothesis is that the fall mosaic pattern observed in the study area resulted from a combination of at least three factors.

1. The undercutting subjected the seedlings to moisture stress.
2. The study area was well

drained and moisture could have been a limiting factor.
3. Mycorrhizae on seedlings in yellow areas were either not as well developed in August or were separated from the seedlings during the undercutting and lateral root pruning.

It has been demonstrated that undercutting can stress seedlings. In fact, undercutting is often practiced in nurseries to decrease height growth. The presence of Pt has been shown to decrease moisture stress in pine seedlings *(1).* The observed decrease in the amount of soil nutrients from areas in plots with green seedlings infers that absorption of water and nutrients by these seedlings was greater than by the yellow seedlings. Undercutting to a soil depth of 18 cm not only reduced the amount of roots but also initially confined the remaining root mass to the upper 18 cm of soil.

Limiting seedling roots to the upper layer of soil can result in a reduction of available water, which under certain conditions could result in seedling stress. If seedlings with abundant mycorrhizae are more efficient in absorbing water and nutrients, then they may have been less affected by stress imposed by undercutting.

Fall mosaic has been observed in portions of other nurseries where Pt was not the mycorrhizal species involved. This suggests that other mycorrhizal symbionts may play a similar role in the fall mosaic phenomenon. Although we have attempted to document that fall mosaic exists in forest nurseries, we do not know all the factors that contribute to its cause. In addition, we do not know the potential economic impact of planting chlorotic seedlings from the fall mosaic area. We hope that making others aware of this phenomenon will eventually result in the collection of data required to answer these questions.

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Shading Reduces Growth of Longleaf and Loblolly Pine Seedlings in Containers

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Development of longleaf (Pinus palustris *Mill.) and loblolly* (P. taeda *L.) pine seedlings growing under three light conditions—full sunlight, 30% shade, and 50% shade—was evaluated. Although there was little difference between development of seedlings in 30% and 50% shade, those grown in full sunlight were significantly larger than shaded seedlings in diameter and in top and root dry weight after 20 weeks. Longleaf pine responded better than loblolly pine in both root and shoot growth under full sunlight. The greatest response to higher levels of light was in root growth. These results have major applications to the culture of longleaf pine seedlings in containers.* Tree Planters' Notes 40(1) :23-26; 1989.

One of the problems in producing southern pine seedlings in greenhouse facilities is controlling excessive temperatures, particularly in the late spring and summer. Shadecloth can be used to help control high temperatures by reducing incoming solar radiation. Greenhouse temperatures can be lowered 5°C or more. Recommended levels of shading range from 30 to 55% *(2)* . Although it is generally known that shading can result in etiolated seedling development, its effect on the growth of greenhouse-grown southern pine seedlings has been generally ignored.

The recent interest in producing longleaf pine (*Pinus palustris* Mill.) seedlings in containers has reaffirmed the sensitivity of this species to competition. Current recommendations for producing longleaf pine in containers include the use of larger containers, which results in a smaller number of seedlings per unit area. *(1)* . To develop quality stock, no more than 550 longleaf pine seedlings should be grown per square meter (50 per square foot). Other southern species can be grown at up to 1,000 seedlings per square meter (100 per square foot). The greater sensitivity of longleaf pine is undoubtedly related to its massive needle development, because epicotyl elongation does not occur for 2 or 3 years.

Preliminary evaluations have indicated that shading longleaf pine seedlings may reduce seedling quality. The purpose of this study was to evaluate the development of longleaf pine seedlings grown in containers at different levels of shade and to compare their performance with that of loblolly pine seedlings (*P. taeda* L.).

Methods

Longleaf and loblolly pine seedlings were grown in Ray Leach Stubby® containers filled with a 1:1 peat-vermiculite medium. Untreated longleaf pine seeds and loblolly pine seeds that had been stratified for 30 days were sown and germinated under uniform greenhouse conditions (30% shade). When germinants dropped their seed coats, seedlings of each species were divided into three groups and grown under the following conditions:

1. no shade (grown outdoors).
2. 30% shade (greenhouse with shadecloth).
3. 50% shade (trusshouse with shadecloth).

A standard cultural regimen was used to grow seedlings in each treatment *(1)*. Efforts were made to maintain uniform growing conditions among facilities. However, there were some differences in growing temperatures (± 5°C). Although such differences can influence development, the effects of shade were expected to be of much greater magnitude.

Seedlings from four replications were sampled at monthly intervals beginning at 8 weeks of age. Height was measured in centimeters, diameter in millimeters, and dry weights in milligrams. Measurements continued through age 20 weeks.

Differences in seedling responses were tested for statistical significance at the 0.05 level by analyses of variance. Separate analyses were run for each species, and differences in treatment means were evaluated by orthogonal polynomial comparisons.

Results

Differences in development of both longleaf pine and loblolly pine seedlings due to age, shading treatments, and their interaction were statistically significant. There were major differences in all variables measured due to shading of seedlings. However, there were only minor differences due to the levels of shade (30 or 50%). Consequently, data for these two levels were averaged to simplify presentation.

A 55% increase in stem diameter of longleaf pine seedlings was seen when seedlings were grown in full sunlight (table 1). Increases in top and root weights with exposure to full sunlight were 68 and 210%, respectively. The percentages of increase in diameter and top weight were relatively constant with seedling age. However, the percentage of increase in root weight was high at 8 weeks and decreased steadily as the seedlings grew to 20 weeks of age. There were no differences in longleaf pine development due to different amounts of shade.

Loblolly pine seedlings followed the same trends as those for longleaf pine, but differences between sun and shade exposures were not as great. Increases in seedling height resulting from full sunlight ranged from 7% at 8 weeks to 33% at 20 weeks. Increases in seedling diameter and top weight were fairly constant with age, averaging 18 and 40%, respectively, with exposure to higher light levels (table 1). The trends for root weight agreed with those for longleaf pine, that is, the percentage of difference due to shade decreased with age (118 to 79%).

