VALUE CREATION THROUGH FOREST BIOTECHNOLOGY

by

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(Under the Direction of David H. Newman)

ABSTRACT

A financial analysis framework is presented for analyzing the impacts of intensive silvicultural regimes through forest biotechnology applications, which promise substantial returns by enhancing stand development, raising wood quality standards, and increasing uniformity. Three important aspects of forest biotechnology are addressed. First, gains in volume through genetics or other silvicultural improvements are analyzed. Results show that more intensively-managed regimes with higher growth rates produce more forest products from less land at a lower cost, and increase marginal returns. Second, regulations and general policy for protecting intellectual property are presented, and a methodology for capturing genetic advances using royalty price premiums is developed. A hypothetical case is made wherein a high tech seedling producer can be financially indifferent between selling seedlings for reforestation or for propagation, while protecting its intellectual property. Third, using data from loblolly pine plantations, a descriptive analysis and assessment of the uniformity trait in vegetatively propagated and zygotic stands is made. Effects on current growth and yield models, and their implications for economic analysis, are evaluated.

INDEX WORDS: Financial analysis, forest biotechnology, genetic advances, growth and yield, intellectual property, loblolly pine, royalty, uniformity

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

This dissertation addresses how value is created through forest biotechnology. Although biotechnology applications in forestry are in their infancy compared to those in agriculture, propagation (rooted cuttings and/or somatic embryogenesis) is one of the major areas of development in forest biotechnology (Sedjo, 2004; 2001). This research focuses on analyzing certain implications of vegetatively propagated trees when they are deployed in commercial plantations. In general, the performance of elite varieties is compared to improved trees that have undergone rigorous selection by breeding programs.

The format of this dissertation will be to address three distinct components of the value gained from biotechnology in forestry. These values are generated by increasing the quantity and/or quality of the forest product and through the marketing of the technology itself. The first chapter considers the profitability of current and potential biotechnological advances in a general sense. The second chapter reviews legal instruments for protecting such advances and offers a financial application showing means for valuing the technology. The third chapter describes and assesses one value component of elite varieties: between-tree and within-varietal uniformity.

The first chapter began under the sponsorship of the Institute of Paper Science and Technology (IPST) in 2001. The project was titled, “Commercialization of Forest Biotechnology: Economic Targets for Enhanced Global Competitiveness of the U. S. Pulp and Paper Industry,” and was led by Dr. Gary Peter. The project was conceived, as a whole, to encompass the entire production process, from tree growth to finished rolls of paper, including an economic analysis of the effects of biotechnology and silvicultural practices that have the greatest potential to enhance the global competitiveness of the U. S. pulp and paper industry.

The forest cost model considered fiber production (pulpwood/unthinned regime) and timber production (multiproducts/thinned regime) under the highest standards of forest management practices. This model incorporated the latest Growth and Yield (G&Y) equation systems, along with the functions developed by the Plantation Management Research Cooperative (Harrison and Borders, 1996; Pienaar et al. 1996; Pienaar and Rheney, 1995) for incorporating growth responses to site preparation, fertilization, and weed control for loblolly pine in the Lower Coastal Plain. The last module added was harvesting and transportation costs using the Auburn Harvesting Analyzer Simulator developed by Tufts et al. (1985). The model was assembled in Visual Basic and Excel, and assessed the profitability of intensive silviculture management, from plantation establishment to delivered timber, for a hypothetical kraft linerboard mill (344,000 ADMT/yr of softwood kraft pulp).

For simulating increased G&Y production levels, site index was used as the trigger for incorporating gains in volume that result from improved forest management methods, enhanced seedling quality, or other biotechnological advances in both thinned and unthinned management regimes. Beginning with a site index of 60, adjustments were set in increments of 10% to generate up to an approximately 50% higher volume over the base case (unimproved seedlings) at final harvest. The differences in BLVs, used as a proxy for computing financial gain, provided the marginal value at which forest investors could afford to pay for improved seedlings and/or any biotechnological advance. From this value, marginal rates of returns and break-even costs were determined.

The model found that more intensive management regimens with higher growth rates increased marginal returns. For the base case scenario with site index 60, in a commonly used fiber production regime (no thinning), returns were maximized at year 18 with an optimal bare land value of $124/acre vs. $850/acre and a potential 50% gain in volume. For the thinned, sawtimber oriented regime, returns were maximized at year 23 with an optimal bare land value of $200/acre for the reference case vs. $850/acre for a potential 50% gain in volume. At stand level, the delivered timber cost for the unthinned base case scenario was $36.8/ton vs. $27.4/ton at the 50% gain in volume, and for the thinned base case, the reference delivered timber cost was $37.0/ton vs. $28.2/ton at the 50% gain in volume. The break-even costs ranged from $0.16/seedlings to $0.90/seedling for the 10% or 50% gain in volume, respectively. Yin and Sedjo (2001) reported similar results. The more intensive the management, the better the financial returns.

Since these results are based only on total volume gain, they are conservative in the light of other attributes that add value to end-products, which were not quantified, including straightness of stem, reduction of defects like forking, or diseases like rust. Indirect aspects, such as inventories and logging, were also not accounted for. Given better and more predictable uniformity in stem diameter, inventory costs and labor would be reduced, and logging equipment designed to better fit specific sites and stand structures would increase productivity.

The recent advent of commercial production of vegetatively propagated seedlings, by either rooted cuttings or tissue culture, has sparked global interest in establishing elite variety plantations; however, there is a paucity of knowledge that addresses other concerns associated with this new technology. These were the main motivations in Chapter 4 for characterizing vegetatively propagated loblolly pine plantations, both to understand their stand dynamics along with evaluation of other traits, and to exploit product differentiation that enhances potential economic benefits.

Clonal forestry will surely follow traditional forestry in that early predictions for the gains from second generation seedlings in conjunction with intensive management seem overly optimistic. For example, Borders and Bailey (2001) stated that growth rates of over 9-14 m3/ac were possible along with shorter rotation ages. The immediate effects of more intensive silviculture combined with improved tree stocks resulted in faster growth and higher yield, as well as benefits related to wood quality, such as producing more uniform plantations. Today, these robust predictions for such yield gains seem quite defensible, even including some of the higher yield figures.

Researchers and producers have forecast significant gains from vegetatively propagated seedlings in both productivity and quality. Volume gains of 42% average yield improvement (53% for one commercial variety) over unimproved stock were reported by Weir et al. (2006). Wright and Dougherty (2006) presented an average volume gain of 22.8% (when 5% of the top varieties were retained) over mass control pollinated plots, which showed a gain of approximately 25% over unimproved check lots. These researchers concluded that the use of elite varieties, would raise sawtimber proportion over 50% (Weir) or even 80% (Wright and Dougherty) at harvest time. Remarkable results were reported by Wright and Dougherty, in a 9-year old study regarding rust infection reduction. They found that while the Control OP-7-56 recorded 70% rust infection, the Variety-93 was 11%. As per forking and ramicorn defects, the OP-7-56 was 35%; the Variety-93 was 11%. For sawtimber potential, the control was 25% vs. 89% for the variety. Fox et al. (2004), based on results from clonal plantations in other parts of the world, estimated increments on productivity in intensively managed pine plantations in the Southeast U.S. of at least 50% when matching specific clones to specific soil types.

As a consequence of their great potential for growth and improved quality, and the ability to tailor clones to specific end products, the necessity arises as to how to capture the value created and how to protect these "new products." The third chapter considers the value of this intellectual property and estimates the worth of exploitation rights for others.

Chapter 3 tracks the progress made in the agricultural sciences in assessing and protecting the value of genetic assets, like vegetatively propagated seedlings. Little research has accumulated for considering infringements that put at risk the commercial potential of elite variety seedlings, as the technology for operational production is about five years old. Therefore, it became necessary to follow the literature related to the development and history of other agricultural products with the following questions in mind: 1) How do producers protect cost-intensive research and development investments? 2) What regulations exist, and which might be related to forest biotechnology? 3) How do producers define price premiums, and what valuation methods are used? 4) Other questions arose as the research evolved, such as ones related to payment mechanisms, time frames for protection, and yield of rooted cutting production.

This chapter also discusses common valuation techniques for assessing royalties on tangible and intangible assets, and provides a price premium analysis that allows a potential buyer to propagate tested elite seedlings. Common methods of valuation for any type of property are the cost approach, the income approach, and the market approach, which are discussed in Denton and Heald (2004), and Smith and Parr (2005). Six common methods for valuing intellectual property include the use of industrial standards, tried-and-true rating/ranking methods, rules of thumb, discount cash flow analyses (with risk adjusted hurdle rates), advanced tools (probabilistic modeling), and auctions (Razgaitis, 2002).

A hypothetical case study is presented: A forest investor wants to develop a large reforestation program with varietal seedlings. One option for her is to buy sufficient elite seedlings in the open market (propagated by somatic embryogenesis) to meet her planting needs. Another option is to buy fewer SE seedlings but obtain the right to propagate more seedlings from them. The questions the producer faces are, what is a fair price to charge for a mother plant in order to maintain profitability, and what mechanism is best suited for such royalty payments?

To answer these questions, the price must reflect the “normal” or listed price plus a premium for the right to propagate, which is the royalty. A royalty is meant to compensate the producer for potentially lost sales when his intellectual property is transferred to the buyer.

The case study estimates royalty rates needed to capture the value created and intellectual property inherent in elite pine varietal seedlings when they are used for propagation rather than for reforestation. The approach follows a well-defined and broadly accepted methodology applied to a hypothetical case study, which includes the price that the end user will pay, the cost of producing and selling varietal seedlings, and the profit or margin.

The formulation of royalties, as described by Willey (2002) and Razgaitis (2002), is considered by many to be a black box art, and others are not comfortable evaluating technology and defining its monetary value at all. There is no right or wrong royalty rate; royalties usually result from a negotiation process between a willing seller and a willing buyer. However, in the end, the market place determines the selling price. The market will pay for value, not for cost. The market does not care how much the producer paid for developing its technology. If the product does not work, it has no value.

Smith and Parr (2005) illustrate a fair royalty rate for intellectual property of a hypothetical pharmaceutical company that is guided by market transactions at approximately 7% to 10% of net sales. Another approach is derived from the investment's rate of return, indicating a reasonable royalty fee of over 20%. For venture capital investments, required rates of return are a function of the developmental stages of a new technology, ranging from 50%, at start up, to 20%, in the final stages.

In Chapter 3, several possible royalty (compensation) payment structures were also considered, including paying up-front (a one-time payment); a series of scheduled payments (down payments) in conjunction with or without royalties (i.e. constant annual payments); and minimum payments, increasing over time, or vice versa, coinciding with actual propagation over a five-year period. For the case study, the payment structures ranged from $10.96/seedling to $3.75/seedling per year. These prices represent the payment to the producer for intellectual property rights.

Similar to the situation of scant literature related to protection of intellectual property for forest biotechnology, little has been published on the benefits of clonal uniformity in trees. For many, this value is simply treated as a natural outcome associated with genetic gains. However, what is often overlooked is the concept of uniformity as including consistent external and internal features from tree to tree of either zygotic or vegetatively propagated plantations. Being that clones are genetically identical, it is expected that this kind of plantation will be much less variable from tree to tree than plantations from seeds. Tree variability likely creates inefficiencies in the goods production chain. Therefore, increasing uniformity by using vegetatively multiplied seedlings should reduce variability and create additional value for a producer beyond any growth gains.

To exploit the value of the uniformity (in addition to growth and wood quality) offered by elite varieties, it is necessary to better understand the impact of genetic and local environmental variables on the desirable attributes required by end users. Thus, a tree's external features such as height and diameter (but also many others: straightness, stem taper, branch angle, branch and knot diameters, number of branches, whorls, internode lengths, and crown architecture; and internal features, such as specific gravity, tracheid properties, resin pockets, stiffness, microfibril angle, coarseness, and tolerance to diseases) must be evaluated in order to assess the economic value delivered by elite varieties with predictable characteristics.

Although varietal plantations usually show greater uniformity than zygotic plantations, potential risks exist. For example, a clone could exhibit an undesirable characteristic, such as diseases susceptibility or rough branching. If a clone exhibits negative reactions to extreme biotic or climatic events, such as drought or plague attacks, an entire plantation could be lost in absence of intervention. However, most risks can be managed given rigorous testing procedures for attributes like disease resistance, as is done in both agriculture and horticulture involving genetically fixed hybrids or vegetatively propagated plants.

Several studies have shown that tree-to-tree uniformity exists in asexually propagated trees. This reduces the coefficient of variation for a number of traits, some being very evident, such as diameter and volume, and may provide cost savings and increased product value (Sorensson et al, 2004; Nester, 2000; Shelbourne, 1997).

As clonal plantation data have developed, some hypotheses have been confirmed or rejected. One rejected hypothesis (Nance and Bey, 1979) is that as the variance of diameter is reduced, so would stand total volume/value be reduced. There has also been some skepticism about the main benefits from clonal plantations, whether they can be derived from quality attributes, such as uniformity in DBH distributions, rather than from gains in volume. By focusing on gains in volume, some also believe that given the significant impacts of environmental factors, harvesting conditions, and log segregation on clonal forest, the added value of uniformity is likely to be small.

Several scientists have published on several aspects of clonal forestry (C. Balocchi, B. Baltunis, C. Bey, R. Burdon, J. Brawner, M. Carson, S. Carson, M. Dieters, M. Foster, K. Harding, D. Huber, K. Jayawickrama, P. Jefferson, S. Knowe, S. Kumar, C. Lambeth, I. Last, W. Libby, D. Lindgren, E. Mason, R. Nakada, W. Nance, M. Nester, C. Matheson, D. Rockwood, A. Shelbourne, C. Sorensson, J. Tombleson, T. White, H. Wu, and undoubtedly others, particularly in New Zealand, Australia, Brazil, Chile, and in the U.S.). Unfortunately, many publications are theoretical, or use real data limited by either the scale of experimentation or crop age (Mike Carson, Forest Genetics; Charles Sorensson, Horizon2, personal communication, 2006).

Fortunately, there are several informative and classic articles in IUFRO Proceedings from the past decade that have relevance to various aspects of clonal forestry, for instance, *Genetics of Added Value to the End-Products of Radiata Pine* by A. Shelbourne, who compiled several clonal studies with radiata pine in New Zealand. Others studies reflect several concerns in clonal forestry, such as C-effects, physiological ageing from tissue culture clones on traits, and clonal wood properties of wood, stems, paper, and lumber.

The first opportunity for analyzing a sizable dataset for a uniformity study is presented in Chapter 4. It began two years ago with a large database of clonal and non-clonal eucalyptus plantations. However, the usefulness of these data is limited for valid comparison between clonal and non-clonal because of lack of historical and silvicultural information, and the difficulty of tracking multiple harvesting cycles (L. Estraviz, University of São Paulo, personal communication, 2005).

Except for those plantations from New Zealand, the majority of well-designed studies of softwood clones in the southern hemisphere began, basically, in the 1990s, and scale results are just becoming available. Other potential sources of information included large-scale clonal plantations; however, as was the case in Australia, these types of plantations were usually established without seedling controls for comparison (Mark Dieters, University of Queensland, personal communication, 2004). As a remedy, the Australians began in 2005 to establish seedling blocks scattered throughout clonal areas to provide fair-basis comparisons of clones vs. seedlings.

Another limitation of older experiments is that many were established with poorly-selected clones (single clonal and mixed blocks) that would make any analysis focused on genetic gain weak. In addition, only recently have research groups begun assembling growth and yield information from clonal trials, primarily overseas, of radiata pine and slash pine, and of loblolly pine in the U.S., like that compiled by the PMRC for this dissertation.

Chapter 4 uses both experimental and anecdotal evidence of clonal development and takes into consideration clonal repeatability estimates, notably those from M. Carson for sawtimber, wood quality, disease resistance traits, as well as visually, for diameter growth (personal communication, 2006). He also discussed one tangible benefit from uniform clonal radiata plantations: savings of 5-10% in pruning costs.

Another interesting argument discussed with New Zealand scientists throughout the progress of this research is: On the one hand, clonal uniformity exists; but on the other, site effects are real. Therefore, if Clone "A" is planted on a low-density and a high-density site, will they have the same density? Answer: No. In addition, if Clone “A” is planted on sites that are not flat (at the valley bottom, and up the hill, and at the hilltop), will all the stems look identical? Answer: No they probably will not.

These arguments also consider operational perspectives, for example: if a clonal stand has some regeneration that can not be controlled, and non-clonal logs are harvested and mixed in on trucks/skid sites/log processing yards, how can landowners obtain full benefits from clonal uniformity? Answer: If that mix reduces the crop value, it should be controlled *in situ*, and ensure that wood processors catch a "pure" flavor of the clonal logs so that they can recognize the true value of that clone “A” in that forest. Thus, they should be willing to pay a price premium, even considering the log yard’s segregation costs. This question and answer referred to DBH uniformity. Undoubtedly avoiding small or large diameter logs that a processor can not handle has economic value. Another: how valuable is the DBH uniformity of radiata in New Zealand? Answer: There is some value in NZ radiata from any DBH uniformity, but there might be relatively less value added to NZ radiata from a specific level of DBH uniformity, than for example, to loblolly pine in the U.S. In fact, because log specifications are larger in New Zealand than here, DBH uniformity there is more flexible. The real value of uniformity in radiata pine involves all key traits being more uniform, and this also helps break adverse correlations, such as big trees having big branches and poor wood stiffness (Charles Sorensson, Horizon2, personal communication, 2006).

In April 2006, after two years of research, it became possible to measure one of the oldest demonstration clonal blocks of loblolly pine in the U.S. at a crop age of 17 years old. A total of nine locations were cruised (16,000 trees), the last measurement performed in May 2007. With loblolly clonal data at hand, and permanent well-monumented plots for future monitoring on the ground, it became possible to begin to address many questions about the likely deployment of clonal pines in commercial plantations of the Southeast U.S.

Chapter 4 is purposefully broad since it asks basic questions like: 1) Do external tree features in single clonal plots differ from those in non-clonal plots? 2) What improved family could be used as industry standard (benchmark) for comparison? 3) Do current growth and yield systems need to be adjusted for modeling clonal plantations? 4) If so, what are the economic implications for using current models that do not reflect genetic differences between clonal and zygotic stands? 5) Do the uniformity growth parameters of clonal loblolly pine compare well to those reported in other clonal conifer species?

These questions among the others included here set the stage for considering how U.S. forests can remain globally competitive. The evolution of this dissertation begins with the examination of improving growth and yield through intensive silviculture. However, intensive silviculture is not enough. Advances in technology through vegetatively propagated trees can capitalize on the research and experience associated with traditional breeding programs, but the current state of the art is emergent. Therefore, Chapter 3 seeks to address one aspect of the burgeoning innovations: protection of intellectual property. Chapter 4 describes one attribute conferred by forest biotechnology, tests current tools for forest management, and establishes a benchmark for considering additional traits.

Literature Review

Competitiveness

Developing countries with cheaper land, lower labor costs, potential for higher tree growth rates, and relatively open economies have a competitive advantage over temperate countries (Cossalter and Pye-Smithl, 2003). Given this economic situation, investors must consider the cost contributions of wood growth, harvesting, and transportation (among other components) to the delivered-to-mill cost for plantation pulpwood.

The U.S. pulp and paper industry is in the process of significant changes in raw material supply. In the southern hemisphere, pine grows more quickly. As a result, over the past two decades in the U.S., fiber suppliers have shifted their focus from mature, non-cultivated trees to intensively managed trees and recycled fiber. These changes in raw material supply are driven by a shrinking land base and competition from other countries (NCFA, 2003; Peter et al. 2001).

The research by Greene et al. (2006) confirms that the U.S. forest products industry is dealing with greater global competition, population pressures, and changes in ownership and land use. Greene's study states that "the industry was a low-cost producer, benefiting from excellent infrastructure, productive forests on low-cost land, innovative logging contractors, and strong product markets," (p.3.4) but the South is no longer the lowest cost producer, even considering the impact of the recent weak dollar.

Harris et al. (2004), in their article *How competitive is the Southern Timber Industry?*, and Siry et al. (2006) describe the magnitude of forest business in the South: 203 million acres of forest (88% private/industry), including 39 million acres of yellow pine plantations, with high levels of harvest from Virginia to Texas (335 million tons annual harvest, 65% softwood, 35% hardwood), produces 18 percent of the world's industrial roundwood and 25 percent of global wood pulp production (40 million tons as of 2003) with just two percent of the world's forestland.

Silviculture and Biotechnology

As pointed out by Simpson (1999), biotechnology is a driving force for addressing global competition in permanent change. Recently, pulpwood companies have begun to get away from producing a uniform commodity pulp and are producing specialized pulp for targeted markets. Customized products often require customized raw materials. Using biotechnology techniques, desired fiber characteristics can provide more desired pulping properties, which in turn would be reflected in the properties of pulpwood and paper products, such as paper tear strength, surface texture, whiteness, and so forth. In the solid wood products segment, wood fiber is being processed more progressively into structural products that have their own assortment of desired fiber properties. Clones have been developed with specific wood properties that enhanced production and profitability (Fox et al, 2006).

However, fast timber growth rates may have drawbacks when compared to mature wood. Fast-growing trees that are harvested at younger ages have a higher proportion of juvenile wood, which is less dense, contains shorter fibers, have lower cellulose to lignin ratios, thinner cell walls, and decreased stiffness due to higher microfibril angles (Clark, 2006). Thus, growth rate is intimately tied to wood and fiber quality (Peter, 2002). Due to these interrelationships, cost models must account for simultaneous and flexible changes in tree growth rates and wood properties.

McKeand (2006) stated that landowners should plant the highest quality seedlings and apply more intensive management regimes (in their more productive sites) in order to obtain higher returns. Increased returns of $100/ac to $200/ac, when SI was increased 5 or 10 feet respectively, were found as a result of better loblolly pine genetics and several management intensities.

Forest optimization and Growth and Yield models

A number of systems have been developed for predicting the growth and yield in loblolly pine (*Pinus taeda L.)* plantations under various management regimes (Harrison and Borders, 1996; Borders, 2001; Amateis et al. 2001; Zhang et al. 2002). These systems generally include a set of equations to predict individual tree volume, green and dry weight, and a breakdown of likely products; they also include whole-stand growth and yield models with equations to predict volumes and basal areas of both thinned and unthinned tracts. A major challenge for such systems is incorporating state-of-the-art intensive management regimes within their predictions of incremental yield. These involved mechanical site preparation, herbaceous weed control, and fertilization (Borders, 2001; Pienaar et al. 1996). Using information from previous studies, the basic yield system can be adjusted to predict a "true" yield when different levels of treatment are evaluated. For example, estimates can be made for thinning stands, which include the computation of thinned basal area as a function of removals and the growth response for the remaining stand (Harrington, 2001 and 2002; Pienaar et al. 1996). Similarly, the response to midrotation treatments may be accounted for by including its additive impact on the dominant height and basal area baseline of the stand (Borders et al. 2001).

Several studies at national and regional levels have analyzed major factors that have the potential for boosting the competitiveness of forest resource industries in the U.S. (Borders et al. 1991; Bullard and Straka, 1998; Yin, 1998; Alig et al. 2000; Borders and Bailey, 2001; Smidt et al. 2005; and Hancock, 2001). Particularly influential was a study by Borders et al. (1991) entitled "Variable bedding, planting, harvesting and transportation costs impact on optimal economic management regimes," which used maximization of bare land values (BLV) as the decision criterion to optimize site preparation costs, planting density, and rotation age. BLV is defined as the net present value of a perpetual series of rotations associated with a specific forest management regime.

BLV for timber production is calculated assuming that land will be used to produce a perpetual series of even-aged or uneven-aged stands. Each stand in the perpetual series is assumed to have the same revenues and costs that are projected for the first rotation or the first cutting cycle (Wagner et al. 1995, Bullard and Straka, 1998). A number of studies have reported that maximization of the BLV, referred to as the Faustmann formula, is the most realistic financial measurement when values for cost and revenue streams vary along the rotation age and/or the planning horizon. This objective financial criterion is widely used for profit-oriented forest investments to evaluate their potential capital investments in timberland, to calculate optimal timber management regimes for numerous assumed levels of growth gains, and to compute their corresponding break-even costs at each gain level (Clutter et al. 1983; Newman, 1988; Borders et al. 1991, Wagner et al. 1995; Bullard and Straka, 1998; Borders and Shiver, 2001; Davis et al. 2001; Siry et al. 2001; Newman, 2002).

Although this paper focuses on timber production costs, it is important to highlight the role of various production factors in influencing the optimal timing of harvests (opportunity cost of harvesting now vs. the economic effect of delaying final harvest). Samuelson's (1976), Hyde's (1980), and Chang's (1982) research, among others, contributed to explaining the relationship of BLV variables and went beyond the theory of optimal rotation outlined by Faustmann. For instance, Chang (1982) evaluates the effect of changes in stumpage price and production costs on the optimal rotation age and planting density (particularly how site preparation costs, planting costs, stumpage price, interest rate, and taxes impacts the rotation length). The behavior of these variables helps us understand the traditional Faustmann formulation (1849), which shows that higher interest rates reduce optimal rotation length and planting density. Low stumpage prices extend rotation age and reduce planting density, while high site preparation costs increase both rotation age and planting density. Finally, higher planting costs decrease both rotation age and planting density.

Samuelson (1976) provided additional corroboration for using the classical Faustmann algorithm in determining the optimal age for a tree to be cut in a steady state process. The correct competitive solution for determining optimal rotation periods (maximizing the land rent in a steady-state forest) is the BLV approach, which maximizes present discounted value over an infinite number of repeated cycles. Maximizing soil rent, or BLV, guides the optimal rotation, which can be used in the one-period net present value mode (NPV is the present value of all revenues minus present value of all costs discounted to the present with a determined compound interest rate).

Hyde (1980) explained how the rotation age and timber supply could be affected when incremental prices and technological changes are considered in timber production. In Hyde's analysis, long-term aggregate supply is positive, and annual harvest increases for two reasons: higher prices justify land-intensive silviculture (higher production on fixed land base), and they bring some marginal land into timber production. Newman et al. (1985) analyzed the impact of rising prices (either a one-time change in price level or a continuing rate of price increase over time) on optimal timber management. They found that increases in the relative price level decreased the optimal rotation age, while a continually increasing rate of price change initially increased the optimal rotation age, although the optimal rotation age subsequently decreased over time.

In order to provide an economic framework within which to evaluate possible scenarios of simultaneous changes in global sustainable raw material supply and production methods, the need arises to quantify and prioritize the economic impact of biotechnology on fiber and timber production. In this effort, Sedjo and Lyon's (1996) Timber Supply Model 96 (TSM96) incorporates the effects of technological changes in tree growth (genetic improvement), embodying in the yield function an initial progressing rate of 0.5% annually, decreasing linearly to zero in year 50.

McKeand et al. (2006) recently quantified the financial benefits of using the best loblolly pine genotypes regionally. A sensitivity analysis covers two management regimes, fiber and solid wood production, across eight site indices which vary from 60 to 95 in increments of 5 feet. Main findings show, at 8% rate of return, that forest investors can easily justify an additional cost of $40/ac to $250/ac, across sites and management regimes, for the best seedlings.

In order to generate a complete picture to determine the delivered-to-mill cost, it is necessary to consider the harvesting and transportation costs that provide the final inputs. The Auburn Harvesting Analyzer tool (AHA) (Tufts et al. 1985) is a spreadsheet template that analyzes system balance, production rates, and costs determined by the potential hourly productivity for each machine as influenced by tree and tract size (Greene and Lanford, 2001). Harvesting equipment cost data from Brinker (2000) is a basis for fixed and variable costs per scheduled machine hour. The hauling rate is a variable that is a function of distance to the mill and of payload (Greene and Lanford, 2001). Tract size has a large impact on timber harvesting costs as it has been reported that tracts of 50 acres or more have significant economic advantages over smaller tracts (Greene et al. 1996 and 2001).

Vegetative Propagation of Trees for Forestry

Vegetative propagation, as opposed to seed propagation, refers to any method used to replicate individual plants. Vegetative propagation has been practiced for centuries in plants such as grapes, potatoes, and fruit trees. A simplistic description of vegetative propagation consists of taking cuttings from a plant (branch or root) and then planting them. The collection of newly regenerated plants is a clone, and each member of the clone has identical genetic features to the "mother plant". If the mother plant is superior, the ramets will capture all of the genetic gain of the improved ortet without diminishing that gain through sexual reproduction.

In forestry, this process starts with plus trees selected through traditional breeding programs. Some trees like eucalyptus and poplars are easily propagated vegetatively by cuttings. However, this technique has not been as effective for most conifers; thus, for southern pines, for example, clones are also produced from embryos. This requires tissue culture, a more sophisticated technique, which is a biotechnological extension of the traditional breeding process.

> Development of elite varieties begins with loblolly or slash pine seed obtained from the mating of the very best parents selected from offspring performance in progeny tests…Seeds are harvested while still immature, extracted from the green cones, and placed on special culture media to induce tissue production, or embryogenesis. The media stimulates the immature embryo into replicating itself, instead of growing into a fully developed pine seedling. The resulting tissue culture will continue to divide into hundreds and eventually even millions of embryos, each an exact copy of the original embryo from a single seed. When a sufficient amount of tissue is accumulated, it is placed in cryogenic storage, where the culture can be held indefinitely for future use.
>
> When several hundred embryogenic cultures have been cryo-preserved, a small amount of tissue from each individual culture is removed, and the embryos are stimulated to mature and germinate. From these germinated embryos, finished seedlings are grown for testing on forest sites. As these replicated tests reach four to six years of age, the very best trees are selected and designated as elite varieties. The embryogenic cultures of these can then be used to produce seedlings for large-scale commercial production, which are genetically exactly the same as the best tree selected in the test plots (Weir et al, 2006).

Assessing Royalties

There are three traditional valuation techniques: market, costs, and income approaches, and several variants of these for standard intellectual property (IP) valuation.

The market approach (comparable sales) is used for transactions of similar property and when transaction details are released.

The market approach uses industry standards to determine royalties. Some sources of industrial standard royalty rates are: surveys, proposed "norms," available court cases/infringement lawsuit awards, price lists, published agreements, institutional experience, consultants, in-house licenses, major accounting firms, RoyaltySource.com, IPresearch.com, and RoyaltyStat.com. Although it is positive to apply market values, this method is uncommon because very few transactions have similar intellectual property features. In addition, market segmentation (electronics, pharmaceuticals…) may be inappropriate, and the range of royalty rates may be too broad.

The cost approach is typically used for the valuation of tangible assets and seeks to equalize these assets with future upstream economic benefits of ownership. For intangible assets, such as intellectual property, this method can present a significant discrepancy between the cost of creating intellectual property and its value. In general terms, cost is not the same as value. Costs are irrelevant unless economic benefits can be earned from ownership of property (Smith and Parr, 2005; Razgaitis, 2002).

The cost approach measures the amount of money that is required to create/replace the future benefits associated with tangible asset ownership. However, for intangible assets (e.g., IP), there are no price guides for the application of this approach. Thus, a word of caution is required when this method is applied for valuing IP. For instance, the cost approach does not integrate information on economic benefits, risks, or time frame. Neither does it capture the effects of market forces. Although the cost approach for valuing intangible assets has potential for mistakes, it can be used as a reference point and also to provide an indication for the other approaches.

The income approach is defined by Smith and Parr, 2005, as the "present value of future economic benefits of ownership". This technique is used when the property's future economic benefits (cash inflow/outflows) are known or predictable.

The income approach is advantageous because of its flexibility to adapt to a specific business and market developments. It is also useful when the information needed to implement this approach, at least in theory, is well-known to the firm. However, all the information required for the income approach may not be available in the case of new technologies (Denton and Heald, 2004). In this case, analysts should take into consideration technological risks, such as failure to move from laboratory scale to operational scale, non-competitive production costs, competitors (with more competitive products), regulations, and public concerns.

In forestry, this valuation method is often used for assessing timberland opportunities for pre-merchantable stands (i.e., stands that currently have little or no timber value). The income approach is a discounted cash flow (DCF) technique, when used for a conventional forest valuation, is slightly more complicated than either the market or the cost approach, but it provides the most accurate means for valuing forest production. It also requires more information about growth and yield to determine its optimum economic rotation age and the bare land value (BLV). The break-down of products at different stages of the growth process is required as are an expected rate of return and its tradeoff between risk and return. The mechanics used to work with this approach involve discounting all future income, such as land leasing, timber sales, and the bare land value assessed from its optimal rotation age in the current rotation to present, and also discounting all costs, such as midrotation silvicultural practices, annual taxes, and administrative costs. The net sum is the value of land and timber; from there, BLV is subtracted to obtain the value of the timber (Bullard and Straka, 1998, Clutter et al, 1983, Davis et al, 2001, and Klemperer, 1996).

Because the valuation of intangible assets and intellectual property rests upon the same financial principles as property valuation does: present value of future royalty payments (marginal/differential analysis of enhanced returns vs. traditional product/technology), the income approach is appropriate for intangibles and IP.

Smith and Parr, 2006, divided the techniques to compute the value of intangible assets by the income approach into two categories. These categories are a function of the information available:

- Direct Approach: premium pricing and cost savings
- Indirect Approach: valuation using “relief from royalty,” analytical methods,

earnings analyses, overall rate of return requirements (return rate on both equity invested plus debt, WACC), allocation of returns among assets categories, appropriate return on monetary / tangible / intangible assets / or on research and development costs, fixed percentage of operating profit, ratings/rankings (to differentiate the product), rules of thumb (royalty in percentage of net sales), auctions, more advanced techniques such as Monte Carlo simulations (probabilistic approach), modified or risk adjusted DCF/NPV, and real option pricing (Black and Scholes' model).

