Deployment of Tree Resistance to Insects in Short Rotation Biomass Plantations

D.R. Coyle, *US Forest Service, New Ellenton, South Carolina*
J.D. McMillin, *US Forest Service, Rapid City, South Dakota*
R.B. Hall and E.R. Hart, *Iowa State University, Ames, Iowa*

Short rotation woody crop (SRWC) plantations use fast-growing tree species (such as Populus and Salix) grown under intensively managed conditions much like traditional agricultural crops (Dickmann and Stuart 1983). Typical rotation age ranges from 3–15 years, with the end products including energy and paper (pulp) products. Operational biomass plantations currently use a limited number of clones that probably exhibit modest host plant resistance to insects and may be promoting insect adaptation to resistance. Current control methods include clonal rotation and pesticide use (Abrahamson et al. 1977). There is a need to find and implement more effective insect resistance mechanisms and clonal deployment strategies into SRWC plantations.

Scientists still debate the number of clones needed for large-scale deployment. Theoretical models suggest up to 20 (Libby 1982, 1987) and even more than 30 (Roberds and Bisher 1997). However, most large scale operations currently use far less than that. More pest resistant clones need to be developed for use in SRWC systems in order to provide adequate pest control and to make the clonal deployment strategies work. Clonal deployment strategies of host plant resistance include monoclonal stands, mosaics of monoclonal blocks that contain varying resistance traits, clonal rows, and single tree and small groups of trees (Zsuffa et al. 1993). Pest risk in SRWC systems is negatively correlated with cultural intensity and financial input. Thus, risk decreases from monoclonal stands to single and small groups of trees, whereas the cost and labor required increases.

Monoclonal stands are large, single clone stands (up to 20 ha in size) both treated and harvested uniformly (Hall 1993). Of the four strategies mentioned, monoclonal plantations are the most cost- and labor-efficient and generally most-used by industry (Eaton 2000). However, large monoclonal blocks increase susceptibility to pest problems, as once a pest becomes established it can spread unimpeded throughout the entire plantation. The monoclonal block mosaic plantation strategy consists of several clones, each planted in relatively small monoclonal blocks so that no two like clonal blocks are adjacent (DeBell and Harrington 1993). This system allows clones to be continually removed and replaced, thus keeping a fully stocked plantation and constant supply of wood. From a pest management perspective, this planting pattern is more desirable than pure monoclonal blocks. In the event that one of the clones becomes infested with an insect or pathogen, individual clonal blocks can be managed separately. Clonal rows are generally used in selection trials and cutting orchards (Coyle, personal observation). Clones are planted in adjacent single rows, allowing the assessment of pest susceptibility and various growth parameters on many clones at one time. Research at Long Ashton, U.K. suggested that mixing rows of susceptible and resistant willow clones may both delay the onset of rust epidemics and reduce the movement and subsequent damage caused by chrysomelid beetles (Royle et al. 1998; Peacock et al. 1999). The planting method with the least pest risk entails single tree mosaics or small groups of trees. This method is by far the most time and labor intensive to establish but provides the greatest protection from pests. Single-tree or polyclonal plots also are subject to more inter-plot competition and therefore can result in overall reduced biomass production compared with monoclonal plots (DeBell and Harrington 1997). Single-tree plots can be beneficial for research activities, primarily because they eliminate environmental variances that can occur within plots (Libby and Cockerham 1980). However, should a single clone become infested, it is much more difficult to remove without harming the other trees.

Incorporating host plant resistance into SRWC systems can be accomplished in several ways. Traditional tree breeding is the standard technique in which superior clones are generated for SRWC systems. This method is labor-intensive and can take years to develop suitable clones.

However, opportunities to discover more lines of resistance may occur during large clonal screening trials. Also, this is the most socially acceptable and environmentally friendly means of improving stock used in SRWC systems.

Genetic engineering has recently surged to the forefront in many scientific fields, and SRWC clonal development is no different. There have been several attempts to use genetic engineering to insert resistance genes, including *Bacillus thuringiensis* and protease inhibitor genes, into *Populus* clones (McCown et al. 1991; Klopfenstein et al. 1997). However, environmental and societal concerns may affect the operational status of genetically-engineered clones. Transgene contamination in natural species and the possibility of transgenics escaping and becoming weeds are risks associated with genetically engineered crops (Gould 1998). Several mitigation options do exist, however, including plant sterility, wound inducible genes, and harvesting before trees reach sexual maturity.

Integrated pest management (IPM) incorporates several pest control methods into one pest management strategy. The development of an IPM plan for SRWC pests should be a priority. *Chrysomela scripta F.* (Coleoptera: Chrysomelidae) is the most damaging defoliator to *Populus* in the US (Burkot and Benjamin 1979). *Populus* clones vary in their susceptibility to *C. scripta* (Caldbeck et al. 1978). The use of resistant clones will serve as the foundation for *C. scripta* control, as beetles will spend less time feeding and ovipositing on these clones (Bingaman and Hart 1992). Leaf surface phagostimulant amounts also exhibit clonal variation (Lin et al. 1998), and could be used for clonal selection or trapping mechanisms. Natural enemies do contribute to *C. scripta* population control, but seemingly not to a great extent (Burkot and Benjamin 1979; Jarrard 1997). Because of the multivoltine lifestyle and reproductive potential of *C. scripta* (Coyle et al. 1999), natural enemies alone do not seem to be able to control populations effectively in plantations. Present management for *C. scripta* is dependent upon applications of insecticides, often on a calendar schedule. Unfortunately, this process encourages the development of resistant biotypes, thus negating the efficacy of the control method. Biorational sprays are an effective chemical control method (Coyle et al. 2000), but care must be taken not to overuse one formulation. Insecticide applications can be reduced further by incorporating an accurate economic injury level (EIL) (Pedigo et al. 1986) for *C. scripta* on plantation *Populus.* Economic gain would occur only when populations or damage above the EIL were treated.

Population monitoring is an essential aspect of *C. scripta* management. Visual (Coyle et al. 2000) and trapping (Nebeker et al. n.d.) methods have been used successfully to determine *C. scripta* life stages. This information could be used in conjunction with biorational sprays, as early life stages are the most vulnerable (Bauer 1990; Coyle et al. 2000). Plantation managers can use this information to best predict the optimal time to apply treatment. Degree–day (DD) calculations also can be used to predict appropriate spraying times (Nebeker et al. n.d.). Jarrard (1997) found that predicted DD requirements were within two calendar days of development observed in the field. This information can be used to create a better spray schedule based on insect life stage rather than on a strict calendar schedule.

In summary, many components of an IPM program for *C. scripta* have been developed. What is needed is the integration of all these aspects together for at least one rotation. This could serve not only to test the accuracy of the information elucidated to date, but would serve as a benchmark to determine the most effective directions for additional research.

Traditional agriculture's use of IPM strategies for pest management is more advanced than that of forestry systems. Future strategies using IPM for the control of insect pests of short rotation *Populus* systems will include a combination of host plant resistance, genetic engineering, biorational sprays, planting design strategies, and biological control. Research needed to reach this integrated approach includes further identification of host plant resistance, large-scale testing of different deployment schemes, and further examination of the impact that natural enemies have on *Populus* insect pests.

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