PROSPECTS FOR INTEGRATED PEST MANAGEMENT IN SOUTHERN PINE SEED ORCHARDS

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__Abstract.--The__ concept of Integrated Pest Management (IPM) for southern pine seed orchards is based upon the use of all suitable techniques in an organized way to reduce and maintain cone and seed insect populations at levels low enough so that any seed losses which occur can be tolerated. The prospects for developing such a system based upon traditional methods of chemical and biological control are good. Short-range IPM objectives should be aimed at reducing the frequency, rates, and costs of insecticide use through timing and efficiency of applications and by minimizing the impact of insecticides on beneficial insects. Long-range objectives require the development of better methods of monitoring, as well as the acquisition of the basic information needed to adequately understand the population dynamics of the cone and seed insects found in seed orchards.

__Additional keywords:__ cone and seed insects, Leptoglossus, Dioyctria

Seed orchards are small areas of extremely valuable forest real estate; they are intensively managed for a single purpose--to produce adequate supplies of genetically improved tree seeds. The prevention of seed losses caused by insects has greatly improved seedling production. It is essential to insure a continued increase. In this paper, I argue that Integrated Pest Management (IPM) offers a rational approach to the prevention of unacceptable losses to insects in seed orchards.

IPM for our purposes can be defined as the utilization of all suitable techniques in an organized way, to reduce pest populations and maintain them at levels low enough so that losses can be tolerated. A conceptual model can be used to show the interactions of various components (fig. 1). In my opinion, IPM is also a common sense approach to pest control, whereby the strengths of various tactics are emphasized, and precautions are taken to avoid any repercussions due to weaknesses. Forest entomologists have promoted this idea for years, but the emphasis on a systems approach where a number of techniques are utilized in an organized manner is new.

BACKGROUND

More than 10,000 acres of grafted trees have been established in the South during the past 30 years (Lantz 1979). Eight state forestry organizations, 36 forest industries, and one forest tree seed company belong to three active tree improvement cooperatives--the North Carolina State University-Industry Cooperative, the University of Florida Forest Tree Improvement Cooperative, and the Western Gulf Forest Tree Improvement Cooperative. Five other state forestry organizations, Region 8 of the U.S. Forest Service, and TVA have tree

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improvement programs. The South's seed orchards produced more than 60 tons of genetically improved seed in 1977. Annual nursery production has reached 1 billion seedlings, and 370 million or 41 percent of the seedlings grown in 1978 were genetically improved trees.

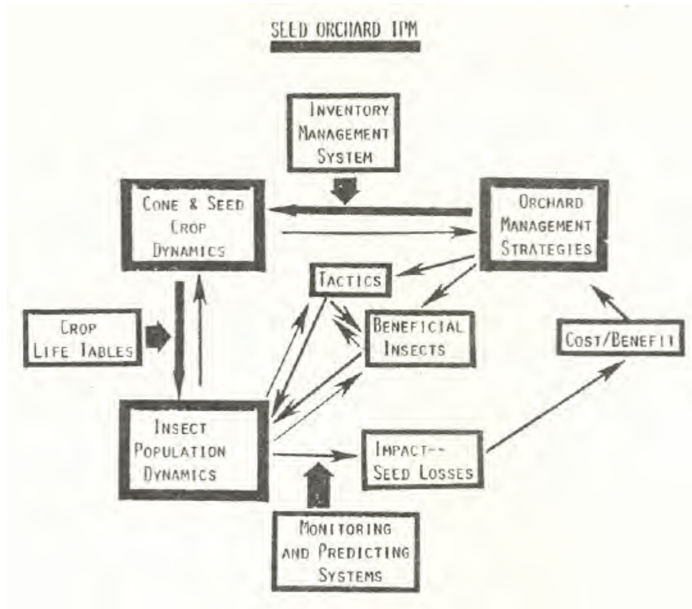

Figure 1.--A conceptual model of a pest management system for southern pine seed orchards (adapted from Waters and Cowling 1976).

