SIMULATING THE EFFECTS OF SITE INDEX VARIATION WITHIN LOBLOLLY PINE PLANTATIONS USING AN INDIVIDUAL TREE GROWTH AND YIELD MODEL

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Abstract—Site index is the most common metric of site productivity in loblolly pine plantations. Generally applied as a constant for a particular stand, it provides an overall measure of a site's ability to grow trees. It is well known, however, that even the most uniform stands can have considerable variation in site index due to soil factors that influence microsite, variation in genetics from tree to tree, or the uneven application of silvicultural treatments. To better account for such variability, input options to the PTAEDA (version 4.1), an individual tree growth and yield model, were expanded to allow groups of trees at time of planting to be assigned to different site index classes and the variability within those classes to be specified by the user in different ways. This capability allows comparison of alternative methods of introducing site variability into individual tree simulators such as PTAEDA. Preliminary results suggest that the individual tree distance dependent growth and yield model architecture is a useful platform for defining site productivity patterns within stands and evaluating the impact of those patterns on growth and yield.

INTRODUCTION

Characterizing the productive capacity of a site to grow trees is one of the first and most important assessments land managers must make. Site index, defined as the height of the dominant portion of the stand at a standardized (index) age, has long been accepted as the most direct, common measure of overall productivity for loblolly pine plantations. It has the advantages of being quantifiable, easy to measure and relatively insensitive to changes in stand density (Clutter and others 1983; Burkhart and Tomé 2012). While usually treated as a constant for a given stand, site index is actually an average height whose value depends on the sampling scheme used to obtain an estimated dominant stand height (Smith and Burkhart 1983) as well as the definition of dominant stand height itself (Sharma and others 2002). Further, it can vary due to changes in edaphic and climatic factors over time and the influence of management treatments.

Although the term implies a measure of productivity, it is only meaningful for the particular trees growing on that site. That is, site index is really a composite measure of a site's productive potential to grow a specific population of trees. For example, the same acre of land might be excellent for growing loblolly pine with a high loblolly pine site index value but poor for growing yellow poplar with a correspondingly low value for yellow poplar.

Ameliorative treatments that alter the productive potential of a site must also be weighed when assigning a site index value to a stand of trees. Draining and/or bedding of inherently wet sites and adding phosphorus to phosphorus deficient sites are examples of early treatments that can have a large impact on the site index of loblolly pine (Allen 1987; Allen and others 1990). Mechanical site preparation prior to stand establishment can also affect site index. For a cutover site-prepared loblolly pine plantation established in the North Carolina Piedmont following clear cutting, Fox and others (1989) found that piling logging slash into windrows following harvest resulted in a 23 percent reduction in volume yield compared to an adjacent site that received a broadcast burn site preparation treatment following harvest. On the same tract, they found the site index between the windrows to be 11 feet less than the broadcast burn area. Within the windrowed area, the height of the trees decreased rapidly as distance from the windrow increased so that the average height of windrow-adjacent trees was 10 feet taller than windrow-interior trees.

Stand conditions such as those just described produce variations in site index that are visually obvious from the height growth of the trees on the site. However, even the most uniform sites have microsite and genetic variation across the landscape and from tree to tree that affect growth. These sources of variation and their interactions

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may not be visually obvious but can have an impact on overall stand productivity and product distributions at harvest. Growth and yield models that can account for variation in site productivity due to microsite and genetic influences and unevenness in treatment applications should be useful for assessing the impact of these important factors on the productivity of loblolly pine.

The loblolly pine individual tree distance dependent (IDD) model PTAEDA (Daniels and Burkhart 1975) for old field loblolly pine plantations has a general model structure that appears suitable for studying these factors. In PTAEDA juvenile mortality is assigned at random, trees are set out on the landscape in an x-y grid and the initial heights and diameters at time of initiation of intraspecific competition are obtained from the Weibull distribution. The core individual tree growth equations are comprised of a potential height increment equation based on a site index equation and a potential dbh increment equation defined by the open grown diameter increment equation of Daniels and Burkhart (1975). These potential equations are then modified by a competition index (Hegyi 1974; Daniels 1976) that reflects the intraspecific competitive pressure exerted by neighboring trees. Random components obtained from the fitted growth equations are then added to the height and dbh increment to account for the variation in tree growth from year to year.

