Abstract. A prototype expert system for diagnosis of forest nursery problems was developed, using the expert system shell EXSYS, to clarify the requirements for an operational system. Knowledge acquisition was facilitated by the organization of relevant domain knowledge in existing manuals. Success of system development lay in the ability to differentiate fungal causal agents from abiotic causes or insect feeding damage. The importance of choice of viewpoint (host species, part of plant, disease, clinician or nursery manager) in setting weightings in the system was illustrated. Rules developed in the prototype were able to successfully differentiate two abiotic factors, 22 fungal diseases, and feeding damage of 22 insects and mites.

Prototyping an Expert System for Diagnosis of Forest Seedling Nursery Problems

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Approximately 300 million seedlings are grown annually in forest nurseries in British Columbia (Glerum 1990). Loss of stock from pests, disease, or adverse abiotic factors such as frost or excessive fertilization causes financial hardship to nurseries, affects nursery reputations, and disrupts reforestation planning (Sutherland et al. 1989).

Diagnostic services for nursery problems are available at Forestry Canada's Pacific Forestry Centre (PFC), Victoria, British Columbia. Consultations are first made by phone, with preliminary diagnosis and tentative treatment recommendations being made at that time. If the nursery manager suspects a major problem and is conscientious, samples of affected seedlings along with cultural records and observations on nursery conditions are submitted for laboratory confirmation. Often the information on culture and nursery conditions lacks completeness or is inaccurate, making the correct diagnosis difficult. In making their diagnoses, PFC experts are very dependent on the past history of the nursery and experience of the nursery manager.

A recent change from government to private forest nurseries in British Columbia has produced increased competitiveness for seedling growing contracts. Personnel do not want a "record" of disease incidence in their nursery, so they perform their own diagnosis of nursery problems. As a consequence, consultations are now restricted to major unrecognized problems. The new competitive regime leads nursery managers to take chances. Sometimes they agree to production levels that have only a marginal chance of success. This increases the potential for pest and disease impact.

An example of the consequences of a nursery manager's misdiagnosis follows. *Rosellinia minor*, which causes a blight superficially like the common disease known as gray mold, can be a problem in British Columbia forest nurseries. When it was first observed, it was misidentified by nursery managers as *Botrytis cinerea*, the fungus causing gray mold, because the characteristic fruiting bodies (perithecia) of *Rosellinia* were overlooked. Because no samples were submitted to the diagnostic clinic, it was some time before the experts became aware of the new disease and could develop a response. Now that nursery managers know to look for the dark perithecia, there is a problem of misidentifying the fruiting bodies of other diseases which also have dark spore-producing organs.

Illustrated manuals for diagnosis of nursery problems are available to assist in disease and insect identification (Landis et al. 1990, Sutherland et al. 1989), but nursery managers tend to rely on the pictures rather than the text. Because of space limitations, pictures cannot illustrate the entire symptom range, especially color patterns. Pictures also tend to illustrate the later stages of disease progression, because in the early stages, when treatment is most appropriate, many problems are difficult to differentiate. The term "disease" is used to refer to the conditions, signs, and symptoms associated with the disease, not just to the organism itself.

Because increasing numbers of problems are being diagnosed by nursery managers, and given the limitations of available manuals, we decided to develop an expert system for preliminary diagnosis of nursery problems. Diagnostic expert systems are best known from the field of medicine (Clancey 1987), but have also been developed for applications in forestry (e.g., Thomson and Taylor 1990) and agriculture (e.g., Latin et al. 1990).

Prototyping is an approach used in developing expert systems to identify the characteristics that a system should have to be useful (Mathieson 1988). Expert system shells may be used to facilitate prototype development. The present study describes the major facets of a prototyping exercise using one such shell, EXSYS[1] (version 3.2, EXSYS Inc, Albuquerque, New Mexico) to develop a prototype of an expert system for diagnosing forest nursery problems.

