EXTENDING THE CAPABILITIES OF AN INDIVIDUAL TREE GROWTH SIMULATOR TO MODEL NON-TRADITIONAL LOBLOLLY PINE PLANTATION SYSTEMS FOR MULTIPLE PRODUCTS

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ABSTRACT

Demand for traditional wood products from southern forests continues to increase even as demand for woody biomass for uses such as biofuels is on the rise. How to manage the plantation resource to meet demand for multiple products from a shrinking land base is of critical importance. Non-traditional plantation systems comprised of two populations planted on the same site and managed for multiple products may be an economical and environmentally attractive alternative. In order to examine the feasibility and profitability of these systems, growth and yield models flexible enough for such regimes will be needed. In this paper we describe how an individual tree growth and yield simulator for loblolly pine (PTAEDA) can be altered to accommodate two populations of loblolly pine trees planted at different densities and spacings on the same site and managed for alternative product objectives. Investigations underway suggest that the individual tree growth model architecture may be a suitable platform for modeling such stands.

INTRODUCTION

By the turn of the 21st century, plantation forestry was practiced across 32 million acres of land in the Southern United States (Fox et al. 2004). The methods of intensive plantation management currently available to managers, including genetically improved planting stock, mechanical and chemical control of competition, the use of fertilizers and the manipulation of stand density through thinning, have equipped them to increase production from less than 90 cubic feet per acre per year common in the 1950s and 1960s to over 400 cubic feet per acre per year today (Fox et al. 2004). The vast majority of these plantations have been established with one population at a specific planting density. While income is sometimes obtained from wood harvested at intermediate thinnings, these plantations generally are managed under the assumption of removing primarily pulpwood in thinnings and aiming at sawtimber at final harvest.

Growth and yield models are tools for making informed decisions about the management of plantations and for estimating the outcomes of those decisions on productivity. As such, most growth and yield models for southern pine plantations are developed at the stand level to model operational management practices that are made at the stand level. Growth data from trees measured on plots in operational stands or from research studies are expanded to per acre values and used to model the growth and development of the stand. Stand-level models for predicting unthinned stand yields were among the first growth and yield models to be developed (MacKinney and Chaiken 1939). Subsequently, size-class distribution models have been developed to distribute total yield across the diameter distribution at any specified age so that estimates by product can be obtained (Avery and Burkhart 2002). In recent years as plantation forestry has become more intensive, data from designed experiments have been used to construct response models for various silvicultural treatments such as thinning (Amateis 2000) and fertilization (Amateis et al. 2000). Component models are often assembled into decision support systems for making stand-level predictions and projections (Amateis et al. 1996). Due to the regularity of the growth and development of single-species even-aged plantations established at a uniform planting density, growth and yield models developed at the stand-level have generally been adequate for modeling the southern pine plantation resource.

NON-TRADITIONAL "FLEX" STANDS

Recently, interest has been growing in non-traditional even-aged plantations, sometimes called "flex" stands. Flex stands are comprised of two populations of trees planted on the same site and managed for alternative product objectives. One population may have genetic, growth or wood quality characteristics that warrant a different planting spacing than the other population. Trees from each population are mixed together on the landscape. Distances between rows and between trees within rows may vary for each population. This creates stands with a different number of trees per acre and different spatial patterns for each population.

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Management regimes may vary for each population. Some of the advantages of non-traditional flex stands over conventional plantations where only one population of trees is grown include:

1. Efficiently produce multiple products on the same site
2. Attractive for areas where markets for biomass and pulpwood are strong.
3. Permits herbicides and fertilizers to be focused on the crop tree component of the plantation.
4. Permits the deployment of expensive technology and genetic material across more acres.
5. Presents high-efficiency thinning opportunities with take-out rows of non-crop trees.