Seedling development in response to shading varied greatly by species (fig. 1). Both stem diameter and weight were greater for longleaf pine than for loblolly pine when seedlings were grown in shade, but the differences were not as great when seedlings were grown in full sunlight. This suggests the greater intolerance of longleaf pine to shade. Root development was about the same for both species when seedlings were grown in shade, but the root systems of longleaf pine were 65% larger than those of

Table 1—*Effects of shade and full sunlight on development of longleaf and loblolly pine seedlings at 8 to 20 weeks*

Developmental characteristics	8 wk	12 wk	16 wk	20 wk
Stem diameter (mm)				
Longleaf pine				
Shade	2.2	2.8	3.2	4.1
Sun	3.2	4.3	5.2	6.3
% Increase	49	56	62	54
Loblolly pine				
Shade	1.6	2.2	2.4	2.7
Sun	2.0	2.5	2.8	3.2
% Increase	25	14	14	19
Top weight (mg)				
Longleaf pine				
Shade	382	807	1,285	1,870
Sun	613	1,530	2,148	2,936
% Increase	60	90	67	57
Loblolly pine				
Shade	323	716	1,158	1,499
Sun	451	1,040	1,589	2,043
% Increase	40	45	37	36
Root weight (mg)				
Longleaf pine				
Shade	62	161	218	334
Sun	224	493	706	836
% Increase	261	206	224	150
Loblolly pine				
Shade	76	161	241	282
Sun	166	337	469	505
% Increase	118	109	94	79

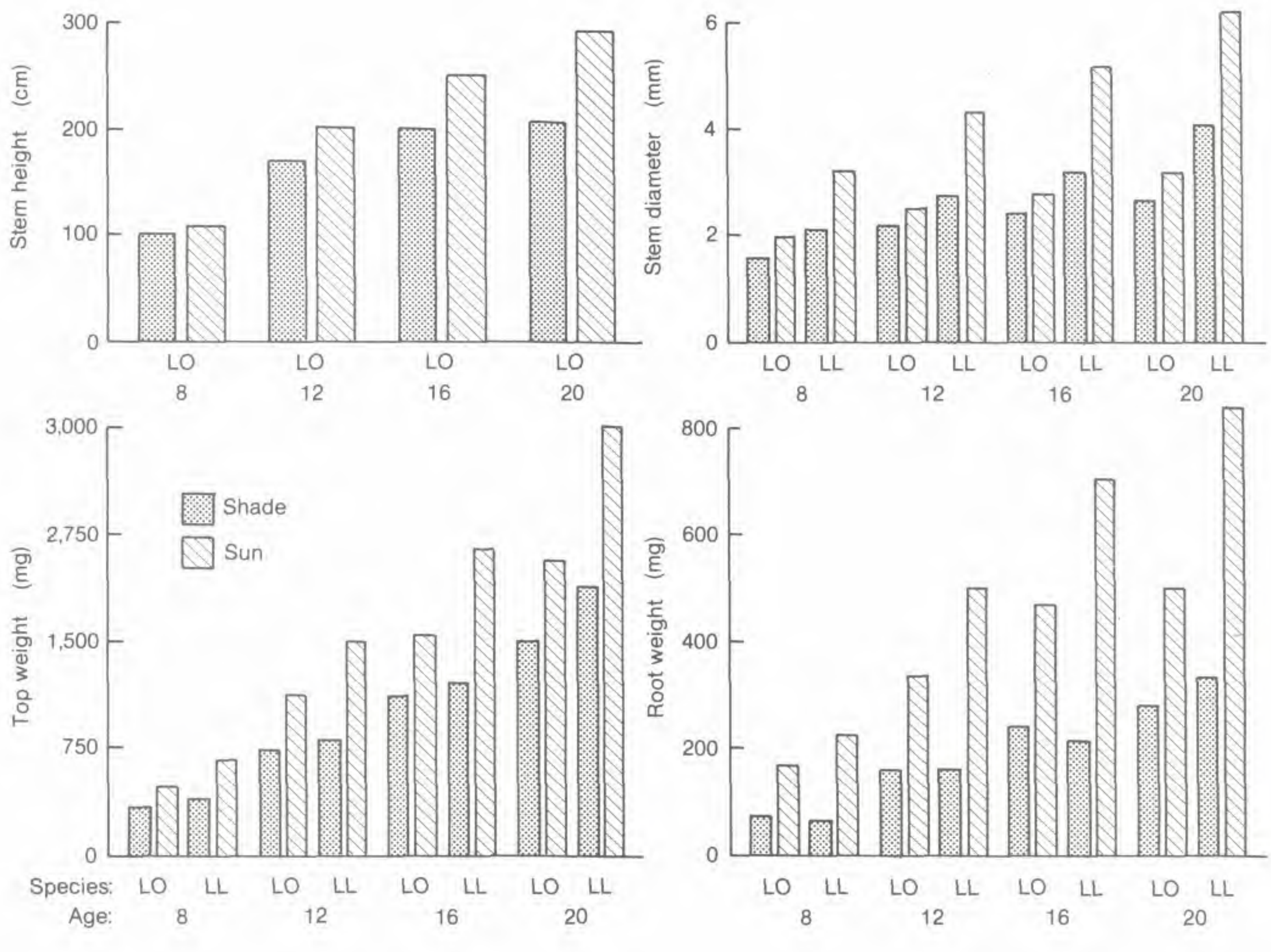

Figure 1—*Response of longleaf* **(LL)** *and loblolly* **(LO)** *pine seedlings to different levels of light. Stem heights were measured for loblolly pines only.*

loblolly pine at 20 weeks of age when grown in full sunlight.