Intellectual Property Protection and Regulation

As presented by Smith (2005), intellectual property includes patents, trademarks, copyrights, and trade secrets or know-how, and its holder is protected by law from unauthorized utilization/commercialization by others. Legal protection of inventions/innovations started two centuries ago with the United States Patent and Trademark Office (USPTO) under the Department of Commerce, which promoted the advance of science by protecting the exclusive right to their inventions of creators and entrepreneurs for a fixed period of time (United States Patent and Trademark Office's web pages).

However, it was after 1930 that intellectual property rights were available for plants (represented by horticulturists) through the Plant Patent Act, which was adopted by the U.S. Congress in 1930 (Caldwell, 1989). This Act protects only plants that are asexually reproduced (clonally propagated by rooted cuttings, grafting, etc).

Plant Patents: A plant patent is a grant of a property right, issued by the United States Patent and Trademark Office (USPTO), to a breeder who "invents or discovers and asexually reproduces any distinct and new variety of plant, including cultivated sports, mutants, hybrids and newly found seedlings, other than a tuber propagated plant or a plant found in an uncultivated state…" (Plant Patent Act 35 U.S.C. § 161). A plant patent grants the breeder the right to exclude others, generally for a term of 20 years, from asexually reproducing the plant or selling, or using the plant or any of its parts for propagation. (Smith and Parr, 2005, and, Plant Patent Act, and United States Patent and Trademark Office's web pages).

The path for intellectual property rights and patents for plants, which protected plant breeding investments, was paved by the corn industry (the first to bring hybrid varieties to the market). However, plant patents do not encourage profit oriented seed organizations to breed non-hybrid crops because, although the latter may be improved, they can not be protected by this legal mechanism by definition.

Plant Variety Protections: Another type of protection for crop breeding is through the Plant Variety Protection Act (PVPA) under the United States Department of Agriculture. PVPA has been available over almost 40 years and provides legal intellectual property rights protection to breeders of new varieties of plants that are sexually reproduced (by seed) or are tuber-propagated. PVPA protects the plant breeder by conferring legal control over seed production and sales. Farmers are allowed to save limited amount of these protected seeds only for planting purposes on their own land, which matches the area of the first crop. The term of protection is 20 years for most crops and 25 years for trees (Wright, 2006, USDA, Agricultural Marketing Service web page).

Utility Patents: This patent is usually obtained for new machines, chemicals, drugs, and processes, and confers to developers the right to exclude others from making, using, or selling, its invention for a period of 17 years (Jondle, 1989). However, the "United States Supreme Court, in a 1980 decision, found that living matter that owes its unique existence to human intervention is patentable subject matter" (Smith and Parr, 2005, p28). This decision opened the door for the patenting of numerous biotechnological products, such as corn inbreds, corn hybrids, and soybean varieties by companies like Monsanto and Pioneer-DuPont, and "gives them the right to prohibit breeding with as well as selling the patented cultivar" (R. Fincher, Plant Technology Commercialization, UGA, personal communication, 2007). Today, there are hundreds of utility patents for biotechnological products (Kjeldgaard and Marsh, 1994).

Other Plant Protections: Two additional categories of plant protection in the United States are: a) trade secrets, which imply no public disclosure of any information, process, or genetic resources that provides competitive advantages to developers; and b) contracts like licensing agreements, and conditions/restrictions of sale agreements.

Uniformity

The first recorded clonal forest programs began in China with Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook.) and in Japan with sugi (*Criyptomeria japonica* D. Don), 800 and 500 years ago respectively (Burdon and Libby, 2006). Chinese fir is the most important conifer species in southern Asia, supplying China 20-25% of its commercial timber. This species is easily propagated vegetatively because after harvest, stumps produce plentiful sprouts with high rootability. During the 1960s to 1980s, new techniques, like tissue culture, for cloning seedlings were developed and used in seed and sprout orchards. Genetic gains have been reported between 10 and 20% (Li and Ritchie, 1999). Growth and Yield (G&Y) models for Chinese fir are now published in English.

Most conifers are difficult to clone. The first formal program for clonal forestry of pine was with radiata pine in New Zealand during the late 1960s, which began commercialization during the late 1980s. Today, over 20,000 hectares (50,000 acres) have been planted, and this remains the most extensive and oldest clonal pine plantations in the world.

Clonal forestry is defined minimally as forest plantations with trees of selected, tested clones (Sorensson and Shelbourne, 2005). A commercial or "production" clone is a clone selected following field-replicated tests of a large number of candidate clones. Production clones must contain good genes (phenotypes) for several attributes, and individual trees of each clone should exhibit good inter-tree consistency or "uniformity". Thus, by definition, without intense genetic screening, simple deployment of vegetatively propagated trees does not represent clonal forestry.

There are few studies about uniformity in genetically improved forest plantations. Carson and Hayes (1998) analyzed diameter and diameter distributions of genetically improved seedling

Pinus radiata in New Zealand. They compared four sites, two constraints management regimes, and from four levels of improved seedlots: land race (at least two generations of natural and silvicultural selection), climbing select (seeds from the best trees in selected stands), open-pollinated orchard (seed orchard from plus trees), and control-pollinated (pollen from selected parents). Quadratic mean diameter and mean height were significantly different among sites (except one) at age 14 or 15 years. Differences in mean diameter and mean height were statistically significant among genetic levels ($P < 0.005$). However, differences for standard deviation, skewness, and kurtosis were never significant ($P < 0.05$). Interestingly, stem diameter distributions (variance) did not decrease with higher genetic improvement levels, and that the tendency for the highly improved seed lot was to have flatter (platykurtic) distributions, slightly skewed to the right. Additionally, Carson and Hayes concluded that using individual tree models, predicted diameter distributions for all levels of genetic improvement will not require adjustment when stand parameters are correctly specified. In accordance with these findings, they reject the hypothesis that reduced diameter variance (as a result from genetic improvement) causes a loss in either total volume production or average stem diameter as compared with an unimproved control.

Two older studies, analyzed diameter distributions of improved and unimproved forest plantations. Spirek et al. (1981) adjusted the Weibull parameters to diameter and height data from *Pinus elliottii* progeny tests after finding slight differences among progenies. These findings should be taken with caution because the results from row plots or single-tree plots may not clearly indicate performance when progeny of the best parents go to operational plantations. Janssen and Sprinz (1987) fitted probability density functions to diameter data from *Pinus taeda* trials and contrasted plots grown from plus trees' seeds to plots grown from nearby unimproved trees. Predicted diameter distributions for improved seed lots showed higher negative kurtosis values (more platykurtic or flatter distribution) than those from unimproved seed lots.

Hornsby (2006) investigated the variation of wood qualities (target height level for collecting cores was 2.5 feet) in *Pinus taeda*, between clones, full-sib zygotics, and half-sib zygotic trees at age four years old, focusing on wood density (specific gravity), latewood proportion, stem oven-dried weight, and microfibril angle (MFA). He found that the merchantable wood produced by vegetatively propagated plantations had increased uniformity and improved wood quality characteristics with respect to weighted core specific gravity, and to latewood percentage as compared to half-sib open pollinated trees, but not significantly different to full-sib zygotics. However, he found no significant differences among types of propagation with respect to dry stem weight. Results on MFA were inconclusive: MFA was not stable enough at age four to interpret differences among individuals.

Growth and Yield Models

In the absence of specific/published studies for G&Y modeling, indications of clonal plantation development can be observed in other studies, such as those established for genetic valuation. For instance, a loblolly pine study conducted by Baltunis et al. (2007), consisting of six field trials with clones (1,212) and seedlings (+14,000) from 61 families, was established in the U.S. South in 2002, and early results have been released. A key finding was that there was not much genotype x environment interaction across installations at the parental, family, or clonal levels for stem diameter. Thus, general clonal behavior can be captured and incorporated into G&Y models.

A study of Growth and Yield predictions at age 4.8 years for nine clones of *elliottii x caribaea* established as pure clonal plots or as single tree plots (STP) in 1995, was conducted (Rockwood, 2000). Rockwood investigated alternatives for adapting *Pinus elliottii* and *Pinus caribaea* G&Y models to hybrids and clones of *Pinus elliottii* x *Pinus caribaea*, for survival and wood density traits, as well as for stem taper prediction, diameter distribution, and height-age relationships. For a rotation age of 20/30 years, his analysis estimated an interim volume gain of 20% for clonal plantations over seedlots of *Pinus caribaea* plantations. These results, on an additive basis, suggest breakdown gains as follows: height 5%, stem taper 10%, and wood quality 5%, all of which need to be verified as new data become available.

Carson et al. (1999a) discussed the use of pre-existing G&Y models for plantations of diverse genetic origin, which generate different yields and allow for quantification of genetic gain. G&Y models are derived from extensive regional data and cover broad characteristics of site indices and management practices. These factors are more significant contributors to determining yield than genetic effects per se. Thus, by taking into consideration initial tree size and other growth factors, a growth rate for a limited level of genetic gain, could be incorporated into existing models without modifying the models. Existing models for *Pinus radiata* show that the differences in growth due to genetic responses are modest compared to growth differences that result from extremes of site and silvicultural managements (Carson et al. 1999b).

Diameter at breast height (DBH) has been one of the most comprehensively studied and used growth parameters for modeling purposes Garcia (2006). Garcia and others authors have identified the effects of plot size on tree growth models. He states "that variability in larger areas tends to be higher than in smaller areas, as larger areas have a greater probability to including different conditions" (p2). Garcia focuses on DBH variances estimated in single random plots, where spatial correlation plays a significant role in estimation; whereas, the mean and total estimations are trivial. Thus, G&Y models for clonal plantations should also consider this effect of plot size.

Stand tables, the number of trees per acre by diameter class, also provide essential information for assessing product volume, as well as the necessary inputs for financial analyses in forest investments. The stand table projection approach is based on current stand tables from which can be predicted the surviving trees for each diameter class, and the growing tree diameters over time, which in turn, produce a stand table for a future age. This projected stand table must be compatible with observed values, or to stand tables derived from whole stand models (Clutter and Jones, 1980; Pienaar and Harrison, 1988; Cao and Baldwin, 1999). Similar mechanisms should be applied to develop a more accurate clonal stand table projection algorithm as a component of the G&Y system, which, when available, will contribute to a better understanding of clonal growth dynamics.

Financial Valuation

Clonal forestry has emerged as a revolutionary option for transforming the course of the forest industry. Forest landowners in the Southern hemisphere agreed it was more profitable to grow and harvest genetically improved trees than unimproved plantations (Shelbourne, 1997). Clonal forestry appears to have multiple advantages over traditional breeding programs that consider half-sib or full-sib families. The uniformity effect is one advantage of a single-clone stand that requires analysis of its economic value.

A forest industry partnership between Tenon and Horizon2 (previously Fletcher Challenge Company, and Trees and Technology) constituted a multidisciplinary task force called

Genetic Optimization Team (GOT) in New Zealand in 2001. GOT's objective was to create a reliable atmosphere through which customers could critically assess the benefits of forest genetics through clonal technology. One of GOT's focuses was accuracy and transparency in analyzing value prediction and clonal pricing. One key finding was the estimation of clonal benefits in the production of sawtimber alone: well over $300/ac (Sorensson et al. 2004).

McKeand et al. (2006) recently quantified the financial benefits of using the best loblolly pine genotypes regionally. Their sensitivity analysis covers two management regimes, fiber and solid wood production, across eight site indices which vary from 60 to 95 in increments of 5 feet. Main findings show, at an 8% rate of return, that forest investors can easily justify an additional cost of $40/ac to $250/ac, across sites and management regimes, for the best improved seedlings.

Value prediction and price of a single commercial clone are the key components of financial analysis in forestry. In addition, in the context of a comprehensive forest plan, deployment alternatives have been investigated. Carroll et al. (2006) assessed four hypothetical deployment methods for elite planting stock compared to second generation improved seedlings. Their results show increased production, revenues, and returns. The allowable cut effect (ACE) affords for deployment of elite plantations except when clone deployment rate follows traditional harvest rate.

CHAPTER 2

WHEN THE EXPENDITURE ON FOREST BIOTECHNOLOGY PAYS OFF

A CASE STUDY[1]

[1] De La Torre, R.E. and D. H. Newman. To be submitted to *Southern Journal of Applied Forestry*. August 2007.

Abstract

Current economic analysis shows that fiber costs represent up to 40% of the total cost of manufacturing paper in the U.S. To compete with emerging forest industry in countries located near the equator whose costs are significantly lower, the American forest industry could incorporate biotechnology through genetically improved seedlings and more intensive silviculture, leading to increased yields, as well as better wood and fiber qualities. This would maximize processing efficiency and product performance, and provide a better economic return.

This study develops a cost model from two perspectives: industry's (fiber production, no thinning), and nonindustrial private forest landowners' (timber production, one thinning). The model incorporates variables like rates of return (6% and 8%); site indices (60, 65 and 70); intensive stand management prescriptions, with correspondent growth responses; and harvesting and transportation costs, in addition to publicly available cost data, and the latest available loblolly pine growth and yield models for the Lower Coastal Plain. It also allows for the estimation of the mill-delivered cost of wood under various "likely" scenarios (volume gain levels).

This model efficiently assesses the profitability of current and potential biotechnological advances. Yields of traditional stands are compared to improved stands (better genetics) at five levels of gain in volume (10% to 50%), for both, thinned and unthinned regimes. The model determines the land base required to supply a 1.5-million ton/yr mill. Multiple scenarios are explored to determine factors that optimize profitability and to suggest operating strategies.

For the base case scenario with SI 60, no thinning regime, returns are maximized at year 18 with an optimal bare land value of $124/acre vs. $850/acre, a potential 50% gain in volume.

For the thinned, sawtimber oriented regime, returns are maximized at year 23 with an optimal BLV of \$200/acre for the reference case vs. \$850/acre for a potential 50% gain in volume.

At stand level, the delivered timber cost for the unthinned base case is \$36.8/ton vs. \$27.4/ton, at 50% gain in volume. Results for the thinned base case are similar. Break-even costs range from \$0.16/seedlings to \$0.90/seedling for the 10% or 50% gain in volume, respectively.

INDEX WORDS: Silviculture, growth-and-yield, biotechnology, cost modeling, harvesting

Introduction

This chapter grew out of a larger project, "Commercialization of Forest Biotechnology: Economic Targets for Enhanced Global Competitiveness of the U. S. Pulp and Paper Industry," performed through the Institute of Paper Science and Technology (IPST, 2001-2003). The study, as a whole, encompassed the entire production process, from tree growth to finished rolls of paper. The goal of this research was to provide an economic assessment framework within which to assess the effects of biotechnology and silvicultural practices that have the greatest potential to enhance the global competitiveness of the U. S. pulp and paper industry. The original study has been significantly updated and overhauled by adding an analysis of growing timber at stand level and by improving the marginal analysis.

Recent economic analyses show that fiber costs represent up to 40% of the total cost of manufacturing paper in the U.S. (Peter et al. 2001). The U.S. paper industry must compete with emerging forest industry in countries located near the equator, whose costs are significantly lower. In order to offset cost disadvantages, the American forest industry should incorporate biological technologies and more intensive management regimes, leading to improved tree growth, as well as to better wood and fiber qualities.

It has been shown that advanced tree improvement programs that match specific full-sib families from the best parents to specific sites can produce volume gains beyond 50% (Jansson and Li, 2004, cited by McKeand et al. 2006). The technology with the highest potential to capture additional returns is the clonal seedling developed for specific traits, which maximizes processing efficiency and product performance, and provides a better economic return, from landowners to manufacturers.

Fox et al. (2004) described the contributions in the last 50 years of intensive management practices to productivity in southern pine plantations in the U.S. Natural yellow pine stands in 1940s yielded less than 50 ton/ac at harvest time in contrast to almost 200 ton/ac, in a shorter rotation, in 2000. This dramatic change was possible through improvements in the artificial regeneration programs, which progressed from genetically improved seeds, better nursery practices, chemical and mechanical site preparations, competing vegetation control, fertilization, tree improvement, to integrated site-specific silvicultural treatments. A similar discussion who charts five stages of the evolution of productivity gains in southern pine plantations from 1 m^3/ac/yr to 8 m^3/ac/yr between 1920 and 2000 (Stanturf et al. 2003).

Borders and Bailey (2001) conducted research on several sites in Georgia with loblolly pine, in which the cultural treatments, and their combinations, involved intensive site preparation, multiple applications of herbicide for complete weed control, and annual fertilization schedules. On 10- to 12-yr old plantations, a range of mean annual increments (MAI) of 9 to 14 m^3/ac was found, while with the control treatment, which received only intensive mechanical site preparation, the range of MAIs was 4 to 7 m^3/ac.

For the economic assessment of the effects of the biotechnology and intensive management practices on increased forestry production, an integrated Excel spreadsheet, incorporating publicly available cost data (silvicultural and harvesting costs), and the latest loblolly pine growth-and-yield models for the Lower Coastal Plain, was used. The model developed for this study allows for the estimation of the mill-delivered cost of wood under various likely scenarios. In general, findings show that it is possible for investors to improve their competitiveness with best-suited intensive management, the best genetic seedlings available, a balanced harvesting system, and stands located close to receiving mills.

Overall project objective

The general objective of the larger IPST project was to develop a cost model to assess the potential impact of biotechnology advances on profitability in wood supply for the U.S. pulp and paper industry. The first question was to determine the profitability of using more integrated and intensive forest management regimes. This analysis naturally led to a second question: to determine the forest investor's willingness to pay for intensive management / biotechnology versus relying on traditional management.

Study Objectives

- Develop a delivered-to-mill cost model for forest production that can be achieved through intensive silvicultural management and elite seedling genotypes.
- Analyze marginal rates of return based on several seedling improvement scenarios.

<u>Literature Review</u>

Competitiveness

Developing countries with cheaper land, lower labor costs, potential for higher tree growth rates, and relatively open economies have a competitive advantage over temperate countries (Cossalter and Pye-Smithl, 2003). Given this economic situation, investors must consider the cost contributions of wood growth, harvesting, and transportation (among other components) to the delivered-to-mill cost for plantation pulpwood.

The U.S. pulp and paper industry is in the process of significant changes in raw material supply. In the southern hemisphere, pine grows more quickly. As a result, over the past two decades in the U.S., fiber suppliers have shifted their focus from mature, non-cultivated trees to intensively managed trees and recycled fiber. These changes in raw material supply are driven by a shrinking land base and competition from other countries (NCFA, 2003; Peter et al. 2001).

The research by Greene et al. (2006) confirms that the U.S. forest products industry is dealing with greater global competition, population pressures, and changes in ownership and land use. Greene's study states that "the industry was a low-cost producer, benefiting from excellent infrastructure, productive forests on low-cost land, innovative logging contractors, and strong product markets," (p.3.4) but the South is no longer the lowest cost producer, even considering the impact of the recent weak dollar.

Harris et al. (2004), in their article *How competitive is the Southern Timber Industry?*, and Siry et al. (2006) describe the magnitude of forest business in the South: 203 million acres of forest (88% private/industry), including 39 million acres of yellow pine plantations, with high levels of harvest from Virginia to Texas (335 million tons annual harvest, 65% softwood, 35% hardwood), produces 18 percent of the world's industrial roundwood and 25 percent of global wood pulp production (40 million tons as of 2003) with just two percent of the world's forestland. This study also identifies the major factors that have contributed to this leading position: location near active markets, level and rolling terrain, good climate, solid infrastructure, good management skills, good government, and a unique system of private timberland ownership. Their study also discusses competitive disadvantages, such as changing paper demand, high labor costs, high tax rates, and high fiber costs.

This chapter addresses fiber cost production as a critical component of the forest cost model equation. Competitive fiber costs can contribute to maximizing and exploiting the South's timber resources and future potential in a global market. Given the magnitude of this commodity business, small percentage gains in production can drive significant reductions in the delivered cost of fiber.

Silviculture and Biotechnology

As pointed out by Simpson (1999), biotechnology is a driving force for addressing global competition in permanent change. Recently, pulpwood companies have begun to get away from producing a uniform commodity pulp and are producing specialized pulp for targeted markets. Customized products often require customized raw materials. Using biotechnology techniques, desired fiber characteristics can provide more desired pulping properties, which in turn would be reflected in the properties of pulpwood and paper products, such as paper tear strength, surface texture, whiteness, and so forth. In the solid wood products segment, wood fiber is being processed more progressively into structural products that have their own assortment of desired fiber properties. Clones have been developed with specific wood properties that enhanced production and profitability (Fox et al, 2006).

However, fast timber growth rates may have drawbacks when compared to mature wood. Fast-growing trees that are harvested at younger ages have a higher proportion of juvenile wood, which is less dense, contains shorter fibers, has lower cellulose to lignin ratios, thinner cell walls, and decreased stiffness due to higher microfibril angles (Clark, 2006). Thus, growth rate is intimately tied to wood and fiber quality (Peter, 2002). Due to these interrelationships, cost models must account for simultaneous and flexible changes in tree growth rates and wood properties.

McKeand (2006) stated that landowners should plant the highest quality seedlings and apply more intensive management regimes (in their more productive sites) in order to obtain higher returns. Increased returns of $100/ac to $200/ac, when SI was increased 5 or 10 feet respectively, were found as a result of better loblolly pine genetics and several management intensities.

Forest optimization and Growth and Yield models

A number of systems have been developed for predicting the growth and yield in loblolly pine (*Pinus taeda L.)* plantations under various management regimes (Harrison and Borders, 1996; Borders, 2001; Amateis et al. 2001; Zhang et al. 2002). These systems generally include a set of equations to predict individual tree volume, green and dry weight, and a breakdown of likely products; they also include whole-stand growth and yield models with equations to predict volumes and basal areas of both thinned and unthinned tracts. A major challenge for such systems is incorporating state-of-the-art intensive management regimes within their predictions of incremental yield. These involved mechanical site preparation, herbaceous weed control, and fertilization (Borders, 2001; Pienaar et al. 1996). Using information from previous studies, the basic yield system can be adjusted to predict a “true” yield when different levels of treatment are evaluated. For example, estimates can be made for thinning stands, which include the computation of thinned basal area as a function of removals and the growth response for the remaining stand (Harrington, 2001 and 2002; Pienaar et al. 1996). Similarly, the response to midrotation treatments may be accounted for by including its additive impact on the dominant height and basal area baseline of the stand (Borders et al. 2001).

Several studies at national and regional levels have analyzed major factors that have the potential for boosting the competitiveness of forest resource industries in the U.S. (Borders et al. 1991; Bullard and Straka, 1998; Yin, 1998; Alig et al. 2000; Borders and Bailey, 2001; Smidt et al. 2005; and Hancock, 2001). Particularly influential was a study by Borders et al. (1991) entitled "Variable bedding, planting, harvesting and transportation costs impact on optimal economic management regimes," which used maximization of bare land values (BLV) as the decision criterion to optimize site preparation costs, planting density, and rotation age. BLV is defined as the net present value of a perpetual series of rotations associated with a specific forest management regime.

BLV for timber production is calculated assuming that land will be used to produce a perpetual series of even-aged or uneven-aged stands. Each stand in the perpetual series is assumed to have the same revenues and costs that are projected for the first rotation or the first cutting cycle (Wagner et al. 1995, Bullard and Straka, 1998). A number of studies have reported that maximization of the BLV, referred to as the Faustmann formula, is the most realistic financial measurement when values for cost and revenue streams vary along the rotation age and/or the planning horizon. This objective financial criterion is widely used for profit-oriented forest investments to evaluate their potential capital investments in timberland, to calculate optimal timber management regimes for numerous assumed levels of growth gains, and to compute their corresponding break-even costs at each gain level (Clutter et al. 1983; Newman, 1988; Borders et al. 1991, Wagner et al. 1995; Bullard and Straka, 1998; Borders and Shiver, 2001; Davis et al. 2001; Siry et al. 2001; Newman, 2002).

Although this paper focuses on timber production costs, it is important to highlight the role of various production factors in influencing the optimal timing of harvests (opportunity cost of harvesting now vs. the economic effect of delaying final harvest). Samuelson's (1976), Hyde's (1980), and Chang's (1982) research, among others, contributed to explaining the relationship of BLV variables and went beyond the theory of optimal rotation outlined by

Faustmann. For instance, Chang (1982) evaluates the effect of changes in stumpage price and production costs on the optimal rotation age and planting density (particularly how site preparation costs, planting costs, stumpage price, interest rate, and taxes impacts the rotation length). The behavior of these variables helps us understand the traditional Faustmann formulation (1849), which shows that higher interest rates reduce optimal rotation length and planting density. Low stumpage prices extend rotation age and reduce planting density, while high site preparation costs increase both rotation age and planting density. Finally, higher planting costs decrease both rotation age and planting density.

Samuelson (1976) provided additional corroboration for using the classical Faustmann algorithm in determining the optimal age for a tree to be cut in a steady state process. The correct competitive solution for determining optimal rotation periods (maximizing the land rent in a steady-state forest) is the BLV approach, which maximizes present discounted value over an infinite number of repeated cycles. Maximizing soil rent, or BLV, guides the optimal rotation, which can be used in the one-period net present value mode (NPV is the present value of all revenues minus present value of all costs discounted to the present with a determined compound interest rate).

Hyde (1980) explained how the rotation age and timber supply could be affected when incremental prices and technological changes are considered in timber production. In Hyde's analysis, long-term aggregate supply is positive, and annual harvest increases for two reasons: higher prices justify land-intensive silviculture (higher production on fixed land base), and they bring some marginal land into timber production. Newman et al. (1985) analyzed the impact of rising prices (either a one-time change in price level or a continuing rate of price increase over time) on optimal timber management. They found that increases in the relative price level decreased the optimal rotation age, while a continually increasing rate of price change initially increased the optimal rotation age, although the optimal rotation age subsequently decreased over time.

In order to provide an economic framework within which to evaluate possible scenarios of simultaneous changes in global sustainable raw material supply and production methods, the need arises to quantify and prioritize the economic impact of biotechnology on fiber and timber production. In this effort, Sedjo and Lyon's (1996) Timber Supply Model 96 (TSM96) incorporates the effects of technological changes in tree growth (genetic improvement), embodying in the yield function an initial progressing rate of 0.5% annually, decreasing linearly to zero in year 50.

McKeand et al. (2006) recently quantified the financial benefits of using the best loblolly pine genotypes regionally. A sensitivity analysis covers two management regimes, fiber and solid wood production, across eight site indices which vary from 60 to 95 in increments of 5 feet. Main findings show, at 8% rate of return, that forest investors can easily justify an additional cost of \$40/ac to \$250/ac, across sites and management regimes, for the best seedlings.

In order to generate a complete picture to determine the delivered-to-mill cost, it is necessary to consider the harvesting and transportation costs that provide the final inputs. The Auburn Harvesting Analyzer tool (AHA) (Tufts et al. 1985) is a spreadsheet template that analyzes system balance, production rates, and costs determined by the potential hourly productivity for each machine as influenced by tree and tract size (Greene and Lanford, 2001). Harvesting equipment cost data from Brinker (2000) is a basis for fixed and variable costs per scheduled machine hour. The hauling rate is a variable that is a function of distance to the mill and of payload (Greene and Lanford, 2001). Tract size has a large impact on timber harvesting costs as it has been reported that tracts of 50 acres or more have significant economic advantages over smaller tracts (Greene et al. 1996 and 2001).

Data Collection and Assumptions

Using the Plantation Management Research Cooperative (PMRC) loblolly pine 1996-growth and yield equation system, two base case models, thinned and unthinned, for the lower coastal plain of the southeastern U.S. were formulated. The thinned model focuses on private landowner perspectives, such as growth of timber (volume) with the highest quality. The unthinned model is more relevant to vertically integrated forest product companies whose fiber production focuses more on wood quality characteristics, such as specific gravity, microfibril angle, and lignin content with the primary objective of producing fiber for kraft linerboard. Gains in volume were made via site index for both silvicultural regimes considered. Both models were run on three site indices (SI) of 60, 65 and 70.

To develop a delivered-to-mill cost model (stand simulator), silvicultural prescriptions were determined with active discussions of PMRC and IPST industrial members. Tables 1 and Table 2 in Appendix A summarize by activity and time allocation, the formulated prescriptions for intensive management regimes that include activities and costs, such as site preparation, chemical herbaceous release, seedlings, fertilization, and annual management costs. Table 3, Appendix A, considers revenue of $5/acre for recreational leases. Total regeneration costs, thus, range from $538/ac to $610/ac.

The financial assumptions used to calculate the BLV and its associated optimal rotation age were devised using publicly available information, such as *Costs and Cost Trends for Forestry Practices in the South* (Smidt, et al. 2005), the Texas Forest Service's web page, Fertilizer Works' web page, and Timber Mart-South data (2006). Another set of cost assumptions was derived from the literature review of intensive silvicultural treatment costs reported by researchers, such as Borders and Shiver (2001), and Rogers and Munn (2003). For one rotation analysis, at the optimal rotation age, NPVs were assessed either including a land value of $400/acre or not. These scenarios, based on the compiled information and the feedback from potential users and project cooperators, were used as benchmarks for all sensitivity analyses.

By reconciling figures and finding consensus for mechanical (shearing, raking, piling, and bedding) and chemical site preparation, the average reported cost for 700 trees per acre (TPA) was $200/ac and $110/ac, respectively. Based on the number of beds required, mechanical site preparation costs were increased up to 25% for planting densities greater than 700 TPA, or decreased up to 20% if planting density was less than 700 TPA, Planting costs ($60/ac, which reflects a banded –no grass environment), and costs associated with herbaceous weed control ($42/ac to $65/ac). The current average market cost of a seedling is $0.05, with the final cost being a function of planting density. The planting density inputs ranged between 300 and 1100 TPA, and their associated costs varied in increments of hundreds of TPA. From year 1 to year 35, mortality was simulated using the criteria appropriate for each age. Regeneration costs were computed from these parameters. Planting density was defined using a spacing of 6 feet by 12 feet (605 TPA); see Table 4, Appendix A.

Empirical evidence indicates how site preparation, herbaceous release, and fertilization affect pine survival during the first year after planting (Borders et al. 2001). For the first year, a survival rate of 98% is assumed. This percentage is the new population number. For the second year, the criteria developed by Borders et al. (2001) were applied. They hypothesized the yearly mortality rates from year two to the age at which inter-tree competition-related mortality begins (defined as the point when relative spacing, RS equates to 0.4). Thereafter, a survival prediction equation, developed by Harrison and Borders (1996), was used.

The Weibull distribution function was used to predict diameter distribution, which allows the calculation of merchantable volume: 4 in. DBH (Diameter at Breast Height), by product class. The threshold product class for pulpwood (PW) was defined as all stems between 4.5 and 7.5 in. DBH to a 3.0 in. top; for chip-and-saw (CNS), between 7.5 and 11.5 in. DBH to a 6.0 in: and, sawtimber (ST) was defined as all stems greater than 11.5 in. DBH to a 7 in. top. See Table 5, Appendix A.

A matrix of yields by product, site index (base age 25), adjusted dominant height and basal area, cash flow, and BLV was generated for ages 5 to 35 years on initial plantation densities between 300 and 1100 TPA. In order to calculate BLV, the following major financial assumptions were included: real rates of return of 6% and 8%, annual taxes and administrative costs of $7/acre, annual compatible land use revenue of $5/acre, and stumpage prices in accordance with TMS 2006 Regional Average Report (PW: $6.56/ton, CNS: $22.10/ton, and ST: $38.25/ton).

Pine stumpage prices for pulpwood, chip-and-saw, and sawtimber came from Timber Mart-South's quarterly report. The selected prices correspond to the average market price across the Southeast U.S. region for each product in 2006. See Table 5 in Appendix A.

The thinning component includes a competition index calculation (CI, defined as the relative degree to which competition affects average tree size in the thinned and unthinned counterpart stands, Harrison and Borders, 1996) by measuring the thinning growth response in the remaining stand. The thinning method considers the removal of 50% of the TPA through a combination of systematic and selective removals (removing every 5^{th} row and any additional TPA to meet 50% TPA goal) as well as other constraints, such as 20 tons/acre as minimum volume to remove, 65 ft^2/acre as minimum residual basal area, and 6.5 in. as minimum Dq (quadratic mean diameter). Timber harvested from thinning is merchandized as pulpwood. Another constraint for the model is that the minimum age for harvesting solid wood products is 15 years for CNS and 18 years for ST. The only criteria for saw timber are age, and DBH; the model did not account for timber quality. Planting densities less than 400 TPA were not considered sawtimber due to more conic stems, broader crowns, and larger branches (Larson et al. 2001).

To address timber density and specific gravity (SG) as an output of the model, volume and weight equations, such as total volume per acre outside bark (TVOB), total volume per acre inside bark (TVIB), total green weight per acre outside bark (GWOB), and total dry weight per acre inside bark (DWIB) were incorporated. Volume units are given in cubic meters per acre, and weight units are given in tons per acre. The ability to compute wood density and specific gravity is one of the most desirable outcomes of the model.