A manual describing insect, disease and environmental problems in British Columbia nurseries (Sutherland et al. 1989) provided a comprehensive overview of expert knowledge in the field, and alleviated the requirement for extensive knowledge acquisition through interviews with experts. Material in the manual was translated into the production rule format of the EXSYS package, and preliminary weightings were assigned to the choices based on the descriptions in the text. The prototyping exercise was used to evaluate the suitability of a purely rule-based approach to diagnosis of nursery problems, and also to evaluate approaches to assigning weightings to choices in the system.

The English-like nature of the rules allowed them to be easily evaluated by a nursery expert, who refined the biological details and provided more accurate weightings than those based on the limited information in the text. An independent nursery expert at PFC was available to test the system and to provide a viewpoint more comparable to a nursery manager, as opposed to the more research-oriented viewpoint of the principal nursery expert. Summer students in the diagnostic clinic provided testing more compatible with the level of knowledge and experience of the average nursery manager.

Domain Description

Expert systems focus on a well-defined and generally narrow domain of application. The present system focuses on problems occurring while the seedlings are either in growing con-

[1] Mention in this paper of specific commercial products or services does not constitute endorsement by Forestry Canada or the Government of Canada.

tainers (container nurseries) or seed beds (bareroot nurseries). Seed-borne diseases are not included unless they can also occur following germination. Similarly, storage problems such as molding following lifting of the seedlings are excluded.

The system is designed on the premise that it would be used by persons such as nursery managers or quality control technicians who are familiar with the nursery setting and who have samples of affected seedlings in hand. It is less suitable for use by inexperienced diagnosticians in a clinical setting where samples are submitted, as shipping and handling damage may be difficult to distinguish from disease symptoms.

Data from traps for insects such as fungus gnats (*Bradysia* spp.) or cranberry girdler (*Chrysoteuchia topiaria*) may permit inferences about possible damaging populations of these pests (Shrimpton 1983), but such trap data are not included in the prototype system. In the prototype, inferences are based only on observable symptoms or descriptions of the nursery environment.

The nursery is a well-controlled environment where staff inspect the crop daily; thus, symptoms of problems tend to be observed sooner than with other crop environments. The causal agent of a problem may be fungi, insects or mites, or abiotic. A basic assumption of the system is that there is a single primary causal agent for any problem, although the possibility of some secondary invaders following environmental injury is allowed. Molding may occur as the result of saprophytic fungi entering tissues previously affected by environmental or other factors. Such secondary saprophytes are not dealt with in the prototype version.

The prototype was designed to be used with either container or bareroot seedlings. Transplant stock, where there was the possibility of moving affected plants into an environment atypical for that problem, was not included. Also, symbiotic mycorrhizal fungi, which can sometimes be confused with root problems, and nutritional disorders were excluded from the prototype. The manner in which symptoms of other problems are modified by the presence of mycorrhizae is not clear.

The insects, diseases, and environmental factors listed in Table 1 were included in the system as choices to be evaluated. "If-then-else" production rules were developed, where, if the conditions were true, choices were assigned confidence factors. A scale of confidence factors from 0 to 10 was used, where the assignment of 0 to any choice excluded that choice regardless of all other considerations. Similarly, assignment of 10 forced selection of that choice. Otherwise, choices were ranked on the basis of the average, over all rules, of all confidence factors assigned to a particular choice.

THE SYSTEM IS DESIGNED FOR NURSERY MANAGERS OR QUALITY CONTROL TECHNICIANS WHO ARE FAMILIAR WITH THE NURSERY SETTING AND WHO HAVE SAMPLES OF AFFECTED SEEDLINGS IN HAND.

Each condition in a rule was made up of two parts, a qualifier and one or more values. The qualifier was usually the part of the condition up to the verb (for example, "The color of the needles is"). Alternative values, such as "red" or "brown," which can complete the sentence were established. Rules were then built around the alternative sentences. When the value to be attached to a particular qualifier was not currently known by the system, and could not be inferred from other information in the system, the EXSYS shell prompted the user for the information in the form of a multiple-choice question giving the qualifier and all alternative answers. The value "unknown" was included to allow choices to be evaluated when information was incomplete.