Loblolly pine, Pinus taeda L., is the most important species and occupies the most orchard acreage. Others include slash pine, P. elliottii Engelm. var. elliottii; shortleaf pine, P. echinata mill.; longleaf pine, P. palustris Bill.; Virginia pine, P. Virginiana mill.; and eastern white pine, P. strobus L. When an orchard is established, about 100 trees are planted per acre. By age 20, an orchard has been rogued several times and may have only 12-15 trees per acre. Orchards are routinely mowed, fertilized, subsoiled and treated with insecticides.

Seed orchards are usually isolated from other pine stands in order to minimize the influx of wind-blown pollen. This practice tends to insulate the orchards, for a short time, from the large reservoirs of both pests (Goldman 1977) and beneficial insects indigenous to natural stands. At about age 10, cone production starts to increase rapidly, and shortly thereafter so does insect depredation.

Several 'key' pests usually occur in a seed orchard. Key pests are the perennially occurring species that must be controlled to prevent intolerable seed losses. One or two species of cone and seed insects predominate in any seed orchard, but in years of good cone crops secondary insect species often become more abundant (table 1). Inter-specific competition is one of the major factors limiting cone and seed insect populations (Mattson 1978). Both intra- and inter-specific competition occurs when cone crops are poor, and often insect survival and fecundity are reduced.

Table 1.--Key cone and seed insect pests of loblolly pine, slash pine, and eastern white pine seed orchards

Host	Key pest	Secondary pest
Loblolly pine	*Dioryctria amatella* (Hulst)	Cecidomyiidae
	Leptoglossus corculus (Say)	*Dioryctria clarioralis* (Walker)
		Dioryctria disclusa Heinrich
		Dioryctria merkeli Mutuura & Munroe
		Eucosma cocana Kearfott
		Laspeyresia ingens Heinrich
		Laspeyresia toreuta (Grote)
		Nepytia semiclusaria (Walker)
		Rhyacionia frustrana (Comstock)
		Tetyra bipunctata (H.-S.)
Slash pine	*Dioryctria amatella* (Hulst)	*Cecidomyia bisetosa* Gagné
	Leptoglossus corculus (Say)	*Dioryctria clarioralis* (Walker)
	Gnophothrips fuscus (Morgan)	*Dioryctria ebeli* Mutuura & Munroe
		Dioryctria merkeli Mutuura & Munroe
		Laspeyresia anaranjada Miller
		Tetyra bipunctata (H.-S.)
Eastern white pine	*Conophthorus coniperda* (Schwarz)	*Eucosma tocullionana* Heinrich
	Leptoglossus corculus (Say)	*Tetyra bipunctata* (H.-S.)
		Megastigmus atedius (Walker)

Flower initiation and seed potential per cone are strongly linked to the genetics of each clonal selection (Bramlett 1974). The greatest losses of potential seed production occur during the first and last few months of strobili development. Flower, conelet, and first-year ovule mortality usually exceeds cone and seed losses (DeBarr and Barber 1975, Yates and Ebel 1978, Fatzinger *a al.* 1980). Yields from unprotected seed orchards are only a fraction of the potential represented by initial flower crops (Godbee et *al.* 1977); insects cause the major loss.

In natural stands, cone and seed insect population densities are related to annual fluctuations in cone crop size (Mattson 1978). Low infestations usually occur in years of heavy production, if the cone crop was small the previous year. Conversely, when a poor cone crop follows several years of good cone crops, insect-caused losses usually are heavy because of a delayed density-dependent relationship.