Harvesting and transportation costs were developed using the AHA (Auburn Harvesting Analyzer) described by Tufts et al. (1985). Tables 6 through 9 in Appendix A present the main cost assumptions by piece of equipment. A typical Southern logging equipment/crew configuration suggested by Greene (personal communication, 2003) is composed of fellers, grapple skidders, loaders, and haulers. Since the machines do not produce at equal rates, some are more productive than others. Thus, it was necessary to define a limiting function and balance the system. The AHA computed the system production rate in $/ton, using a combination of factors that bring the system up to near optimum production and the highest utilization rate

(Greene and Lanford, 2001). In order to apply the machine rate procedure and to find the final harvesting system rate, it was necessary to include additional assumptions. For instance, profit for the logging equipment owner was based on the return on assets (ROA) of 3%, labor costs of $12/hour, fringe benefits at 30% of the labor, and an interest rate of 12%.

Transportation costs are a function of distance (from the tract to the mill), average payload, and loading and unloading time. Hauling rates were derived by estimating hourly ownership and operation costs. Informal surveys with forest truck companies were performed to validate the figures assessed by this approach. The delivered-to-mill costs were the result of adding timber production, timber harvesting, and transportation costs.

Hauling productivity was calculated as a function of distance to the mill and payload. Distance is a function of the amount of land needed to supply a hypothetical mill capable of producing 344,000 air dried metric tons of unbleached kraft pulp (approximately 1.5 million tons of green wood) per year, which is located in the middle of the forest. A hypothetical operational distance was adjusted by a meander factor of 1.5.

Once the productive land base was calculated, the gross land base was derived using a factor of 1.3, which represents a non-productive (protective areas, power line corridors, secondary road systems, and other non-forest land uses) land component.

Methodology

The goal for the model was to predict baseline production costs using the data and assumptions described to analyze trends and impacts on production costs by varying either a single element or a few inputs.

In order to examine the positive potential of forest biotechnology, a forest cost model, considering both mill (fiber production) and NIPF (sawtimber production) perspectives, was developed. Once the problem was defined for profit maximization, the optimal economic analysis of timber production was evaluated, in both thinned and unthinned management regimes, using the bare land value criterion (BLV or Faustmann rule), which yielded the optimum rotation age. With optimum rotation age in hand, costs of growing timber, and harvesting and transportation costs were derived to construct the per ton delivered-to-mill cost of timber.

The cost model developed here (growth stand simulator) incorporates numerous variables, such as rates of return, site indices, intensive stand management prescriptions with their correspondent growth responses, and it becomes input (product break-down and stand tables) for the Auburn Harvesting Analyzer (AHA). The AHA is a harvesting system, which has several components (machine productivity, operating costs, and balancing system), which also served as input to determine the potential hourly productivity for each machine influenced by tree size.

Stumpage and delivered timber costs were assessed for all scenarios. Once the maximum BLV is found and the optimum rotation age defined, the cost of growing timber, NPVs, and IRRs can be determined. The per-unit cost of timber production was computed under two premises: first, as at stand level, which includes cash expenditures plus associated opportunity costs (Clutter et al. 1983). Second, per-unit cost was calculated at fully-regulated forest level, which equates the annual volume removal to annual volume grown (equal area of forest land for each age class, fixed rotation age, and age class for each year of rotation). Given that productivity and structure of the normal forest does not change over time, and same silvicultural management expenses are used every year, adjustment for opportunity costs were not considered. From these outcomes plus harvesting and transportation costs, timber delivered costs were calculated. See Tables 2.1 and 2.2.

Adjustments at several site indices were used to incorporate the gains in volume that result from enhanced seedling quality or other biotechnological advances in both thinned and unthinned management regimes. The adjusted site indices were set in increments of 10% to generate up to an approximately 50% higher volume over the base case (unimproved seedlings) at final harvest. The differences in BLVs, used as a proxy for computing financial gain, provided the marginal value at which forest investors can afford to pay for improved seedlings and/or any biotechnological advance.

Additional analysis was conducted in order to determine the break-even cost for various assumed levels of genetic gain. The break-even point is the value at which income matches expenditures. In this analysis, the break-even level represents the maximum cost for an improved seedling, which a forest landowner is willing to pay for additional genetic gain, and make a predefined real interest rate on the expenditure.

The optimal timber management regime was defined using the BLV formula using either a 6% or 8% interest rate.

BLV was computed using the following equation:

$$BLV = \frac{\mathrm{SY_t} - \mathrm{R} * (1+\mathrm{r})^{\mathrm{t}}}{(1+\mathrm{r})^{\mathrm{t}} - 1} - \frac{\mathrm{TA}}{\mathrm{r}}$$

where,

S	=	Stumpage value (\$/tons)
R	=	Regeneration costs (\$/ac)

TA	=	Annual taxes and administrative costs ($/ac)
Y_t	=	Yield per acre at age t (tons/ac)
r	=	Real discount rate (uninflated)
t	=	Rotation age in years

BLV can be interpreted as the maximum price that an investor can pay for a tract of land for timber production and can expect to earn a rate of return greater than or equal to the discount rate used for its computation. For this reason, land cost was not included in BLV calculations. However, land cost was included to determine its opportunity cost contribution to timber production costs (Hancock 2001). The price of bare land is a single-user-defined input value, which for the base case was set at $400 per acre

In all scenarios, seedling cost was fixed at a market price of $0.05 per seedling. To estimate the maximum value creation obtainable for a genetically improved seedling, the difference between the optimal BLV_u for the base case regime and the optimal BLV_t for the improved regime, assuming that the optimal rotation age does not change for both regimes, was determined. Via breakeven analysis, all additional timber revenue due to improved growth rate, the only attribute included in this research, was placed into seedling cost (but could have been as easily placed into more intensive site preparation, for example, or fertilization at planting time). The breakeven, or indifference investment point, represents the maximum amount an investor should pay every t years for the additional genetic gain and still make the desired real discount rate on the investment (Clutter, 2003).

The break-even cost was derived as follows:

$$BLV_{untreated} = \frac{SY_u - R*(1+r)^t}{(1+r)^t - 1} - \frac{TA}{r} \qquad BLV_{treated} = \frac{SY_{tr} - R*(1+r)^t - C_{tr}(1+r)^t}{(1+r)^t - 1} - \frac{TA}{r}$$

$$BLV_{treated} - BLV_{untreated} = \Delta BLV = P + \frac{P}{(1+\mathrm{r})^{\mathrm{t}}} + \frac{P}{(1+\mathrm{r})^{2\mathrm{t}}} + \ldots + \frac{P}{(1+r)^{\infty}}$$

$$\Delta BLV = P + \frac{P}{(1+r)^t - 1} = P\left(1 + \frac{1}{(1+r)^t - 1}\right) \rightarrow P = \Delta BLV * \frac{(1+r)^t - 1}{(1+r)^t}$$

Payment	*P*	*P*	*P*	*P*	. . .	*P*	*P*	. . .
Year	*0*	*t*	*2t*	*3t*	. . .		*nt*	. . .

where,

S	=	Stumpage value (\$/tons)
R	=	Regeneration costs (\$/ac)
Ctr	=	Additional treatment cost (e.g. elite seedlings, \$/acre)
TA	=	Annual taxes and administrative costs (\$/ac)
Yu	=	Yield without treatment per acre at age t (tons/ac)
Ytr	=	Yield with treatment per acre at age t (tons/ac)
r	=	Real discount rate (uninflated)
t	=	Rotation age in years
P	=	Payment value (\$/acre) at the break-even point

Solve for $i \rightarrow$ Marginal IRR *(i)* is the IRR for the marginal investment *Ctr*.

$$i = \left(\frac{\Delta BLV * (1+r)^t - 1}{P}\right)^{\frac{1}{t}} - 1$$

This derivation can be generalized for regimes with different optimal rotation ages, and multiple costs and revenues. Otherwise, underestimation of the true maximum IRR may occur (Clutter et al. 2006).

Results

The main purpose of this chapter is to illustrate, by comparison, different scenarios for estimating likely delivered-to-mill timber costs, and for gaining a better perspective of changes in growth rates obtained by silvicultural improvements. Numerous simulations were run to determine the impacts on growth via site indexes, cost of seedlings, and trees per acre on BLV, rotation age, and cost/ton of timber production. The effect of changes of each variable was analyzed separately while holding others constant in order to isolate the effects that each variable has on system productivity and costs. However, the model is also capable of analyzing variable interactions for any combination of inputs.

This analysis confirms that BLV increases with site quality, while rotation age does not vary significantly. Figures 2.1 through 2.4 depict BLVs for the thinned and unthinned scenarios at two inherit site indices: 60 and 70, which form the base case. From these reference levels, the SIs are adjusted in order to represent gains in volume from 10 to 50%. To the adjusted SIs, silviculture is added to depict the expressed, or exhibited, site index at year 25.

In this model, rotation age is not sensitive to SIs because treatment responses offset growth and yields. The poorest site index yields the greatest response. Other factors that drive the rotation age convergence are the combination of prices and products mix, constant prescription formulations for all sites, and the effects of artificial constraints, such us thinning age and the minimum age for solid wood products. These factors deserve further research.

For the SI 60 scenario, 50% gain in volume and 8% rate of return, the BLV for the unthinned model provides a range of land rent value between \$124/ac (base case) and \$850/ac, which correspond to an optimal rotation age of 18 years. The BLV for the thinned model provides a land rent value of \$200/ac (base case) to \$849/ac, and its associated optimal rotation age is 23 years (see Tables 2.1 and 2.2). Positive BLV provides the investor with the calculated land rent plus a real rate of return of 8%.

Figures 2.1 through 2.4 reflect the artificial constraints imposed on the analysis. The unthinned model shows a single peak at year 18, which corresponds to optimal rotation age, and the constraint for merchandizing ST is noticeable. In both models, cost/ton estimates were calculated from BLV maximization age. The thinned model shows peaks at years 18 and 23. The 23-year peak is slightly higher; therefore, this age corresponds to optimal rotation age.

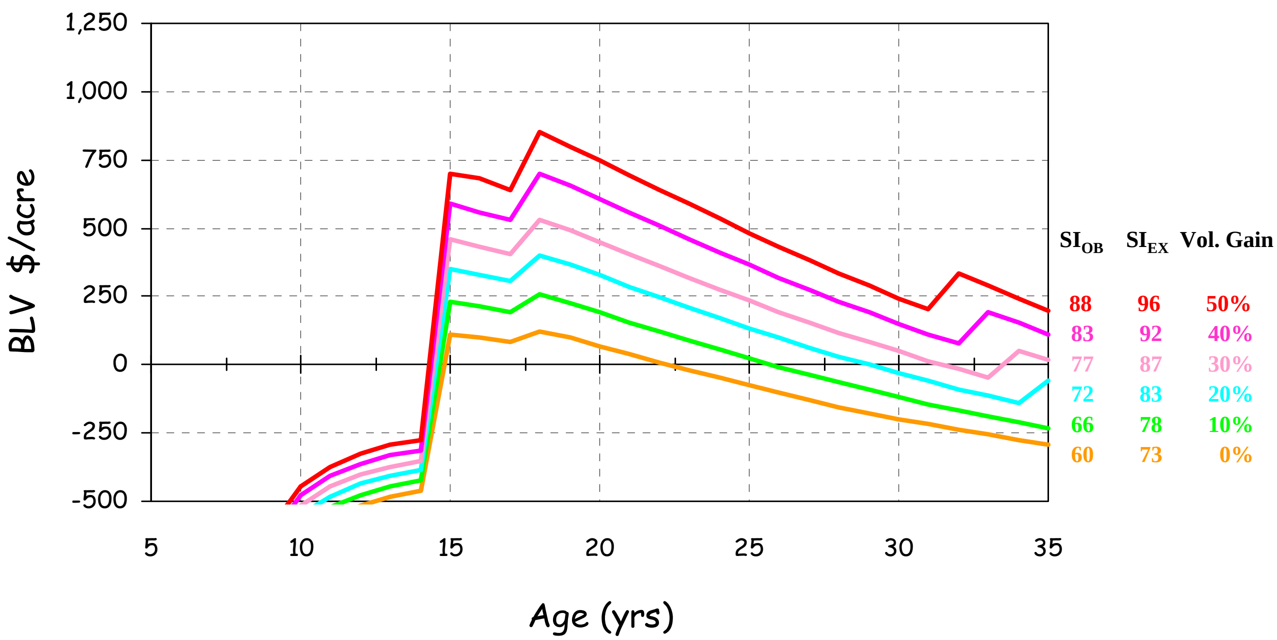


Figure 2.1. BLV and Optimal Rotation Age for the Unthinned Model (Base SI 60, at 8% Rate of Return, and Clear Cut at Year 18)

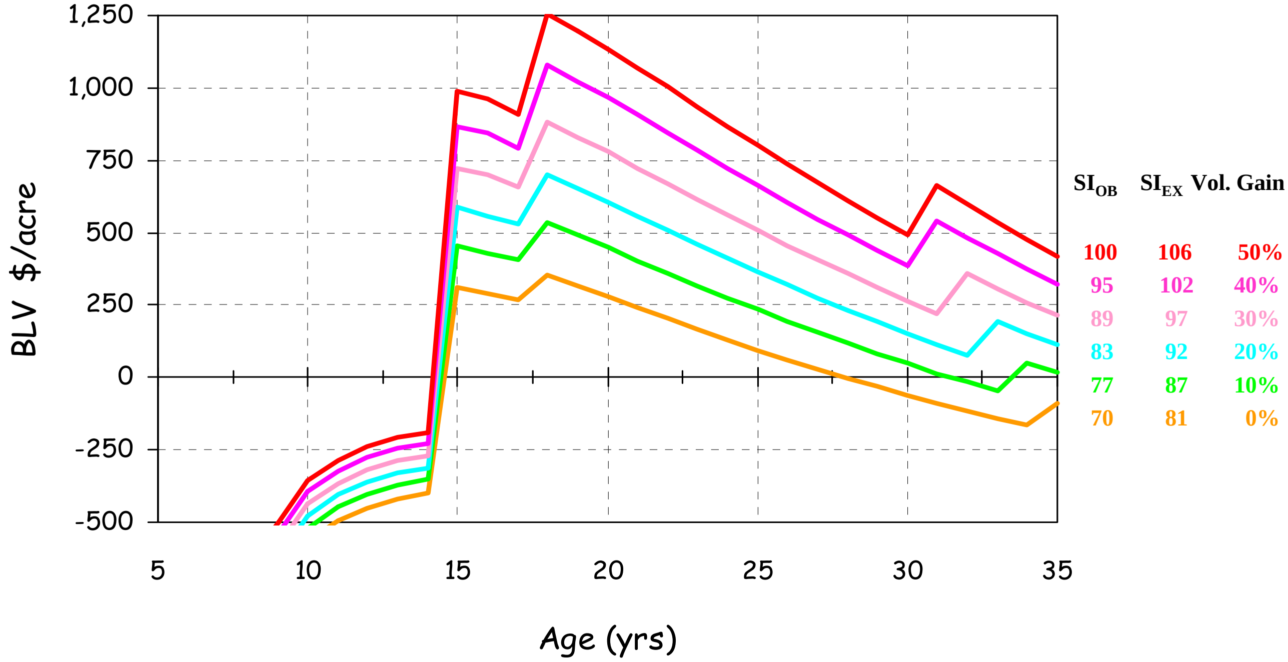


Figure 2.2. BLV and Optimal Rotation Age for the Unthinned Model (Base SI 70, at 8% Rate of Return, and Clear Cut at Year 18)

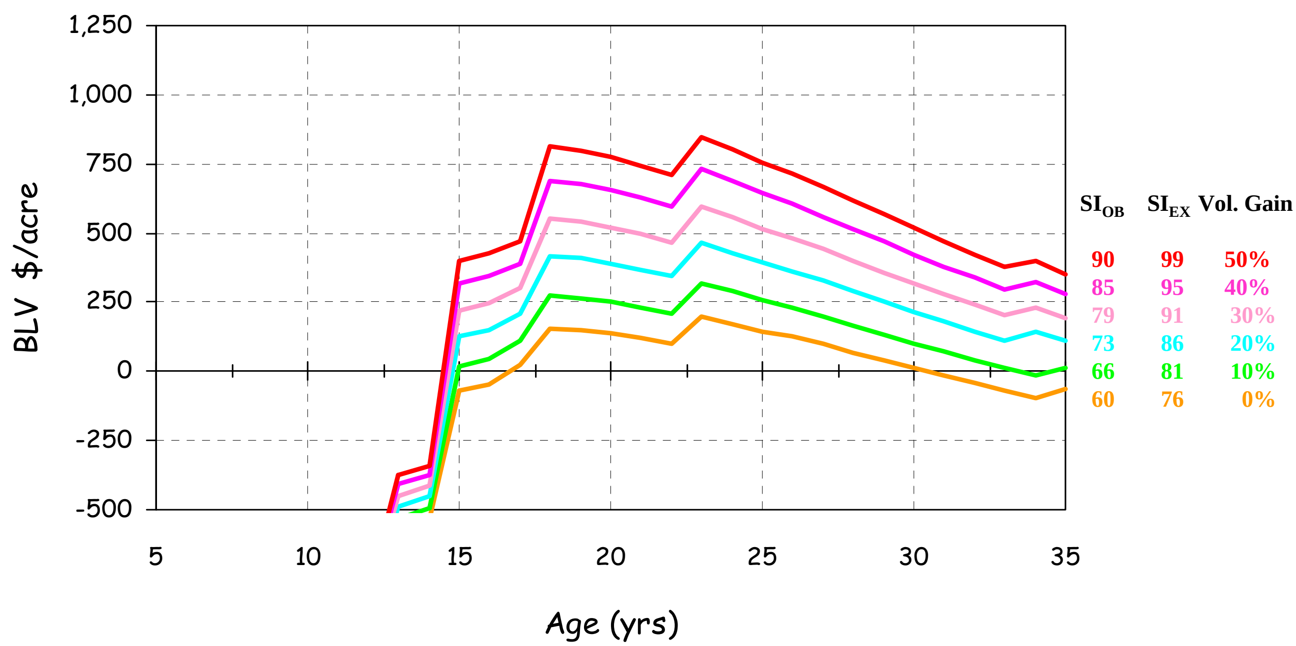


Figure 2.3. BLV and Optimal Rotation Age for the Thinned Model (Base SI 60, at 8% Rate of Return, Thinning at year 10 and Clear Cut at Year 23)

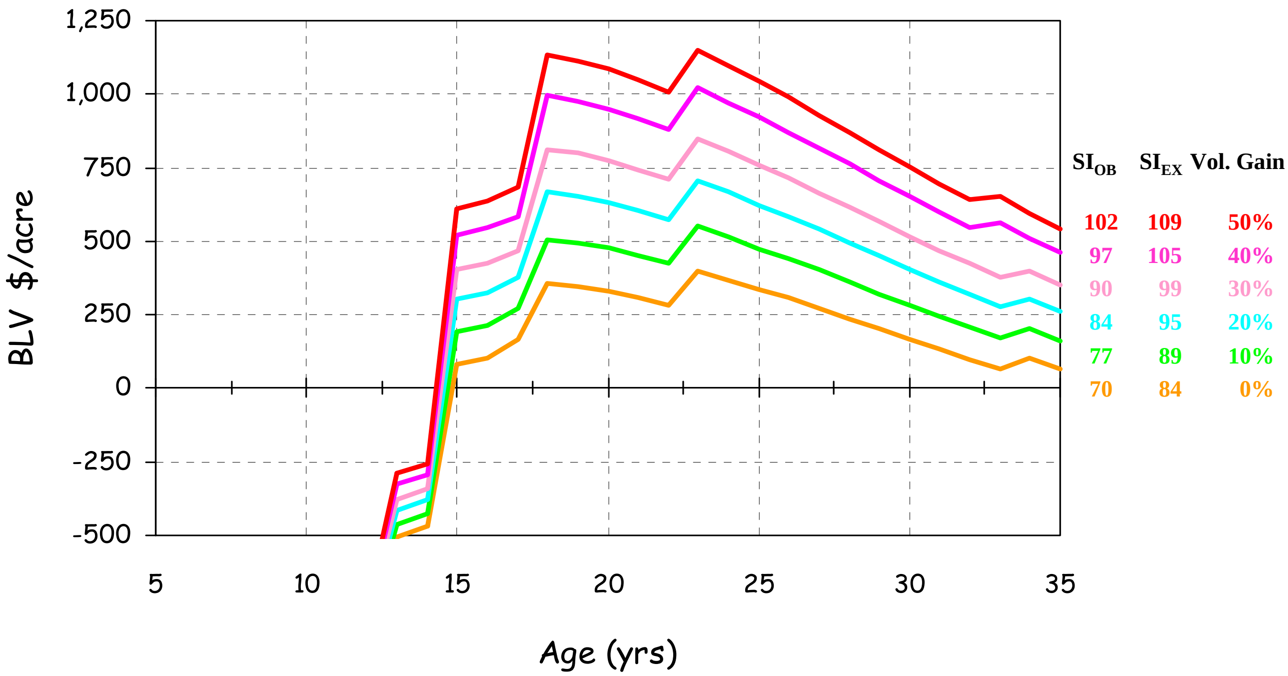


Figure 2.4. BLV and Optimal Rotation Age for the Thinned Model (Base SI 70, at 8% Rate of Return, Thinning at year 10 and Clear Cut at Year 23)

The unthinned base model yields 147, 160, and 172 ton/acre for SIs 60, 65 and 70 respectively vs. the enhanced model of 50% in volume, which yields 222, 239, and 258 ton/acre respectively. The thinned base model yields 186, 200, and 215 ton/acre vs. the enhanced model of 50% in volume, which yielded 278, 298, and 319 ton/acre respectively. For an example of merchantable volume, see Figures 2.5 through 2.10 for SI 60 and two gain levels of 30% and 50%, shown by DBH class for both the unthinned and thinned models.

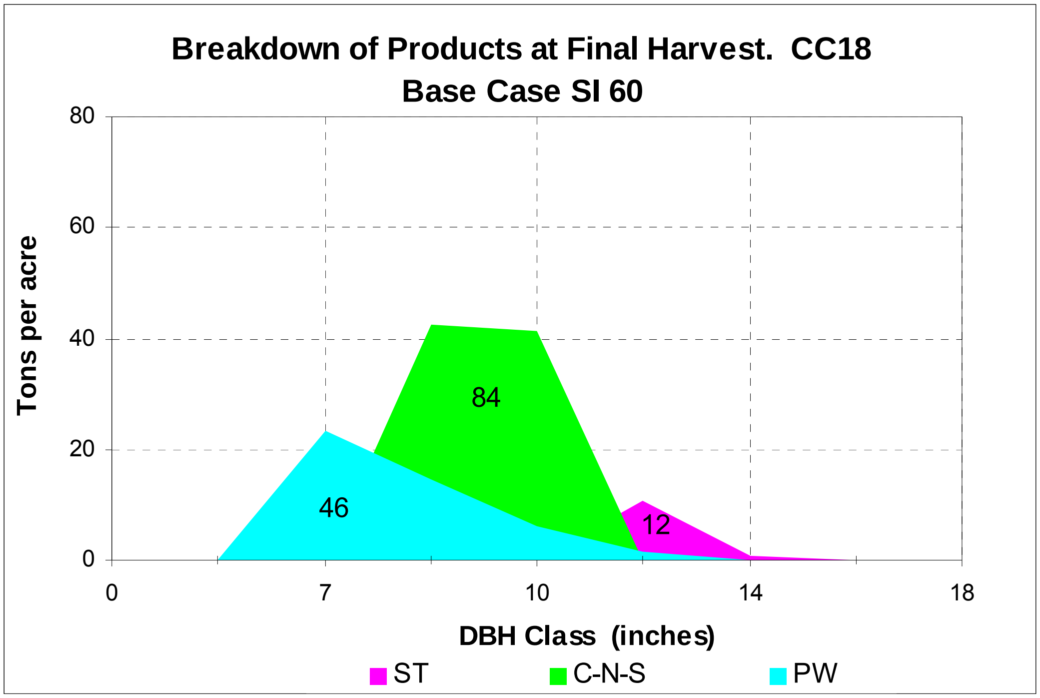


Figure 2.5. Unthinned model: Breakdown of Products, Base Case

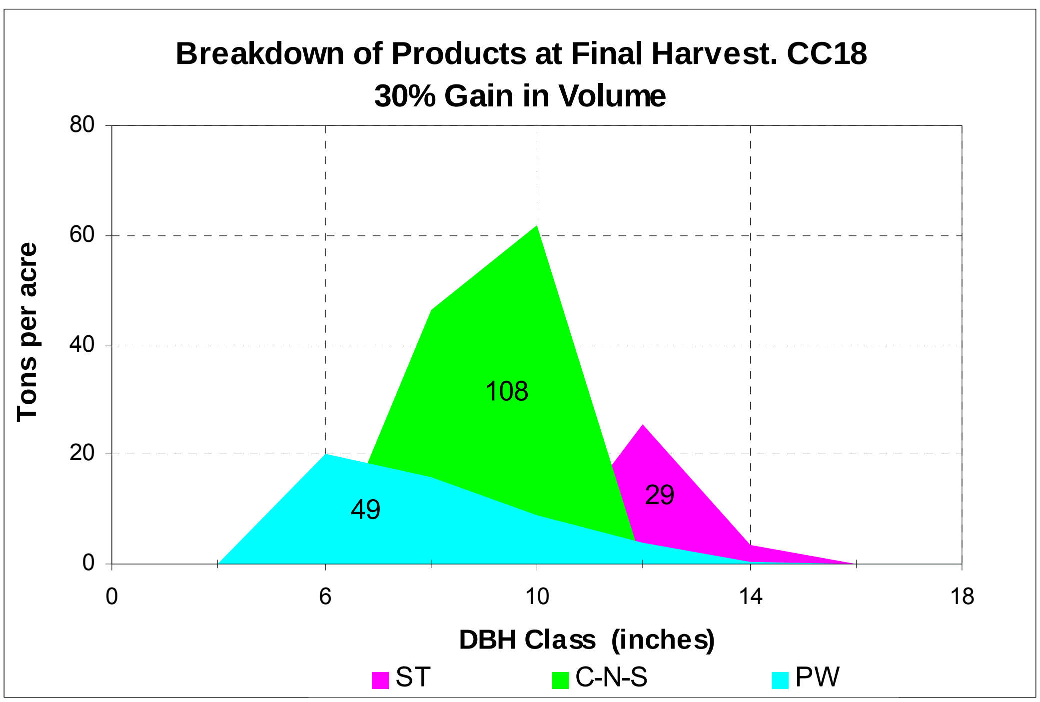


Figure 2.6. Unthinned model: Breakdown of Products, 30% Gain in Volume

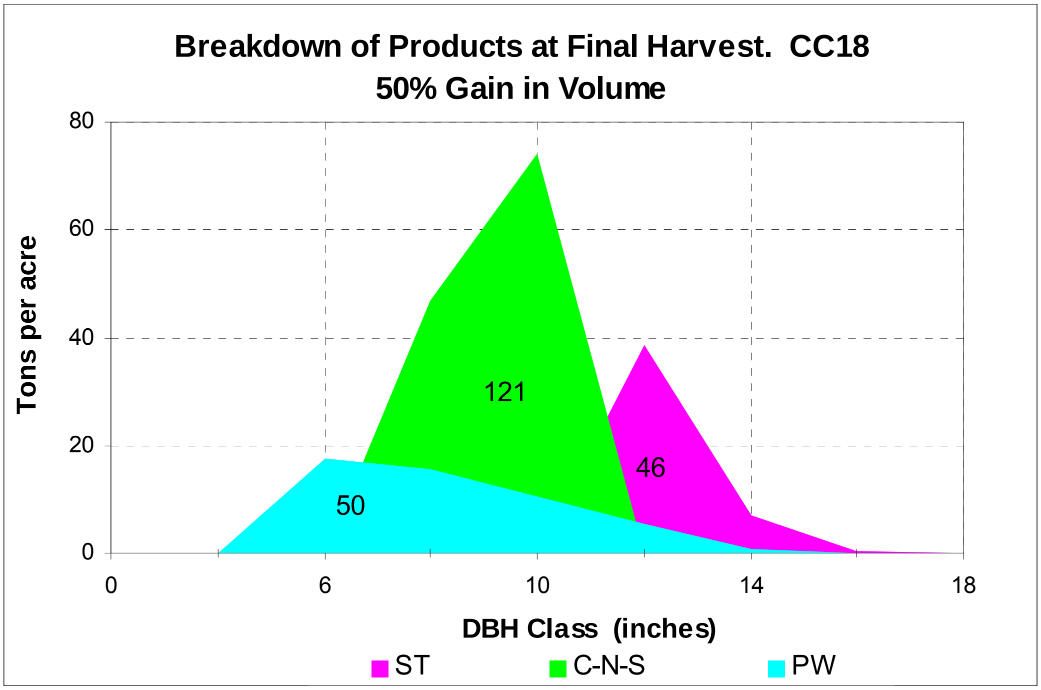


Figure 2.7. Unthinned model: Breakdown of Products, 50% Gain in Volume

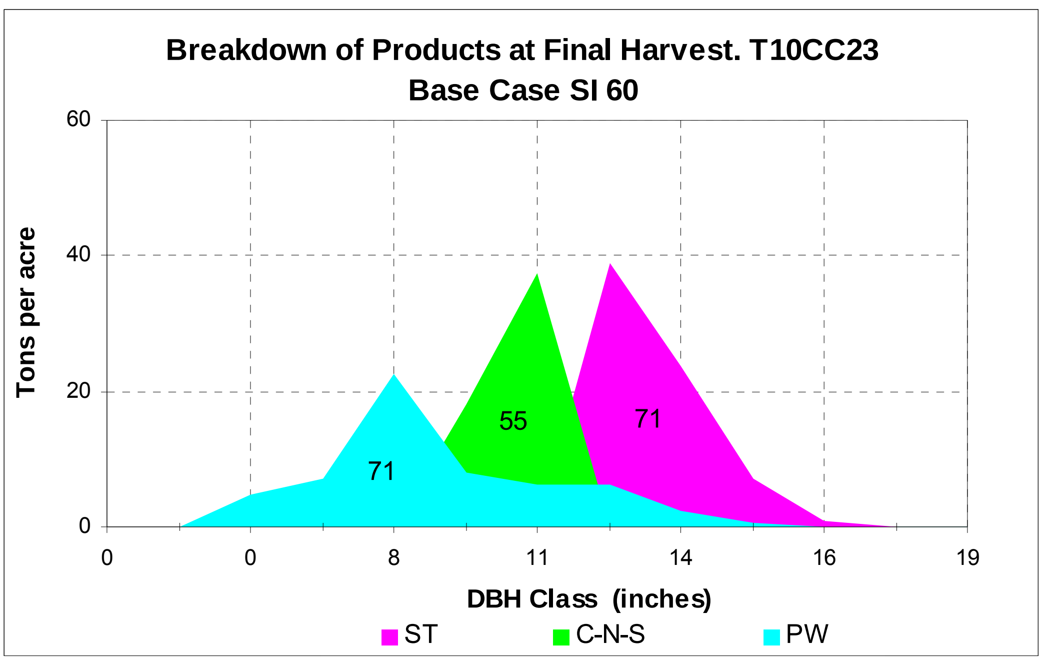


Figure 2.8. Thinned model: Breakdown of Products, Base Case

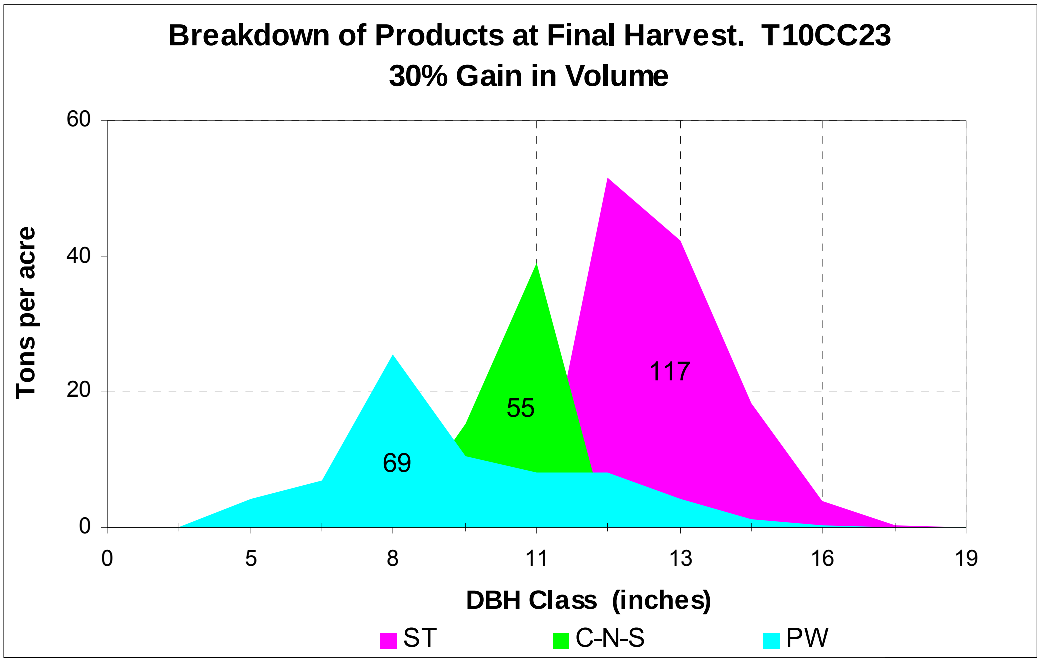


Figure 2.9. Thinned model: Breakdown of Products, 30% Gain in Volume

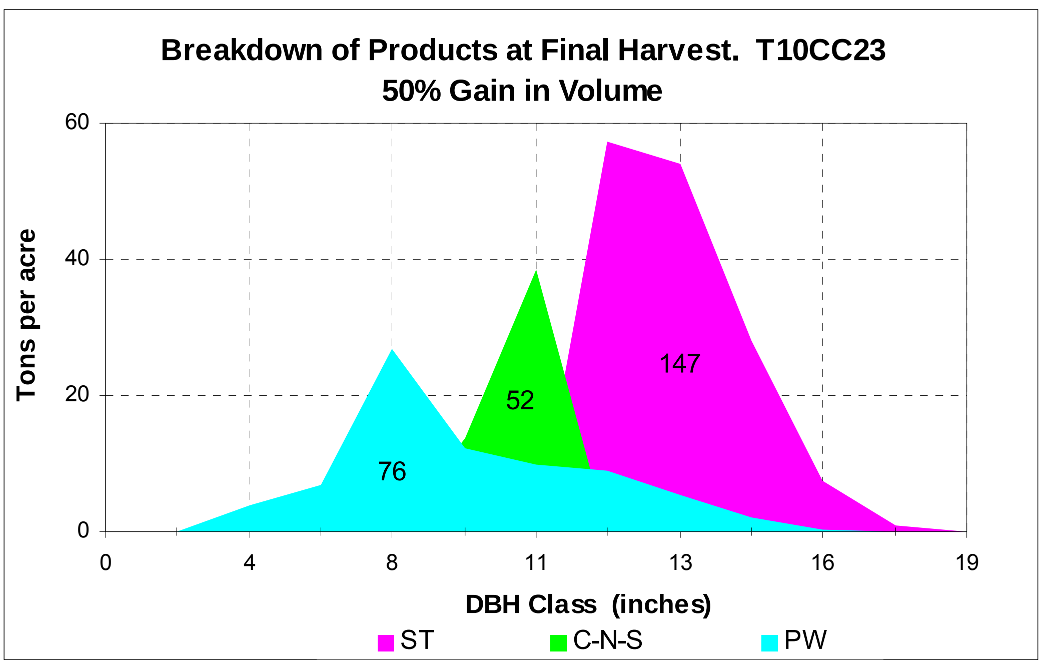


Figure 2.10. Thinned model: Breakdown of Products, 50% Gain in Volume

Table 2.1 shows the composition of the delivered-to-mill costs associated with different SI values for the unthinned model. A sensitivity analysis for site indices 60, 65, and 70 across five levels of genetic gain was assessed. The highest site index generates a greater economic margin for the investor. For instance, at the base case of SI 60 land, production costs at stand level range from $15.8/ton to $24.3/ton; harvesting costs vary from $7.5/ton to $8.2/ton, and transportation costs range from $4.1/ton to $4.3/ton, thus, delivered-to-mill costs range from $27.4/ton to $36.8/ton. While at forest level, the production costs range from $2.9/ton to $4.4/ton, resulting in delivered-to-mill costs from $14.5/ton to $16.9/ton. This table also presents NPVs and IRRs for one rotation whether land value is taken into consideration or not.