Discussion

These results have immediate application for the production of longleaf pine in containers. Previous research with bareroot longleaf pine seedlings has demonstrated the need to plant seedlings when root-collar diameters are near 1.25 cm (½ inch) for successful initiation of height growth. This same response occurs in container-grown longleaf pine. Therefore, cultural practices that speed stem development must be utilized. Growing longleaf pine seedlings in full sunlight is highly desirable. Based on the results of this study, seeds should be sown in containers in late spring or early summer (May or early June) and the seedlings grown in the open throughout the summer. High-quality (larger diameter and greater root system) seedlings are then available for planting in the late summer or fall. Not only are better quality seedlings produced, they are produced more economically because a greenhouse structure is not required.

Although this technology is most appropriate for longleaf pine, it also applies to loblolly and other southern pines as well. It is important to note that root development was the seedling characteristic that responded most to increased light; this may result in improved field performance.

There was little difference in seedling development between the 30% and 50% levels of shade. Some of this lack of difference may have been due to the variations in environmental conditions among the growing facilities. However, these variations were not great enough to mask the differences between shade and full sunlight.

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Cleaning, Pelletizing, and Sowing Eucalyptus Seed

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Eucalyptus seed are irregular in size and shape. The presence of chaff makes seed storage expensive and precision sowing difficult. Methods of cleaning eucalyptus seeds are described, as is pelletizing, a method for making seeds uniform in size and shape, and a simple manual seeder for sowing pelletized seeds. Tree Planters' Notes 40(1):27-30; 1989.

Eucalyptus seedlings are generally grown in containers. Most operations in a container nursery are mechanized, for example, mixing rooting medium, filling containers with rooting medium, and covering seed with gravel. Eucalyptus seeds are irregular in size and about 90% of the weight of uncleaned seeds is chaff. Thus eucalyptus seeds cannot be sown mechanically unless they are cleaned and treated.

Traditionally, unclean seed is sown "by the pinch." With this method each container receives from zero to many seeds. When no seedling develops because no seed is sown or the seed fails to germinate, the expense of cleaning the container, mixing the medium and filling the container, sowing, and covering is lost. If more than one seedling develops in a container, the extra's must be removed, which is costly because of the time and seed wasted.

Once cleaned, eucalyptus seed is still difficult to sow because it is small and irregular in shape. The average number of seeds per ounce for the major species planted in the United States ranges from 25,000 for *Eucalyptus globulus* to 200,000 for *E. camaldulensis* (3). Irregularly shaped seeds must be made uniform in size and shape by pelletizing if sowing is to be mechanized. Once individual seeds can be sown precisely, general equations for predicting number of blank containers, number of excess seedlings to be thinned, and number of plantable seedlings after thinning can be used (4).

The problem of uncleaned, irregularly shaped seed can be partially or wholly avoided by purchasing cleaned or cleaned and pelletized seed. If purchased by weight, cleaned seed is more economical than uncleaned seed because chaff is not shipped or stored. Seed, whether purchased or collected, should be cleaned before storage or other processing. This paper describes methods for cleaning, pelletizing, and sowing eucalyptus seed.

Cleaning

Although eucalyptus seed and chaff are similar in size and weight, enough differences exist to allow a large percentage of the chaff to be removed with sieves and seed blowers (fig. 1). We recommend using U.S. Standard sieves, numbers 18 and 30. Place sieve no. 18 on sieve no. 30 and then place them over a collection pan. Pour seed and chaff onto the top sieve. The larger pieces of chaff will remain on the top sieve while the seed and smaller pieces of chaff fall through to the lower sieve. With some agitation, small seeds and

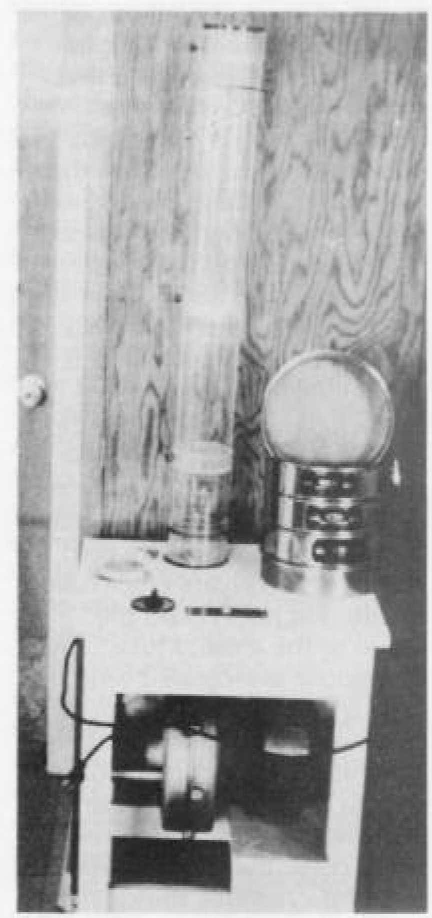

Figure 1—*Sieves* **(right)** *and blower-cleaner* **(left)** *used to clean eucalyptus seeds.*

pieces of chaff will fall through to the collection pan. Discard the mixture of small seed and chaff in the collection pan because it is time consuming to separate and the seedlings that develop from these seed generally are not as vigorous as seedlings that develop from larger seeds (personal observation for eucalyptus species) (1). What remains on the lower sieve is about 85% pure seed.

Use a blower-type cleaner to separate seed from chaff. The air moving through the seed-cleaner tube transports the lighter chaff higher than the heavier seed. Therefore, seed and chaff collect in different pockets on the inside of the cleaner tube. The air velocity is increased until the seed is blown high enough to begin collecting in the pockets holding the chaff. The color change that occurs in those pockets when the dark brown seeds cover the reddish-brown chaff indicates that the cleaning process is complete. After separation, seed purity should approach 100%. Cleaned seed can be sown more precisely and accurately, but not necessarily more efficiently, than uncleaned seed because the irregular shape and size of the seeds prevent mechanized operations.