The goal of intensive management in seed orchards is to maximize annual cone crops. Large recurring cone crops will tend to favor the build-up of cone and seed insect populations, unless control is an integral part of orchard management. Annual cone yields have increased dramatically during the past several years (fig. 2). Improved seed is so valuable that the economics of insect control are easy to justify. Porterfield (1979) described the direct and proportional relationship that exists between seed production and profitability as follows:

"Within the orchard, genetic gain is largely fixed. This means that insect and disease control in the orchard...are of the utmost importance. Allowing a 20 percent loss in seed yield means a 20 percent decline in that year's net present value from tree improvement."

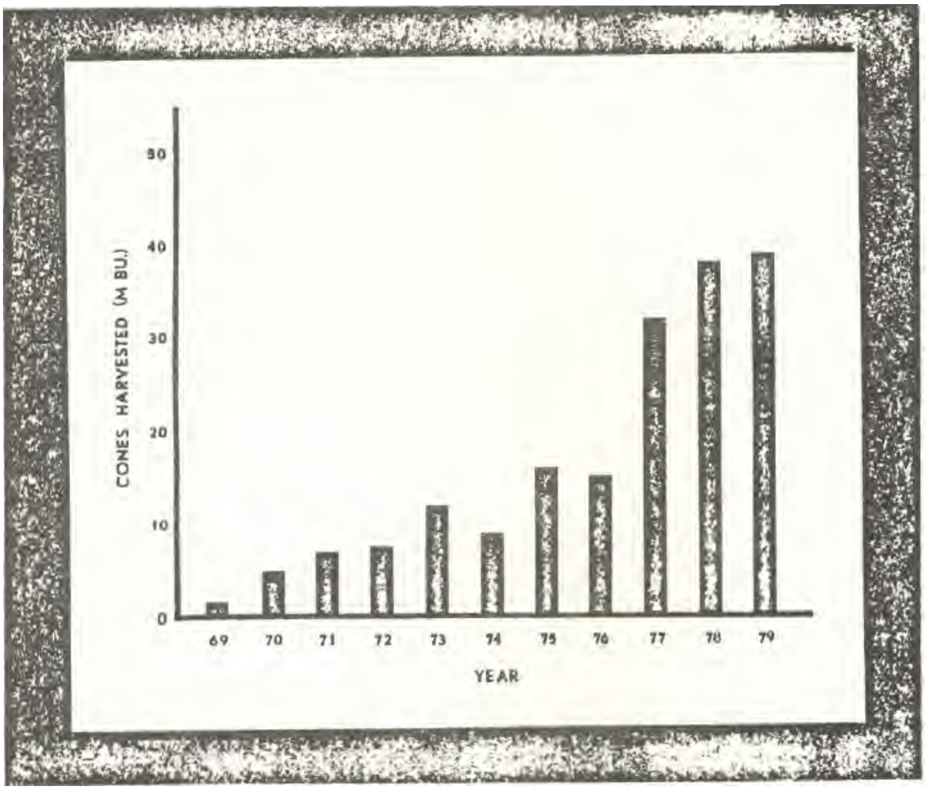

Figure 2.--Cone yields from the N. C. State University-Industry Tree Improvement Cooperative seed orchards, 1969-1979 (Anon. 1980).

NEED FOR IPM

Orchard managers may ask us why it is necessary to spend additional time, money, and effort to develop an IPM system when we already have several effective insecticides that can be used for control. The answer, of course, is that total reliance on chemicals for the suppression of cone and seed insect pests has several serious drawbacks. These include the selection for resistance, outbreaks of secondary pests, resurgence of key pests, hazards to personnel, environmental contamination from residues, and possible legal problems. In addition, broad-spectrum insecticides, such as azinphosmethyl (Guthion®), may limit the role beneficial insects can play in regulating pest populations in orchards. Finally, the use of insecticides represents a direct and ever-continuing expense for labor, equipment, and materials. And, these costs are escalating because the pesticide industry is highly dependent upon petroleum products.

An IPM system for seed orchards most likely will depend heavily upon traditional chemical and biological control. Insecticide application is the only practical method for reducing insect-caused seed losses to a tolerable level in operational orchards. Their use has greatly increased the availability of seed. This in turn has resulted in the establishment of plantations of improved pines capable of yielding additional wood and fiber worth millions of dollars.