Table 2.1. Unthinned Model CC18: Estimation of Timber Production and Delivered Costs at 8% Rate of Return

Gain in Volume	SI	BLV $/ac	NPV w/o land $/ac	NPV with land $/ac	IRR w/o land	IRR with land	Prod costs $/ton	C.grow timber $/ton	Harvest $/ton	Trans. $/ton	Land acres 000	Hauling miles	Forest level Deliv.cost $/ton	Stand level Deliv.cost $/ton
Base case 0%	60	124	93	-207	9.0%	6.5%	4.4	24.3	8.2	4.3	781	30	16.9	36.8
	65	234	176	-124	9.8%	7.1%	4.0	22.3	7.7	4.2	752	29	16.0	34.2
	70	353	264	-36	10.5%	7.8%	3.7	20.5	7.6	4.2	728	29	15.6	32.4
10%	60	257	193	-107	9.9%	7.3%	4.0	21.9	7.7	4.2	747	29	15.9	33.8
	65	377	283	-17	10.7%	7.9%	3.7	20.2	7.6	4.1	723	28	15.4	31.9
	70	533	399	99	11.5%	8.6%	3.3	18.4	7.6	4.1	699	28	15.0	30.1
20%	60	402	302	2	10.8%	8.0%	3.6	19.9	7.6	4.1	719	28	15.3	31.6
	65	533	399	99	11.5%	8.6%	3.3	18.4	7.6	4.1	699	28	15.0	30.1
	70	700	525	225	12.3%	9.3%	3.1	16.9	7.5	4.1	678	28	14.7	28.5
30%	60	533	399	99	11.5%	8.6%	3.3	18.4	7.6	4.1	699	28	15.0	30.1
	65	700	525	225	12.3%	9.3%	3.1	16.9	7.5	4.1	678	28	14.7	28.5
	70	881	661	361	13.1%	10.0%	2.8	15.5	7.5	4.1	659	27	14.4	27.1
40%	60	700	525	225	12.3%	9.3%	3.1	16.9	7.5	4.1	678	28	14.7	28.5
	65	881	661	361	13.1%	10.0%	2.8	15.5	7.5	4.1	659	27	14.4	27.1
	70	1,077	807	507	13.9%	10.7%	2.6	14.4	7.5	4.1	643	27	14.2	25.9
50%	60	850	638	338	13.0%	9.9%	2.9	15.8	7.5	4.1	662	27	14.5	27.4
	65	1,043	782	482	13.7%	10.6%	2.6	14.5	7.5	4.1	646	27	14.2	26.1
	70	1,254	940	640	14.5%	11.2%	2.4	13.5	7.5	4.1	636	27	14.0	25.0

Table 2.2 shows the composition of the delivered-to-mill costs associated with different SI values for the thinned model. A sensitivity analysis for site indices 60, 65, and 70 across five levels of genetic gain was assessed. The highest site index generates a greater economic margin for the investor. For instance, at the base case of SI 60 land, production costs at stand level range from \$15.7/ton to \$23.5/ton; harvesting costs vary from \$8.5/ton to \$9.3/ton, and transportation costs range from \$3.9/ton to \$4.3/ton, thus, delivered-to-mill costs range from \$28.2/ton to \$37.0/ton. While at forest level, the production costs range from \$2.9/ton to \$4.4/ton, resulting in delivered-to-mill costs from \$15.4/ton to \$17.9/ton. This table also presents NPVs and IRRs for one rotation whether land value is taken into consideration or not.

Table 2.2. Thinned Model T10CC23: Estimation of Timber Production and Delivered Costs at 8% Rate of Return

Gain in Volume	**SI**	BLV \$/ac	NPV w/o land \$/ac	NPV with land \$/ac	IRR w/o land	IRR with land	Prod costs \$/ton	C.grow timber \$/ton	Harvest \$/ton	Trans. \$/ton	Land acres 000	Hauling miles	Forest level Deliv.cost \$/ton	Stand level Deliv.cost \$/ton
Base case 0%	60	200	166	-166	9.3%	7.1%	4.4	23.5	9.3	4.3	803	30	17.9	37.0
	65	298	248	-84	9.9%	7.5%	4.1	21.8	9.1	4.2	758	29	17.4	35.1
	70	401	332	0	10.4%	8.0%	3.8	20.3	8.9	4.1	717	28	16.8	33.3
10%	60	318	264	-68	10.0%	7.6%	4.0	21.5	9.0	4.2	750	29	17.3	34.8
	65	442	367	35	10.6%	8.2%	3.7	19.8	8.8	4.1	702	28	16.6	32.7
	70	550	456	125	11.1%	8.6%	3.4	18.5	8.6	4.1	666	27	16.2	31.2
20%	60	464	385	53	10.7%	8.3%	3.6	19.5	8.8	4.1	694	28	16.5	32.4
	65	572	475	143	11.2%	8.7%	3.4	18.3	8.6	4.1	659	27	16.1	30.9
	70	708	587	255	11.8%	9.2%	3.2	16.9	8.5	3.9	619	26	15.6	29.4
30%	60	594	493	161	11.3%	8.8%	3.4	18.0	8.6	4.1	652	27	16.0	30.7
	65	728	467	135	10.9%	8.6%	3.1	16.8	8.5	3.9	617	26	15.6	29.3
	70	849	705	373	12.3%	9.7%	2.9	15.7	8.5	3.9	582	26	15.4	28.2
40%	60	731	606	275	11.9%	9.3%	3.1	16.7	8.5	3.9	613	26	15.6	29.2
	65	874	725	393	12.4%	9.7%	2.9	15.5	8.5	3.9	577	25	15.3	28.0
	70	1,023	848	517	12.9%	10.2%	2.7	14.5	8.5	3.9	544	25	15.1	26.9
50%	60	849	705	373	12.3%	9.7%	2.9	15.7	8.5	3.9	582	26	15.4	28.2
	65	997	827	496	12.8%	10.1%	2.7	14.7	8.5	3.9	549	25	15.1	27.1
	70	1,152	956	624	13.3%	10.6%	2.5	13.7	8.4	3.8	518	24	14.7	25.9

Table 2.3 shows the evaluation of the break-even value that represents the maximum expenditure at which investors are willing to pay for an additional gain in volume and still meet their desirable/expected discount rate (6% or 8% in this analysis). For example, at 8% expected rate of return, investors with the target of producing 30% more in volume on their SI 65 tract with 605 TPA, could pay up to an additional \$0.58/seedling (\$350/acre) and still make an 8% rate of return. For SI 60 land with 10% to 50% gain in volume, the break-even cost indicates that an investor can afford additional payments of \$0.17 to \$0.90/seedling and still make the 8% rate of return. For illustration, marginal IRR that equates the $BLV_{untreated}$ and $BLV_{treated}$ when an investor pays \$0.30/seedling is also included.

Table 2.4 shows the evaluation of the break-even value that represents the maximum expenditure at which investors are willing to pay for an additional gain in volume and still meet their desirable/expected discount rate (6% or 8% in this analysis). For example, at 8% expected rate of return, investors with the target of producing 20% more in volume on their SI 60 tract with 605 TPA, could pay up to an additional \$0.36/seedling (\$218/acre) and still make an 8% rate of return. For SI 60 land with 10% to 50% gain in volume, the break-even cost indicates that an investor can afford additional payments of \$0.16 to \$0.89/seedling and still make the 8% rate of return. For illustration, marginal IRR that equates the $BLV_{untreated}$ and $BLV_{treated}$ when an investor pays \$0.30/seedling is also included.

Table 2.3. Unthinned Model CC18: Break-even Points Evaluated Across and Array of Three Site Qualities, Five Levels of Volume Gains, and Two Real Discount Rates

Gain in Volume	Inherited Site Index	Exhibited Site Index	ThinAges	Rot. age	MAI	Real Discount Rate 6% BLV	ΔBLV	Break-even	Δ$/Seedling	Marg. IRR	Real Discount Rate 8% BLV	ΔBLV	Break-even	Δ$/Seedling	Marg. IRR
Base case 0%	60			18	8.2	524					124				
	65			18	8.9	702					234				
	70			18	9.6	893					353				
10%	60	66		18	9.0	739	215	140	0.23	5.5%	257	133	100	0.17	5.5%
	65	71		18	9.7	933	231	150	0.25	6.0%	377	143	107	0.18	6.0%
	70	77		18	10.6	1,184	291	189	0.31	7.3%	533	180	135	0.22	7.3%
20%	60	72		18	9.9	973	450	292	0.48	9.9%	402	278	209	0.34	9.9%
	65	77		18	10.6	1,184	482	313	0.52	10.4%	533	298	224	0.37	10.4%
	70	83		18	11.5	1,455	562	365	0.60	11.3%	700	348	261	0.43	11.3%
30%	60	77		18	10.6	1,184	660	429	0.71	12.3%	533	408	306	0.51	12.3%
	65	83		18	11.5	1,455	753	489	0.81	13.1%	700	466	350	0.58	13.1%
	70	89		18	12.5	1,747	855	555	0.92	13.9%	881	529	397	0.66	13.9%
40%	60	83		18	11.5	1,455	931	605	1.00	14.5%	700	576	432	0.71	14.5%
	65	89		18	12.5	1,747	1,046	679	1.12	15.2%	881	647	485	0.80	15.2%
	70	95		18	13.5	2,063	1,170	760	1.26	15.9%	1,077	724	543	0.90	15.9%
50%	60	88		18	12.3	1,697	1,173	762	1.26	16.0%	850	726	545	0.90	16.0%
	65	94		18	13.3	2,009	1,307	849	1.40	16.7%	1,043	809	607	1.00	16.7%
	70	100		18	14.3	2,349	1,456	946	1.56	17.4%	1,254	901	676	1.12	17.4%

Table 2.4. Thinned Model T10CC23: Break-even Points Evaluated Across and Array of Three Site Qualities, Five Levels of Volume Gains, and Two Real Discount Rates

Gain in Volume	Inherited Site Index	Exhibited Site Index	ThinAges	Rot. age	MAI	Real Discount Rate 6%					Real Discount Rate 8%				
						BLV	ΔBLV	Break-even	Δ$/Seedling	Marg. IRR	BLV	ΔBLV	Break-even	Δ$/Seedling	Marg. IRR
Base case 0%	60		T10	23	8.1	718					200				
	65		T10	23	8.7	884					298				
	70		T10	23	9.3	1,057					401				
10%	60	66	T10	23	8.8	918	200	148	0.24	5.9%	318	118	98	0.16	6.0%
	65	72	T10	23	9.6	1,128	244	180	0.30	6.8%	442	144	120	0.20	6.9%
	70	77	T10	23	10.3	1,311	254	187	0.31	7.0%	550	150	124	0.21	7.1%
20%	60	73	T10	23	9.7	1,164	446	329	0.54	9.6%	464	263	218	0.36	9.7%
	65	78	T10	23	10.4	1,348	464	342	0.57	9.8%	572	274	227	0.38	9.9%
	70	84	T10	23	11.2	1,578	521	384	0.64	10.4%	708	307	255	0.42	10.5%
30%	60	79	T10	23	10.5	1,385	667	493	0.81	11.6%	594	394	327	0.54	11.7%
	65	85	T10	23	11.4	1,617	733	541	0.89	12.0%	728	430	357	0.59	12.1%
	70	90	T10	23	12.1	1,818	761	562	0.93	12.2%	849	449	372	0.62	12.3%
40%	60	85	T10	23	11.4	1,617	899	664	1.10	13.0%	731	530	440	0.73	13.1%
	65	91	T10	23	12.2	1,859	975	720	1.19	13.4%	874	575	477	0.79	13.5%
	70	97	T10	23	13.1	2,112	1,055	779	1.29	13.8%	1,023	622	516	0.85	13.9%
50%	60	90	T10	23	12.1	1,818	1,100	812	1.34	14.0%	849	649	538	0.89	14.1%
	65	96	T10	23	13.0	2,069	1,185	875	1.45	14.4%	997	699	580	0.96	14.5%
	70	102	T10	23	13.9	2,332	1,275	941	1.56	14.8%	1,152	752	624	1.03	14.9%

Figure 2.11 represents a sensitivity analysis of marginal rate of return for an improved genetic stock of \$0.10 to \$0.60/seedling for both, thinned and unthinned regimes. For example, a 10% gain in volume in SI 60 makes an investor indifferent to spending up to \$0.25/seedling or using traditional planting material at \$0.05/seedling, and makes the target 8% rate of return. In contrast, if the gain in volume is up to 20% over unimproved stock, a forest landowner could choose to invest in better planting if s/he is willing to spend \$0.40 - \$0.45/seedling and would make 8% rate of return for any of the regimes considered here.

The amount of land required to run a 1.5 million ton/yr mill varies depending on SI, level of gain in volume, and regime type involved. For instance, for the unthinned regime, the sensitivity analysis shows that using 46 tons/acre for pulpwood on land with SI 60, the projected timberland area required is 781,000 acres, and for a scenario with 50% gain in volume the projected timberland area required is 662,000 acres. For the thinned regime, using the same assumptions, the land required for the base case is 803,000 acres vs. 582,000 acres. Hauling distance radius, as a function of land area, varies from 27 to 30 miles for both regimes.

Finally, a sensitivity analysis for the thinned model of SI 60 was performed to analyze the logger enterprise return on assets (ROA). When ROA varies from 0% to 10%, the harvesting and transportation costs for the base case vary from \$13.2/ton to \$14.3/ton, respectively. In the same manner, for the case with 50% gain in volume, harvesting and transportation costs vary from \$12.2/ton to \$13.1/ton.

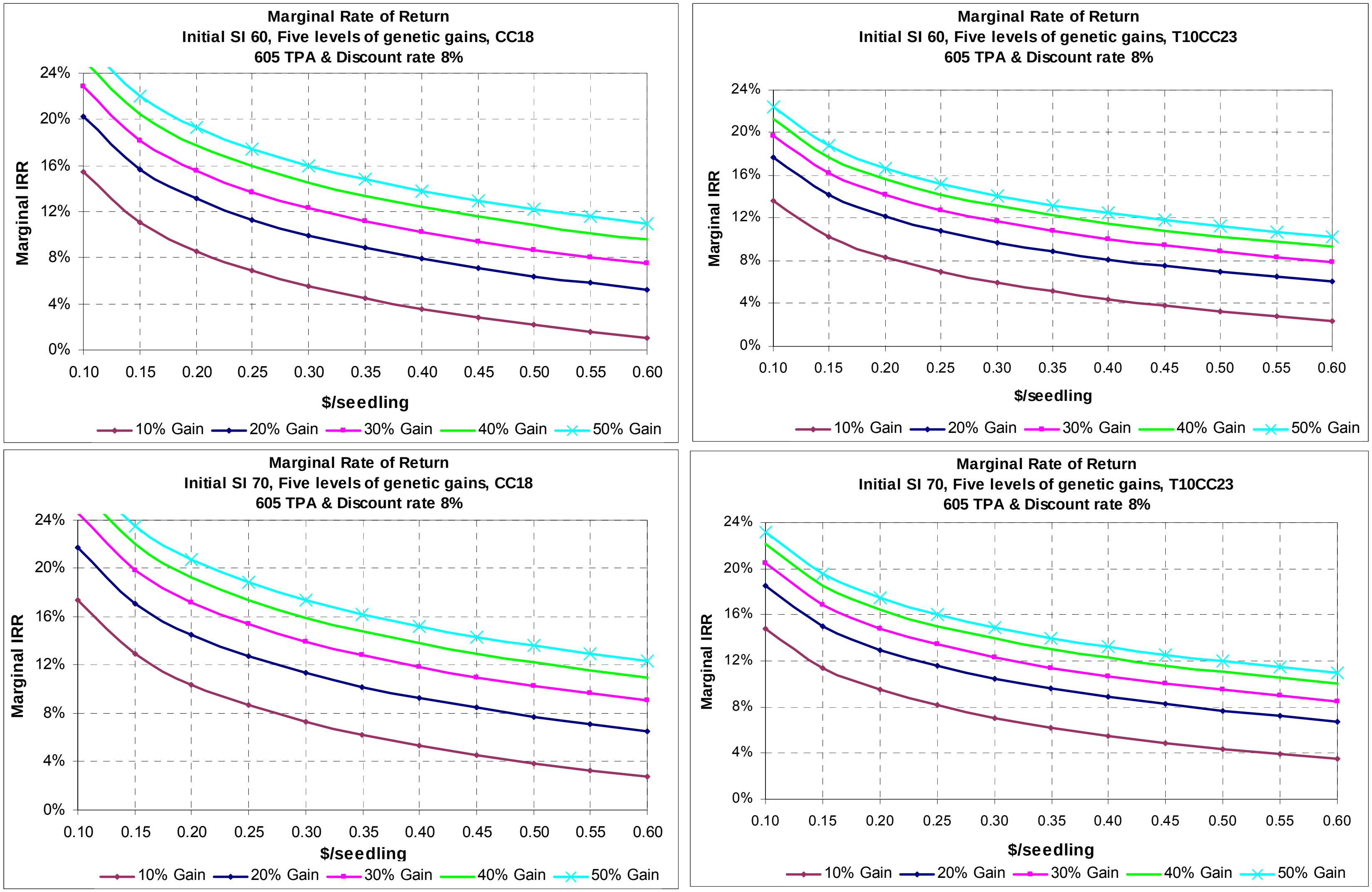


Figure 2.11. Marginal IRR, Seedling Price, and Site Quality: Across an Array of Two Site Qualities, Five Levels of Genetic Gain, 8% Discount Rate, and Thinned and Unthinned Regimes

Conclusions

Although it is difficult to make general statements about an "ideal" forest management regime, the findings from this study show that it is possible for investors to improve their competitiveness with best-suited intensive management, the best genetic seedlings available, a balanced harvesting system, and stands located close to receiving mills.

The base case scenario provides benchmarks for comparisons between countless regime configurations and selected forest leaders/competitors. It also serves as a reference for further analysis of forest production costs, such improved seedlings and their associated yield impact on growth. Another application is to identify and analyze specific management regimes and their implications by changing some of the model's endogenous or exogenous variables in the study region. Under a given set of assumptions and policies, the base case scenarios (thinned and unthinned) could be viewed as an example for evaluating future biotechnological and technical developments that could dramatically increase the profitability and global competitiveness of the U.S. forest industry.

The flexible stand simulator (unthinned and thinned models) developed for this study for Southern pine has proved useful for evaluating biological technologies (including cloning, and enhanced selection methods) to accelerate growth rates and produce modified fibers that are tailored to specific processing methods that provide higher value while simultaneously decreasing processing costs.

The unthinned loblolly pine model with an optimal rotation age of 18 years, for a lower coastal plain physiographic region, starting site indices of 60 or 70, a discount rate of 8%, and intensive site preparation and management at forest level, leads to timber production costs of \$3.7 to \$4.4/ton of roundwood. At stand level, the unthinned model under the same conditions leads to a timber production cost of $20.5 to $24.3/ton of roundwood, and at both forest and stand levels, to $11.8 to $12.5/ton of logging and transportation costs.

The thinned loblolly pine model with an optimal rotation age of 23 years, one thinning at year 10, for a lower coastal plain physiographic region, starting site indices of 60 or 70, a discount rate of 8%, and intensive site preparation and management at forest level, leads to timber production costs of $3.8 to $4.4/ton of roundwood. At stand level, the unthinned model under the same conditions leads to a timber production cost of $20.3 to $23.5/ton of roundwood, and at both forest and stand levels, to $13.0 to $13.6/ton of logging and transportation costs.

For assessing the maximum amount that a landowner is willing to pay for a better plantation to obtain an additional gain in volume and still make the desirable real discount rate, a single variable cost (seedlings) was selected to capture the potential marginal return for investments in forest management and biotechnology. The break-even points for the unthinned regime at five levels of genetic gain on SI 60 land with 605 TPA, a discount rate of 8%, and gains between 10%, 20%, 30%, 40% and 50%, showed that an investor could pay an additional $0.17, $0.34, $0.51, $0.71, and $0.90, respectively, per seedling.

The break-even points for the thinned regime at five levels of genetic gain on SI 60 land with 605 TPA, a discount rate of 8%, and gains between 10%, 20%, 30%, 40% and 50%, showed that an investor could pay an additional $0.16, $0.36, $0.54, $0.73, and $0.89, respectively, per seedling.

In addition, this higher seedling cost can be seen to justify the scale of investment for the implementation of more intensive and integrated silvicultural regimes, as well as for forest tree biotechnology research, development, and implementation. Initiatives in the U.S. South to enhance seedling properties should positively affect its relative competitive advantage compared to other countries. However, a word of caution may be advisable. Current growth and yield systems contain discrepancies among them because of the nature of the various data used to derive the different models. Also, projecting and predicting growth and yield of improved pine families is not sufficient via site index alone (Knowe, 2007).

This entire analysis is focused on how to simulate gains in volume through genetics or other silvicultural improvements. However, gains in quality may be as important as, or more important than, solely considering gains in volume for creating additional value. Tree breeding, cloning, and biotechnology provide the potential for producing more forest products from less land at a lower cost. Improved seedlings should enhance stand development and raise wood quality standards (specific gravity, microfibril angle, fiber length, juvenile wood characteristics, crown form, and branching habits), as well as reduce fusiform rust and other diseases, and develop higher uniformity with narrower diameter distributions. (Uniformity is the topic for Chapter 4 in this dissertation).

The importance of thinking strategically about landholdings and thinking holistically about the role of fiber in profitability shows that intensively managed, high-site-index land near a mill in the U.S. Southeast Coastal Plain can compete on a delivered-to-mill cost basis with most areas in the world.

Implications

Researchers have calculated a very broad range of delivered-to-mill costs around the world. For intensively managed stands on the Lower Coastal Plain, this research estimates a delivered production cost of $27/ton to $37/ton for the unthinned model, and $28/ton to $37/ton for the thinned model. In spite of intensive and increasingly global competition, for the U.S. South, opportunities exist to continue being the forest basket of the world. See Table 2.5.

Table 2.5. Logging, Transportation, and Delivered Costs vs. Costs and Prices Estimated for Selected Countries (adapted from Siry et al. 2006)

$US/green short ton	Unthinned	Thinned	US South	Australia	Brazil	W Canada	Sweden
	SI90 - SI60	SI90 - SI60	Lo - Hi	Lo - Hi	Lo - Hi	Lo - Hi	Lo - Hi
Harvesting	7.5 - 8.2	8.5 - 9.3	11 - 13	6 - 18	5 - 7	9 - 12	10 - 17
Transportation	4.1 - 4.3	3.9 - 4.3	4 - 11	4 - 9	2 - 4	9 - 13	4 - 8
Total Harvest. & Transport.	11.6 - 12.5	12.4 - 13.6	15 - 24	10 - 27	7 - 11	18 - 25	14 - 25
$US/green short ton			PW - ST	PW - ST	PW - ST	PW - ST	PW - ST
Average Delivered Price			25 - 55	33 - 52	23 - 65	32 - 45	40 - 62
Composite Delivered Cost	27 - 37	28 - 37					

Caveats

Growth response adjustments to several silvicultural management regimes for dominant height and stand basal area were developed for a second rotation in the Piedmont and Upper Costal Plain of the U.S. South; the forest cost model used here was developed using the existing the Upper Coastal Plain and Piedmont responses and applying them to the Lower Coastal Plain Region.

Other caveats include operating the model outside geographical limits of the data (Alabama, Florida, Georgia, and South Carolina), and operating the model within a limited range of planting density, age, and site quality. In addition, mortality and diameter distribution changes have implications on growth and yield modeling but this model is not yet equipped for dealing with advanced seedling generations. Further research is needed to ensure appropriate growth and yield modeling.

Users of the model also should be aware that it does not cover every possible treatment combination, and users must, by closest match, select one of the twelve options offered in the table of responses. Finally, results must be viewed with caution regarding different configurations of the typical harvest equipment selected. A weak calculation results from a lack of disaggregate information surrounding freight costs. Based on an informal survey and current hauling rate market, a payload table was derived to match transportation costs and hauling distance.

Further research should be designed to extend the above work by developing a similar economic framework for hardwood plantations, along with additional scenarios that focus not only on volume gains, but also on quality attributes for both unthinned and thinned regimes.

CHAPTER 3

ASSESSING ROYALTIES FOR PROPAGATION RIGHTS

A CASE STUDY[2]

[2] De La Torre, R.E. and D. H. Newman. To be submitted to *Canadian Journal of Forest Research*. August 2007.

Abstract

Tree improvement programs in the Southern U.S. formally began in the second half of the 20th century. The evolution of this process consisted of finding plus trees from wild tree populations that exhibited outstanding features such as volume, form, and health. These were relocated and propagated in seed orchards, usually by grafting. Progeny were tested to evaluate and rank parents. Trees with lower rankings were removed from the seed orchards, and thus, improved seeds were produced. Second generation selections were made in progeny tests. The best individuals were selected from offspring of the best parents and established in Second Generation Seed Orchards. Using this recurrent selection process, producers currently harvest seed sufficient to produce over one billion seedlings annually. Along with improved intensive silviculture, these improved seeds have increased timber production by more than four times since the first round of tree improvement began (Fox at al, 2004).

Although these advanced generation seeds delivered increasingly higher volumes to forest landowners, their market price has not reflected their value. Especially with the advent of vegetative propagation techniques that are able to expedite and capture additional gains in volume and quality traits, the forest seed industry is challenged with how to recoup the investments devoted to developing these "miniature factories." The solution lies in understanding the combination of value creation and strategies to capture and protect the value of elite pine varieties.

This chapter follows the progress made in the agricultural field for protecting the value of genetic assets and examines available protections for developers, and discusses common valuation techniques for assessing royalties on tangible and intangible assets. A case study is presented that attempts to estimate royalty rates to capture the value created and intellectual

property inherent in elite pine varietal seedlings when they are used for propagation rather than for reforestation. An analytical technique derived from the income approach was used to derive the royalty rates with a sensitivity analyses on three variables: levels of net profits, number of cuttings per mother plant, and payment time frames were further performed to allow the development of five payment mechanisms.

In summary, this chapter provides a background for valuation methods that may address the intangibles of genetic advances and for protecting intellectual property of biotechnology developers.

INDEX WORDS: Biotechnology, genetic advances, elite variety, intellectual property, royalties, valuation methods.

Introduction and Literature Review

Global wood harvested in 2005 exceeded 3 billion m^3, of which about 60 percent was industrial roundwood and 40 percent, wood-based fuel. The reported value at that time was about $64 billion: $57 billion coming from industrial roundwood, and the remainder from wood fuel. Total natural and commercial forest area is estimated at 4 billion hectares (30 percent of the total land area on Earth). Productive forest plantations represented 1.9 percent of global forest area in 1990, 2.4 percent in 2000, and 2.8 percent or about 109 million hectares (270 million acres) in 2005. Productive forest plantations have been increasing by 2.5 million hectares per year since 2005 (FAO, 2005). The Food and Agriculture Organization and the World Wildlife Fund (FAO, 2000; WWF, 2001) estimated that the contribution of forest plantations to global industrial wood needs could reach 50-75 percent by 2030.

In the past decades, the application of biotechnology to agriculture has resulted in a number of advances (Sedjo, 1999, Fernandez-Cornejo and Caswell, 2006). Many biotechnological innovations from agriculture have been adapted to forestry. Improved forest seedlings through breeding programs have become the most common procedure for boosting forest production for the last five decades. Particularly for conifers, open pollinated and mass control pollination have been successful, although some potential gains are diluted because of pollen contamination, and some traits are not fully expressed because of gene segregation. The most recent approaches are vegetative, or clonal, propagation. While genetically modified crops were rapidly developed and accepted by crop growers and now are common across the world, genetic engineering for commercial application in forestry is in its infancy.

An overview of forest improvement progress follows. Burdon and Libby (2006) discuss the first documented reforestation attempt in Egypt 2,300 years ago to mitigate timber shortages.

Across Asia, the Middle East, and Mediterranean regions, planting poplar and willow rooted cuttings was a common practice for erosion control and feeding animals. China has records of reforestation management using valuable species and selected trees of Chinese fir from the 1200's. During the 1700's and 1800's, the British developed the science of natural selection, and in Germany, landowners planted large stands with conifers. In the early 1900's, France established 2 million acres of maritime pine for protection and to support the resin industry. At the same time, the major forest countries in the Southern Hemisphere started forest plantations.

In the middle of the 20th century, both tree breeding experiments from Scandinavian scientists and the potential technology transfer from agronomic crop breeding caught the attention of U.S. government, mainly universities, and the U.S. forest products industry. As a result, since the 1970's, large tree cooperatives in Texas, North Carolina, and Florida, and private industry involved with tree breeding programs, have been responsible for offering advanced generations of seeds from their recurrent tree improvement programs. Currently, over one billion seedlings are supplied each year for plantations in the U.S. South (McNabb, 2005). Figure 3.1 shows the evolution of tree breeding programs and the contribution of silvicultural practices during the last seventy years.

Traditional breeding consists of first selecting superior trees from natural or planted populations, based on their phenotypes. They are then established by grafting, for example, in a seed orchard. At the time of flowering, pollination may be open or controlled; mature seeds are collected and progeny tests are established. At six years (the usual age for making reliable predictions), the potential genetic gains for the various genotypes are analyzed. Parents in the seed orchard are ranked, and the next cycle of breeding begins.

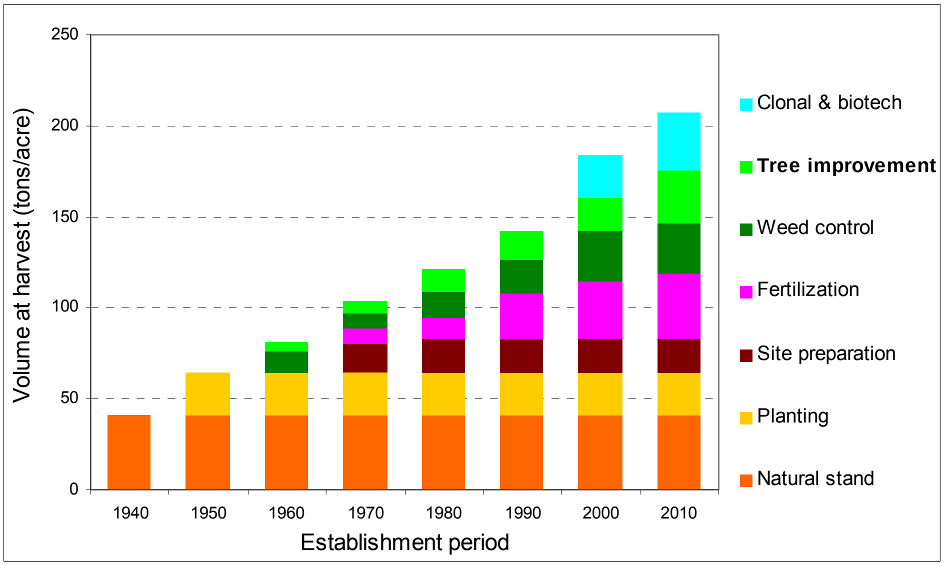


Figure 3.1. Contributions of Intensive Management Practices to Productivity in Pine Plantations in the Southern United States from 1940 through 2010 (Fox, et al, 2004)

Seeds from first generation open pollinated seed orchards were available by the 1960's and yielded 8%-12% gains in volume over unimproved seedlings. Second generation seeds, yielding 14%-23% gain, were available in the 1980's (Fox, 2004). However, potential gains were not expressed in full because of pollen contamination and gene segregation.