The Manual

Two features of the manual (Sutherland et al. 1989) were of relevance to the development of the diagnostic system prototype: the diagnostic procedure used and the method in which expert knowledge was summarized. In diagnosing a problem, the nursery manager is first queried to determine if the problem is environmental in origin, based primarily on the pattern of damage on the plants or within the nursery. Non-environmental causes are then differentiated into insects and mites or pathogenic fungi based on the presence of the insects or indications of tissue consumption on the plants. The manual implies that it is easy to distinguish consumption patterns. In practice, it is often difficult to distinguish consumption from a fungal disease symptom. A key based primarily on the part of the plant affected is then used to obtain a preliminary diagnosis. The nursery manager may then turn to a detailed description of the organism, where the expert knowledge is captured in three forms: a table indicating the nursery conditions under which the problem occurs (Table 2), photographs illustrating signs or symptoms, and a verbal description.

Viewpoints

Weightings assigned in the system depend on the viewpoint from which the system is constructed and determine the accuracy of the system. The manual gives a particular viewpoint, that of the clinician, on the interrelationship of hosts, pests and diseases, season, and nursery setting. This viewpoint is reflected in the language used to describe rarity of problems, and it is this language with which the weightings may be assigned in a diagnostic expert system. The clinician bases his or her language on the frequency with which samples are submitted from different nursery environments. The

Table 1. *Problems included in the system. Those indicated by an asterisk are not in the prototype but will be included in the final version.*

Environmental problems
Frost damage
Fertilizer damage
Nutritional problems *
Water root *
Pollution effects *
Pesticide damage *
Wind damage *

Diseases
Post-emergence damping off (*Fusarium* spp.)
Fusarium root rot (*Fusarium* spp.)
Pythium root rot (*Pythium* spp.)
Cylindrocarpon root rot (*Cylindrocarpon destructans* (Zinssmeister) Scholten)
Phytopthora root rot (*Phytopthora* spp.)
Hypocotyl rot (*Fusarium* and/or *Phoma* spp.)
Corky root disease (*Xiphinema bakeri* Williams)
Gray mold (*Botrytis cinerea* (Fr.: Nocca and Balbis)
Rosellinia blight (*Rosellinia* spp.)
Sirococcus blight (*Sirococcus strobilinus* Preuss)
Keithia blight (*Didymascella thujina* (Durand) Maire)
Colletotrichum blight (*Colletotrichum acutatum* Simmonds)
Colletotrichum blight (*Colletotrichum gloeosporioides* (Penzig) Penzig and Saccardo)
Fusarium top blight (*Fusarium oxysporum* Schlechtendahl)
Phomopsis canker and foliage blight (*Phomopsis* spp.)
Phoma blight (*Phoma* spp.)
Melampsora foliage rust - conifer-aspen rust (*Melampsora medusae* Thuemen)
Melampsora foliage rust - conifer-cottonwood rust (*Melampsora occidentalis* Jackson)
Western gall rust (*Endocronartium harknessii* (J.P. Moore) Y. Hiratsuka)
Larch needle cast (*Meria laricis* Vuillemin)
Needle dieback (*Pythium* spp.)
Smothering fungus (*Thelephora terrestris* Ehrenberg:Fries)
Mycorrhizae *

Insects and mites
Cooley spruce gall aphid (*Adelges cooleyi* (Gilette))
Giant conifer aphid (*Cinara* spp.)
Coniferous root aphid (*Pachypappa tremulae* (Linnaeus) or *Prociphilus xyloster* (De Geer))
Primitive wooly aphid (*Mindarus obliquus* (Cholodkovsky))
Balsam wooly aphid (*Adelges piceae* (Ratzeburg))
Green spruce aphid (*Elatobium abitinum* (Walker))
Lygus bug
Root weevil adults (*Otiorhyncus* spp.)
Strawberry root weevil larvae (*Otiorhyncus ovatus* (Linnaeus))
Black vine weevil larvae (*Otiorhyncus sulcatus* (Fabricius))
Cranberry girdler (*Chrysoteuchia topiaria* Zeller)
Tehana bonifatlla (Hulst)
Fungus gnats (*Bradysia* spp.)
European marsh crane fly larvae (leatherjackets) (*Tipula paludosa* Meigen)
Springtails (*Bourletiella hortensis* (Fitch))
June beetle larvae (white grubs) (*Polyphylla decemlineata* (Say))
Cutworms (*Peridroma saucia* (Hubner))
Rusty tussock moth (*Orgyia antiqua* (Linnaeus))
Spruce budworm (*Choristoneura occidentalis* Freeman)
European pine shoot moth (*Rhyacionia buoliana* (Denis and Schiffermuller))
Spruce spider mite (*Oligonychus ununguis* (Jacobi))
Tricetacus mite

manual uses language such as "principal locally grown host," "sometimes," "least affected," "especially," "other species susceptible," "possibly on," and "never on."