Thus, despite the drawbacks, heavy reliance on insecticides is likely to continue for some time. Our long-range goal, however, should be to use insecticides to suppress rather than prevent outbreaks as we do now.

Unnecessary use of an insecticide occurs when the need to control or suppress the pest insect has not been established. Preventive insecticide applications are common in seed orchards. For example, carbofuran (Furadan®) is routinely applied in February as "insurance" against seed losses caused by seedbugs (DeBarr 1978). Guthion® is applied up to five times per year on schedules based upon the calendar instead of actual need to control Dioryctria (Merkel et al. 1976). These applications might be avoided, costs reduced, and a substantial quantity of insecticide eliminated from the orchard environment if we were able to provide the orchard manager with some method of predicting the need for such tactics.

IMPROVING EFFICIENCY

In the short run, there is plenty of room for improving the efficiency with which insecticides are used. Increased costs, along with trends toward low-volume applications and concern about pollution make it imperative that we apply insecticide on target. In seed orchards, as in other areas where pesticides are used, only a small amount of the insecticide applied acts to kill the target pests. Typical losses between the spray nozzle and site of toxic action for a ground spray or aerial application are shown in fig. 3. Up to one-third of the insecticide applied may be lost as drift or misapplication. In the target area, principal losses include volatilization, leaching or surface transport, and deposition on nontarget surfaces such as the ground. In most cases, only about half is found as toxic residue on the tree. Something less than 1 percent is near the cones or target insect. An even smaller fraction is absorbed by the insect, and only an infinitesimal amount ever reaches the site of toxic action inside the insect. For example, the LD90 for Guthion® topically applied to adult seedbugs is about 2 micrograms/g of insect body weight (J. C. Nord and G. L. DeBarr--unpublished data). One gram of Guthion® A.I. is enough to kill 5 million seedbugs. Each time an orchard manager sprays an acre of seed orchard at the registered rate, he applies about 2 kilograms of Guthion®, or enough to kill 10 billion seedbugs.

Obviously, the potential for increasing the efficiency of insecticide applications is enormous. New technology or simple changes in present application methods can reduce costs and environmental contamination, without sacrificing benefits. For example, as seed orchards reach 20-25 years of age, it becomes increasingly difficult and expensive to apply insecticide with ground equipment on trees 60-70 feet in height. Aerial applications are more efficient.

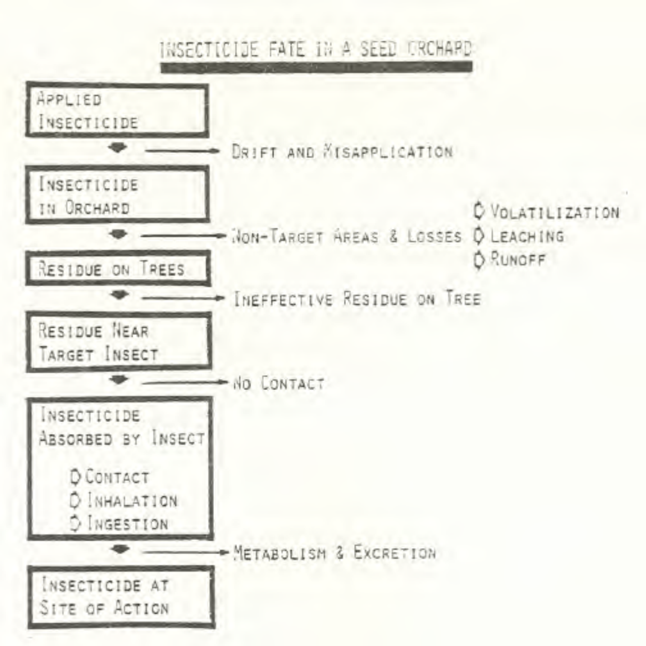

Figure 3.--A conceptual model of the fate of insecticides in southern pine seed orchards (adapted from von Rümker and Kelso 1975).