An alternative breeding technique is hybridization, which crosses trees from different species. For example, hybrids between poplar species exhibit better characteristics than those found in the parent population. *Eucalyptus grandis* x *urophylla*, and *Pinus elliottii* x *caribea* are other examples. In fact, *Pinus elliottii* x *caribea* combines the higher quality logs derived from *elliottii* with the faster growth rate of *Pinus caribea* (Sedjo, 2001, Burdon, 2006).

Advances in vegetative propagation techniques can also leverage forest gains. Taking the best of the best families from well developed breeding programs, super-plus individuals with desired attributes can be copied identically and widely propagated and deployed at operational scales. Depending on the species, rooted cuttings from hedges or branches can easily produce successful plantations; others need more complex techniques, such as tissue culture (organogenesis and somatic embryogenesis) to propagate identical elite genotypes. Tissue culture is capital intensive; thus, using a combination of cultured seedlings and rooted cuttings for propagation may be more cost-effective. This chapter addresses this approach for capturing the value of clonal technology when pine seedlings are sold for propagation.

Successful agricultural breeding programs are powerful evidence that crops with superior yields and some desirable attributes are reachable through traditional breeding and biotechnology techniques, some of which can be applied to pine plantations. Breeding is a platform for biotechnology applications, which conventionally cover three areas: vegetative reproduction methods, genetic markers, and genetically modified organisms (Sedjo, 2004). Agricultural Biotechnology is defined by the USDA (2007) as "a range of tools, including traditional breeding techniques, that alter living organisms, or parts of organisms, to make or modify products; improve plants or animals; or develop microorganisms for specific agricultural uses. Modern biotechnology today includes the tools of "genetic engineering" (GE). Through GE, biotech products like herbicide-tolerant and insect-resistant crops have been developed –seeds, themselves, in which their own resistance to broad spectrum herbicides and/or to insect plagues is incorporated. This kind of biotechnology promises "to turn seeds into miniature factories" (McFarlan, 1998).

To apply biotechnology to forest plantations may be more difficult than applying this technology to plants used for agronomic crops, given the nature of the forest growth process with long rotations, large areas of dedicated land, intensive capital outlays, and a higher level of physical and biological risks (fire, natural disasters, insects, diseases). A forest plantation is probably one of the final large agricultural commodities to become improved through biotechnology. However, forest landowners are now able to capitalize on the advances of the past 10 or 20 years because forest biotechnology has not only the potential of vegetative reproduction methods but also of transgenic trees with optimized yield and quality traits. Table 3.1, developed by *Context Consulting* and cited by Sedjo (2001), lists features that are being addressed by biotechnological advances in forestry.

Table 3.1. Forest Traits that Can Be Improved through Biotechnology

Silviculture	**Adaptability**	**Wood Quality Traits**
Growth rate	Drought tolerance	Wood density
Nutrient uptake	Cold tolerance	Lignin reduction
Crown/stem	Fungal resistance	Lignin extraction
Flowering control	Insect resistance	Juvenile fiber
Herbicide		Branching

Vegetative Propagation of Trees for Forestry

Vegetative propagation, as opposed to seed propagation, refers to any method used to replicate individual plants. Vegetative propagation has been practiced for centuries in plants such as grapes, potatoes, and fruit trees. A simplistic description of vegetative propagation consists of taking cuttings from a plant (branch or root) and then planting them. The collection of newly regenerated plants is a clone, and each member of the clone has identical genetic features to the "mother plant". If the mother plant is superior, the ramets will capture all of the genetic gain of the improved ortet without diminishing that gain through sexual reproduction.

In forestry, this process starts with plus trees selected through traditional breeding programs. Some trees like eucalyptus and poplars are easily propagated vegetatively by cuttings. However, this technique has not been as effective for most conifers; thus, for southern pines, for example, clones are also produced from embryos. This requires tissue culture, a more sophisticated technique, which is a biotechnological extension of the traditional breeding process.

> Development of elite varieties begins with loblolly or slash pine seed obtained from the mating of the very best parents selected from offspring performance in progeny tests…Seeds are harvested while still immature, extracted from the green cones, and placed on special culture media to induce tissue production, or embryogenesis. The media stimulates the immature embryo into replicating itself, instead of growing into a fully developed pine seedling. The resulting tissue culture will continue to divide into hundreds and eventually even millions of embryos, each an exact copy of the original embryo from a single seed. When a sufficient amount of tissue is accumulated, it is placed in cryogenic storage, where the culture can be held indefinitely for future use.
>
> When several hundred embryogenic cultures have been cryo-preserved, a small amount of tissue from each individual culture is removed, and the embryos are stimulated to mature and germinate. From these germinated embryos, finished seedlings are grown for testing on forest sites. As these replicated tests reach four to six years of age, the very best trees are selected and designated as elite varieties. The embryogenic cultures of these can then be used to produce seedlings for large-scale commercial production, which are genetically exactly the same as the best tree selected in the test plots (Weir et al, 2006).

Clonal technology has been used to plant large areas, especially with *Pinus radiata, Acacia spp.* and *Eucalyptus spp.* in Southern Hemisphere countries, e.g. New Zealand, Indonesia, Chile, and Brazil, where timber growth rates and financial returns are higher, and clonal technology is more common than in the Southern U.S. (Burdon and Libby, 2006; Cubbage, 2006; Wright and Dougherty, 2006).

Currently, forest biotechnology in the U.S. is promoted primarily by two companies, ArborGen and CellFor. ArborGen, formed in 2000, is a joint venture involving International Paper, Rubicon, and MeadWestvaco. ArborGen focuses on research and development technologies associated with mass production of transgenic and non-transgenic trees on an operational scale. Its applications and solutions include improvements in softwood and hardwood growth rates, stress tolerance, and quality products for the forestry industry. ArborGen's transgenic products must undergo a deregulation process through the Animal and Plant Health

Inspection Service (APHIS). This process is designed to determine if transgenic trees are as safe as traditional ones and do not present harmful potential to the environment. Thus, ArborGen must carefully weigh the expense of development plus the expense of deregulation against the benefits from the sale of their product (Sedjo, 2004).

CellFor was founded in 1999 through a merger of two leading biotechnology companies with roots in the forestry industry, Pacific Biotechnologies and Silvagen. CellFor's principal institutional investors are ATP Capital, CSFB Private Equity, GrowthWorks Capital, and BDC Venture Capital. To date, CellFor has focused on mass vegetative propagation of loblolly pine, which is the dominant plantation species (close to 1 billion seedlings per year, Schmidtling et al, 2004) in the Southeastern U.S. Through somatic embryogenesis, an advanced form of vegetative propagation, CellFor, to date, has developed elite varieties that account for 20,000 acres of forest plantations world-wide.

For both companies, the financial gain from increased productivity and forest quality is captured in price premiums, which must reflect the value delivered to the consumer by planting elite varieties as trees, as well as the value to the producer of the intellectual property rights. Although the value received by landowners may vary regionally (for example if their tracts are located in a disease hazard region or not, if tracts are in areas with very aggressive weed competition, or not, which would directly affect the management costs), somatic seedling prices are uniform region-wide.

However, buyers may be interested in using somatic seedlings as donor plants for subsequent vegetative propagation, such as rooted cuttings, rather than for forest plantations because they may believe that they can produce inexpensive clones efficiently. In fact, a recent study (Baltunis et. al, 2007) shows that gain in rootability up to 77% is achievable. In addition, these consumers may have sufficient land and trained labor to make this alternative viable. Finally, they would be more comfortable using the rooted cutting propagation technology (no sophisticated labs required) than the tissue culture technology. Therefore, for certain buyers, somatic seedling prices must be adjusted to include the right to propagate this protected material. Otherwise, the somatic seedlings are not returning their inherent value to the developers/producers. The question is how much the propagation rights are worth.

Looking to Agriculture for Guidance

Genetic improvement of agricultural crops has created value through breeding and advance biotechnology, and different financial mechanisms for capturing such value have been developed. Simultaneously, with the remarkable boost in returns and savings from biotechnological implementation, producers have protected their significant investments in new products that have both improved quantity and quality. Although biotechnological applications to forestry are modest compared to crop plants, the following discussion should be a useful illustration for describing parallel efforts in forestry today.

With the advent of commercial hybrids in the 1930's, yields of corn evolved from 20-30 bushels/acre to over 140 bushels/acre in the 2000's (Fernandez-Cornejo, 2004). Similarly, other products, such as cotton, soybean and wheat, have increased yields four, three and two and a half times, respectively (Fernandez-Cornejo, 2004). It is believed that at least half of these gains are due to genetic seed improvement. Because this technology delivers higher values to farmers and customers (plants resistant to certain insects, herbicides, and healthier attributes, for example), it is sold at a premium price. Legal protection for intellectual property has also improved. For example, the Plant Variety Protection Act (PVPA) gives plant developers exclusive rights for 20 years for most crops, and 25 years for trees and vines.

Since the 1970's, the U.S. seed ownership industry has become multinational through mergers and acquisitions. For instance, three decades ago, more than 50 seed companies were acquired by pharmaceutical, petrochemical, and food firms in order to increase their market share in a business with a high profit potential. Today, after another recent round of mergers and acquisitions, the leading seed producers are Monsanto, Du Pont, Syngenta AG, and Limagrain. Table 3.2 includes the market share for the ten top seed companies based on 2006 revenues, commercial seed markets worldwide, and the global proprietary seed market[3]. The top ten seed companies represent 55% of the global commercial seed market, and Monsanto commands 21% of the global proprietary seed market.

Table 3.2. Top Ten Seed Companies Worldwide

Company	2006 Sales US $ millions	Seed Market Share Based on		
		Revenues Top Ten	Worldwide Market	Proprietary Market
1. Monsanto (US)	$4,028	32%	18%	21%
2. Dupont (US)	$2,781	22%	12%	14%
3. Syngenta (Switzerland)	$1,743	14%	8%	9%
4. Groupe Limagrain (France)	$1,035	8%	5%	5%
5. Land O' Lakes (US)	$756	6%	3%	4%
6. KWS AG (Germany)	$615	5%	3%	3%
7. Bayer Crop Science (Germany)	$430	3%	2%	2%
8. Delta & Pine Land/Monsanto (US)	$418	3%	2%	2%
9. Sakata (Japan)	$401	3%	2%	2%
10. DLF-Trifolium (Denmark)	$352	3%	2%	2%
Revenues	$12,559	100%	55%	64%
Value of the overall commercial seed market	$22,900			
Global proprietary seed market	$19,600			

Source: ETC Group

[3] Source: www.etcgroup.org http://www.etcgroup.org/en/materials/publications.html?pub_id=615

Expenditures on plant breeding R&D (see Figure 3.2) provide additional indications of the magnitude and growth of private sector research.

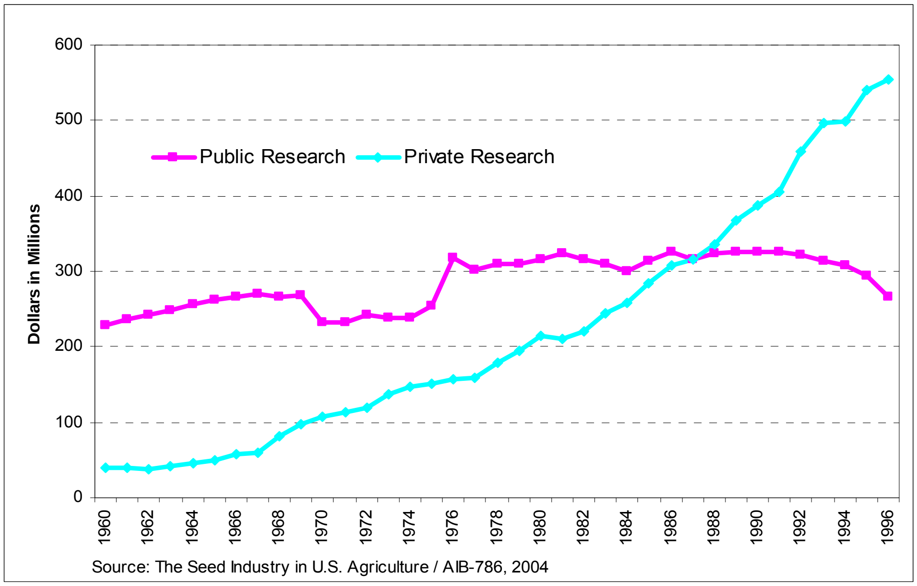


Figure 3.2. Public and Private Research Expenditures on Plant Breeding (1996 Dollars)

Introductions and trials of new varieties are increasing continuously. Seeds represent the scientific knowledge involved in producing new plant varieties with beneficial attributes, such as improved yield, better quality, disease reduction, and chemical tolerance. The number of approved plant variety protection (PVP) applications measures the dynamics of the plant breeding and biotech community. For example, for the four major crops (soybean, corn, wheat, and cotton), an excess of 2,500 certificates had been approved by 2002. In addition, the Figures 3.3, 3.4, and 3.5 exemplify this active effort through field testing, which is regulated by the USDA's Animal and Plant Health Inspection Service (APHIS).

After some initial skepticism, investors are focusing on plant biotechnology again. There is recognition that this revolutionary technology can provide answers for world food security with more productivity, higher nutrition, better taste, reduced energy subsidies (such as less water, fertilizer, and fewer pesticides), and healthier, safer crops and livestock businesses.

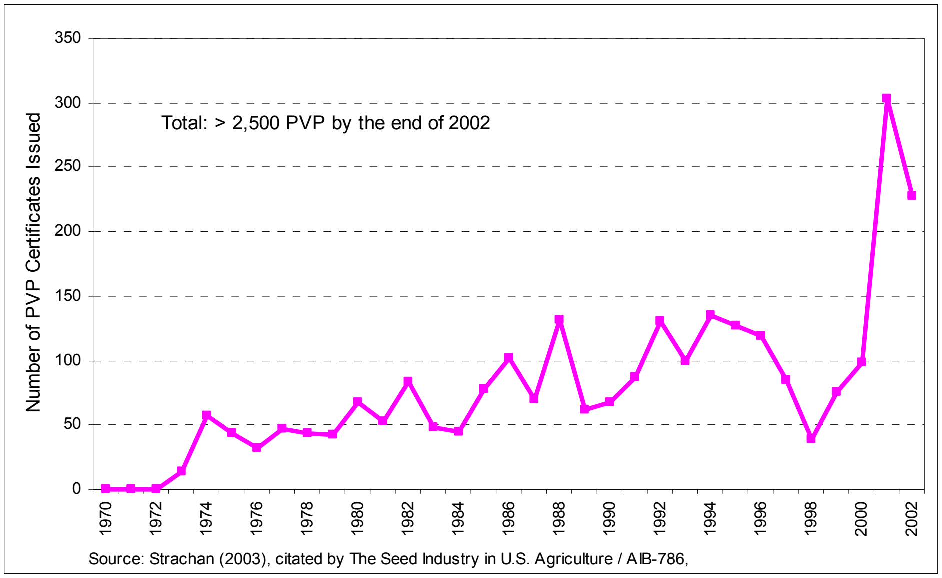


Figure 3.3. Growth in Plant Variety Protection (PVP) Certificates Approved for Major Field Crops

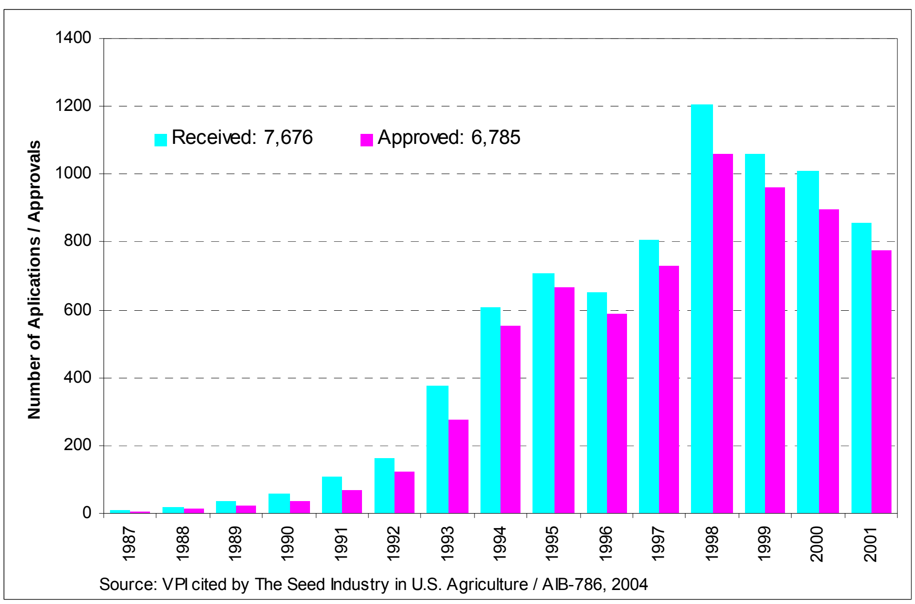


Figure 3.4. Applications Received and Approved by the APHIS USDA's Animal and Plant Health Inspection Service

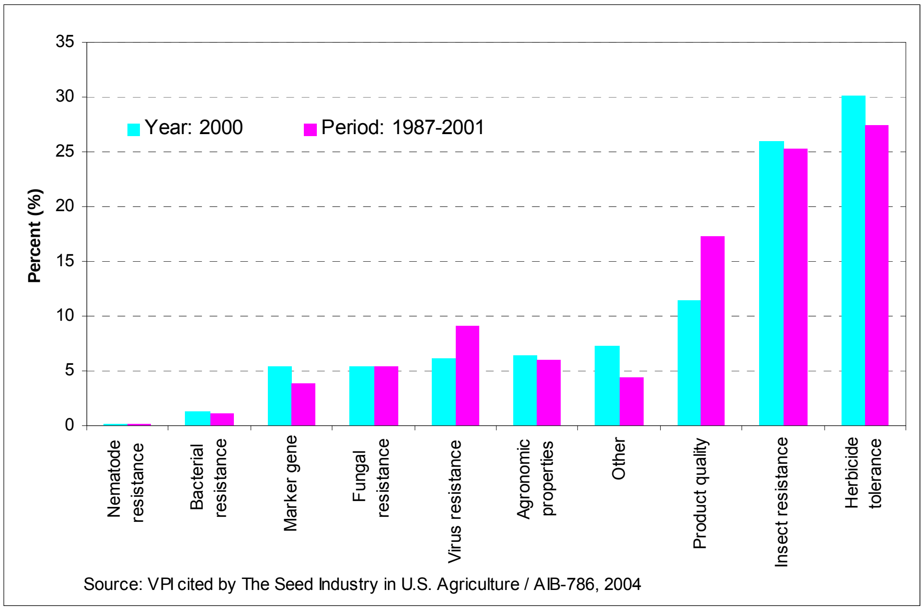


Figure 3.5. Share of Applications for Field Releases Received by APHIS, by Trait. USDA's Animal and Plant Health Inspection Service

Value of Biotechnology –Industry Examples

Production of new plants requires large capital investments and industrial integration. In the past, even the recent past, producers and distributors of seeds, chemicals, and machinery were independent entities. Today, through mergers and acquisitions, these diverse commercial channels have been unified to create a more integrated business environment that focuses on research and development, new product applications, value creation analysis, innovative fee collection approaches, and intellectual property protection.

Examples of Successful Biotech Companies and Product Pricing

Delta & Pine Land in 1996 was the largest breeder, producer, and marketer of cotton seeds. D&PL and Monsanto introduced the Bt (Bacillus thuringiensis) cotton seed with the ability to protect the plant from insect damage (bollworms). The U.S. annual cotton seed market

(15 million acres) was estimated at $125M, and cotton fiber was valued in excess of $7.5B. Cotton was one of the most chemical-intensive crops (farmers spent over $400M/year in herbicides and insecticides). The new seed technology price was set at $32/acre (paying a royalty of 71% to Monsanto). In southern Tennessee, farmers in bollworm hazard areas could recoup this expense by reducing costs, e.g. $60/acre while improving yields (Goldberg and Tasker, 1997).

Calgene in 1993, after 13 years, $90M of research, and $200M in capital investments, created the first genetically-engineered food in the world: the *Flavr Savr* tomato. The estimated U.S. consumption in 1990 was 26 billion pounds, grown on 650,000 acres. The fresh tomato market was $1 billion (eight times the price, per pound, of processed tomatoes), while the market for a processed tomato was $700 million. The *Flavr Savr* tomato was bred for disease resistance, yield, durability (firmness and shelf life), and quality/appearance (size and shape). A retail, farm-fresh tomato typically sold for $1/lb, while premium varieties reached two to three times this value. National surveys were used to determine the consumers' willingness to pay a premium of up to $3.99/lb for high-quality extended-shelf life tomatoes (Goldberg and Gourville, 2002).

Seminis led the vegetable seed industry by adopting biotechnology to enhance and accelerate product development. By 1999, this firm had 4,500 products (from 60 of the most important species), annual sales over $400M. Seminis held 19% of the global vegetable seed market due to innovation of mainly hybrid seed varieties that offered higher yields; greater uniformity; longer shelf-life; better resistance to pests, diseases and environmental conditions (less chemical applications); and improved quality, flavor, and nutrition. As an example, the DiVine Ripe tomato with its long shelf-life lowered production costs by 10%, and distribution costs by 50%. Such a hybrid is expensive to develop, and its economic lifespan is shorter than non-hybrid species. However, this hybrid seed realized much greater premiums in the market, and its sterility, embodied in the seeds, protected Seminis's intellectual property (Goldberg et al., 1999). Seminis's strategy to capture value creation was through premium pricing, and it created a 5x premium for DiVine Ripe seeds compared to traditional tomato seeds.

Monsanto by 2006 completed its transition from a chemical company to a seed company using elite lines as a delivery vehicle for its biotechnology products. The global seed market size was estimated at $30 billion by 2004. Monsanto reached net sales of $7.34 billion, and supplied improved seeds for over 200 million acres in more than 40 countries in 2006. By spending more than $6 billion in acquisitions last decade, Monsanto became the largest seed company in the world. In the early 1970s, Monsanto developed Roundup, an extraordinary successful non-selective herbicide. By 1996, Monsanto's seed breeders were able to neutralize the non-selective Roundup effect by inoculating a soil bacterium gene into plants, such as soybean, cotton, and corn. This new and first generation of seeds was called "Roundup Ready." For "Roundup Ready" soybean, the acceptance and expanded use were astonishing. Growers used this soybean intensively because of significant savings ($12/$16/acre) and easy weed control at any stage of the crop, which positively offset the royalty payment of $5 per 50 lb/bag ($9-$15/acre). In 1999, 50% of the U.S. soybean area was planted with this product (37 million acres); by 2006 the market share was 95%.

In order to protect Monsanto's intellectual property and its significant investment in technology, farmers were not allowed to save harvested product from one year to plant as a seed for the next planting season without paying a license fee. Innovative approaches for collecting fees to use this technology are in place, especially in countries with weak patent systems and cultures with different perceptions about private property rights. For example, soybean growers in Brazil, initially used this technology for free (black market “Roundup Ready” soybeans from Argentina). Thus, Monsanto developed a dual system, which allowed growers to pay the license fee at the time of seed purchase, or wait until harvest to pay. The latter system is called point of delivery (POD), where farmers pay a post-harvest fee for the soybean crop grown from seeds from which royalties have not been collected (Bell and Shelman, 2006; *ASA,* 2003, Magretta, 1997; Goldberg and Urban, 1996).

ViaGen, a cloning services company, is in the forefront of a technology that could revolutionize animal breeding with more than 200 clones to date, including calves, piglets, and foals. With cloning, producers are able to use exact genetic copies of animals with proven performance, bringing a level of efficiency and predictability that was not possible with traditional breeding methods. Cloning reduces the time and effort of what livestock producers have been doing for years—combining the genetics of different animals to increase productivity and quality. Exact copies can be made in very large numbers by accelerating reproduction. In the past, one male could serve 20 females; with artificial insemination, one male can impregnate 180-200 females. But with cloning, the number of impregnations is infinite. Other benefits of cloning are feed efficiency (conversion of feed into edible meat rather than fat or bone), and healthier animals with optimal animal well-being and minimal use of antibiotics, growth hormones and other chemicals, which lower production costs. Also, there is improved product quality and consistency, as the best quality traits can be perpetuated. Meat manufacturers pay a premium to achieve this in their production line. For instance, meatpackers prefer identical pigs to give customers identical hams. The business strategy varies because of the difficulties in developing a one-size-fits-all price for pets or domestic animals like kittens, horses, or cattle. However, for example, horse owners are likely to find a $150,000 price reasonable because a prized horse is likely to make over $1M in its lifetime. The beef industry, however, may be charged $6-8,000 for each head of cattle (Bell et al., 2006).

Biotech Challenge: Capturing Value Creation

Efficient pricing and payment mechanisms used by biotech companies to capture value created (given that traits are embedded in the crops using seeds as their reproductive vehicle) consist of selling seeds at a premium that reflects some proportion of the value-added, making agreements with growers to pay a fee for the enhanced value, or offering a combination of both. The traditional means for capturing the value of biotech products has been through a premium price (royalties or licensing agreements). For example, Monsanto, in order to protect property rights and recover their investments in R&D, sells their products at premium prices, and requires their clients to agree not to save seed from plants grown (nor to resell, retain, or to harvest seeds from their crops) and to allow Monsanto's agents to track their crops (Reinhardt, 2001).

Forestry breeders (university and forest industry) have progressed in selecting the best trees for the production of the best seeds for commercial plantations, but they have not as yet captured the value of these improvements through pricing. In essence, they are ignoring upstream financials. For instance, loblolly pine bare root seedlings, open pollinated (OP), are currently priced at $0.05/seedling. Bare root seedlings, mass-controlled pollinated (MCP), are priced at $0.11/seedling (Dougherty, 2006), which is only ~2x premium. If breeders were to include the value delivered through these improved seedlings to forest investors, prices would be at a much higher premium. Chapter 2 showed that at 8% rate of return for thinned or un-thinned regimes, site index 60, and for 10% - 50% gain in volume, the break-even costs ranged from

$0.15 to $0.90/seedling. Thus, if biotech companies only captured 50% of consumer surplus, then forestry breeders likewise would charge 2x to 9x premium prices.

The bottom line of the biotech developers' philosophy to appraise their technology is "growers pay for value-added delivered." to capture this value while facilitating customer decision-making has been a challenge, and although returns may be delayed for many years, a pricing strategy designed to recoup value created depends on crop traits expressed in terms of yields and cost savings. In forestry, value creation involves enhancing product performance/characterization, such as with higher uniformity, rust/pitch canker reduction, fewer defects, and improved wood quality (stiffness, specific gravity). Such attributes contribute to a premium product that benefits landowners and processors without the degradation to lower value products that often occurs in conventional plantations because of tree defects or low quality properties.

Several studies (Yin and Sedjo, 2001; Sedjo, 1999; and Hyde et al. 1992) show that research boosts and contributes to the productivity of the forestry sector, for example, through intensive silviculture, creation of new products, and forest technologies on softwood timber production. However, Hyde et al. found modest returns for research to enhance softwood growth primarily because of the long period between the implementation of the research and the collection of economic returns at harvest. Another apparent reason for low returns at the time was large inventory of old-growth forests and its effect on timber prices, although this idea loses ground in light of recent regulations (1992). As with the limitations imposed on old-growth forests, other factors are influencing financial returns on investments in research: shorter rotations, new products, streamlined production processes.

Assessing Royalties: Tools / Methods

There are three traditional valuation techniques: market, costs, and income approaches, and several variants of these for standard intellectual property (IP) valuation.

The market approach (comparable sales) is used for transactions of similar property and when transaction details are released.

The market approach uses industry standards to determine royalties. Some sources of industrial standard royalty rates are: surveys, proposed "norms," available court cases/infringement lawsuit awards, price lists, published agreements, institutional experience, consultants, in-house licenses, major accounting firms, RoyaltySource.com, IPresearch.com, and RoyaltyStat.com. Although it is positive to apply market values, this method is uncommon because very few transactions have similar intellectual property features. In addition, market segmentation (electronics, pharmaceuticals…) may be inappropriate, and the range of royalty rates may be too broad. Table 3.3 shows some royalty data, collected through surveys, by industry segment.

Table 3.3. Licensing-out Royalty Rates by Industry[4]

	Royalty Rate Category						
Industry	0-2%	2-5%	5-10%	10-15%	15-20%	20-25%	>25%
Aerospace			40.0%	55.0%	5.0%		
Automotive	35.0%	45.0%	20.0%				
Chemical	18.0%	57.4%	23.9%	0.5%			0.1%
Computer	42.5%	57.5%					
Electronics		50.0%	45.0%	5.0%			
Energy		50.0%	15.0%	10.0%		25.0%	
Food/Consumer	12.5%	62.5%	25.0%				
General Manufacturing	21.3%	51.5%	20.3%	2.6%	0.8%	0.8%	2.6%
Government/University	7.9%	38.9%	36.4%	16.2%	0.4%	0.6%	
Health care Equipment	10.0%	10.0%	80.0%				
Pharmaceuticals	1.3%	20.7%	67.0%	8.7%	1.3%	0.7%	0.3%
Telecomunications				100.0%			
Other	11.2%	41.2%	28.7%	16.2%	0.9%	0.9%	0.9%

[4] Source: Factors Affecting Royalties Rates. McGavock, et. al. *Les Nouvelles*, June 1992, p107. In Razgaitis (2002).

From Smith and Parr (2005), the adapted Figure 3.6 presents the grouped royalty rates for technology, as a percentage of sales (except for royalties reported on per unit bases). Looking at aggregated level of 87%, the royalty rates are ≤ 10%.

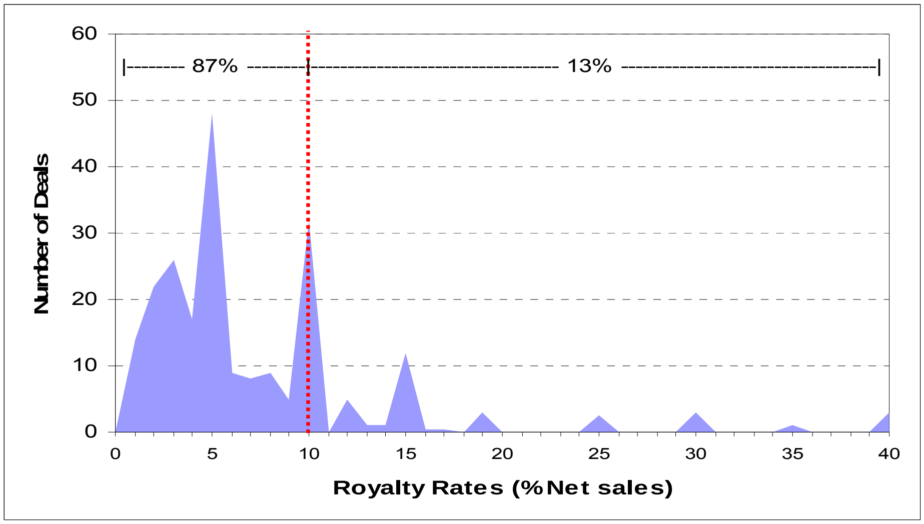


Figure 3.6. Royalty Rates Distributed Across Industries and Products

The cost approach is typically used for the valuation of tangible assets and seeks to equalize these assets with future upstream economic benefits of ownership. For intangible assets, such as intellectual property, this method can present a significant discrepancy between the cost of creating intellectual property and its value. In general terms, cost is not the same as value. Costs are irrelevant unless economic benefits can be earned from ownership of property (Smith and Parr, 2005; Razgaitis, 2002).

The cost approach measures the amount of money that is required to create/replace the future benefits associated with tangible asset ownership. However, for intangible assets (e.g., IP), there are no price guides for the application of this approach. Thus, a word of caution is required when this method is applied for valuing IP. For instance, the cost approach does not integrate information on economic benefits, risks, or time frame. Neither does it capture the effects of market forces. Although the cost approach for valuing intangible assets has potential for mistakes, it can be used as a reference point and also to provide an indication for the other approaches.

The income approach is defined by Smith and Parr, 2005, as the “present value of future economic benefits of ownership”. This technique is used when the property’s future economic benefits (cash inflow/outflows) are known or predictable.

The income approach is advantageous because of its flexibility to adapt to a specific business and market developments. It is also useful when the information needed to implement this approach, at least in theory, is well-known to the firm. However, all the information required for the income approach may not be available in the case of new technologies (Denton and Heald, 2004). In this case, analysts should take into consideration technological risks, such as failure to move from laboratory scale to operational scale, non-competitive production costs, competitors (with more competitive products), regulations, and public concerns.