While the general model structure of PTAEDA has remained foundational since its inception, it has shown itself to be quite flexible and able to accommodate additional enhancements and features incorporated through the years. Major enhancements have included re-estimation of core equations using a large region-wide set of data from cutover site-prepared plantations (Burkhart and others 1987) (version 2.0), addition of mid-rotation fertilization response functions (Hynynen and others 1998), juvenile growth equations (Westfall and others 2004) reflecting the effects of alternative site preparation treatments (version 2.1), addition of individual-tree thinning capabilities, diameter distribution and stem quality input capabilities by diameter class (version 3.1), linkage with the Stand Visualization System developed by the Forest Service, additional merchandizing and economic evaluation options (version 4.0), and the capability of modeling so called “flex” stands comprised of two populations (version 4.1) (Amateis and Burkhart 2012). Table 1 summarizes much of the evolution of PTAEDA through the years.

The purpose of this paper is to show how PTAEDA 4.1 has been adapted to account for variation in site index due to factors that are not constant across the landscape such as microsite influences, variation in genetic potential from tree to tree, and the uneven application of silvicultural treatments.

METHODS

In order for PTAEDA to be useful for studying the impacts of variation in site index, additions to the input options were made to allow the user more control over how initial tree characteristics are defined in the simulation plot. First, a graphical tool was installed to allow definition of groups of trees that are determined by mean site index and coefficient of variation (CV) about that mean under the assumption of a normal distribution. Groups can be circumscribed in the plot as rectangles, ovals or drawn freeform. The number of groups must be at least one, there must be at least two trees in every group, and all trees must be assigned to a group. This relaxes the usual assumption that site index is a constant stand attribute applying to all the trees. Instead, site index is a tree variable with value for any given tree depending on the mean and the CV of the group in which it resides:

$$S=\bar{S}+\bar{S} * CV/100 * st\_nor\_dev$$

where S is the assigned site index for each tree of a group, $\bar{S}$ and CV are the mean and CV for the group, and *st_nor_dev* is a standard normal deviate. When this is done, each tree in the group has its own site index value, or growth potential, that will be somewhat more or less than the mean for the group. The choice of $\bar{S}$ and CV reflect the overall productivity and the variation of that productivity for each group.

Each group of the stand is advanced to age 8, the end of the juvenile period, and the mortality by group, is assigned at random using the stand-level survival equations in PTAEDA. The minimum and average dbh of each group is determined by $\bar{S}$ and the trees surviving for the group. Initial dbh values are assigned to each live tree assuming a Weibull distribution. Initial height and crown ratio are assigned as in Burkhart and others (1987). After assigning all initial tree sizes, a competition index is calculated for each tree based on the size of the tree and its qualifying neighbors who may reside within or outside the subject tree’s group. Information for every tree is then passed to the stand growth algorithm for projection. Mid-rotation management treatments are handled in the usual way. Output options that include exporting the list of tree attributes along with group characteristics have been added to facilitate post-processing of simulation results.

CASE STUDY

The unreplicated case study of Fox and others (1989) was used to test the usefulness of the site index modifications to the PTAEDA simulator. The study consisted of a three acre loblolly pine stand in the North

Table 1—Overview of the evolution of the major data, models and software used in the PTAEDA simulator from its inception to version 4.1

Characteristic	PTAEDA (1975)	PTAEDA2 (1987)	PTAEDA4.1 (2015)
		Data	
Plot	Old field (Burkhart and others 1972)	Cutover site-prepared (Region-wide)	Cutover site-prepared (Region-wide)
Tree Growth	Limited mapped studies	Cutover site-prepared (Region-wide)	Cutover site-prepared (Region-wide)
Potential dbh growth	81 open-grown	81 open-grown	81 open-grown
		Models	
Juvenile mortality	Random	Random	Random
End of juvenile period	CCF = 100	Age 8	Variable or age 8
Site Index	Anamorphic (Burkhart and others 1972)	Polymorphic (Amateis and Burkhart 1985)	Polymorphic (Diéguez-Aranda and others 2006)
Crown Ratio	Linear	Non-linear (Dyer and Burkhart 1987)	Non-linear (Dyer and Burkhart 1987)
Potential Dbh Increment	Linear	Linear	Linear
Competition Index	Weighted Size Ratio (Hegyi 1974)	Weighted Size Ratio (Hegyi 1974)	Weighted Size Ratio (Hegyi 1974)
Height Increment Adjustment	Non-linear	Non-linear	Non-linear
Dbh Increment Adjustment	Non-linear	Non-linear (optional hardwood competition)	Non-linear (optional hardwood competition)
Mortality	Non-linear	Non-linear	Non-linear
Simulated Trees	Fixed at 100	Variable between 25 and 400	Fixed at 625
Planting Patterns	Regular	Regular or Irregular	Regular or Irregular
Silvicultural treatments	Thinning, fertilization	Thinning, fertilization, pruning	Thinning, fertilization, pruning, site preparation
		Software	
Implementation	Mainframe (Fortran)	PC DOS (Fortran)	PC Windows (C++)
Input	Stand variables	Stand variables	Stand, diameter distribution variables
Output	Stand tables	Stand tables, tree list	Stand tables, tree structure, SVS visualization, financial NPV