BIOLOGICAL CONTROLS

There is one outstanding example of cultural control of a seed pest, but entomologists cannot take the credit for it. Seedworms, La *speyresia* spp., overwinter in the cone axis and are inadvertently removed with each year's harvest. The result has been a low incidence of seedworm damage in loblolly pine orchards (G. L. DeBarr--unpublished data). Because cone collection is so difficult and costly, several other alternatives for collecting seed, such as the use of nets, have been proposed. If this particular technique becomes widely accepted, and cones are left in the orchards, seedworms will likely become much more common in orchards.

Chemicals used in seed orchards undoubtedly kill some beneficial insects, but a greater effect may occur because of reduced host availability. Compared with populations of many other forest pests, the numbers of cone and seed insects present on seed orchard trees are quite low. Often they are most abundant at the time of cone ripening, but even then they are scattered over a large canopy of orchard tree crowns. Host finding by natural enemies is likely to be more difficult for these pests than for those of agronomic crops. There, population levels are usually much higher and more concentrated. Following the application of insecticides in seed orchards, the numbers of cone and seed insects may be too low to adequately support beneficial insects. Thus, successful biological control will depend upon our ability to modify parasite-host or predator-host ratios and to maintain favorable ratios when pest populations in orchards are low.

Chant (1966) described conservation, augmentation, and introduction as the three basic kinds of biological control using parasites. "Conservation" is the enhancement of the effectiveness of natural enemies by changing their environment. A simple application of the conservation approach might be a change in concentration, time of application, or kind of insecticide used to control a cone or seed insect pest.

For years we have speculated that systemic insecticides applied to the soil or implanted directly into the tree might be less detrimental to the complex of parasites found in seed orchards. Recently, Belmont (1979) found comparative levels of control by several species of *Dioryctria* spp. parasites in Furadan®-treated and untreated areas of a slash pine orchard in Florida. Guthion®, which remains active on the foliage for long periods after sprays and has a broad spectrum of toxicity, would almost certainly destroy many of these parasites. Therefore, if our primary target pests are seedbugs, it appears there may be an advantage in using Furadan® instead of Guthion® to conserve the effectiveness of *Dioryctria* spp. parasites.

A more complex example of conservation in seed orchards is enhancement of the effectiveness of natural enemies of seedbugs by planting some agricultural crop in or near an orchard. This crop might serve as an insectary for populations of alternate host insects. This strategy is based upon our observation that the predator-parasite complex attacking *Leptoglossus corculus* (Say) and *Tetyna bipunctata* (H.-S.) is composed of many of the same species associated with other cotillion coreid and pentatomid bugs (G. L. DeBarr and G. F. Fedde--unpublished data).

Just as the lack of ecological diversity in agronomic crops disrupts the predatory-prey relationships in favor of pests (DeBach 1964), the pine monoculture of seed orchards undoubtedly has the same adverse effect upon the natural enemies of seedbugs. Monocultures tend to favor development of "exploding" pest populations (Hagen and Hale 1974).

It seems likely that populations of beneficial insects in seed orchards are disrupted by the lack of nearby vegetation in which to overwinter; alternate food supplies such as pollens, nectars or honeydews; and alternate host-prey for food. Cover crops or patch plantings could be used to attract alternate host insects. In turn, the presence of these insects would serve to attract and concentrate indigenous populations or inoculative releases of beneficial insects in the orchard. These plots would also serve as havens for them once the seedbug populations had been diminished.

Studies under way at the Forestry Sciences Laboratory, Athens, Georgia, are aimed at determining the potential of three species of egg parasites, *Anastatus reduvii* (Howard), *Gryon pennsylvanicus* (Ashmead), and *Ooencyrtus trinidadensis* Crawford, in a biological control strategy for seedbugs. The idea of using a diversity of plants to enhance the effectiveness of these parasites as part of an IPM system for southern pine seed orchards is also being evaluated.