Pelletizing

Pelletizing results in uniform seed pellets, each containing one seed (fig. 2) (2). Generally pellets of about 1.5 mm diameter are convenient to prepare, store, and sow.

The materials required for pelletizing seed are an adhesive, silica sand, and a reciprocating-rotating pan. The adhesive is a 5.8% solution of Gelvatol, a cold-water-soluble polyvinyl alcohol resin (58 g dissolved in 942 ml of water). The sand should be Berkeley fine dry silica sand. Sieves are used to obtain sand particles of the right size for "starter" and "outer coating" sand. The starter sand is obtained from the silica particles that pass through a U.S. Standard no. 200 sieve. The outer coating sand is obtained from the particles that pass through a U.S. Standard no. 140 sieve.

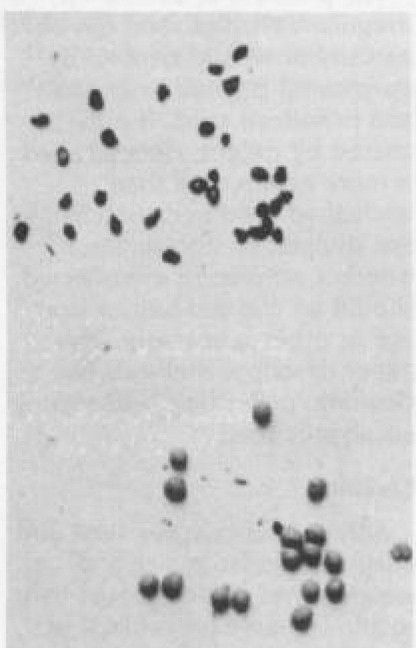

Figure 2—Unpelletized (upper) and pelletized (lower) eucalyptus seed.

To pelletize, place seed in the pan, which is now in operation (fig. 3) and spray them with adhesive at a constant low pressure, generally 2 to 4 pounds per square inch. Shake starter sand onto the seeds. Pellets will begin to form. Recover any seeds that stick to the side of the pan, wash away the sand, dry the seeds, and return them for recoating. When pellets are about the correct size, shake on the outer sand coating. Screen the wet pellets to size with a shot-hole sieve. Wet pellets can be poured but should not be touched. Return undersized pellets to the pan for additional coating. Dry pellets of the correct dimensions in an oven until they are hard, generally for 1 or 2 hours at 40 °C.

Pelletizing seed makes their size uniform. Accordingly, all the seed of a species or of different species are effectively the same size and can be sowed with the same equipment.

Sowing

Pelletized seeds can be sown by hand but are sown more efficiently with a shutterbox seeder (fig. 4) (5). The seeder will place one seed into each container each time it is operated. It can sow seeds singly or into a number of containers at once. The

Figure 3—*Eucalyptus seed being pelletized in a reciprocating-rotating pan.*

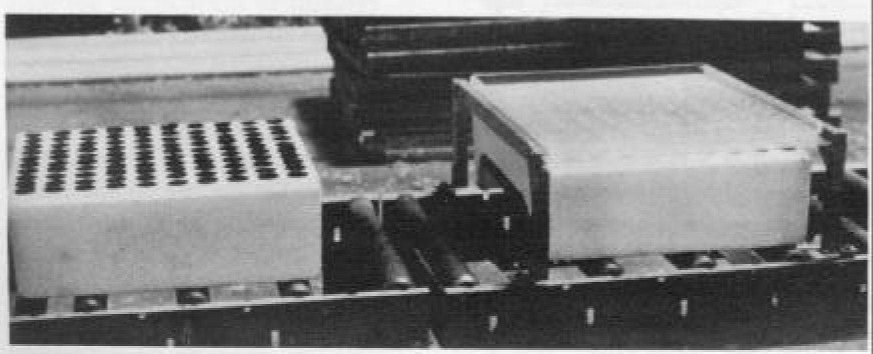

Figure 4—*Manual seeder for sowing pelletized eucalyptus seed into containers.*

seeder consists of a frame that holds 3 Plexiglas® plates above the containers. The top plate is about ½ inch thick, the middle plate is about the same thickness as the diameter of the pelletized seed, and the bottom plate is about ¼ inch thick. The top and bottom plates are held in a fixed position so that their holes do not line up; the middle plate slides between them. The plates have holes in them that are in the same arrangement as the containers to be sown. The holes in the top and bottom plates are about 2.5 times the diameter of the pelletized seeds, while the holes in the middle plate are just slightly larger than the pelletized seeds. The holes in the top plate are countersunk to concentrate the seeds around the holes. The top edges of the holes in the middle plate are beveled to reduce the chance of damaging the seed as the plate is moved back and forth.

For the sowing operation, place seeds in the holes of the top plate (fig. 5A). The middle plate slides so that its holes line up with the holes in the top plate. When the holes in the two plates are aligned, seeds fall into the holes in the middle plate (fig. 5B). As the middle plate slides in the opposite direction and its holes are aligned with the holes in the bottom plate, seeds fall through to the containers (fig. 5C). A sowing cycle of placing containers under the