Carolina Piedmont that was harvested in the fall of 1953. In early 1954 the logging slash was sheared and piled into parallel windrows about 200 feet apart. The windrows were neither burned nor planted leaving about 11 percent of the area unutilized. The area between windrows was planted on 6 feet x 6 feet spacing and grown to age 25 where a mid-rotation thinning removed 1204 cubic feet per acre volume inside bark leaving a standing residual volume of 2783 cubic feet per acre. The residual stand was grown to age 31 when plots were established across the non-windrowed portion of the stand. Approximately twenty-five feet out from the edge of the windrows (about 4 rows) was considered to be "windrow-adjacent" and the center portion between windrows was "windrow-interior". Height and dbh measurements were collected and the stand was clearcut. Plot summaries were compiled and results reported (Fox and others 1989). In the windrow-interior portion of the stand heights were shorter than the windrow-adjacent areas leading to an estimated site index of 56 feet for the windrow-interior areas and 66 feet for the windrow-adjacent areas. This "windrow effect" resulted in a correspondingly higher total volume per acre production in the windrow-adjacent areas compared to the windrow-interior areas.

To test whether PTAEDA could reproduce the growth of this stand, conditions at time of stand establishment were inputted to the PTAEDA simulator. Three groups were defined using the new site productivity pattern capability: (1) an unutilized windrowed area, (2) a windrow-adjacent area, and, (3) a windrow-interior area. (fig. 1). From establishment records and the Fox and others (1989) data, the site index and CV for the windrow-adjacent group were set at 66 feet and 12, respectively, and 56 feet and 10, respectively, for the windrow-interior group. The differentiation in site index between the two groups is apparent by age 8 at the end of the juvenile period (fig. 2). The stand was projected to age 25 where the mid-rotation thinning treatment was applied. Based on assumptions that the thinning was a low thinning with removals of selected larger trees that were unsuitable for a final sawtimber harvest, the basal area of the stand was reduced to 95 square feet per acre resulting in 1265 cubic feet per acre volume inside bark removed. The residual stand was projected to final harvest at age 31.

For comparative purposes, a second simulation was conducted exactly as the first ascribing one overall site index to the stand. Thus, the windrow-adjacent and windrow-interior groups were combined into one group and an area-based weighted average site index of 60 feet with CV set to zero was used. Table 2 compares the volume estimation from the two simulation results against the observed plot data from Fox and others (1989). The results of this comparison suggest that for this case, grouping the trees according to distance from

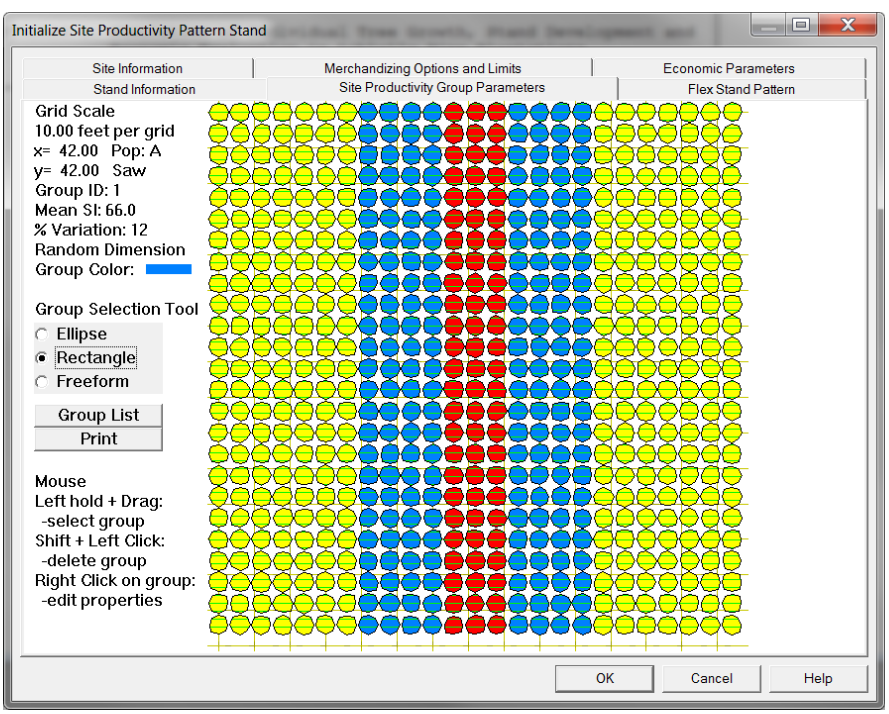

Figure 1—Example site productivity pattern definition comprised of three groups consisting of an unutilized windrow in the center (red) flanked by a windrow-adjacent group of trees (blue with mean site index of 66 feet and CV of 12) and a windrow-interior group of trees (yellow with mean site index of 56 feet and CV of 10).