"Augmentation" or the mass rearing and periodic release of sufficient numbers of a natural enemy to overwhelm a pest population is a promising strategy. Orchards vary in size from 10 to 400 acres. It might be feasible to use parasites in a manner similar to chemical insecticides but without the associated problems of environmental hazard and safety, and with the added possibility of recurring control. Developing mass rearing techniques, producing a strain of parasites competitive in the field, and timing the production and release to coincide with host vulnerability are all problems unique to this particular approach. Inundative releases of egg parasites for the pine seedbugs or *Trichogramma* spp. for *Dioryctria* spp. control appear to have the greatest potential.

Introduction of natural enemies not already present in the United States also may have potential. Research in Europe and Asia sponsored by the PL-480 grant programs has revealed the existence of several natural enemies of Dioryctria spp. that might be introduced as components of our seed orchard IPM system.

INTEGRATED PLANNING

How successful we become in applying the concept of integrated control to seed orchards in the future will depend to a large extent upon our commitment to develop plans to:

1. Identify and answer critical questions related to the dynamics of cone and seed insects and develop predictive models.

2. Standardize methods for collecting, analyzing, and evaluating data.

3. Lay out long-range strategies and short-range tactics, and continually evaluate the progress and potential of each in the context of an IPM system.

In the past, specific plans to carry research from the laboratory to small-scale field tests and finally pilot tests to demonstrate efficacy have often been lacking or incomplete. The planning and cooperation involved in our efforts to test and register insecticides for use in seed orchards clearly demonstrate how a diversity of individual talents and resources can be brought together to fulfill a common goal (DeBarr 1976, van Buijtenen 1981). These experiences should be equally valuable in the development and implementation of other components of an IPM system.

Campbell and McFadden (1979) emphasized that the key to attaining the goals of any pest management research and development program is accountability. If goals are not clearly defined, individuals often hold themselves accountable only for their own self-imposed objectives. Their efforts may contribute new knowledge, but fail to answer questions relevant to the development of an integrated pest management system. Therefore, to make real progress, each research study and pilot test needs to be critically questioned as to its contribution toward an IPM system for seed orchards.

TRANSFERRING TECHNOLOGY

Coordination of successive phases of technology development from research through implementation is far better for seed orchard pest problems than for most other forest pests. There is a general coordination of effort by U.S. Forest Service Research and State and Private Forestry personnel working through the Southern Forest Insect Work Conference, the Southern Forest Tree Improvement Conference, the Tree Improvement Cooperatives, and the Southern Regional Cone and Seed Insect Project (S-118). Our users are a group of about 200 highly committed and enthusiastic forest managers. We know most of them personally. Getting them to implement a new control tactic is usually not as big a problem as talking them out of using it before it has been proven effective. Many of the usual barriers to technology transfer do not exist.

The willingness and rapidity with which orchard managers are going to accept new ideas and alternatives is closely linked to the nature of each particular innovation. Muth and Hendee (1980) listed five characteristics that influence the chances that a new innovation will be quickly accepted by the user--relative advantage, compatibility, complexity, trialability, and observability. These five factors should be kept in mind when we propose components for a seed orchard IPM system.

A new alternative control tactic must possess some relative advantage over any other options currently available. This advantage is often one of economics, but there are also other criteria. As an example, prior to 1974 there were no insecticides registered for cone and seed insect control in loblolly pine seed orchards. When Guthion® was registered its relative advantage was purely economic (van Buijtenen 1981). The alternative was to do nothing and suffer intolerable seed losses.