Because the disease is unknown at the start of a diagnosis, preliminary hypotheses are erected based primarily on the host species. The hypothesis may be modified by nursery setting and season. The clinician's viewpoint is therefore essentially host-species oriented; a particular host has some problems more often than others.

There are a number of other viewpoints, however, on which weightings might be based. For example, a problem (such as disease) viewpoint would be based on the fact that a problem occurs on some hosts or parts of hosts more often than others. A part viewpoint would be based on the fact that a particular part of a seedling has one type of problem more often than others.

The nursery manager's viewpoint is reflected in the fact that in the past there have been more occurrences of a particular problem than others. However, if the manager does not send samples to the clinician, frequencies based on a clinician's records may not be accurate. In addition, frequencies based on experience in one particular nursery setting may not be widely applicable.

The consequences of viewpoint are illustrated by the following example. Consider a rare disease A which can occur on hosts B and C. From the viewpoint of a problem such as disease, if the disease occurs much more often on B than on C, its weighting would be high on B and low on C. From the host viewpoint, because the disease is rare compared to many other problems, the disease would be given a low weighting on both host species B and C. It is therefore essential to define the viewpoint on which the system and weightings are structured. Weightings in the prototype are actually based on a problem (e.g., disease or insect) viewpoint. This facilitates addition of new problems.

The Disease Viewpoint

While the prototype includes pests, diseases, and environmental problems of nursery seedlings, the most complex part of the system is that pertaining to the diseases. Issues relating to the disease viewpoint illustrate some general problems in developing diagnostic expert systems.

At any time, variability exists in the range of signs and symptoms (including death) exhibited by different seedlings in the population. In

Table 2. *Example of a table from Sutherland et al. (1989) summarizing expert knowledge of effects of nursery conditions on a disease* (Sirococcus *blight in this case). Age is recorded as number of years in containers plus number of years of outplanting.*

Principal locally grown hosts	Host age and season when damage appears		Nursery type and location			
			Bareroot		Container	
	Age	Season	Coastal	Interior	Coastal	Interior[a]
All spruces	1+0 2+0	Spring and early summer	Yes	No	Yes	Yes
All hard pines	1+0 2+0	Late summer Fall through spring	Yes	Yes	Yes	Yes
Douglas-fir	1+0 2+0	Late summer Fall through spring	Yes	No	No	No

[a] "Coastal" indicates that part of British Columbia which, by its proximity to the ocean, has a more moderate, wetter climate; the interior of the province is characterized by more extreme temperatures and, in southern British Columbia, by dry summers.

addition, the signs and symptoms on a seedling at that time are the consequences of the progression of the disease over time. There is an interaction of severity and temporal progression of a disease. For example, at a particular time (such as the time of the diagnosis) some individuals may be discolored, while others may be discolored and dead. The degree of discoloration, in terms of distribution and color value, varies among individuals, reflecting severity variations.

The importance of the interaction of severity with temporal progression and variability within the population varies with stage of the host's development. For example, germinants are small and remain in that stage for only a short time. Diseases affecting germinants tend to have symptoms that increase rapidly in severity, but because of the small size of the plants, only obvious symptoms such as color change are generally detected, and many symptoms may be overlooked.

The expert system must consider at least three methods of measuring disease severity: the proportion of individuals affected by the problem, the extent to which affected individuals suffer debilitating effects, and the rate at which the problem develops in the population. These different views of severity allow different inferences regarding future development of the problem and the most appropriate management, as well as influencing the method of symptom interpretation.