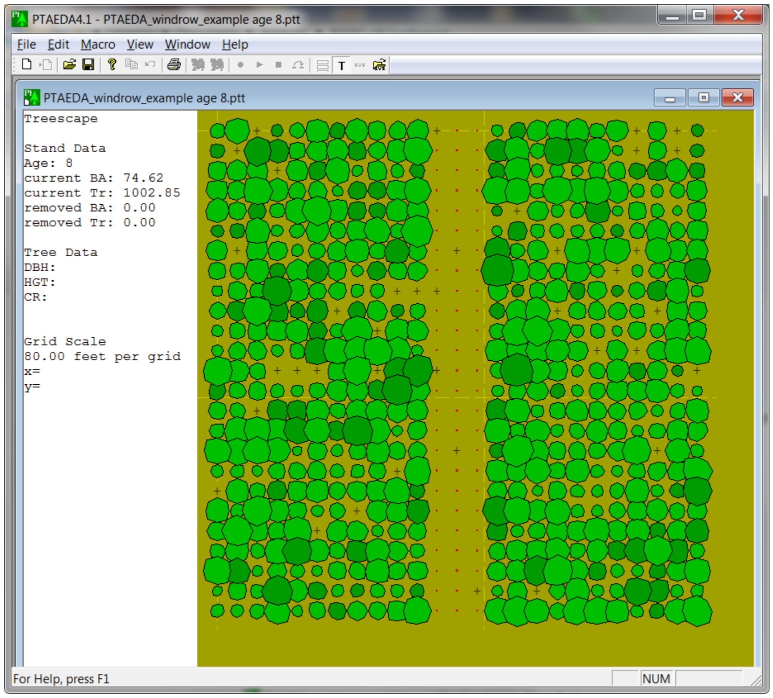

Figure 2—Example stand shown at the end of the juvenile growth period at the initiation of intraspecific competition (age 8).

Table 2—Observed total volume inside bark (cubic feet per acre) through 31 years of a windrowed loblolly pine plantation in the Piedmont of North Carolina compared to two PTAEDA simulations, one using the site productivity pattern capability with site index and coefficient of variation specified by group according to distance from the windrow (PTAEDA Grouped) and a second simulation where no grouping of trees occurs and only a mean site index with no variation is defined (PTAEDA Not Grouped)

Data	Standing Age 31	Total Harvested
Observed	2783	3987
PTAEDA Grouped	2730	3995
PTAEDA Not Grouped	2385	3487

the windrow and ascribing different site index values for each group rather than assigning one overall site index value to the stand will give more realistic yield predictions.

DISCUSSION

As noted in Fox and others (1989) the effect of windrowing on site index is actually a gradient with trees closest to the windrow being the tallest and gradually decreasing in height as distance from the windrow increases approaching some lower plateau toward the windrow-interior area. For simplicity, the area between the windrow was divided into two groups, the boundaries of which were set somewhat arbitrarily. But with the IDD modeling system of PTAEDA, the analysis could be expanded. For example, if data were available, each row could be assigned to a separate group based on distance from the windrow and each group assigned a mean site index and CV. This would expand the number of groups and could account more completely for the height gradient seen in the transect data collected on the site. This level of detail should improve estimates of yield for various portions of the stand and for the stand as a whole.

The case study examined here shows how shearing and piling has impacted the microsite variability within a stand. Other silvicultural treatments such as bedding, fertilization and weed control can also affect microsite variation especially when applied unevenly. If patterns of variation can be identified from soil maps, historical records, ground-based measurements or remotely sensed imaging, PTAEDA should be a useful tool for modeling the growth and development of such stands.

Variation due to planting stock can also affect stand growth. PTAEDA could be used to model two identical sites where one has been established with an elite varietal with a higher exhibited site index value and lower CV than the other site established with open pollen stock. From data, or perhaps assumptions about the effects of genetics on the mean and variation of site index and by holding all other site, stand and management treatment variables constant, it should be possible to simulate the impact of different genetic stock on stand growth using PTAEDA.

By relaxing the usual assumption that site index is a constant for a particular stand and allowing the user to specify groups of trees with a mean site index and associated CV, the IDD modeling system of PTAEDA should be helpful for evaluating the effects of site and tree characteristics that impact stand development. The system is very flexible and able to simulate a wide variety of site, stand and treatment conditions given alternative assumptions about how such conditions affect site index making it ideal for “what if” scenarios.

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