When Furadan® was registered in 1976, it quickly replaced Guthion® for seedbug control, even though both chemicals are about equal in efficacy and costs. This time the relative advantage was safety. Granular Furadan® has a dermal toxicity greater than 10,000 mg/kg compared to about 200 mg/kg for Guthion®. Only a single application of Furadan® is required for season-long control (DeBarr 1978), while multiple applications of Guthion® are necessary (Merkel et at. 1976). The relative advantage of Furadan® was reduced hazard to personnel.

Compatibility is the degree to which an alternative control tactic fits in with other orchard management strategies or the values and needs of the orchard manager. As an example, the development of varieties of plants resistant to pests is an important part of IPM for many agronomic crops. Although clones in pine seed orchards vary widely in susceptibility to almost all the key pests (DeBarr et at. 1972), this approach has little potential for seed orchards. Resistance to cone and seed insects is not a trait of primary concern once the trees have been established in plantations, and forest geneticists believe that only primary traits should be included in the selection process. They say that if a tree has good characteristics, such as growth and form, the problem of susceptibility to cone and seed insects should be overcome by more intensive orchard management. Thus, breeding trees for resistance to cone and seed insects is incompatible with current views.

Complexity is the relative ease with which an innovation can be understood and implemented. Blacklights have been very useful to researchers in monitoring the seasonal occurrence of various species of Dioryctria (Merkel and Fatzinger 1971, Yates and Ebel 1975). However, very few orchard managers have used them, primarily because of the difficulty in separating and identifying the moths of Dioryctria species. In contrast, disposable sticky traps, baited with female sex pheromone are cheap, easy to deploy, and species-specific, catching only Dioryctria moths (DeBarr and Berisford 1981). Although the identification and development of synthetic pheromones to bait the traps requires some rather sophisticated research techniques, practical application is simple.

Trialability is the extent to which an innovation can be tested and evaluated by the orchard manager. And finally, observability is the ease with which an innovation or its effect can be seen. The quick knockdown effect that the pyrethroid insecticides have on seedbugs is easily observed (DeBarr and Nord 1978), but the more subtle effect of egg parasites is not nearly as dramatic. This difference in observability is likely to influence how quickly each of these alternatives is accepted.

Several years ago, the research director for a large forest industry wrote the following in the Journal of Forestry:

> "The most far-out, test-tube, bench-oriented scientist needs to know, understand, and really have a positive conviction that the results of his research will proceed to applied research, to development, to application, to profit or to the good of society. There should be pressure to get research into operation--the research job is not finished until the new information is in use." (Stabler 1975).

Interestingly, a loblolly pine orchard owned and intensively managed by this company was one of the first to produce an average of 200 bushels of cones/ acre and 2 lbs. of seed/bushel--yields thought to be impossible only a few years before. This same company also now does most of its control crosses of loblolly pine on small potted trees in greenhouses using an advanced breeding technology made possible by the rapid implementation of basic research on early flower initiation. These are both fine examples of good accountability, technology transfer and rapid implementation.

SUMMARY

Short-range IPM objectives should be aimed at reducing the frequency, rates, and costs of insecticide use through improved timing and efficiency of applications. We also need to develop better methods of monitoring insect activity, whereby orchard managers can decide to use insecticides only when the threat of damage is real, rather than anticipated or imagined. Finally, we need to find ways to minimize the impact of insecticides on beneficial insects.

The full potential of IPM for seed orchards can only be achieved by a carefully designed, organized effort to identify areas where additional information and understanding are required. There are thousands of variables associated with orchard management and the complex of insects found there. Our challenge is to discover those that we can use to understand the dynamics of this particular biological system.

For the foreseeable future, insecticides will continue to be major components of this sytem. However, we should remain alert to their many shortcomings. I believe that through creative and innovative research we can exploit a variety of biological, chemical and cultural alternatives. At best, this integrated approach to the control of cone and seed insects will minimize outbreaks and the need for a crisis-response. Control will not be absolute. However, the opportunities for developing an IPM system for the South's forest tree seed orchards are so varied and unique that our success is almost a certainty.

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