THE EXPERT SYSTEM MUST CONSIDER AT LEAST THREE MEASURES OF DISEASE SEVERITY: THE PROPORTION OF INDIVIDUALS AFFECTED, THE EXTENT TO WHICH INDIVIDUALS SUFFER DEBILITATING EFFECTS, AND THE RATE AT WHICH THE PROBLEM DEVELOPS IN THE POPULATION.

The situation is complicated by the fact that for some pathogens, such as *Pythium* spp., there are virulent and avirulent strains. Symptom progression depends on which strain is causing the disease. In addition, for a particular disease, the range of signs and symptoms and their temporal progression can vary with host and nursery environment. The importance of a symptom such as color in forming intermediate hypotheses varies with the disease.

Many diseases have similar symptoms in the early stages, as illustrated by the photographs in the manual (Sutherland et al. 1989) for *Fusarium* top blight, *Phomopsis* foliage blight, *Sirococcus* blight and *Fusarium* root rot. This emphasizes the value of a diagnostic expert system, as nursery staff tend to rely heavily on the photographs.

Other potentially confusing signs and symptoms include spider-mite (*Trisetacus* spp.) webbing, which looks like fungal mycelia, and needle dieback (*Pythium* spp.), which causes twisting of needles similar to that caused by boron deficiency. The Cooley spruce gall aphid (*Adelges cooleyi*) on Douglas-fir, after the population has collapsed, leaves seedlings with needle symptoms such as chlorosis, which look like a fungus disease or nutritional problem. Lesions are difficult for nursery managers to distinguish from rot. Water roots, an environmental effect that occurs in some hosts when they are waterlogged, looks like corky root disease, which is caused by the nematode *Xiphenema bakeri*.

Developing the Knowledge Base

As indicated earlier, information is coded in EXSYS in the form of if-then-else production rules. We started with a single widespread disease, *Fusarium* root rot, as an example, and developed rules using a disease-centered viewpoint to capture all the characteristics of that disease, with appropriate weightings. Several indicators were recorded to illustrate the different stages of system development (Fig. 1).

The most obvious measures of system development, or indicators, are number of choices and number of rules. The number of qualifiers, the total number of alternatives in the qualifiers, and the average alternatives per qualifier all provide information on the increasing complexity of the system. The rule base can be printed out, and the file size of the printout, expressed in blocks, is an indicator of system size, while the number of blocks per rule is an indicator of rule size. As rules and qualifiers for each new problem were added, previously en-