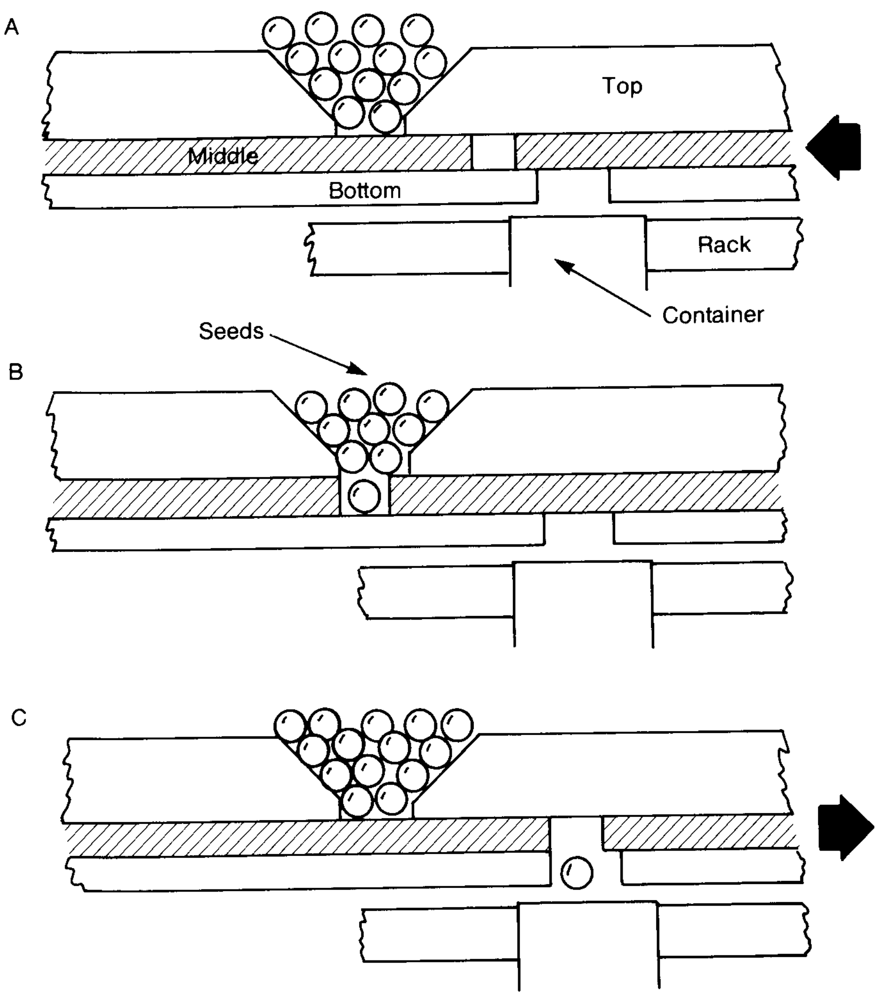

Figure 5—*Schematic of the operation of the manual seeder: holes in the top plate are filled with seeds* (**A**); *middle plate is moved so that the holes are aligned with holes in the top plate, and seeds drop into the holes* (**B**); *middle plate is moved so that the holes in it line up with the holes in the bottom plate, and the seeds fall into the containers* (**C**).

seeder, moving the middle plate back and forth (sowing the seeds), and removing the containers requires about 15 seconds. If more than one seed is required in each container, the middle plate is moved back and forth as many times as needed to sow the correct number of seed.

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The Long-Term Effect of a Single Application of Horse Manure on Soil pH

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The application of 6 inches of composted lime-treated horse manure resulted in an undesirable increase in soil pH. The soil pH has remained high (7.0 or above) for at least 12 years. Tree Planters' Notes 40(1):31-33; 1989.

The presence of organic matter in forest tree nursery soils has long been recognized as essential for high productivity. The amount of organic matter present in soils directly affects moisture-holding capacity, aeration, structure, drainage, buffering capacity, and availability of nutrients. Organic materials commonly incorporated into nursery soils include sawdust, bark, straw, leaves, peat, and green manure from cover crops (5). Many industries burn wood waste to reduce their energy costs thereby reducing the availability of this source of organic matter *(7).* New, inexpensive sources of organic material, suitable for application to nursery soils, should constantly be investigated.

The Saratoga Tree Nursery, Saratoga Springs, NY, is located within a few miles of a major horse racing facility offering a readily available, inexpensive source of organic material in the form of horse manure. A study was undertaken to evaluate the possibility of utilizing this horse manure, including barn sweepings, as a major source of organic matter. The long-term effect of the addition of composted horse manure on soil pH is reported in this paper.

Methods

The Saratoga Tree Nursery produces four to five million conifer seedlings annually (10). The nursery is located on deep loamy sand soil that requires periodic addition of organic matter to maintain productivity. A single 6-inch application of composted horse manure was applied to various blocks in one section of the nursery between 1973 and 1975. This resulted in some blocks in the study area being untreated in 1974. Soil samples have been collected periodically since 1974 and analyzed for pH, organic matter, total nitrogen, available phosphorus and exchangeable potassium, calcium, and magnesium according to standard methods (4) as part of an ongoing soil analysis program.

Results

The composted horse manure, including barn sweepings, was highly alkaline (pH 8.4) because hydrated lime, sprinkled on the floor of the stables to control odor, was mixed into the material (table 1). The application of lime to horse stalls is common practice.

Table 1—*Analysis of composted lime-treated horse manure applied to the Saratoga Tree Nursery*

pH	8.4
% N	0.78
% P	0.20
% K	0.67
% Ca	3.67
% Mg	1.74
% Mn	0.025
% Na	0.11

Soil pH of areas that had not received composted horse manure was 5.7 in 1974 (table 2); that of areas that had received composted horse manure during 1973 was 6.7 in 1974. Soil pH has varied between 7.0 and 7.3 since composted lime-treated horse manure was applied, with no significant downward trend indicated.