In forestry, this valuation method is often used for assessing timberland opportunities for pre-merchantable stands (i.e., stands that currently have little or no timber value). The income approach is a discounted cash flow (DCF) technique, when used for a conventional forest valuation, is slightly more complicated than either the market or the cost approach, but it provides the most accurate means for valuing forest production. It also requires more information about growth and yield to determine its optimum economic rotation age and the bare land value (BLV). The break-down of products at different stages of the growth process is required as are an expected rate of return and its tradeoff between risk and return. The mechanics used to work with this approach involve discounting all future income, such as land leasing, timber sales, and the bare land value assessed from its optimal rotation age in the current rotation to present, and also discounting all costs, such as midrotation silvicultural practices, annual taxes, and administrative costs. The net sum is the value of land and timber; from there, BLV is subtracted to obtain the value of the timber (Bullard and Straka, 1998, Clutter et al, 1983, Davis et al, 2001, and Klemperer, 1996).

Because the valuation of intangible assets and intellectual property rests upon the same financial principles as property valuation does: present value of future royalty payments (marginal/differential analysis of enhanced returns vs. traditional product/technology), the income approach is appropriate for intangibles and IP.

Smith and Parr, 2006, divided the techniques to compute the value of intangible assets by the income approach into two categories. These categories are a function of the information available:

- Direct Approach: premium pricing and cost savings
- Indirect Approach: valuation using "relief from royalty," analytical methods, earnings analyses, overall rate of return requirements (return rate on both equity invested plus debt, WACC), allocation of returns among assets categories, appropriate return on monetary / tangible / intangible assets / or on research and development costs, fixed percentage of operating profit, ratings/rankings (to differentiate the product), rules of thumb (royalty in percentage of net sales), auctions, more advanced techniques such as Monte Carlo simulations (probabilistic approach), modified or risk adjusted DCF/NPV, and real option pricing (Black and Scholes' model).

In this chapter, the income approach is applied with an analytical method that provides a reasonable benchmark value for the right to propagate protected technology in the forest business. As discussed by Smith and Parr, 2005, this approach has been applied to define royalty rates in the infringement litigation arena, which recognizes the financial contribution of intellectual property, and in this case study, the royalty for propagation rights is seen as analogous to royalty to protect against infringement. The equation for the analytical method adapted from Smith and Parr, 2005, is:

$$\underbrace{\textbf{Expected Net Profit}}_{\textbf{Business as usual}} = \underbrace{\textbf{Normal Net Profit}}_{\textbf{Initial price}} + \underbrace{\textbf{Royalty Rate}}_{\textbf{Royalties}}$$

The Expected Net Profit on the left of the equation represents the net profit from seedlings sold for plantations. The right side of the equation, Normal Net Profit + Royalty Rate, represents the net profit from seedlings sold for propagation. This equation equates the profit the company makes by selling SE seedlings to the profits made from selling Mother Plants plus royalties.

Intellectual Property Protection and Regulation

As presented by Smith (2005), intellectual property includes patents, trademarks, copyrights, and trade secrets or know-how, and its holder is protected by law from unauthorized utilization/commercialization by others. Legal protection of inventions/innovations started two centuries ago with the United States Patent and Trademark Office (USPTO) under the Department of Commerce, which promoted the advance of science by protecting the exclusive right to their inventions of creators and entrepreneurs for a fixed period of time (United States Patent and Trademark Office's web pages).

However, it was after 1930 that intellectual property rights were available for plants (represented by horticulturists) through the Plant Patent Act, which was adopted by the U.S.

Congress in 1930 (Caldwell, 1989). This Act protects only plants that are asexually reproduced (clonally propagated by rooted cuttings, grafting, etc).

Plant Patents: A plant patent is a grant of a property right, issued by the United States Patent and Trademark Office (USPTO), to a breeder who "invents or discovers and asexually reproduces any distinct and new variety of plant, including cultivated sports, mutants, hybrids and newly found seedlings, other than a tuber propagated plant or a plant found in an uncultivated state…" (Plant Patent Act 35 U.S.C. § 161). A plant patent grants the breeder the right to exclude others, generally for a term of 20 years, from asexually reproducing the plant or selling, or using the plant or any of its parts for propagation. (Smith and Parr, 2005, and, Plant Patent Act, and United States Patent and Trademark Office's web pages).

The path for intellectual property rights and patents for plants, which protected plant breeding investments, was paved by the corn industry (the first to bring hybrid varieties to the market). However, plant patents do not encourage profit oriented seed organizations to breed non-hybrid crops because, although the latter may be improved, they can not be protected by this legal mechanism by definition.

Plant Variety Protections: Another type of protection for crop breeding is through the Plant Variety Protection Act (PVPA) under the United States Department of Agriculture. PVPA has been available over almost 40 years and provides legal intellectual property rights protection to breeders of new varieties of plants that are sexually reproduced (by seed) or are tuber-propagated. PVPA protects the plant breeder by conferring legal control over seed production and sales. Farmers are allowed to save limited amount of these protected seeds only for planting purposes on their own land, which matches the area of the first crop. The term of protection is 20 years for most crops and 25 years for trees (Wright, 2006, USDA, Agricultural Marketing Service web page).

Utility Patents: This patent is usually obtained for new machines, chemicals, drugs, and processes, and confers to developers the right to exclude others from making, using, or selling, its invention for a period of 17 years (Jondle, 1989). However, the "United States Supreme Court, in a 1980 decision, found that living matter that owes its unique existence to human intervention is patentable subject matter" (Smith and Parr, 2005, p28). This decision opened the door for the patenting of numerous biotechnological products, such as corn inbreds, corn hybrids, and soybean varieties by companies like Monsanto and Pioneer-DuPont, and "gives them the right to prohibit breeding with as well as selling the patented cultivar" (R. Fincher, Plant Technology Commercialization, UGA, personal communication, 2007). Today, there are hundreds of utility patents for biotechnological products (Kjeldgaard and Marsh, 1994).

Other Plant Protections: Two additional categories of plant protection in the United States are: a) trade secrets, which imply no public disclosure of any information, process, or genetic resources that provides competitive advantages to developers; and b) contracts like licensing agreements, and conditions/restrictions of sale agreements.

Hypothetical Case for Determining Royalties on Elite Pine Varieties

Study Case: A forest investor wants to develop a large reforestation program with varietal seedlings. One option is to buy elite seedlings in the open market (propagated by somatic embryogenesis). Another option is to buy fewer SE seedlings along with the right to propagate.

If forest landowners choose to propagate from somatic seedlings, they will establish hedges using cuttings from these plants. In this case, the customers will be able to propagate the planting material at there own means, risk, and expense. Supposing a target planting program of 2,000 acres with 500 TPA annually, customers will need to buy 1,000,000 seedlings for $300,000 (at $0.30/seedling), or they can produce rooted cutting seedlings themselves. In order to undertake this challenge, hedges will be established that can produce an average of 200 cuttings each during its five-year life span (assuming 50 cuttings/year for the last four years).

Thus, for this reforestation through propagation plan, the customer needs 20,000 mother plants to plant 2,000 acres/year, at a cost of $6,000. This significant margin of saving, $294,000 the first year and $300,000/yr following three years, which may be used to manage the propagation[5], leads to the questions: What is a fair price for a mother plant in order to maintain profitability? And what mechanism is best suited for royalty payments?

Study Objectives

- Develop an approach for selling elite variety seedlings with the right to propagate for reforestation purposes, maintaining profitability at a level similar to that when seedlings are planted directly for reforestation.
- Define a royalty rate, such that:

If a forest company buys 20,000 SE seedlings with a right to propagate them and can produce 1,000,000 plantable rooted cutting seedlings per year for four years from these 20,000 Mother Plants, the producer's profit from selling 20,000 Mother Plants plus royalties must be

[5] Propagation and management costs range from $210 to $250/thousand rooted cutting seedlings (Barry Goldfarb, NCSU, personal communication, April 2005, and Wayne Bell, IFCO, personal communication April 2005).

compared to the profit the company would otherwise make by selling 1,000,000 seedlings per year for four years.

- Define several payment mechanisms

Methodology

When somatic seedlings are sold for reforestation, the price is defined by the market or by the company's sale policies. However, when this biotech product is sold for propagation, the price must reflect the "normal" or listed price plus a premium for the right to propagate, which is a royalty[6]. This royalty is meant to compensate the producers for potentially lost sales and is transferred to the buyer. A floor price that makes the producers indifferent to both situations must be that it does not affect profits (Net profit = Revenues [net sales] – All expenses [COGS, selling expenses, administrative expenses, interest expenses …]). The decision rule equation, shown below, equates Business as Usual to Business with Propagation Rights. Solving the equation for royalty yields a simpler equation after some algebraic rearrangement (geometric progressions).

- *Business as usual:* Simply sell seedlings over time and exclude propagation rights.

[6] Royalty: Payment made for the right to use intellectual property (IP), especially a patent, copyrighted work, franchise, or natural resources. Many consider royalties as a black box art, others are concerned with evaluating technologies and assigning value. Royalties are usually derived from intensive negotiation processes between a willing technology developer (seller) and a willing buyer to converge in a royalty rate and payment mechanisms, within a free market framework (Razgaitis, 2002; Willey, 2002). Indicators of rationale/defensible royalty rates for biotechnology products are available from well-established, analytical approaches and models. Given that IP is a critical component of a business's profits, royalty rates based on industry standards and rules of thumb are not sufficient. As per Smith and Parr (2005), a deeper analysis that includes revenues, profits, costs, and investments is a better way to determine the intellectual property contribution to the technology developers' income, and to establish the basis for a range (upper and lower thresholds) of royalties before beginning negotiations between seller and buyer.

- *Business with propagation rights:* Sell X seedlings as Mother Plants (MP) at price P_0, plus a required Royalty for the right to propagate.

Figure 3.7 shows the reforestation schedule for 1,000,000 seedlings per year. A landowner could choose to buy SE seedlings ready for planting (business as usual), or to buy 20,000 SE seedlings with the right to propagate them (business with propagation rights), to produce 1,000,000 rooted cutting seedlings per year for four years.

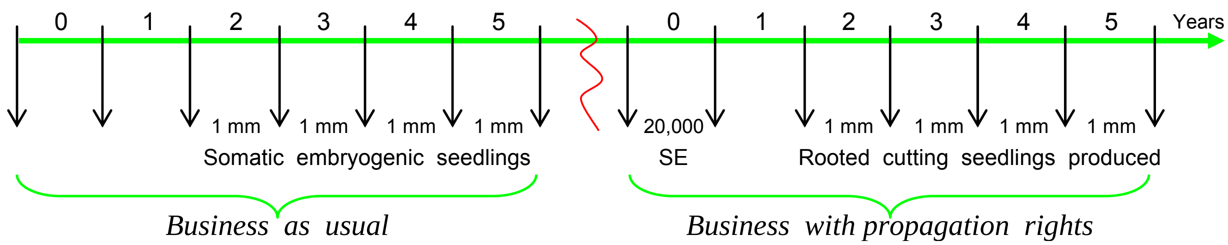


Figure 3.7. Reforestation Schedule: Two Business Models

Basic Decision Rule Equation

Net Profit Business as Usual = Payment Stream on Business with Propagation Rights

$$\underbrace{N_0*(P_{S0}-C_0)+N_1*\left(\frac{P_{S1}-C_1}{1+k}\right)+N_2*\left(\frac{P_{S2}-C_2}{(1+k)^2}\right)+\cdots+N_5*\left(\frac{P_{ST}-C_T}{(1+k)^T}\right)}_{Business\_as\_Usual}=\underbrace{P_0*X-C_0*X}_{Initial\ Price}+\underbrace{X*\frac{P_1}{1+k}+X*\frac{P_2}{(1+k)^2}+X*\frac{P_3}{(1+k)^3}+\cdots+X*\frac{P_T}{(1+k)^T}}_{Royalties}$$

where,
N_i = Number of seedlings at time i
P_{Si} = Seedling price at time i, (i = 1, 2, …, T -years)
P_0 = Mother plant price
P_i - PT = Royalty
C_i = Direct cost/seedling at time i
X = Number of mother plants
T = Time horizon
k = Assumed discount rate
$P_S > C$

The equation's left side is Business as Usual; the right side describes how and when to recover the profit when propagation rights are included.

Variants of the decision rule equation allow for formulating several payment mechanisms. For this particular case study, five scenarios of payment mechanisms were considered. First: pay up front; second: pay constant royalties over time; third: pay royalties at increasing/decreasing growth rate (g); fourth: same as third, but includes one year "grace period"; and fifth: net profit (P_0-C_0) is computed for the sale of 4,000,000 seedlings in year zero, neither is the purchase spread over a time horizon, nor is it discounted.

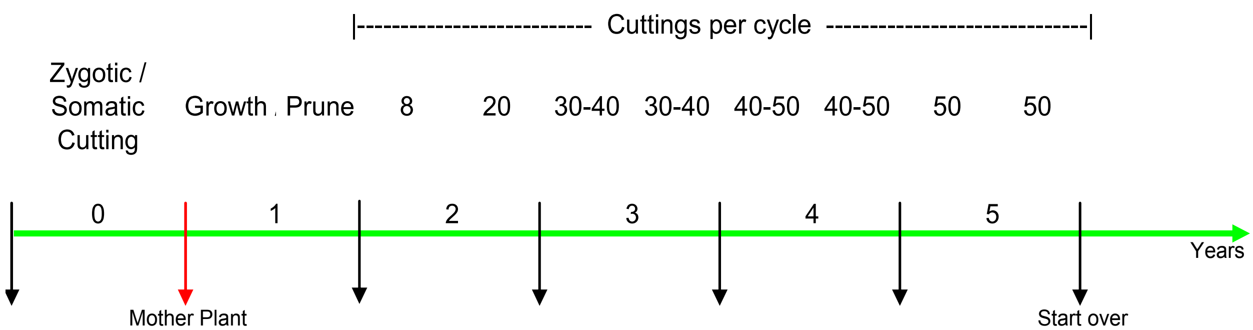
For all five scenarios, three variables for sensitivity analyses were selected: seedling costs ranging from $0.15 to $0.30 in increments of one cent, production of suitable rooted cuttings for plantations ranging from 10 to 120 per hedge per year in increments of ten, and time line from year 3 to year 8 in increments of one year. For illustration, the seedling cost was fixed at $0.23, plantable cuttings produced at 50 rooted cuttings/hedge/year, and the time-frame was set at year five. However, any other variable, such as rate of return or seedling price could also easily be used for additional sensitivity analyses.

Assumptions and Sensitivity Analyses

Biological assumptions

Vegetative propagation by rooted cuttings of loblolly and slash pine is practiced in the Southern U.S. with some success, reaching 70% rootability (Goldfarb, NCSU, personal communication, 2005). However, this percentage declines over the age of the ortet. Only juvenile material, usually less than 4-6 years old, can achieve this degree of success (Foster, 1981). In order to maintain a consistent production of ramets, it is necessary to rejuvenate the ortets, and in this case study, 5 years old was the selected age for starting the cycle over. The number of cuttings per hedge and the number of harvesting periods per year were other variables defined.

The rooted cutting production average was simplified to 50 cuttings/hedge/year. If the distribution probability of number of cuttings/hedge/year were available, this distribution could be used because it would, ultimately, define a single average royalty fee per line, reducing tracking costs, and simplifying the analysis. Figure 3.8 shows this critical set of assumptions.



		AvgCutting/cycle	14	35	45	50
		Cycles/yr	2	2	2	2
Unrooted	→	Cutting/hedge/yr	28	70	90	100
		Rooting success	70%	70%	70%	70%
Rooted	→	Cutting/hedge/yr	20	49	63	70

Figure 3.8. Rooting Cutting Production, Useful Economic Life: 5 years
(B. Goldfarb, Department of Forestry, NCSU, personal communication, 26-Apr-05)

Financial Assumptions

g: constant growth rate	5%	P_0: mother plant price	?
k: discounted rate	8%	R: royalty	?
N: number of seedlings per year	1,000,000		
n: avg. number of cuttings/hedge/year	50		
X: number of mother plants	20,000		
P_S: seedling price	$0.30		
C: direct cost/seedling	$0.23		
T: time horizon (years)	5		

Five Possible Payment Mechanisms

Pattern 1: Pay upfront, no royalties: charge one time fee for MP plus right to propagate.

From the basic equation, make royalties zero and solve for P_O.

P_0 = Fee, and $P_1, P_2, \ldots, P_T = 0$

$$P_0 = \left(\frac{1}{X} * \left(N_0(P_{S0} - C_0) + N_1 \frac{P_{S1} - C_1}{1+k} + N_2 \frac{P_{S2} - C_2}{(1+k)^2} + N_3 \frac{P_{S3} - C_3}{(1+k)^3} + N_4 \frac{P_{S4} - C_4}{(1+k)^4} + N_5 \frac{P_{S5} - C_5}{(1+k)^5} \right) + C_0 \right)$$

Pattern 2: Charge same $0.30 per MP initially and charge constant royalties (R) over T years.

Thus: $P_0 = P_S$, and $P_1 = P_2 = P_3 = P_T = R$

$$\frac{1}{X} * \left(N_0(P_{S0} - C_0) + N_1 \frac{P_{S1} - C_1}{1+k} + \cdots + N_5 \frac{P_{S5} - C_5}{(1+k)^5} \right) + C_0 - P_{S0} = R * \left(\frac{1}{1+k} + \frac{1}{(1+k)^2} + \frac{1}{(1+k)^3} + \cdots + \frac{1}{(1+k)^T} \right)$$

$$R = \left(\frac{1}{X} * \left(N_0(P_{S0} - C_0) + N_1 \frac{P_{S1} - C_1}{1+k} + \cdots + N_5 \frac{P_{S5} - C_5}{(1+k)^5} \right) + C_0 - P_{S0} \right) * \left(\frac{k(1+k)^T}{(1+k)^T - 1} \right)$$

Pattern 3: Charge same $0.30 per MP initially and charge increasing/decreasing royalties (R) by g% over T years. g: Constant growth rate per year

Thus: $P_0 = P_S$, and $P_1 = R$, $P_2 = R(1 \pm g)^1$, $P_3 = R(1 \pm g)^2$, …, $P_T = R(1 \pm g)^{T-1}$

$$\frac{1}{X} * \left(N_0(P_{S0} - C_0) + N_1 \frac{P_{S1} - C_1}{1+k} + \cdots + N_5 \frac{P_{S5} - C_5}{(1+k)^5} \right) + C_0 - P_{S0} = \frac{R}{(1+k)} * \left(1 + \left(\frac{1+g}{(1+k)} \right)^1 + \left(\frac{1+g}{(1+k)} \right)^2 + \cdots + \left(\frac{1+g}{(1+k)} \right)^{T-1} \right)$$

$$R = (1+k) * \left(\frac{1}{X} * \left(N_0(P_{S0} - C_0) + N_1 \frac{P_{S1} - C_1}{1+k} + \cdots + N_5 \frac{P_{55} - C_5}{(1+k)^5} \right) + C_0 - P_{S0} \right) * \frac{\left(\frac{1+g}{1+k} \right) - 1}{\left(\frac{1+g}{1+k} \right)^T - 1}$$

Pattern 4: Charge same \$0.30 per MP initially and charge increasing/decreasing royalties (R) by g% over T years, and make P1 = 0 (one year 'good will' grace period).

g: Constant growth rate per year

Thus: $P_0 = P_S$, and $P_1 = 0$, $P_2 = R$, $P_3 = R(1 \pm g)^1$, $P_4 = R(1 \pm g)^2$, …, $P_T = R(1 \pm g)^{T-2}$

$$\boxed{\frac{1}{X} * \left(N_0 (P_{S0} - C_0) + N_1 \frac{P_{S1} - C_1}{1+k} + \cdots + N_5 \frac{P_{S5} - C_5}{(1+k)^5} \right) + C_0 - P_{S0} = \frac{R}{(1+k)^2} * \left(1 + \left(\frac{1+g}{(1+k)} \right)^1 + \left(\frac{1+g}{(1+k)} \right)^2 + \cdots + \left(\frac{1+g}{(1+k)} \right)^{T-2} \right)}$$

$$\boxed{R = (1+k)^2 * \left(\frac{1}{X} * \left(N_0 (P_{S0} - C_0) + N_1 \frac{P_{S1} - C_1}{1+k} + \cdots + N_5 \frac{P_{55} - C_5}{(1+k)^5} \right) + C_0 - P_{S0} \right) * \frac{\left(\frac{1+g}{1+k} \right) - 1}{\left(\frac{1+g}{1+k} \right)^{T-1} - 1}}$$

Pattern 5: Charge same \$0.30 per MP initially and charge increasing/decreasing royalties (R) by g% over T years. Note: Left side of basic equation (net profit) is neither split nor discounted.

g: Constant growth rate per year

Thus: $P_0 = P_S$, and $P_1 = R$, $P_2 = R(1 \pm g)^1$, $P_3 = R(1 \pm g)^2$, …, $P_T = R(1 \pm g)^{T-1}$

$$\boxed{N * P_s - C * N = \underbrace{P_0 * X - C * X}_{Initial\ \_\ price} + \underbrace{X * \frac{P_1}{1+k} + X * \frac{P_2}{(1+k)^2} + X * \frac{P_3}{(1+k)^3} + \cdots + X * \frac{P_T}{(1+k)^T}}_{Royalties}}$$

$$\boxed{\frac{N}{X}(P_s - C) + C - P_s = \left(\frac{R}{1+k} \right) * \left(1 + \left(\frac{1+g}{(1+k)} \right)^1 + \left(\frac{1+g}{(1+k)} \right)^2 + \cdots + \left(\frac{1+g}{(1+k)} \right)^{T-1} \right)}$$

$$\boxed{R = (1+k) * \left(\frac{N}{X} * (P_s - C) + C - P_s \right) * \frac{\left(\frac{1+g}{1+k} \right) - 1}{\left(\frac{1+g}{1+k} \right)^T - 1}}$$

Note: The annual net profit ($P_{st} - C_t$) does not account for opportunity costs (hold constant, no adjustments over time); thus, Pattern 5 yields higher net profit.

Results and Discussion

Table 3.4 compiles the main findings on royalty and net profit values under the five scenarios analyzed, which are discussed in detail pattern by pattern. The net profit that the seller (biotech developer) preserves is that expected when four million SE seedlings are sold: $214,675 for the first four cases, and $280,000 for the fifth case.

Table 3.4. Royalties and Net Profit for the Right to Propagate 20,000 SE Seedlings to Four Million Seedlings in a Five Year Time Horizon ($/Seedlings)

Time	Pattern 1 Pay Upfront	Pattern 2 Constant Royalties	Pattern 3 Variable Royalties	Pattern 4 Pattern 3 + Grace Period	Pattern 5 Sell all in Yr 0
Yr 0	10.96				
Yr 1		2.67	2.43	0.00	3.18
Yr 2		2.67	2.56	3.24	3.34
Yr 3		2.67	2.68	3.40	3.51
Yr 4		2.67	2.82	3.57	3.68
Yr 5		2.67	2.96	3.75	3.87
Net Profit	$214,675	$214,675	$214,675	$214,675	$280,000

Pattern 1

Pay upfront, no royalties

P0 = Mother plant price $10.96

Net Profit = $214,675

Figure 3.9 illustrates Mother Plant prices derived from a sensitivity analysis at six levels of seedlings costs ($0.15 through $0.25/seedling), and at six production levels of cuttings per MP per year (10 through 60 rooted cuttings/MP/yr). For instance, for a production cost of $0.23/seedling and under an annual production of 50 plantable rooted cuttings per hedge, the seller would charge a buyer an upfront payment of $11 per Mother Plant for the right of propagation.

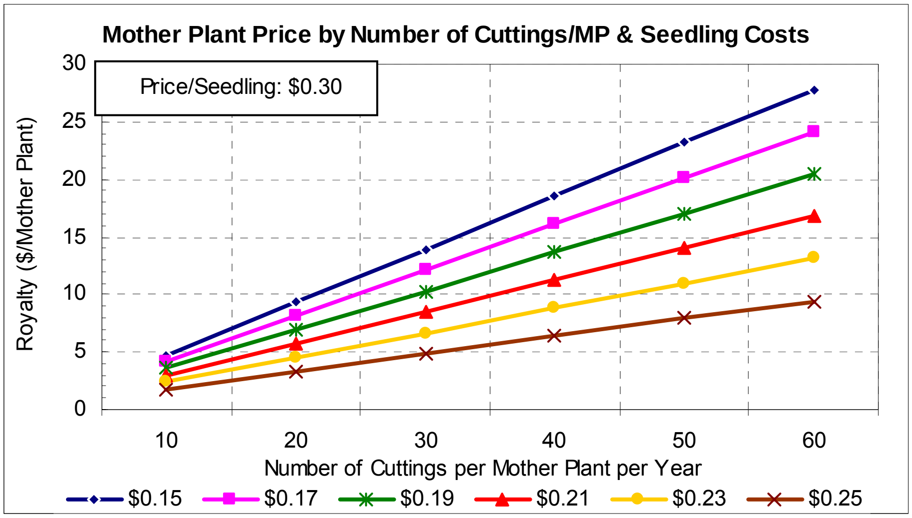


Figure 3.9. Pattern 1, Pay Upfront, no Royalties: Seedling Costs

Figure 3.10 shows the MP price at six seedling prices ($0.24 through $0.34/seedling), and at six production levels of cuttings per MP per year (10 through 60 rooted cuttings/MP/yr). Following the example above, for the selling price of $0.30/seedling, and under annual production of 50 plantable rooted cuttings per hedge, the seller would charge a buyer an upfront payment of $11 per Mother Plant for the right of propagation.

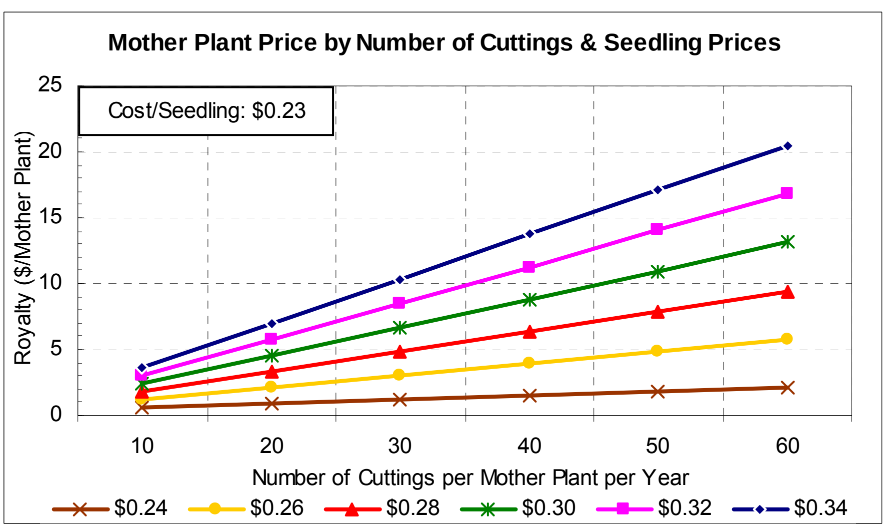


Figure 3.10. Pattern 1, Pay Upfront, no Royalties: Seedling Prices

Pattern 2

Charge \$0.30/MP and charge constant royalties

$P_0 = P_S$ = Mother plant price \$0.30

Royalty (R) = \$2.67/seedling/year for five years

Net Profit = \$214,675

Figure 3.11 illustrates Royalty values derived from a sensitivity analysis at six levels of seedlings costs (\$0.15 through \$0.25/seedling), and at six production levels of cuttings per MP per year (10 through 60 rooted cuttings/MP/yr). For a production cost of \$0.23/seedling and under a annual production of 50 plantable rooted cuttings per hedge, the seller would charge a buyer a royalty payment of \$2.67 per Mother Plant for the right of propagation.

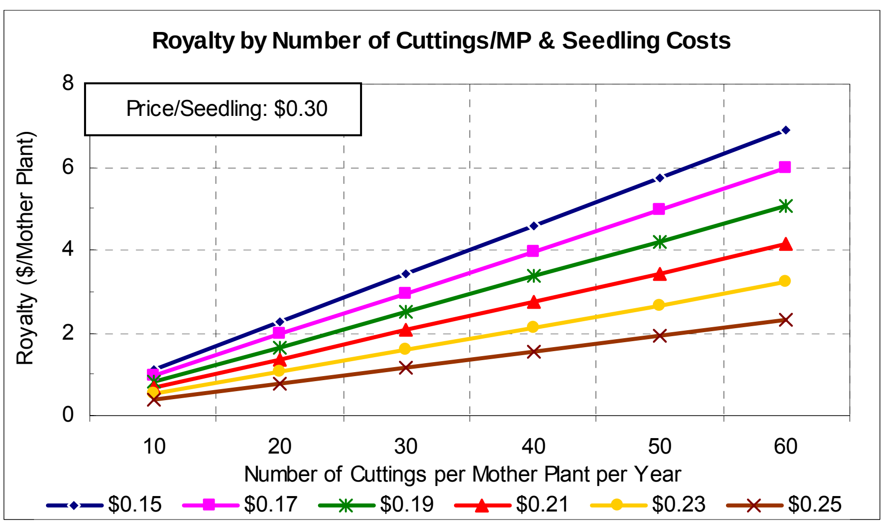


Figure 3.11. Pattern 2, Constant Royalties: Seedling Costs

Figure 3.12 shows the Royalty price at six time periods (three through eight), and at six production levels of cuttings per MP per year (10 through 60 rooted cuttings/MP/yr). Following the example above, for the 50 rooted cuttings production level, and under annual production of

50 plantable rooted cuttings per hedge, the seller would charge a buyer a Royalty rate of $2.67 for five years per Mother Plant for the right of propagation.

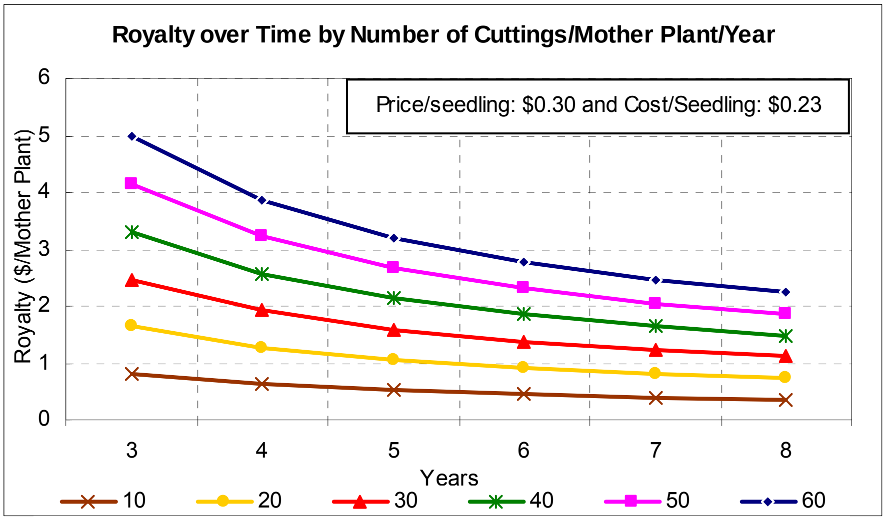


Figure 3.12. Pattern 2, Constant Royalties: Over Time

Pattern 3

Charge $0.30/MP and charge royalties at constant growth rate, g = 5%

$P_0 = P_S$ = Mother plant price $0.30

Royalty (R) = $2.43, $2.56, $2.68, $2.82, $2.96/seedling/year

Net Profit = $214,675

Similar discussions in Figures 3.11 and 3.12 are applicable to Figures 3.13 through 3.18. It should be noted that Pattern 5 has a different selling assumption (collect for all seedlings and future production at the time of purchase).