Currently there is no extant growth and yield model in the public domain for modeling flex stands. The dual-population nature and atypical spatial patterns characteristic of flex stands makes traditional stand-level growth and yield models cumbersome tools for estimating yields of these stands. A more useful approach for modeling flex stands may be the individual-tree distance dependent (IDD) modeling architecture. The modeling unit for the IDD modeling approach is the individual tree. Tree height and diameter growth models are developed from parameters associated with the site and characteristics associated with each tree and its neighbors. Tree mortality is a function of the site, the vigor of each tree, and the competitive pressure exerted on each tree from its neighbors. The spatial nature of the IDD framework makes it attractive for modeling the atypical spatial planting patterns associated with flex stands. The loblolly pine IDD model, PTAEDA (Daniels and Burkhart 1975), is a published model that appears promising for use with flex stands. The purpose of this paper is to suggest how PTAEDA can be modified to model flex plantations comprised of two populations of loblolly pine trees growing on the same site and managed for different product objectives.

METHODS AND RESULTS

The PTAEDA IDD model framework has been used for modeling the growth and development of loblolly pine plantations since the mid-1970s. The core individual tree growth equations comprising the PTAEDA simulator are composed of potential height and dbh increment equations modified by functions that take into account individual tree attributes and the competitive environment in which the trees grow. A stand-level equation expressing the potential height increment of all trees in the stand based on site index and a tree-level potential diameter increment equation based on how open grown trees of the same dbh and age grow are modified by a competition index (Hegyi 1974) that reflects the intra-specific competitive pressure exerted by neighboring trees. Trees are assigned coordinate locations on a x-y grid and annual growth is predicted. Suppression induced mortality occurs as the growth rate of less vigorous trees slows in relation to more vigorous neighbors. Over the past 35 years, the PTAEDA IDD simulator has evolved to keep pace with changes in loblolly pine plantation management. In the mid-1980s the core equations in the simulator were applied to a region-wide set of growth data collected from operational loblolly pine plantations established on cutover, site-prepared areas (Burkhart et al. 1987). Mid-rotation fertilization response functions (Hynynan et al. 1998) and juvenile growth response to early site preparation, fertilization and competition control treatments (Westfall et al. 2004) were fitted to appropriate data and incorporated into the simulator in the 1990s. Enhanced thinning and pruning algorithms were added during the same period.

The software has evolved over the same period as well. Originally coded in fortran and executed on large mainframe computers common in the 1970s, the fortran code was migrated to the DOS-based PC platform of the 1980s to make the simulator available to a broader base of users. In the 1990s the fortran code was converted to C and the simulator was made compatible with Windows-based operating systems gaining favor at the time. The current version (version 4.0) has enhanced graphical capabilities, a streamlined user interface, customizable merchandizing and output options, and an economic analysis package. It is fully compatible with the latest Windows-based computers.

In order for PTAEDA to be applied to the current generation of flex stands some additions and alterations to the software have been made:

1. A graphical tool was created and added to the user input options to allow a user to define a flex stand pattern. The pattern is the spatial arrangement of one or two populations (A or B) of loblolly pine in the stand. Any flex stand pattern that can be expressed with up to 5 rows and 5 trees within the row can be simulated. Distances between rows and distances between trees within each row can be set by the user. The determination of which rows and which trees within each row are assigned to population A and population B are made by the user. Once the flex pattern has been defined it is propogated within the simulator to create an entire stand.
2. Each population is defined by two attributes: site index and the percent of the trees of sawtimber and pulpwood quality. Edit boxes were created to accept these inputs from the user. In the simulator each tree is assigned to a population (either A or B) with an associated site index value and stem quality code (sawtimber or pulpwood quality).
3. An additional thinning algorithm was added to allow the removal of all population B trees.