The application of manure increased soil organic matter from 5.0% in untreated areas to over 8.0% in areas where manure had been applied (table 2). The soil organic matter content has decreased since 1977 and is currently being maintained at approximately 3.5%. The concentration of exchangeable calcium increased from 450 ppm to 2,950 ppm as a result of applying the manure and the concentration of exchangeable magnesium increased from 50 ppm to 750 ppm (table 2). The concentration of exchangeable calcium and magnesium appears to have stabilized at approximately 1,200 ppm and 200 ppm, respectively. The recommended

Table 2—*Chemical properties of soil at the Saratoga Tree Nursery before and after application of composted lime-treated horse manure*

Year	pH	% OM	% N	Composition (ppm)			
				P	K	Ca	Mg
Before compost							
1974	5.7	5.0	0.08	136	69	454	50
After compost							
1974	6.7	8.0	0.12	138	119	1,321	156
1977	7.2	8.1	0.19	196	246	2,947	756
1982	7.3	4.5	0.14	182	131	1,326	227
1983	7.0	3.4	0.11	170	138	1,250	200
1986	7.0	3.5	0.11	152	81	1,136	194

OM = organic matter.

concentration of exchangeable calcium and magnesium for conifer seedling production is 500 ppm and 150 ppm, respectively (13).

Discussion

The single application of 6 inches of composted limetreated horse manure was equivalent to applying 3.5 tons per acre of lime. A guideline for the application of lime to sandy nursery soils is that 1 ton per acre of lime should increase soil pH by 0.5 units (13).

The initial increase in soil pH was not as large as the guideline suggested. There are several possible reasons for this. First, the soil organic matter content before the application of composted horse manure was higher than normally found in sandy soil. Soil organic matter and clay serve as a buffer, thus preventing large changes in soil pH. Second, some of the calcium and magnesium present in the material applied was contained within the organic matter itself. The organic matter had to decompose before the calcium and magnesium could react with the soil. Third, the particle size of the lime used in the horse stalls may have been larger than the particle size of lime normally applied to soil, thus increasing the length of time required for the lime to completely react with the soil (6). The initial change in soil pH, as a result of adding organic matter, was not an indication of the total change in soil pH or the duration of the change.

The soil pH has not decreased with time. Calcium and magnesium are lost from soils in three ways: (a) erosion, (b) crop removal, and (c) leaching (6). The loss of nutrients by erosion in this nursery is minimal. The amount of calcium removed in seedling crops is insignificant in comparison to the amount of exchangeable calcium present in the soil to which the composted horse manure was applied. Harvesting 2 + 0 white pine (*Pinus strobus* L.) seedlings grown in an area treated with horse manure removed 23 pounds per acre of calcium (3).

The nutrients taken up by cover crops are returned to the soil during decomposition and thus are not removed from the site. Another possible reason that soil pH in the treatment area has not decreased is because the irrigation water contains 30 ppm of calcium. Twelve inches of irrigation water per year contributes 80 pounds per acre per year of calcium. This is equivalent to applying 150 pounds per acre of lime per year.

Problems with poor seed germination, early survival, and poor seedling growth have been experienced in areas where the composted lime-treated horse manure was applied. High soil pH is believed to be the main cause of these problems (3, 9). Poor early seedling survival may be attributed to damping-off, which is favored in cool and wet, neutral to basic soils containing large amounts of organic matter (8). The problems with poor seedling growth may be attributed to soil nutrient imbalance. Phosphorus availability to plants is greatest when soil pH is between 6.0 and 7.0. Potassium and ammonium become fixed and therefore unavailable to plants when soil pH is too high. Solubility of micronutrients such as zinc, copper, manganese, and iron decreases as soil pH increases, thus decreasing the availability of these nutrients to plants. Plants may exhibit nutrient deficiencies when soil pH is too high (11).

Reports in the literature indicate that some conifer species are intolerant to soil pH above 6.0. Dry weight of red pine (*Pinus resinosa* Ait.), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings were found to be greatest when soil pH was 5.5 (1, 12). The tallest Norway spruce (*Picea abies* (L.) Karst.) seedlings were produced when soil pH was 4.5 (2).

Conclusions

It can be concluded that an undesirable increase in soil pH occurred after a single 6-inch application of composted lime-treated horse manure. The effect of applying this material on soil pH and chemical properties has persisted for at least 12 years. There are indications that the high soil pH is responsible for poor early survival and growth of conifer seedlings.

Organic materials having a pH above 7.0 and containing large amounts of calcium and magnesium should not be applied to soils in conifer nurseries where moderately acid soil conditions are desirable. It must be stressed that there is a need to test new sources of organic matter and application rates in small areas of the nursery before applying the material to the entire nursery. This testing program should be designed to include several tree species with a duration of at least two rotations of seedlings.

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Germinating Common and Cat Greenbrier

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Seeds of common (Smilax rotundifolia *L.) and cat greenbrier (*S. glauca *Walt) were tested for germinative energy, total germination, and germinative potential. Light appears to be a requirement for common greenbrier.* Tree Planters' Notes 40(1) :34-37; 1989.

Greenbriers are tremendously important for wildlife. They produce fruits nearly every fall, and the fruits hang on the vine until the next spring or summer if they are not consumed before then. In many places, they are the preferred food of ruffed grouse, white-tailed deer, black bear, cottontail rabbits, golden mice, and fish crows. They are also eaten by other species when their preferred food items are scarce (2).

Germination requirements for seed of the many greenbrier species found throughout the United States have not been reported, although common and cat greenbrier stem and rhizome cuttings have been propagated (3). Seed germination research is needed to develop an additional method of establishing greenbrier as a source of food for wildlife. In this study, we report on conditions for germination of seeds of common greenbrier (*Smilax rotundifolia* L.) and cat greenbrier (*S. glauca* Walt).

Materials and Methods

Fruits of common and cat greenbrier were collected from 175 tangles at 34 locations in northern West Virginia and in southwestern Pennsylvania. They were cleaned with a depulping machine designed for cleaning black cherry (1). Seeds used in the study were either freshly depulped or depulped, air dried, and stored at 2 to 5 °C until treated.