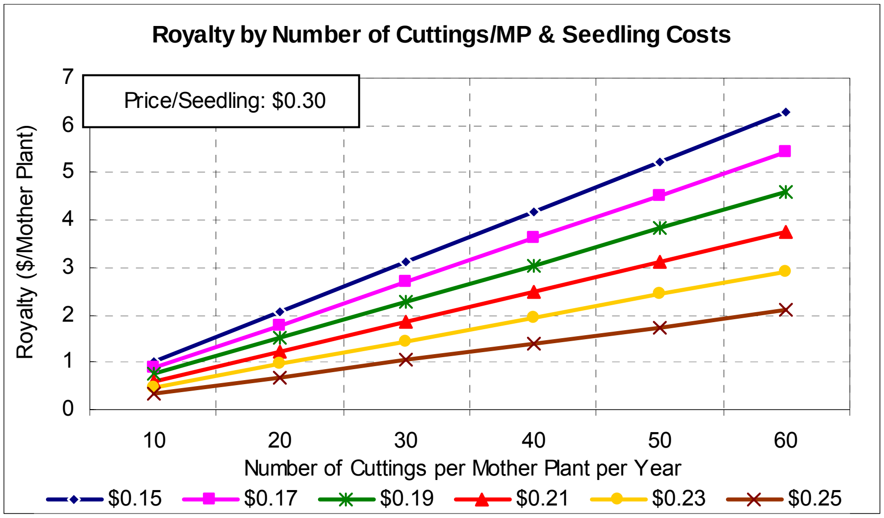


Figure 3.13. Pattern 3, Charge Royalties at Constant Growth Rate

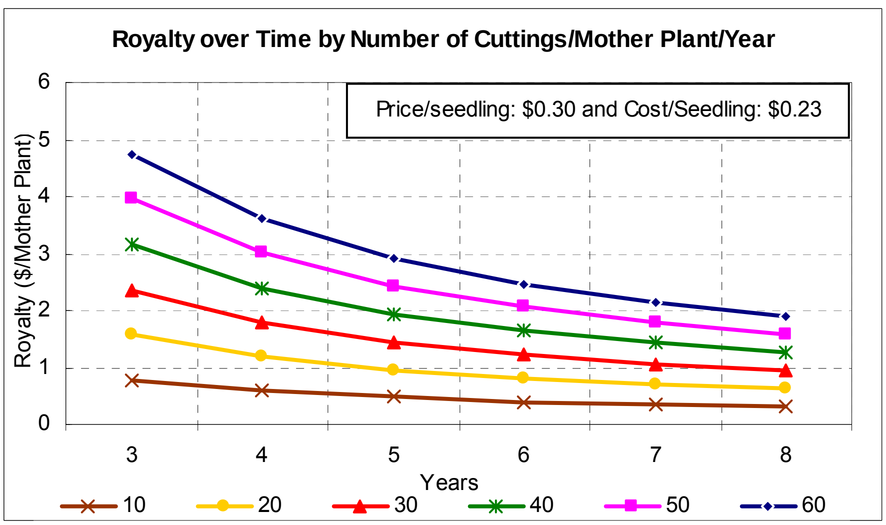


Figure 3.14. Pattern 3, Charge Royalties at Constant Growth Rate: Over Time

Pattern 4

Charge $0.30/MP and charge royalties at constant growth rate, with grace period

g = 5%, & one-year grace period ($P_1 = 0$)

$P_0 = P_S$ = Mother plant price $0.30

Royalty (R) = \$0.00, \$3.24, \$3.40, \$3.57, \$3.75/seedling/year

Net Profit = \$214,675

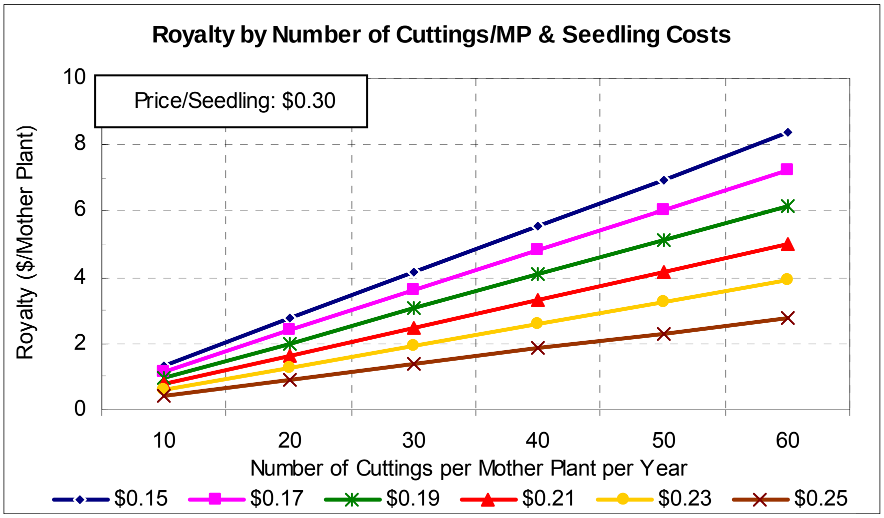


Figure 3.15. Pattern 4, Charge Royalties at Constant Growth Rate, with Grace Period

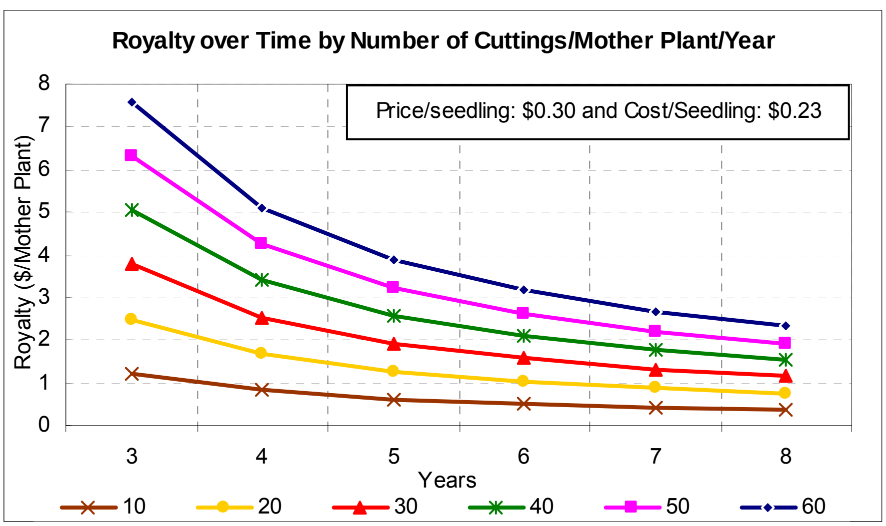


Figure 3.16. Pattern 4, Charge Royalties at Constant Growth Rate, with Grace Period: Over Time

Pattern 5

Charge \$0.30/MP and charge royalties at constant growth rate, but collect for all seedlings and future production at the time of purchase

g = 5%, and net profit (P_0-C_0)

$P_0 = P_S$ = Mother plant price \$0.30

Royalty (R) = \$3.18, \$3.34, \$3.51, \$3.68, \$3.87/seedling/year

Net Profit = \$280,000

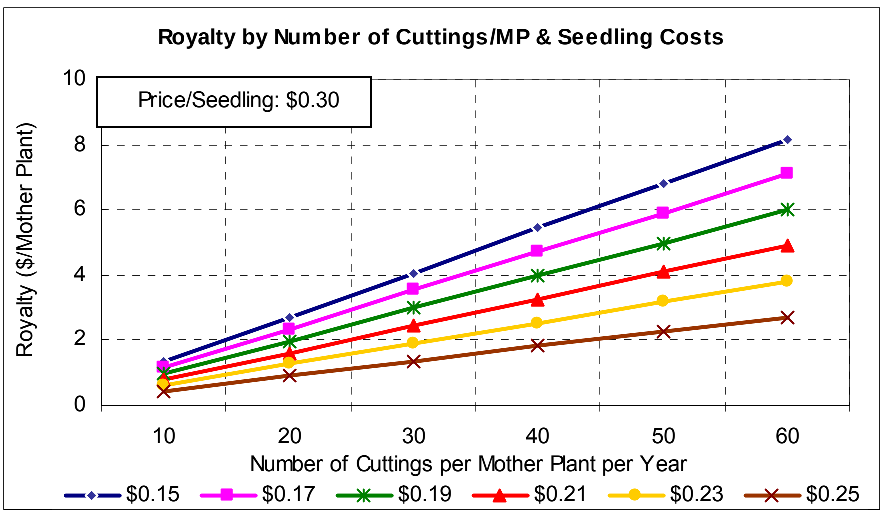


Figure 3.17. Pattern 5, Charge Royalties at Constant Growth Rate: Collect for all Seedlings and Future Production at Time of Purchase

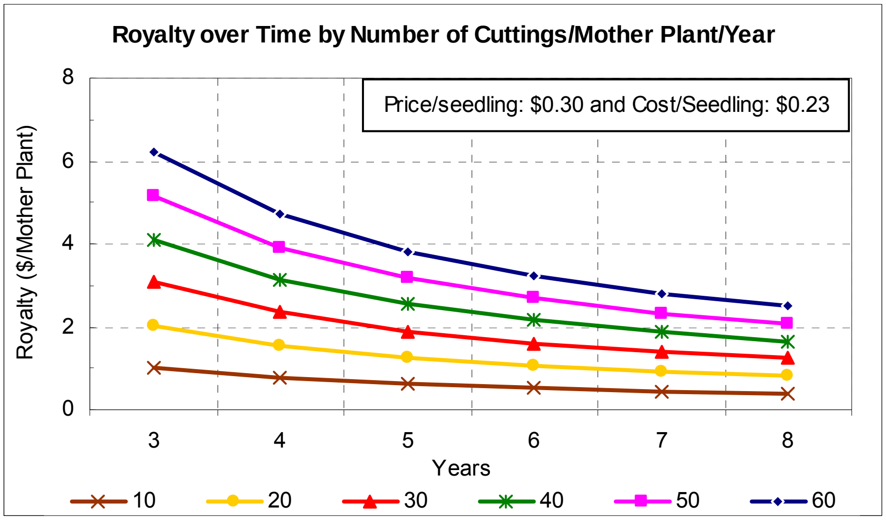


Figure 3.18. Pattern 5, Charge Royalties at Constant Growth Rate:
Collect for all Seedlings and Future Production at Time of Purchase, Over Time

Additional Notes

- Business as usual and patterns 1 through 4, with different payment mechanisms, result in the same profit of $214,675 for selling 20,000 MPs with the potential to produce 4,000,000 rooted cuttings during the economic life of the hedges.
- Producer's net profit for Pattern 5 is $280,000. This choice yields higher profit for the biotech producer, and requires that the buyer pays for all 4,000,000 rooted cutting seedlings to be propagated in advance at year 0 (not accounting for opportunity costs).
- Sensitivity analyses show that special attention must be given to the number of plantable cuttings assumed for each mother plant. Royalty fees are very sensitive to this input.
- Determination of the payment mechanism depends on biotech producer's sales policy and customer's financial needs. Mother Plants are not efficiently propagated beyond five years, so it is unreasonable to expect that a buyer is willing to pay royalties for "propagation rights"

on plants that do not propagate anymore. Therefore, the propagation cycle drives the financial cycle. Each five-year period is independent from others.

- For biotech companies, it is more convenient to tie royalties to mother plants rather than seedlings. There are more certainties and lower monitoring costs; otherwise, a biotech company unnecessarily shares in risks taken by customers.
- The assumption of keeping the net profit constant makes perfect sense because this approach finds a price that allows the producer to be indifferent between the two options.
- A more important assumption in this hypothetical case is the constant cost per seedling on both sides of the Basic Decision Rule Equation. The cost of producing 1,000,000 seedlings may be somewhat different from producing 20,000. On the one hand, any fixed cost of production would normally be spread over a larger number of seedlings and thus, cost per seedling would be lower for 1,000,000 than for 20,000. On the other hand, a 1,000,000 seedling order might stretch a producer's capacity limitations, creating extra costs. In this case, cost per seedling could be higher for the 1,000,000 seedling order. In any case, the model would not change. It would only require a different cost per seedling on each side of the Basic Decision Rule Equation.

Summary and Conclusions

Advances in forest biotechnology have promoted the creation of intellectual property assets. As a result, several legal options for protecting plant-based technology have evolved. Forest biotechnology companies face the same dilemma as agricultural biotechnology companies do in terms of how producers can protect their inventions and recoup their significant investments in research and development. Plant patent protection through the Plant Patent Act is ideal for forest biotech companies as it applies specifically to clonal plants. It does not protect plants bred from seeds, only the clones. Once a patent is issued, a specific clone will be recognized as a variety protected from unauthorized propagation.

While there are legal protections on record, there is little background available as to how these laws may be adapted to forest biotechnology in its early stages. For this reason, the history of biotech agricultural products, such as corn, soybean, cotton, and wheat has, by necessity, been chosen to guide this research. In addition, little has been published as to how forest biotechnology products should be valued. Developers tend to strictly control not only their technology, but also their decision-making approaches. Understandably, there is a high perception of business risk associated with sharing information. Therefore this chapter provides insights in how to compute royalties for biotech forest products in their early stages, and should contribute to creating a firm foundation to compare other valuation techniques as information improves.

Given the literature at hand, the income approach was selected. Although some experts consider it a reasonable approach to lead to appropriate conclusions on minimum market valuation (floor value) for intellectual property, others are critical for the following reasons: forecasted cash flows on new technologies are uncertain; the income approach does not recognize other players in the market; and although profits are closely related to investment in complementary business assets, the profit and loss statement is derived from the management of the investments reported on the balance sheet.

This chapter demonstrates that using the royalty price premium, a producer can be financially indifferent while being intensely aware of protecting intellectual property. However, the question of enforcing a right to propagate agreement regarding the number of cuttings permitted over a specific period of time remains open. Inspection and destruction of hedges may be considered. As for the buyer, the continuous development of new and better varietal lines could discourage interest in propagation. Nevertheless, at this time, customers face a decision to pay this premium or to resort to business as usual. Should buyers be confident in their ability to propagate elite varieties despite the associated risks, they will be willing and able to pay the premium price.

Finally, this research sets a starting point for those searching for a deeper understanding about what is available to plant-based biotechnology companies in terms of regulations, protection, and approaches to assessing value creation, which can yield significant economic returns to plant breeders as well to forestland owners.

CHAPTER 4

THE VALUE OF UNIFORMITY IN CLONAL PLANTATIONS

A QUANTITATIVE AND QUALITATIVE ANALYSIS[7]

[7] De La Torre, R. and B. Borders. To be submitted to *Forest Ecology and Management*, August 2007.

Abstract

The promising benefits of planting clonal seedlings in the southern United States have not been fully considered in current modeling efforts; thus, this study attempts to answer some of the remaining questions about the impact of monoclonal crop uniformity on forest plantation returns using, for the first time, empirical data from this region. These data, collected in 2006-2007, include inventories from 360 permanent plots with 16,000 loblolly pine trees at ages between 3 and 18 years, and were gathered following PMRC standards across the southern U.S.

All segments of timberland investors in southeastern U.S. forests are increasingly using elite varieties. These landowners, including integrated and non-integrated forest products companies, institutional investors, and private landowners are coping with uncertainties associated with new biotechnologies. Cutting-edge forest biotechnology implies intensive forest management, which rests upon accurate predictions and projections of growth and yield of timber products, which in turn rely on proper diameter distributions that are based on measured or predicted stand parameters.

A key factor in forest management involves quantitative improvements in timber yields. Not as obvious is the question of qualitative attributes like uniformity and disease resistance, and how they contribute to value creation. Therefore, it is necessary to clarify and assess the attribute of uniformity to support forest managers in their decision making process, regarding deploying clonal seedlings on their timber holdings.

To uncover the value of the attribute of uniformity, this study describes and quantifies uniformity in clonal and non-clonal stands. It then analyzes these data's effects on current G&Y models, using the Generalized Stand Table Projection (GSTP) and the Diameter Distribution Recovery Model (Weibull Recovery). Comments on and suggested revisions to these models are

offered, and the reliability of growth projections and their implications on economic analysis addressed.

INDEX WORDS: Forest biotechnology; elite variety; uniformity; value creation, diameter distribution; loblolly pine

Introduction and Literature Review

Uniformity

Although the terms *variety, elite variety, varietal, asexual* or *vegetative propagated products, cultivar, commercial line,* and *clone* vary and may be used specifically in certain scientific disciplines, in this study, they are used herein interchangeably. All plants produced by vegetative propagation are genetically identical individuals similar to the donor plant from which they have been obtained.

Techniques of cloning, testing, and commercializing woody plants for timber have been applied to few species. The most common are Chinese fir, redwood (genus *Sequoia*), eucalyptus, willow (genus *Salix*), and poplar (genus *Populus*).

The first recorded clonal forest programs began in China with Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook.) and in Japan with sugi (*Criyptomeria japonica* D. Don), 800 and 500 years ago respectively (Burdon and Libby, 2006). Chinese fir is the most important conifer species in southern Asia, supplying China 20-25% of its commercial timber. This species is easily propagated vegetatively because after harvest, stumps produces plentiful sprouts with high rootability. During the 1960s to 1980s, new techniques, like tissue culture, for cloning seedlings were developed and used in seed and sprout orchards. Genetic gains have been reported between 10 and 20% (Li and Ritchie, 1999). Growth and Yield (G&Y) models for Chinese fir are now published in English.

Most conifers are difficult to clone. The first formal program for clonal forestry of pine was with radiata pine in New Zealand during the late 1960s, which began commercialization during the late 1980s. Today, over 20,000 hectares (50,000 acres) have been planted, and this remains the most extensive and oldest clonal pine plantations in the world.

Clonal forestry is defined minimally as forest plantations with trees of selected, tested clones (Sorensson and Shelbourne, 2005). A commercial or "production" clone is a clone selected following field-replicated tests of a large number of candidate clones. Production clones must contain good genes (phenotypes) for several attributes, and individual trees of each clone should exhibit good inter-tree consistency or "uniformity". Thus, by definition, without intense genetic screening, simple deployment of vegetatively propagated trees does not represent clonal forestry. Pure clonal stands are genetically identical, and thus present considerably less variation between, among, and within trees compared to seedling forest stands. Crops of monoclonal stands, being both highly productive and uniform, should create additional value to sawmill, and pulp and paper industries, e.g. by enabling precise management regimes, and cheaper and more reliable/accurate estimation of product inventories (Shelbourne, 1997).

Uniformity, as a biological attribute, has diverse manifestations along the length of the forest industry's production chain from standing trees to final products. The following uniformity traits illustrate the value creation potential of clonal biotechnology in the forest sector. Flesh

- Stand Development: narrower stem diameter distribution, less crown stratification, higher survival
- Stand Management: shorter rotations, more predictable yields, thinnings for spacing only, lower inventory and harvest costs; virtual elimination of *fusiform rust* and other diseases
- Wood Quality and Stem Properties: predictable specific gravity, microfibril angle, and tracheid (fibre) length; straightness, crown form, stem taper, and branching habit
- Pulp and Solid Wood Technology / End-products: increased pulp and sawtimber yields, product quality, and environmental performance (resource or energy use efficiency)

There are few studies about uniformity in genetically improved forest plantations. Carson and Hayes (1998) analyzed diameter and diameter distributions of genetically improved seedling *Pinus radiata* in New Zealand. They compared four sites, two constraints management regimes, and from four levels of improved seedlots: land race (at least two generations of natural and silvicultural selection), climbing select (seeds from the best trees in selected stands), open-pollinated orchard (seed orchard from plus trees), and control-pollinated (pollen from selected parents). Quadratic mean diameter and mean height were significantly different among sites (except one) at age 14 or 15 years. Differences in mean diameter and mean height were statistically significant among genetic levels ($P < 0.005$). However, differences for standard deviation, skewness, and kurtosis were never significant ($P < 0.05$). Interestingly, stem diameter distributions (variance) did not decrease with higher genetic improvement levels, and that the tendency for the highly improved seed lot was to have flatter (platykurtic) distributions, slightly skewed to the right. Additionally, Carson and Hayes concluded that using individual tree models, predicted diameter distributions for all levels of genetic improvement will not require adjustment when stand parameters are correctly specified. In accordance with these findings, they reject the hypothesis that reduced diameter variance (as a result from genetic improvement) causes a loss in either total volume production or average stem diameter as compared with an unimproved control.

Two older studies, analyzed diameter distributions of improved and unimproved forest plantations. Spirek et al. (1981) adjusted the Weibull parameters to diameter and height data from *Pinus elliottii* progeny tests after finding slight differences among progenies. These findings should be taken with caution because the results from row plots or single-tree plots may not clearly indicate performance when progeny of the best parents go to operational plantations.

Janssen and Sprinz (1987) fitted probability density functions to diameter data from *Pinus taeda* trials and contrasted plots grown from plus trees' seeds to plots grown from nearby unimproved trees. Predicted diameter distributions for improved seed lots showed higher negative kurtosis values (more platykurtic or flatter distribution) than those from unimproved seed lots.

The Queensland Forestry Research Institute (QFRI) and the DPI-Forestry, a commercial business group of the Department of Primary Industries and Fisheries, in Australia are active in clonal forestry involving slash-caribaea pine hybrids (*P. elliottii* x *P. caribaea*). Given the rapid deployment rate of clonal plantations of this hybrid pine, at a rate of 10,000 ac/year (Dieters et al. 2004; Sorensson, 2002) in southeast and central Queensland, the QFRI and DPI-F are clearly committed to maximizing economic returns from clonal forestry. One area of DPI's interest is deployment strategy: if clones are deployed in pure blocks as opposed to polyclonal mixtures, will total volume production increase or decrease? Another question is whether single tree plot design evaluations are applicable to pure clonal plots. A third concern is how yield estimation and volume gains compare between monoclonal plots and polyclonal mixture plots (Nester, 2000).

Nester (2000) analyzed the *Experiment 315 GYM* (*elliottii x caribaea* established in 1995 with both pure and intimate mixtures of nine organogenic clones) and generalized the following:

- A clone that grows quickly will grow more quickly if planted in polyclonal plot. The reverse is true for slow growing clones.
- Both mixtures and monoclonal stands produce the same total volume at age 4.8 years.
- Some monoclonal plots exhibit higher within-plot variation than adjacent clonal mixture plots.

- Heritabilities, derived from single tree plots, for traits sensitive to competition, such as diameter and volume, may be overestimated compared with those obtained in single clonal plots, and this similar biased age-age diameter growth correlations. Height, which proves insensitive to competition, is unaltered by method of deployment.
- A clone's ranking in a pure clonal plot may differ from its ranking in a single tree plot design for diameter.
- For clones in pure and mixed plots, for height, DBH (diameter at breast height), and DGL (diameter at ground level), the coefficients of variation decrease over time. During the initial two years, the CVs plummeted, and then slowly leveled off. Volume CVs tended to decrease evenly over time over a period of three years.

Rockwood (2000) discusses Nester's study and adds that based on volume CVs, we would expect that pure operational clonal plantations would have a narrower range of diameter class distributions because tree volumes in pure clonal plots are more uniform than mixed clonal plots compared to seedlot plots.

Hornsby (2006) investigated the variation of wood qualities (target height level for collecting cores was 2.5 feet) in *Pinus taeda,* between clones, full-sib zygotics, and half-sib zygotic trees at age four years old, focusing on wood density (specific gravity), latewood proportion, stem oven-dried weight, and microfibril angle (MFA). He found that the merchantable wood produced by vegetatively propagated plantations had increased uniformity and improved wood quality characteristics with respect to weighted core specific gravity, and to latewood percentage as compared to half-sib open pollinated trees, but not significantly different to full-sib zygotics. However, he found no significant differences among types of propagation with respect to dry stem weight. Results on MFA were inconclusive: MFA was not stable enough at age four to interpret differences among individuals.

Sorensson (2007) compiled a list of fifteen reasons why improved wood quality (WQ) is vital in softwood plantations. Since WQ attributes are generally more predictable (high heritability) than growth rate, WQs have less uncertainty/risk for both producers and consumers. WQ improvements are reflected and capitalized in transformation processes (optimized resources, decreased waste, and increased conversion), forest land-base reduction (for fiber/lumber production), harvest scheduling flexibility, greater potential revenues from bio-fuel products, among others. These WQs added-value attributes should be recognized by the market and included into any forest investment analysis. Improvements in WQ features like stiffness and velocity (used to assess structural quality), and associated economic benefits, are achievable through clonal selection; they can not be achieved by intensified silviculture alone.

Generally, commercial clonal plantations show evidence of uniformity: size (diameter and height), shape, crown architecture, and branching system. Some studies in New Zealand show that internal and external uniformity exist for clones of radiata pine, which reduce the CVs around 20 to 40% for a number of attributes (Sorensson et al. 2004).

In other cases, experimental clones express little or no “desirable” uniformity. This is particularly so for undesirable tendencies like compression wood formation, variability in specific gravity, or vulnerability to diseases. Thus, the clonal selection process is crucial. If clones are mis-selected, the program will backfire and will spoil the stand’s worth.

Growth and Yield Models

Following the progress of genetic improvement in growth rate for more than three decades, efforts to incorporate log quality into forest planning and G&Y models began last decade in New Zealand and the Southern U.S. By mimicking precision forestry systems, forest planning tools have been developed for improving the sustainability, productivity, and profitability of forest management. With some degree of sophistication, these tools can customize products for specific purposes. For example, seedlots can be matched to specific sites in order to maximize economic returns. As illustrated by Carson (1996), given two sites, one sandy (low productivity) and one highly productive, high genetic quality for straightness may be important for the more productive site where fast growth rates may increase stem defects.

Another example is the integration of mortality functions into the G&Y models that consider the specific impact on low- or high-hazard sites where diseases such as rust or pitch canker occur. Zhao et al. (2006) developed a survival model for predicting tree number reduction for fusiform rust infected loblolly pine plantations, which could be incorporated into the G&Y models to improve accuracy of forest production. Thus, for forest decision-making managers, timber quality attributes need to be included into G&Y models, either by adjusting or by modifying current G&Y models as new data become available. These data come primarily from improved plantations using traditional breeding programs. However, data available from plantations/trials established with vegetative propagated seedlings are limited and currently represent a critical gap for modeling clonal forestry. Tested clones give greater flexibility for tailoring site, management regimens, and final products that optimize forest investments. Thus, unlike G&Y models for traditional plantations, development of a G&Y model that predicts performance of a single clone is a challenge that demands at least a similar or higher degree of accuracy in order to reflect the effects of genetic advances.

Assessment of the impact of genetic improvement on diameter distribution (log size) is crucial for accurate prediction/projection of forest products, timber yields, and valuation.

Clonal testing is an extensive and capital intensive effort. Rockwood (2000) reported, for instance that in New Zealand, over 10,000 *Pinus radiata* clones were tested prior to deploying very few commercial lines. From more than 31,000 trees of *Eucalyptus grandis* established in Florida, only three were found freeze resistant. The QFRI and the DPI-Forestry tested over 1,700 clones of *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis,* and only nine were planted operationally. Baltunis et al. (2004) reported a trial planted in 2002, where more than 239,000 cuttings from almost 2,200 loblolly clones were set in five rooting trials. Rooting success across these trials was 43%. The successful cuttings were used to establish six studies across the Southeast U.S. Jayawickrama et al. (2004) discussed a Douglas fir breeding effort involving 2,600 crosses, 95 tests, and about 300,000 planted trees. Only about 10% of the crosses made it to the planting stage. Huber and Powell (2004), through The Cooperative Forest Genetics Research Program (CFRP) at the University of Florida, reported that the slash pine program had reached the third cycle of improvement, planning to test 43,000 trees (in 11 years) compared to one million trees tested in the first cycle (34 years).

In the absence of specific/published studies for G&Y modeling, indications of clonal plantation development can be observed in other studies, such as those established for genetic valuation. For instance, a loblolly pine study conducted by Baltunis et al. (2007), consisting of six field trials with clones (1,212) and seedlings (+14,000) from 61 families, was established in the U.S. South in 2002, and early results have been released. A key finding was that there was not much genotype x environment interaction across installations at the parental, family, or clonal levels for stem diameter. Thus, general clonal behavior can be captured and incorporated into G&Y models.

This type of study provides a platform for a better understanding of clonal dynamics and some of their most important commercial features, as described by Jayawickrama (2001), who analyzed DBH, straightness, malformation, crop acceptability, needle retention, *Dothistroma* infection, wood density, and spiral-grain angle for radiata pine in New Zealand.

A study of Growth and Yield predictions at age 4.8 years for nine clones of *elliottii x caribaea* established as pure clonal plots or as single tree plots (STP) in 1995, was conducted (Rockwood, 2000). Rockwood investigated alternatives for adapting *Pinus elliottii* and *Pinus caribaea* G&Y models to hybrids and clones of *Pinus elliottii* x *Pinus caribaea*, for survival and wood density traits, as well as for stem taper prediction, diameter distribution, and height-age relationships. For a rotation age of 20/30 years, his analysis estimated an interim volume gain of 20% for clonal plantations over seedlots of *Pinus caribaea* plantations. These results, on an additive basis, suggest breakdown gains as follows: height 5%, stem taper 10%, and wood quality 5%, all of which need to be verified as new data become available.

Carson et al. (1999a) discussed the use of pre-existing G&Y models for plantations of diverse genetic origin, which generate different yields and allow for quantification of genetic gain. G&Y models are derived from extensive regional data and cover broad characteristics of site indices and management practices. These factors are more significant contributors to determining yield than genetic effects per se. Thus, by taking into consideration initial tree size and other growth factors, a growth rate for a limited level of genetic gain, could be incorporated into existing models without modifying the models. Existing models for *Pinus radiata* show that the differences in growth due to genetic responses are modest compared to growth differences that result from extremes of site and silvicultural managements (Carson et al. 1999b).

Diameter at breast height (DBH) has been one of the most comprehensively studied and used growth parameters for modeling purposes Garcia (2006). Garcia and others authors have identified the effects of plot size on tree growth models. He states "that variability in larger areas tends to be higher than in smaller areas, as larger areas have a greater probability to including different conditions" (p2). Garcia focuses on DBH variances estimated in single random plots, where spatial correlation plays a significant role in estimation; whereas, the mean and total estimations are trivial. Thus, G&Y models for clonal plantations should also consider this effect of plot size.

Stand tables, the number of trees per acre by diameter class, also provide essential information for assessing product volume, as well as the necessary inputs for financial analyses in forest investments. The stand table projection approach is based on current stand tables from which can be predicted the surviving trees for each diameter class, and the growing tree diameters over time, which in turn, produce a stand table for a future age. This projected stand table must be compatible with observed values, or to stand tables derived from whole stand models (Clutter and Jones, 1980; Pienaar and Harrison, 1988; Cao and Baldwin, 1999). Similar mechanisms should be applied to develop a more accurate clonal stand table projection algorithm as a component of the G&Y system, which, when available, will contribute to a better understanding of clonal growth dynamics.

Financial Valuation

Clonal forestry has emerged as a revolutionary option for transforming the course of the forest industry. Forest landowners in the Southern hemisphere agreed it was more profitable to grow and harvest genetically improved trees than unimproved plantations (Shelbourne, 1997). Clonal forestry appears to have multiple advantages over traditional breeding programs that consider half-sib or full-sib families. The uniformity effect is one advantage of a single-clone stand that requires analysis of its economic value.

Direct and indirect economic benefits of exploiting clonal plantations have just begun, and will slowly snowball across the forest value chain. Modern forest valuation should focus not only on growth and yield rates, but also on desirable attributes like defect and disease minimization, wood quality, and yield-to-end products. As stated by Sorensson "...big trees provide gross initial volume, but say little about conversion to final product. Open up two trees and they can be wildly different for wood/product qualities like stiffness or twist. Nothing on the outside of a tree will lead you to reliably differentiate which is which. And therein lies the basis for a natural unwillingness to believe that there can be such extraordinary differences in value amongst stems of similar age and external size and shape" (2002, p29).

A forest industry partnership between Tenon and Horizon2 (previously Fletcher Challenge Company, and Trees and Technology) constituted a multidisciplinary task force called Genetic Optimization Team (GOT) in New Zealand in 2001. GOT's objective was to create a reliable atmosphere through which customers could critically assess the benefits of forest genetics through clonal technology. One of GOT's focuses was accuracy and transparency in analyzing value prediction and clonal pricing. One key finding was the estimation of clonal benefits in the production of sawtimber alone: well over \$300/ac [8] (Sorensson et al. 2004).

Another tool for exploring clonal attributes is SILVIS, a piece of software that focuses on assisting foresters/consumers to recognize which, what, and how much clonal attributes influence the value of sawtimber. In a sawtimber recovery analysis, SILVIS showed a potential value creation, resulting from genetic improvement, of \$37/m^3 or more, that landowners and processors could share (Sorensson et al. 2004).

McKeand et al. (2006) recently quantified the financial benefits of using the best loblolly pine genotypes regionally. Their sensitivity analysis covers two management regimes, fiber and solid wood production, across eight site indices which vary from 60 to 95 in increments of 5 feet. Main findings show, at an 8% rate of return, that forest investors can easily justify an additional cost of \$40/ac to \$250/ac, across sites and management regimes, for the best improved seedlings. As seen in Chapter 2, in a SI 60 (planting 605 TPA) with expected gains in volume from 10 to 50%, a landowner could pay in addition to the base price of \$0.05/seedling (traditional, half-sib open pollinated) an additional price between \$0.16 to \$0.90 for vegetatively propagated seedlings, and remain financially indifferent. Sorensson (2005) presented a radiata pine price for a rooted cutting commercial clone in New Zealand of \$0.80/seedling (three to five times that of full-sib or half-sib seedlings, correspondingly), which is \$0.09 below the assessed break-even cost.

Value prediction and price of a single commercial clone are the key components of financial analysis in forestry. In addition, in the context of a comprehensive forest plan, deployment alternatives have been investigated. Carroll et al. (2006) assessed four hypothetical

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[8] Exchange rate: US\$1 = NZ\$1.34, in June 2007

deployment methods for elite planting stock compared to second generation improved seedlings. Their results show increased production, revenues, and returns. The allowable cut effect (ACE) affords for deployment of elite plantations except when clone deployment rate follows traditional harvest rate.

While this chapter is focused on analyzing uniformity in the main growth (morphological) parameters, and in a few quality traits, Shelbourne (1997) made an extensive compilation of clonal studies on radiata pine in New Zealand on heritabilities and predicted gains of ten 16-year-old clones, and with ten 28-year-old clones for sawtimber, with 90 attributes: tree growth and morphology (37), wood chemical properties (8), kraft and thermomechanical pulp and paper (23), and sawtimber (22). Using these 90 tree/timber features, it is possible to estimate the value created from clonal forestry for a particular product. Adapting Shelbourne's example to illustrate the benefits of clonal forestry in the pulp and paper industry, and assuming that the value of softwood Kraft[9] is $785/ton, and stumpage pulpwood value to produce that paper is about $25, the improvement in wood quality increases the value of the paper, or reduces the processing costs by 3%. The pulp-mill would then be able to pay double for the pulpwood value, or three times, if higher paper value is combined with cost savings, to reach its break-even point. Finally, Shelbourne states that given the wide array of heritabilities, the value of uniformity may exceed the gains from other attributes.