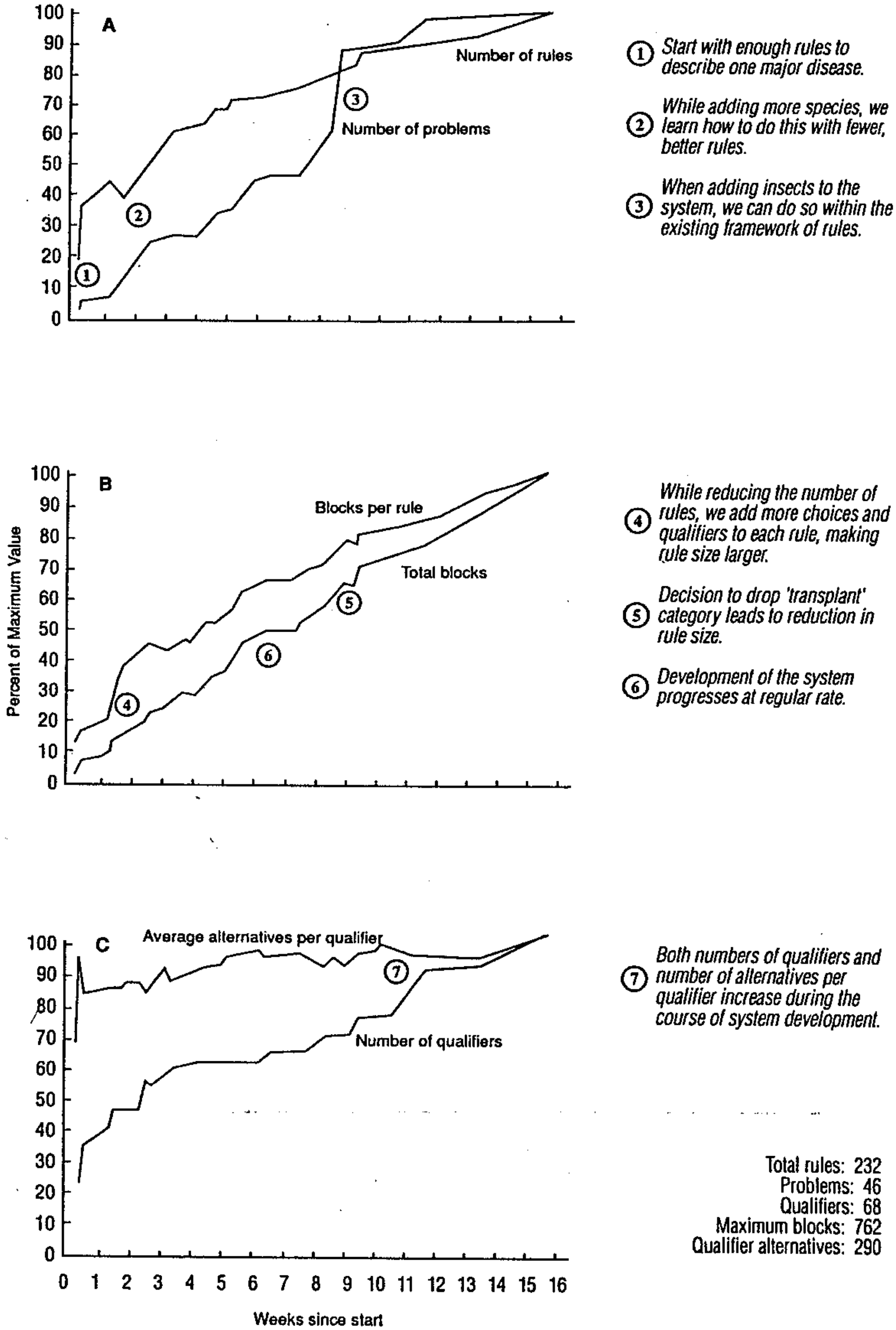

Figure 1.
Stages in development of the expert system, using different indices of size and complexity. (a) number of rules, number of problems, (b) blocks per rule, total blocks, (c) number of qualifiers, average alternatives per qualifier.

tered problems were checked, using the manual to guide responses to questions and to ensure that additions had not resulted in adverse changes elsewhere in the system.

Rules were developed in the following sequence. First, those related to the expert's normal sequence of questions were developed. These related to nursery environment and host species. Season was asked for specifically, although the expert normally infers this from date and weather. Rules regarding signs and symptoms were then developed under the assumption that representative specimens were in-hand and that each part of the plant would be examined in sequence from top to bottom. The shoot is where symptoms are first observed.

Several other diseases were entered, then the issue of distinguishing environmental damage from diseases was addressed. Environmental damage is distinguished on the basis of the pattern of symptoms within the nursery and on the seedlings. Later, when insects were added, category of problem was determined in the following sequence. First, it was determined if insects were actually feeding on the seedlings, then it was determined whether environmental damage had occurred. Visible consumption by insects that were not present on the plants at the time of diagnosis was determined, and finally fungus disease was distinguished. Once the category was established, the specific problem was explored.

Qualifier Formulation

The manner in which the alternative values of a qualifier are formed by EXSYS into questions has already been discussed. Issues such as the expected knowledge and attitudes of the users must be considered carefully in formulating these values. We found that increasing question complexity can lead to errors even by an expert. Questions where multiple alternatives were possible, such as those relating to symptom description in the population, were distinguished from those where a single choice was appropriate.

A prototype system is not intended for operational use, being rather for characterizing the requirements of the system. Qualifier alternatives (and thus questions) may therefore be developed in a fashion that would not necessarily be appropriate in an operational system. It may be advantageous to trade off ease of rule development in the prototype against unrealistic assumptions about user knowledge and characteristics. These unrealistic assumptions should be documented and corrected in the operational system.