A complete random design was used for the study. Two hundred seeds of each species, divided into four replicates of 50 seeds each, were used for each treatment.

Treatments were designed to test the effects of cold stratification, germination promoters, light, and seed longevity on greenbrier seed germination.

Seed stratification. Stored seeds were planted 12 to 15 mm deep in a soilless mixture in 50-seed flats and kept at 4 °C for 0, 90, 150, 180, or 210 days. The soilless mixture comprised equal parts (v:v) sphagnum peat and vermiculite, with 1 pound dolomitic limestone, 3 ounces 20% superphosphate, 2.5 ounces $Ca(N0^3)^2$, 1.5 ounces $MgS0^4$, 1 tablespoon iron chelate, and 1 tablespoon fritted trace elements added per .1 cubic yard of peat-vermiculite mix.

Germination promoters.

(a) Freshly depulped or stored seeds were soaked for 24 or 48 hours in a 1, 2, or 3% thiourea solution and sown 12 to 15 mm deep in the soilless mix in 50-seed flats.

(b) Stored seeds were placed between paper towels, which were then rolled in a thin sheet of plastic; the rolls were placed upright in beakers containing 0, 1, 50, or 100 ppm gibberellic acid.

(c) Seeds were sown 12 to 15 mm deep in the soilless mix in 50-seed flats and watered with a 200-ppm formic acid solution (first watering only).

Light requirements. Stored seeds were sown on the surface of the soilless mix and placed in dark (yellow) or clear plastic bags.

Seed longevity/light.

(a) Seeds stored for 16 months were either (1) sown on top of the soilless mix in 50-seed flats, (2) sown 12 to 15 mm deep in the soilless mix, or (3) given 5 days of light and then sown 12 to 15 mm deep in the soilless mix.

(b) Seeds stored for 5 years were placed between paper towels, which were then rolled in a thin sheet of plastic, and the rolls were placed upright into beakers of water. These seeds were also given continuous light.

For treatments using the soilless mix, the 50-seed flats were randomly assigned to trays. These trays were placed in clear plastic bags, except for one treatment group that was placed in a dark (yellow) plastic bag. Bags were then sealed to retard moisture loss.

Germination test for each treatment was conducted by placing the plastic-covered trays about 0.5 m, and the beakers about 1.5 m, from 40-watt cool white fluorescent bulbs (lighted 10 hours per day) in a laboratory at about 22 °C. Germination was recorded at least once a month. The following germination parameters were calculated for each treatment:

Germinative energy, the percentage of seeds that germinate during the period of most rapid germination with respect to time.

Total germination, the percentage of seeds germinated by the end of the test period.

Potential germination, the percentage of seeds germinated in the study plus all ungerminated seeds that are capable of germinating (those that appear healthy and normal).

Light intensities were measured. Clear plastic bags allowed up to 160 foot-candles of light to reach the surface of the medium. Yellow plastic bags allowed up to 20 foot-candles of light to reach the surface. At a depth of 6.25 mm (¼inch), less, than 1 to 3 foot-candles of light filtered through the medium. At a depth of 12.5 mm (½ inch), less than 1 foot-candle filtered through the medium. Light under the paper towels was 6 foot-candles or more.

At the end of 2 years, healthy-looking ungerminated seeds in all treatments planted below the surface of the soilless mix were sifted out of the medium and seeds from all treatments were mixed together and planted on

Table 1—*Greenbrier seed germination after 2 years under various treatments (in percent); germinative energy was measured in common greenbrier from 2 to 4 months and in cat greenbrier from 10 to 14 months*

	Common greenbrier			Cat greenbrier		
Treatments	Germinative energy	Total germination	Germinative potential	Germinative energy	Total germination	Germinative potential
Paper towel						
Distilled water	91.0	95.5	95.5	75.5	82.0	86.5
1 ppm Gibberellic acid	63.5	74.5	74.5	62.0	69.0	74.5
50 ppm Gibberellic acid	43.5	45.0	45.0	39.0	43.0	44.0
100 ppm Gibberellic acid	33.5	39.5	39.5	25.0	25.0	25.0
Seeds on top of medium						
Clear plastic bag	62.0	97.0	97.0	31.0	40.5	73.0
Dark plastic bag	59.5	71.0	74.5	34.5	40.5	60.5
Seeds inside medium						
Control	4.5	9.0	74.0	1.0*	1.5	39.5
90 Days at 4 °C	12.0	17.5	66.5	1.0*	3.0	44.0
150 Days at 4 °C	0.5	37.5	80.5	9.5	12.5	51.0
180 Days at 4 °C	—	—	—	0.0	3.5	46.0
210 Days at 4 °C	—	—	—	1.0*	3.0	44.0
Formic acid (200 ppm) soaked medium at start	1.0*	8.0	87.5	8.5	12.5	63.0
Thiourea soaked 24 hr†	4.0	12.5	84.0	8.5	10.0	46.0
Thiourea soaked 48 hr†	10.0	19.0	87.0	11.0	15.0	61.0
Thiourea air-dried†	6.0	16.5	89.0	11.5	15.0	63.0
Thiourea freshly depulped†	8.0	14.5	82.0	8.0	10.0	44.5

*Germination after 3 months for common greenbrier, 12 months for cat greenbrier. Germinative energy could not be established in these.

†For thiourea the average percent germination is shown; there was no discernible difference between 1, 2, and 3% solutions.