Figure 1 shows an example flex stand pattern developed for two populations of loblolly pine. One row of population A is followed by two rows of population B. Inter-row distance between population A and adjacent row of population B is 8 feet. Inter-row distance between adjacent rows of population B is 4 feet. Twelve feet separate the trees in the population A rows and 5 feet separate the trees in the population B rows. In this example, population A and B trees would have exhibited site indexes of 80 and 70 feet (base 25), respectively. The percent of trees of sawtimber quality would be 80 and 50 for populations A and B, respectively. Figure 2 shows how this flex stand looks on a per unit area basis after it is propagated within the simulator.

By relaxing the single population and uniform spacing constraints of the original PTAEDA, a modified simulator was developed that can accommodate the dual population and non-uniform spacings associated with flex stands. Data from a few very high site index flex stands were available to test and debug the modified simulator. Preliminary results from projections of these stands to rotation age indicate:

1. The IDD modeling architecture looks promising for easily defining and modeling the growth and development of a wide range of flex stands.
2. Estimates of yields on moderate to good sites appeared reasonable. However, under prediction of yields at rotation for very high site index stands planted with elite genetics was also exhibited.

DISCUSSION

Evaluating the growth, development and ultimately the profitability of flex stands presents unique challenges. The use of two populations of trees with different growth or wood quality characteristics and planted at non-traditional spacing arrangements for different product objectives means that traditional even-aged stand-level growth and yield models may not provide adequate estimates of the productivity of the stand as a whole or of either individual population. An individual tree distance dependent (IDD) modeling system may prove tractable for such stands. In IDD systems where the individual tree is the modeling unit of interest, trees grow based on their individual genetic characteristics, their environment and the competitive forces around their individual growing space. Distributional assumptions common with stand-level models need not be applied to IDD systems. Instead, with IDD systems, individual tree attributes such as volume or weight are summed to obtain stand-level or diameter class-level estimates of yield. In an IDD simulator, management treatments such as weed control, fertilization, thinning and pruning can be applied to a particular population of trees in the stand. This makes it possible to evaluate the impact of management scenarios on specific portions of the stand as well as how those scenarios affect the stand as a whole.

The modifications to the PTAEDA software discussed above allow flex stands to be modeled within the framework of an IDD growth and yield model. Preliminary evaluation of the performance of the model suggests that reasonable predictions can be made for flex stands established on moderate to good sites. However, the core growth and yield equations within the simulator will need modification in order to properly represent the growth relationships associated with flex stands exhibiting very high site index values. In particular, growth relationships associated with genetically different populations must be understood and then modeled in order to properly extend the IDD system to the elite genotypes currently being deployed as flex stands. Investigations are now ongoing in the following areas:

1. There is some evidence that the simple diameter ratio, distance weighted competition index (Hegyi 1974) currently employed in PTAEDA may not be the best measure of competition for all populations at all ages of stand development. Additional measures of competition that include height may improve the predictive capability for some populations of loblolly pine deployed in flex stands.
2. The identification of competitors in IDD models is critical because the number and size of competitors determine the competition index associated with each tree. The variable radius plot methodology used in PTAEDA to identify competitors of subject trees is being tested against other methods of identifying competitors in order to find the best method for non-traditional spatial patterns.
3. Questions concerning competitive relationships between trees are also under investigation. For example, will trees in plantings of varietals compete more or less aggressively with each other than individuals planted in stands of varying genetic makeup? Do different genotypes use available growing space differently and, if so, how? Will some genotypes favor diameter growth over height growth compared to other genotypes and, if so, how can this disposition be accounted for in the competition index?

The outcome of these and other investigations will lead to a more robust simulator that should better reflect the growth dynamics in non-traditional flex stands.

The flex stand simulator discussed here was developed for one or two populations of loblolly pine. The populations are defined by different site indexes, planting densities, and stem quality characteristics. The system is flexible enough, however, to accommodate additional defining characteristics for each population, including different species, as long as the competitive relationships between the two populations can be quantified. For example, future versions of PTAEDA could accommodate flex stands comprised of pines and hardwoods growing together on the same site if the competitive relationships between the populations were known.

Relatively few operational flex stands comprised of two populations of loblolly pine have been established to date.