In developing the system, we assumed that it was not necessary to address all user characteristics until we could show that it is possible to diagnose nursery problems using an expert system. User characteristics were ignored in four main ways in developing qualifiers for use in rules. First, terms such as pycnidia and perithecia (spore-producing structures of certain pathogens) were used, while in an operational system, presence of these structures might be evaluated through a graphical interface. Second, qualifiers were used which were much more complex than would be appropriate for those in an operational system. This permitted information and concepts to be included quickly, whereas in the final system, such knowledge would be built up in parts using simpler concepts and language appropriate to the user.

The third way in which user characteristics were ignored in developing the prototype related to conceptual differences in which the experts and nursery staff used the same terms. This is illustrated by the use of time in container and outplanting as a surrogate for age (Table 2). The expert viewed this value as an elapsed time in constructing the tables in the manual. However, nursery staff view this number as a planned objective for seedlings, and will use a term such as 2+0 to refer to a batch of germinants planned to be grown for two years.

Finally, it is known that nursery managers are unlikely to admit to poor cultural practices of various sorts that may predispose a nursery to problems. Qualifiers were included to reflect such poor practices specifically, whereas in an operational system such information would have to be inferred in some other manner, perhaps from answers to more innocuous questions or through a weighting based on an expert's experience of individual nurseries or operators.

Results and Discussion

The prototyping exercise was successful in defining the required characteristics of an expert system for diagnosis of forest nursery problems, providing a definition of the system domain, and clarifying the framework in which such a system would be used. The extreme importance of correctly identifying the viewpoint (host species, part of plant, disease, clinician or nursery manager) from which rules and weightings in the system are assigned quickly became apparent. A disease-centered viewpoint was determined as most appropriate for the knowledge-representation aspects of the system, while the user interface would be oriented to the nursery manager.

The ability to differentiate biotic from abiotic causes of nursery problems was a fundamental contributor to a successful system. This differentiation hinges on the fact that abiotic problems tend to have a distinct spatial distribution on seedlings or within the nursery. The prototyping revealed the difficulty of developing verbal descriptions of such patterns that could easily be understood by nursery staff, indicating that a graphics-based user interface would be valuable. This interface would also be useful in dealing with evidence of disease that is difficult to describe in simple terms, such as spore-producing perithecia (a scientific term not understood by most nursery managers). The system must also allow for the fact that an expert can easily put a verbal question in perspective with an overall range of conditions, while a non-expert tends to view a particular question in isolation and has a much higher likelihood of misidentifying a sign or symptom.

Using a shell that imposed a rule-based structure on the system permitted rapid development of a prototype system that performed successfully in identifying all the test problems. However, many limitations of this format became apparent, especially compared to previous PROLOG-based diagnostic system development in our experience (Thomson and Taylor 1990). The shell format lacks flexibility: the shell does not allow the rule base to be interrogated to answer questions such as, "What are the three most significant foliage blights of 1+0 Douglas-fir in container nurseries in coastal British Columbia?" Although this question is more database oriented than expert system oriented, the knowledge should be captured in a manner that allows maximum flexibility of interrogation. Related to this is the fact that in the purely rule-based system, entry of new problems becomes progressively more difficult, because more rules must be checked against the characteristics of the disease.

THE PROTOTYPING EXERCISE QUICKLY REVEALED THE EXTREME IMPORTANCE OF CORRECTLY IDENTIFYING THE VIEWPOINT (HOST SPECIES, PART OF PLANT, DISEASE, CLINICIAN OR NURSERY MANAGER) FROM WHICH RULES AND WEIGHTINGS IN THE SYSTEM ARE ASSIGNED.

A domain-related issue was the difficulty in capturing the interrelationship of temporal progression of a disease and severity; a particular symptom was of more diagnostic value for some diseases than others, and different views of severity are possible. The above points argue for the necessity of developing a protocol for disease knowledge representation that adequately captures the interrelation between temporal progression and severity of symptoms, and the variability within a population. Such a protocol will be the focus of our research in the near future. Knowledge representation considerations and choice of viewpoint were found to be more important than the choice of a weighting scale in developing the system.