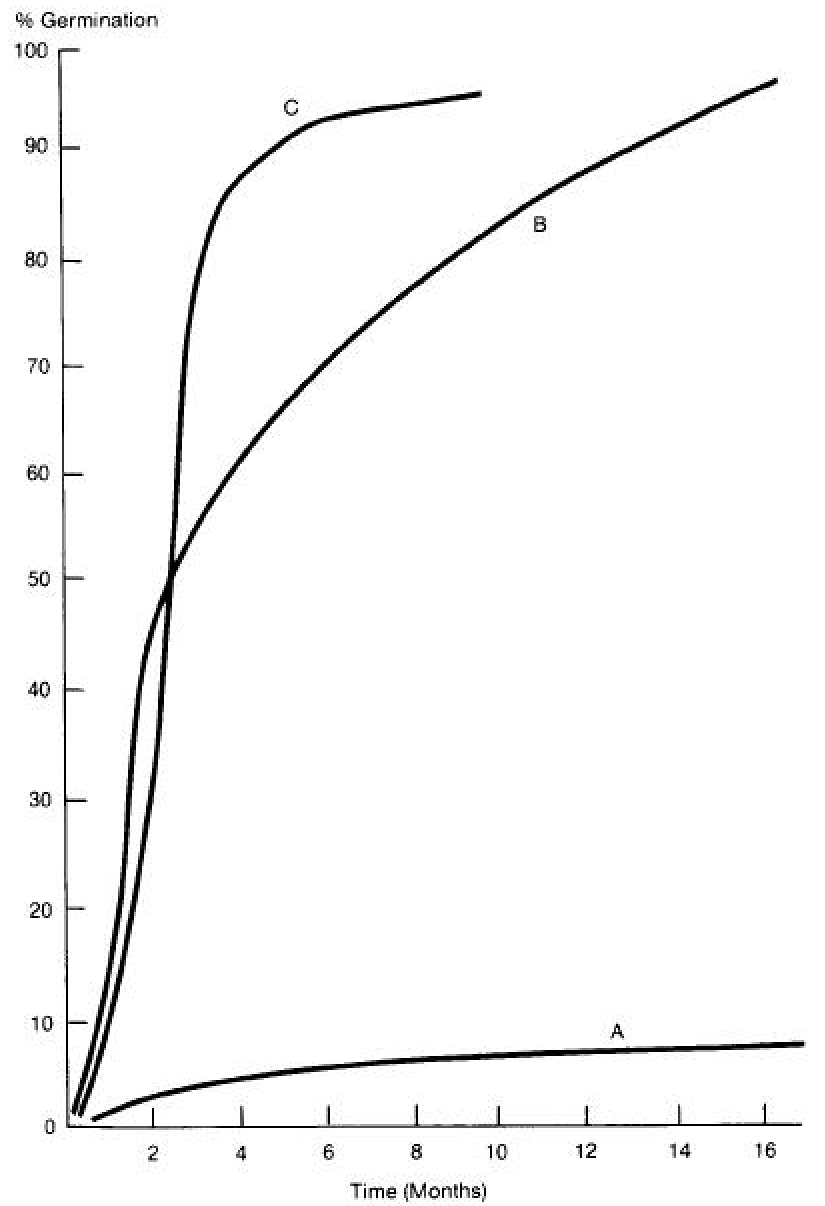

Figure 1—*Effect of light on common greenbrier seed germination.* **A** = *seeds inside medium,* **B** = *seeds on top of medium, clear plastic bag,* **C** = *seeds between paper towels.*

the surface of a new soilless mixture. They were placed under fluorescent lights as before and observed for 10 months.

Results

Exposure to light increased germination significantly in both species of greenbrier (table 1, fig. 1). Common greenbrier seeds germinated in 2 to 4 months under light (table 1). Germinative energy under paper towels with distilled water was 91% after 4 months. Total germination for seeds receiving light averaged from 95 to 97%, and in some replications it was 100%. Response of cat greenbrier seeds was slower; germinative energy in seeds placed between paper towels in distilled water was only 75.5% after 15 months. Total germination after 2 years was 82% and germinative potential was 86.5%.

Giving common greenbrier seeds 5 days of light was not enough. Of common greenbrier seeds stored for 16 months, then given 5 days of light and planted 12 to 15 mm deep; only 4% germinated (table 2).

No treatment carried out—formic acid, thiourea, gibberellic acid, and stratification at low temperature—significantly increased seed germination (table 1).

Seeds sifted out of the soilless mix at the end of the 2-year study and placed on top of a

Table 2—*Storage and light treatments on the germination of common greenbrier seeds*

Treatment	Length of tests (months)	% germination	% potential germination
Stored 16 months—light	7	43.0	—
Stored 16 months—5 days of light, then no light	7	4.0	—
Stored 16 months—no light	7	0.0	—
Stored 61 months—continuous light	9	83.5	97.0

new soilless mix (all treatments mixed together) yielded results similar to those from seeds in the study receiving light.

Viability remained high in seeds stored for 5 years at 2 to 7 °C at about 2% moisture content. After 9 months, 83.5% of the common greenbrier seeds placed under continuous light had germinated (table 2). Germinative potential was 97%. In cat greenbrier seeds, germination was only 19.8%, after 9 months, but germinative potential was still 92.8%.

Discussion

The intensity of light in our studies was not very high, but it produced excellent germination in common greenbrier seeds. Cat greenbrier may require higher light intensities. Common greenbriers usually grow in or along edges of deep woods and fencerows where light intensities are low. Cat greenbriers are usually found in the open where light intensities are quite high.

Constant light at room temperature did not increase germination of cat greenbrier seeds in our studies, but the same flats later placed under mist in a greenhouse produced a nice uniform stand of seedlings. In the greenhouse, the seeds received much more light, and this may be the reason they germinated well there. Duration of light may also be important, because 5 days of light did not result in good germination in common greenbrier.

In our studies, light appears to be a requirement for germination of at least the common greenbrier. This may explain why a great many more common greenbriers are found in recently logged (and other) areas where soil has been disturbed, even lightly, than in undisturbed areas. In these areas, both the buried seeds brought to the surface and freshly distributed seeds will obtain light yet are firmly in contact with the soil.

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