An earlier diagnostic system for plantation nutritional disorders (Thomson and Taylor 1990) showed the value of identifying basic assumptions that could facilitate system development. In the present system, a basic assumption is that there is a single primary causal agent, although a secondary agent may be possible under certain conditions. Essential features of an operational system include the ability to determine signs and symptoms that are not consistent with the top-ranked hypothesis, or those that would be expected with the top-ranked hypothesis but have not been described.

Expert systems are supposed to mimic the reasoning processes of an expert, and a key feature of this reasoning process is the manner in which hypotheses are erected and tested. Although the system diagnosed problems successfully, it did so by a "brute force" method, rather than through a hypothesis generation and test procedure. Such a procedure could have been developed (with difficulty) using the shell by creation of a set of linked expert systems, the first of which developed a preliminary hypothesis based on the host and nursery setting and wrote the ranked choices to a file. A second system could read that file and attempt to disprove the hypotheses in order by evaluating the signs and symptoms. However, such an elaborate system was not consistent with the primary aims of the prototyping exercise.

In developing a prototype, it is very useful to identify constraints on the operational system which can be relaxed in the prototype. Constraints relaxed in the present exercise centered on end-user characteristics that would influence the language and concepts of the question format. The role of the prototype is to guide system development, so the evaluation criteria do not rely on performance comparisons with experts to the same extent as an operational system.

The system was also evaluated for its ability to answer "why not...?" questions, i.e., the ability to describe why a particular hypothesis has been rejected. The EXSYS shell permits such evaluation only through manually backtracking through the rules that were tested. The optimal approach to hypothesis testing and answering "why not ...?" questions will depend on the viewpoint. In developing an operational system around a disease knowledge-representation protocol, the system will be provided with the ability to answer such questions, as well as the ability to generate test data sets to evaluate the most important criteria.

The framework in which an operational diagnostic system for forest nursery problems would be used may be defined as follows. A prerequisite to use of the system is a product that describes to the nursery manager the manner in which nursery conditions should be assessed, how samples should be collected, and how the samples should be handled and examined for signs and symptoms. Such a product could form a front end to the expert system or be incorporated in help documents accessible through a facility such as hypertext (Rauscher and Host 1990) or a video laserdisc system.

The use of such a system would provide a tentative diagnosis which could then then be processed by a management advisory system which would give recommendations based on whether the diagnosis was tentative or confirmed. A management prescription on the basis of a tentative diagnosis would take possible alternative causes into account and advise only on the most urgent measures which should be undertaken pending confirmation (e.g., through a private, and thus confidential, laboratory).

A final aspect of the operational framework of a diagnostic expert system is that many container nurseries are in computer-controlled greenhouses, with extensive and intensive monitoring of environmental conditions. In addition, stock, weather, and treatment and performance records may be kept in databases. Linkages should be developed between the expert system and these other records so that inferences may be made through evaluation of data rather than through questioning the user.

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Marilyn E. Blache (Draper) graduated in 1973 with a B.Sc. (Hons.) in biology (botany) from the University of Victoria. She spent two years in a Masters program at the University of Waterloo, Ontario, conducting research in the area of stream mycology. She recently supplemented her education and experience by completing a basic course in microcomputers from Camosun College, Victoria, B.C. She has worked short terms in a wide range of fields: as a technician in seed biology at the Central Experimental Farm for Agriculture Canada, Ottawa, Ontario; as a laboratory instructor in biology at Kootenay Community College, Cranbrook, B.C.; and as a technician for the B.C. Ministry of Forests in both Nelson and Victoria, B.C. She is presently on contract with the B.C. Ministry of Forests Research Branch, Victoria, B.C., assisting with a project on carbon dioxide emissions from old growth forests.

John J. Dennis graduated from the B.C. Institute of Technology in 1971. He joined Forestry Canada as a research technician and has done studies on mycorrhizae, nutrition, and related problems of containerized forest seedlings. In 1983 he began working in pathology and has managed a Pest Diagnostic Clinic for British Columbia forest nurseries. This entails processing and identifying over 300 disease samples each year and providing advice and recommendations on disease control and prevention. Because of his avid interest in mycology, he also provides mushroom identification courses and services to poison control centers, schools, and associations.