[9] Foex indices. The PIX Pulp EUROPE Benchmark Indexes NBSK PIX value Softwood USD/ton. URL: http://www.foex.fi/default.asp?navigate=pix_pulp_select.asp. Last accessed on June 17, 2007.

Study Objectives

- Compare the uniformity of several clones at three different ages to related and unrelated non-clonal seedlings.
- Determine if the PMRC-1996 growth and yield models can be used for varietal plantings.
- Address implications of growth projections for economic analysis.

Data Collection: Species and Management Regimes

Novel data from varietal loblolly pine demonstration blocks allow one to evaluate the hypothesis that elite varieties are associated with narrower diameter distributions and with more uniform quantitative and qualitative parameters (height, diameter, volume, disease resistant, form / straightness) compared to seedling (zygotic) plantations involving several levels of genetic improvement.

Pure clonal loblolly pine blocks from rooted cuttings or SE seedlings "varieties" were established in 1989, 1990, 1999, 2000, 2001, and 2003 in the Lower Coastal Plain in North Carolina, South Carolina, Georgia, Alabama, and Mississippi (see Tables 4.1 and 4.2). Related and unrelated seedling control blocks were also planted adjacent to the clonal blocks. None of the clones was selected with respect to growth, except those for the 2001 and 2003 trials, which included some commercial lines. The primary purpose of establishing these blocks was simply to compare clonal and non-clonal stands for uniformity.

Silvicultural regimes differed from location to location --in total, nine different regimes were applied. Only in one location were plots thinned (at age 12, 5th row-thinned and selected within). Planting density varies broadly, from 450 to 800 TPA (6x 9 = 807, 6x10 = 726, 6x12 = 605, 7x11= 570, 8x10 = 544, 9x9 = 538, and 8x12 = 454). Varietal and control seedlings were containerized or bare root, and planted by hand. Exceptions are the trials planted in 1999, which were containerized seedlings, mechanically planted; and the 2003 trials, which resemble operational plantings rather than trial plantings, used bare root seedlings, also planted by machine. The majority of all trials involved intensive site prep such as chopping, disking, subsoiling, piling, raking, bedding, and sometimes, drainage as needed. Chemical site preparation differed by site. Fertilization at planting time and at mid rotation (urea and DAP) was scheduled. Full or partial herbaceous competition control, and tip moth control were often applied. Thus most of these trials may be considered "Best Practices".

In addition to measurement completed in 2007, previous measurements for the 18-year-old varietal demonstration block (870 trees in location number 7, NC) at ages 0, 1, 2, 3, 4, 6, and 9 years were integrated into this analysis. In addition, records for the loblolly pine family 7-56 (3,500 new records), collected by PMRC as a part of the Improved Planting Stock / Vegetation Control Study (known as the Herb-Gen study), were included. Herb-Gen study measurements were taken every three years (6, 9, 12, 15, and 18) since its establishment in 1986, and are considered useful for contrasting the uniformity results between varietals and one of the best OP families, which has traditionally been used as the industry benchmark.

Finally, data from eucalyptus plantations were gathered from a Colombian forest company that shared raw data of three *E. tereticornis* clones (306 records at six different points in time) and two seedling tree plots of *E. pellita* (1053 records of at four different ages).

Description of Trials

Tables 4.1 and 4.2 summarize the diverse number of sources (four forestry companies, nine locations) for collecting data. The majority of these unique data comes from areas established for “demonstration” and are not replicated. In two cases, 3- and 6-year old planting blocks were replicated both within their tracts and in other locations. For these replicated trials, analyses of variance were used to examine differences among the parameters and variables of interest. For those that are not replicated, results are descriptive.

Silviculture management regimes for the trials are recorded in detail in Appendix H.

Table 4.1. Cruised General Information

Company	Locations	Area (ac)	Plots	Age (yr)	Clones	Zygotics	Trees
1	3	4.60	40	6 and 17	8	4	1,837
2	1	1.02	25	6	10	3	721
3	2	5.32	42	3	6	1	4,128
4	3	17.28	253	6 and 18	70	9	9,222
Total	9	28.22	360		94	17	15,908

Methods for Evaluating Uniformity

Descriptive Analysis

Nine locations across the Southeast and 14,041 trees in 360 permanent plots were analyzed. Ninety-four clones and seventeen non-clonal entries were evaluated. The clones’ ages breakdown as: 20 at 18-years old; 2 at 17-years old; 66 at 6-years old; and 6 at 3-years old. Various clones were compared to related or unrelated zygotic trees, and some to both. For instance, the two 17-year old clones were compared to their parents (as controls), 50 6-year old clones were compared to eight zygotic trees (as controls), which covered all levels of tree breeding improvements from wild trees to advanced generations of mass-control pollinated trees. The data collected from multiple sources and field studies not only enrich the analysis but also

Table 4.2. Cruised Clonal and Non-clonal Demonstration Blocks Across Southeastern U.S. (* Replicated Studies)

Source	Stock type	State	Number of plots	Plots size (acres)	Date installed	Date measured	Trees measured	Trees analyzed
Clone	Cuttings	GA	4	0.12-0.18	12-1988	04-2006	125	125
Control	Seeds	GA	4	0.13-0.15	12-1988	04-2006	136	136
Clone	Cuttings	GA	4	0.18	01-1989	04-2006	176	176
Control	Seeds	GA	1	0.16	01-1989	04-2006	35	35
Clone	Somatic*	GA	8	0.08-0.09	12-1999	04-2006	409	399
Control	Seeds	GA	2	0.09	12-1999	04-2006	109	107
Clone	Somatic	SC	15	0.08-0.11	02-2000	05-2006	750	712
Control	Seeds	SC	2	0.10	02-2000	05-2006	97	91
Clone	Somatic	MS	22	0.02-0.08	03-2001	07-2006	541	485
Control	Seeds	MS	3	0.08	03-2001	07-2006	180	154
Clone	Somatic*	GA	36	0.11-0.13	12-2003	11-2006	3,555	3,555
Control	Seeds	GA	6	0.12-0.13	12-2003	11-2006	573	573
Clone	Cuttings	NC	20	0.03-0.09	05-1990	04-2007	750	471
Control	Seeds	NC	1	0.15	05-1990	04-2007	120	47
Clone	Cuttings*	NC	100	0.07-0.08	11-2000	04-2007	3,600	3,333
Control	Seeds	NC	16	0.07-0.08	11-2000	04-2007	576	517
Clone	Cuttings*	AL	100	0.05-0.07	11-2000	05-2007	3,600	2,761
Control	Seeds	AL	16	0.05-0.07	11-2000	05-2007	576	364
	Total		360	28.2			15,908	14,041

create a challenge for identifying systematic, homogeneous, and comparable outcomes. Descriptive analysis was used for all data collected, from which selected outputs are used to illustrate key results. First, for instance, outputs from field data for the 18-year-old trials and various cruises were used to characterize a desirable clone and a check family (in this case, the 7-056 family), which were run from a description of growth parameters to all uniformity measures. Second, for analyzing diameter distributions, an output sample from all locations and ages was selected, including one 6-year old commercial clone compared to three different check seed lots. Third, for the younger replicated plots (3- and 6-years old), main statistical findings for four growth parameters (DBH, height, basal area, and volume) are presented. Finally, another subset of outputs was used for testing models and assessing the financial impact of using the current G&Y models.

The recorded data from each tree were DBH, Height (3 categories), Cronartium rust (5 categories), Crown classes (8 categories), and Sawtimber acceptability (5 categories), where sawtimber is defined as a tree that has at least one log 12" in diameter and 16' long. Total height was measured on odd numbered trees, and the height for even numbered trees was estimated regressing Ln Ht = a + b(1/DBH).

Analysis of raw data: At plot level, and when data were replicated, at average plot level. DBH, BA, HTotal, HDomCod, HLiveCrown, HCrownLength, LCrownProp, GWob, Sawtimber, and Rust were computed under basic statistics and main uniformity measures, such as Average, Standard deviation[10], CV[11], Min, Max, Median, Mode, IQR[12], Kurtosis[13], and Skewness[14]. The matrix output developed to

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[10] The standard deviation (σ) is the most common measure of statistical dispersion, measuring how widely spread the values in a data set are. The SD is the root mean square deviation of values from their arithmetic mean. Available from http://en.wikipedia.org/

[11] The coefficient of variation (CV) is a measure of dispersion of a probability distribution. It is defined as the ratio of the standard deviation σ to the mean μ and then multiplying by 100. Ibid.

facilitate clonal comparisons is 360 x 70. This matrix was created in worksheets using PivotTables and Visual Basic, which was written in order to compile these outcomes systematically.

In the Results section, only a few quantitative and qualitative attributes were selected from these worksheets, such as DBH, GWob, Sawtimber, and Rust, for illustrative purposes.

Statistical Analyses for Replicated Plots

The database contained data from two designed field trials that used a replicated Randomized Complete Block Design (RCBD). This design assumes that a population of experimental units can be divided into a number of relatively homogeneous subpopulations or blocks, replicated in two installations/locations. The treatments (labels/clones/controls) are then randomly assigned to experimental units (plots), such that each treatment occurs equally often in each block, i.e. each block contains all treatments. Blocks usually represent naturally occurring differences not related to the treatments. In the analysis, the variation among blocks can be partitioned out, usually reducing the experimental error (MSE).

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[12] In descriptive statistics, the interquartile range (IQR), also called the midspread and middle fifty is the range between the third and first quartiles and is a measure of statistical dispersion. The interquartile range is a more stable statistic than the (total) range, Because it uses the middle 50% of the data, the IQR is not affected by outliers or extreme values. Ibid.
[13] Kurtosis is a property of a probability function which describes how well that function matches the bell curve. Measures the fatness of the tails of a probability distribution (kurtosis is a measure of the "peakedness" of the probability distribution). Kurtosis is sometimes referred to as the volatility of volatility. Kurtosis gives value of zero (mesokurtic) if the distribution is normal. Negative values of kurtosis (platykurtic) mean the distribution has ‘thin tails” than normal, so it goes to zero "quicker". A positive value for the kurtosis (leptokurtic) indicates a narrower distribution than a normal Gaussian (a more acute "peak" around the mean), a negative value indicates a flatter and broader distribution. Ibid.
[14] Skewness is a measure of symmetry of the probability, or more precisely, the lack of symmetry. Normal distributions will have a skew value of approximately zero. Right-skewed distributions will have a positive skew value (longer 'tail' to the right than to the left, the mass of the distribution is concentrated on the left). Left-skewed distributions will have a negative skew value (the left tail is the longest; the mass of the distribution is concentrated on the right). Typically, the skewness value will range from negative 3 to positive 3. Ibid.

Experimental design for two studies with replicated plots

- Age 3: 4,128 trees

Installations: 2 (1, 2)

Blocks: 3 (within each installation 1, 2, 3, 4, 5, 6)

Labels (clones/control): 7 (in each block: clones 1 to 6, and control 1)

- Age 6: 6,975 trees

Installations: 2 (1, 2)

Blocks: 2 (within each installation 1, 2, 3, 4)

Labels (clones/control): 58 (in each block: clones 1 to 50, and controls 1 to 8)

Installation: random effect

Block: fixed effect

Label: fixed effect

Block is nested in Installation [block (installation)]

- Model

$$Y_{ijk} = \mu + \tau_i + \beta_j[I] + I_k + (\tau \cdot I)_{ik} + \varepsilon_{ijk}$$

k = 1, 2 (installation), j= 1, 2, 3, 4/6 (block), i = 1, …, 7/58 (labels/treatments)

where,

Y_{ijk} = Expected value of the response (DBH, HTadj, BA/ac, D^2H/ac / GWob/ac) at Installation k^{th}, Block j^{th}, and Label i^{th}.

μ = General mean

τ_i = Treatment effect (i^{th} label)

$\beta_j[I]$ = Block effect (nested in installation)

I_k = Installation effect (Random Effect)

$(\tau \cdot I)_{ik}$ = Installation*Label interaction effect

Method for Testing Models

Accurate prediction and projection of forest growth can be generated from models that function at the stand or at the tree level, and can project stand parameters, such as diameter distributions. Equation systems developed by Harrison and Borders (1996) and Pienaar and Harrison (1988) are widely accepted for G &Y modeling of loblolly pine in the South. Both were used to run this analysis at stand and tree level, respectively. A commercial software that incorporates both models is the Simulator for Managed Stands (SiMS), which was developed by ForesTech International LLC, and it was selected as the stand generator platform.

SiMS uses whole stand models to predict and project estimates of surviving trees/acre, stand dominant height (ft), and stand basal area (ft^2/acre). SiMS can also estimate /predict the associated stand table using a Weibull (Bailey and Dell 1973) probability distribution function developed for the stand type. However, if a stand table is recorded from a cruise, it is fed into the SiMS system, and a projection can be made from this initial stand table using the Generalized Stand Table Projection Algorithm of Pienaar and Harrison (1988). This procedure projects from the current stand table condition to the expected future stand table condition such that the projected stand table is compatible with the projected whole stand estimates of trees/acre and basal area/acre. In addition, tree characteristics by diameter class (Tree Quality Index, TQI), and product allocation tables for each harvesting type (as a percentage of trees in each diameter class by product) can be defined and put into the system, which confers more realistic information for financial analysis. Once a predicted and/or projected stand table is available, a height – diameter function is used to estimate heights for each diameter class. Volume and/or weight per acre by diameter classes are then obtained using individual tree volume and/or weight equations that are appropriate for the stand type.

PMRC-1996 growth and yield models built into SiMS were used to make projections based on current cruise information as well as on cultural treatment history. Figure 4.1 describes the scenarios defined to analyze the projected and predicted diameter distributions at age 25 based on observed stand parameters, and predicted data at ages of 6 and 17 years. In order to exemplify the analysis, a sample of this database, which includes 40 plots in locations 1, 2, and 3 was selected for simulation.

Scenario 1: PMRC-1996, given observed diameter distributions:

It uses generalized Stand Table projection algorithms.

It uses Stand Table data (observed and projected).

For financial analysis, this scenario includes two variants: with and without tree quality information.

Scenario 2: PMRC-1996 Diameter Distribution Recovery (Weibull):

It does not use Stand Table data (predicted and projected).

- Both scenarios require trees per acre, age, basal area, and dominant height as basic inputs. Scenario 1 with the observed stand table also includes trees/acre by DBH class, and TQI (tree quality index for sawtimber or non-sawtimber).
- For both scenarios, a common cultural treatment history includes planting, seedlings, site preparation, vegetation control, fertilization, and thinning regime, as well as product specification, stumpage values, and other relevant economic data for each area.
- Silvicultural inputs were provided by the landowners, and the economic assumptions, from private databases or *Forest Landowner*.
- These scenarios were run for current ages and were projected/predicted to the final harvest age of 25.

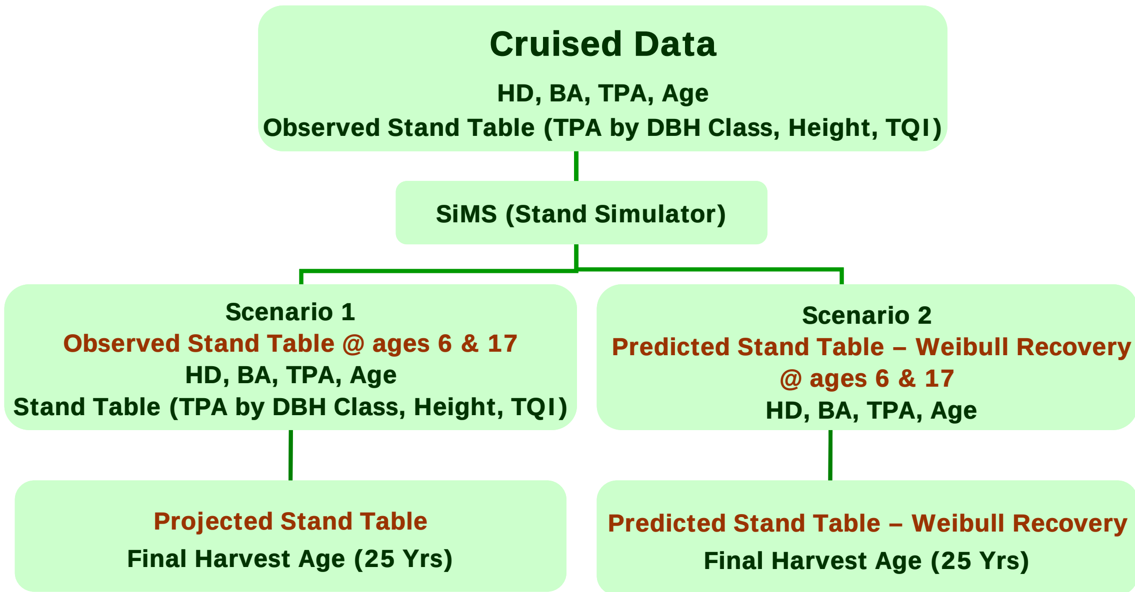

Figure 4.1. Model Testing Diagram

Method for Economic Evaluation and Financial Assumptions

To address the financial significance of these traits, the data used in the example for testing models will also be used for economic evaluation. This financial analysis focuses on uniformity as expressed by narrower diameter distributions, and tree quality expressed by proportion of sawtimber. The valuation of these key attributes of clonal plantations illustrates the worth of capturing at least two aspects of growing mono-varietal forests.

Capital Budgeting Criteria (NPV and IRR) were used to perform this financial analysis by comparing stands of more uniform trees against traditional stands. Financial inputs are shown in Tables 4.3 and 4.4.

To simplify the financial comparison for both existing clonal stands of ages 6 and 17 years, for both G&Y scenarios (see Figure 4.1), rotation age was fixed to year 25, which approximates age of maximum BLV and is the optimum rotation age. For the six-year old stands, one thinning was simulated at age 14.

Discounted cash flow techniques and IRR (discount rate at which the NPV is equal to zero) are usually the preferred capital budgeting decision criteria used in the forestry industry. However, the Net Present Value (NPV) is thought a superior criterion, and the appropriate measure when investment objective is to maximize wealth (Bullard and Straka, 1998; Wagner et al., 1995; Redmond and Cubbage, 1985).

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t}$$

where,

R_t, C_t = Revenues and Costs in year t
i = Discount rate
n = Investment life

The differences in Net Present Value for one rotation were used, at the defined rotation age, between projected or predicted stands, by using generalized stand table projection algorithm or Weibull recovery method. These differences determined the valuation of using G&Y models developed for seed lots when the models are used for modeling vegetatively propagated forest plantations. In addition, for the stand table projection algorithm, the Tree Quality Index (TQI) economic impact was assessed. This feature, built into the selected stand simulator, provides the means to sort the cruised qualitative attributes at tree level by diameter class, which allows for more realistic growth and yield projections, and more objective stand valuations for financial decisions. By inputting an observed quality into the model, it is possible, for example, to discriminate final products, among trees at age 10 in the 8-inch diameter class.

This approach can be used as a framework for similar analyses. For example, the NPV for the optimal BLV at SI 70 minus the NPV for the optimal BLV at SI 60 would be the value of using varietals over any level of improved seed, which would increase the site index from 60 to

70 feet for this base case regime for one rotation. This example of the framework considers only one component of a comprehensive silvicultural regime, but it could be extended and applied to any component or practice of that regime.

Table 4.3. Base Case Regime, Financial Inputs[15]

Year	Activity	$/acre
0	Chemical site prep ($90) + Single bed ($80)	170
0	Seedlings: 544/**566**/605 TPA (BR:¢4.5 & CT:¢12)	25/68
0	Hand planting (BR: ¢8/seedling / C: ¢10/seedling)	45
0-1	HWC band early	80
1/3	Tip moth control	15
1	Fertilization with DAP - 125 lbs/ac (P: 20% & N: 18%) No fertilization in location 4	26
12/14	First thinning (Residual BA 80 ft^2/ac, 5th row+select.)	
25	Final Harvest	
	Annual tax & administration costs	9
	Annual hunting lease	8
	Tax Structure: None, Rate of Return: 8%	

Table 4.4. Stumpage Prices & Product Specifications (Source, TMS 2006)

	ST	CNS	PW
FL, GA, NC, SC			
Markets ($/ton)	46.5	29.2	7.3
Min DBH (in)	12.5	8.5	4.5
Max DBH (in)	40.0	12.5	8.5
Min Top (in)	8.0	6.0	3.0

15 Forest Landowner Magazine, 2005. Costs and Cost Trends for Forestry Practices in the South http://txforestservice.tamu.edu/main/popup.aspx?id=1808

Results and Discussion: Clones vs. Non-clones

Characterization of Pure Clonal Plantation

The oldest documented pure elite variety loblolly pine block from rooted cuttings was established in May 1990 in the Lower Coastal Plain of North Carolina. The purpose of establishing these demonstration blocks was to compare, quantitatively and qualitatively, clonal vs. non-clonal plantations. The oldest clonal trial includes 20 clones and one selected family as control. The previous land use was loblolly pine plantation. At measurement time, the study was 18 years old. The Wasda series soil (Histic Humaquept) that occurs on this tract is characterized by an O horizon ranging from 0 to more than 12 inches in depth over low chroma (gray) sandy clay loam to clay loam Bg horizon. The combined thickness of the O, A and B horizons is less than 60 inches deep and is underlain by a sand to sandy clay loam C horizon. These wet areas were improved for pine growth with drainage or water control by raising beds. Site preparation involved shearing, piling, bedding and raking. For herbaceous weed control, Oust and glyphosate were applied, and mechanical weed control included brush chopping by machete and ax when needed. Fertilization with phosphorus at planting was applied. Containerized rooted cuttings were planted by hand for an intended density of 605 TPA (6'x12'); the standard regime for this type of study does not include thinning.

Figures 1 and 2 in Appendix B present trajectories of three growth parameters: DBH, HT, and GWob, and as well as survival/mortality trends through time for the "old" clonal study, and for the industry check, 7-056 family.

Figure 4.2[16] includes DBH and its CV for 20 clones and one check through an 18 year period with five cruises in years 4, 6, 7, 9, and 18 for all clones and check. An exception is for the check plot, whose measurement, in year 9 was not available. The selected fastest growing clone at every cruise appears among those with the highest DBHs and lowest DBH CVs. In contrast, the check seed lot, from year 4 to 7, was in the lowest DBH class. From year 7 to 18, the check seed lot had the highest mortality rate, and its DBH at age 18 was higher than the "winners" (clonal trees with highest volume). However, the same check plot was among the highest DBH CV plots through the period of 18 years. Skewness and kurtosis for DBH were calculated. The fastest growing clone (winning clone based on volume) also had the highest positive kurtosis and the highest negative skewness during the first 9 years, as is observed in Figure 8 in Appendix D. However, these statistical parameters approached zero by year 18. Thus, the winning clone, at this specific site (plot 19), initially had diameter distributions with a big peak and a slightly longer tail to the left. Over time, its diameter distribution normalized.

Figure 9 in Appendix D also includes the Green Weight outside bark and CVs for all 21 plots analyzed. It shows the winner at age 18, as the most productive in terms of volume. Comparing the winner (202 ton/ac) to the control (116 ton/ac) provides a gain of 75%. However, this comparison is biased because stocking, measured as TPA, for the control was 60% lower, while volume per tree was only 6% different. However, the control seed lot was not the worst plot in this study; there were clones that performed worse than the check.

[16] Within the text of this manuscript and in the Appendices for the majority of Figures, the bars, dots, or lines colored in blue represent clonal plots, and the pink represent controls or check plots. When more than one check is in the block, the 7-056 family is depicted in green, and the best two clones (in terms of highest volume), the first in orange, and the second best clone in brown/dark purple.

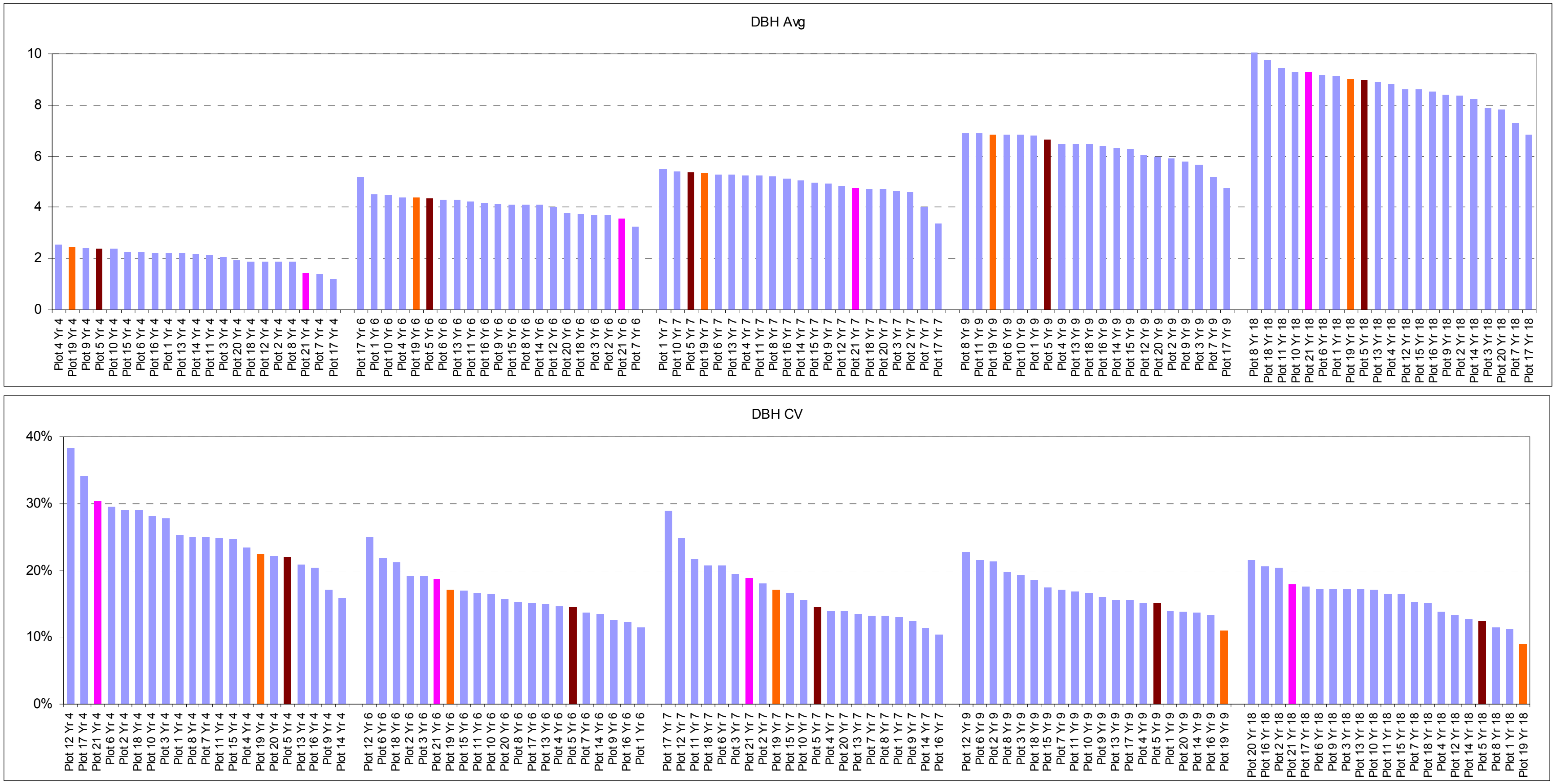

Figure 4.2. DBH Averages and DBH CVs by Plot, North Carolina: Twenty Clones, One Check, over 18 Years

In addition, for an accurate picture of the relative variability in the data set, coefficients of variation for volume were computed, and as was expected, the winning clone presented the lowest GWob CV. Figure 9 in Appendix D also presents the relative dispersion for the data, where the better plots show consistently lower CVs than the check CV. However, the winning clone for volume, and sawtimber potential (97%), was not as successful for tolerance to rust, with rust infecting 23% of the trees.

Figure 4.3 shows the diameter distribution dynamics from age 4 through age 18. At age 18, the winning clone (plot 19), yields a Dq 9.0 inches, while check yields a Dq 9.4 inches. It is important to note the large difference in TPA between the winning clone and the check.

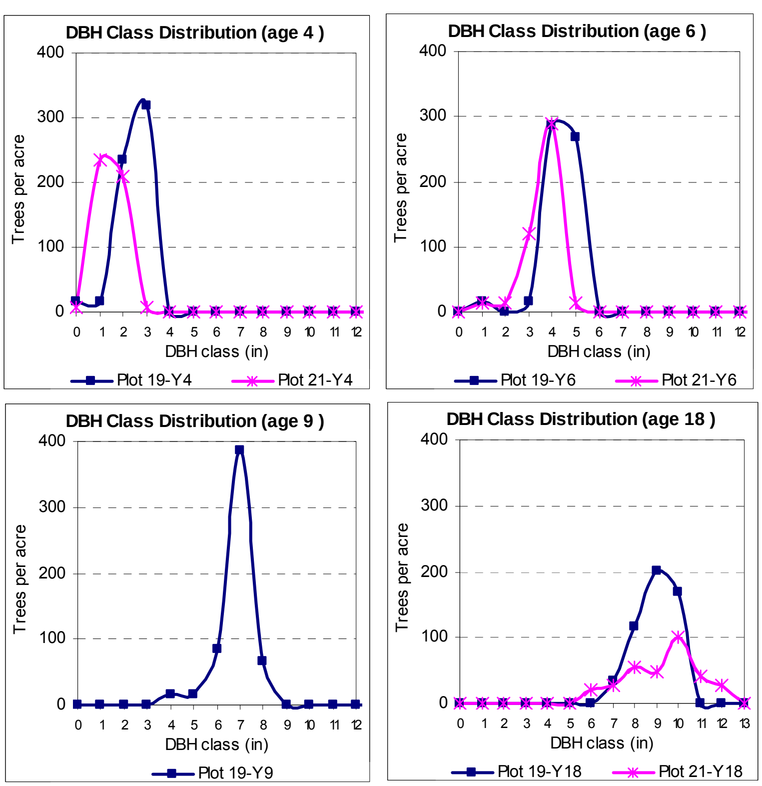

Figure 4.3. Clonal Stand Dynamics: Best Clone (Plot 19) vs. Check (Plot 21)

Characterization of the Loblolly Pine OP-7-056 Family: The Industry Standard

The 7-056 open pollinated family dataset in this study comes from the PMRC Study: “Effect of improved planting stock and vegetation control on stand structure and yield.” This PMRC study was established in the 1986-1987 planting season with loblolly pine in the Coastal Plain region, locating sites over a wide range of Cronartium hazard areas. Suggested spacings were 6x10 feet and 5x12 feet. Seedlings may have been machine planted, but care was taken to plant between 700 and 750 seedlings per acre. Plot sizes varied between 0.17 to 0.20 acres. Operational vegetation control was chemical or mechanical.

In the PMRC study, among several treatments, for the sixth (single-family improved stock, no vegetation control) and seventh (single-family improved stock, complete vegetation control) treatments, the single-family improved stock was 7-056. Plots have been measured every three years starting at age 6 for four consecutive periods.

For this uniformity analysis, seven plots in three locations (three per location in two locations, and one plot in a single location). Four plots are under no vegetation control (treatment A), and three plots are under complete vegetation control (treatment B). The analysis was performed at plot and treatment level, and more than 40 uniformity measurements were assessed. The assessment of plots at age 6-years measured only 40 trees/plot, but subsequent measurements included 120 trees/plot. In addition, the sawtimber characterization was done only at ages 15 and 18.

Results are not surprising in terms of volume. Under complete vegetation control, single family improved stock, at age 18, expressed better growth rates (50% higher productivity) than the plots without competition control. It is important to notice that across locations and ages, all coefficients of variations for the complete control were lower than those without vegetation control. This observation confirms that a more intensive silvicultural regime produces more uniform stands. See Figure 4.4 for DBH parameter and DBH CV, and Figure 11 in Appendix D, where a positive kurtosis and negative skewness for the DBH in the majority of plots are observed.

Figure 12 in Appendix D also includes the average GWob and GWob CVs for all 35 plots. It shows that one plot (50-8-7-18) in location 50, plot 8, with complete vegetation control, at age 18, is the most productive in volume. Figure 12 also represents the relative dispersion for the data, where the plots with complete vegetation control show consistently lower CVs than plots without vegetation control. However, the best performing plot for volume, 50-8-7-18, was not as successful for susceptibility to rust. The rust incidence destroys 5% of its value potential. See Figure 13 in Appendix D.

As for sawtimber potential, the plot with the highest volume yields the lowest percentage of sawtimber recovery (less than 40% at year 18). In contrast, the second best plot in volume, yields 75% in the sawtimber product class at the same age. The same analysis at treatment level produced an unexpected result: treatment A yielded a higher proportion of sawtimber potential than treatment B. See Figure 14 in Appendix D. This might be explained if fast-growth trees reveal their defects at an earlier age than trees with moderate growth rates. However, this plot (without vegetation control) yielded 155 ton/ac vs. the plot of faster growing trees (with vegetation control) with 186 ton/ac.

Crook/sweep was the main factor for degrading timber value in the 7-056 family. Figure 15 in Appendix D shows a reduction of this defect from year 15 to year 18. The reduction is likely due to the fact that trees have grown and now reach the stem-size criterion for sawtimber, and added diameter growth has lessened visual perception of crook or sweep.

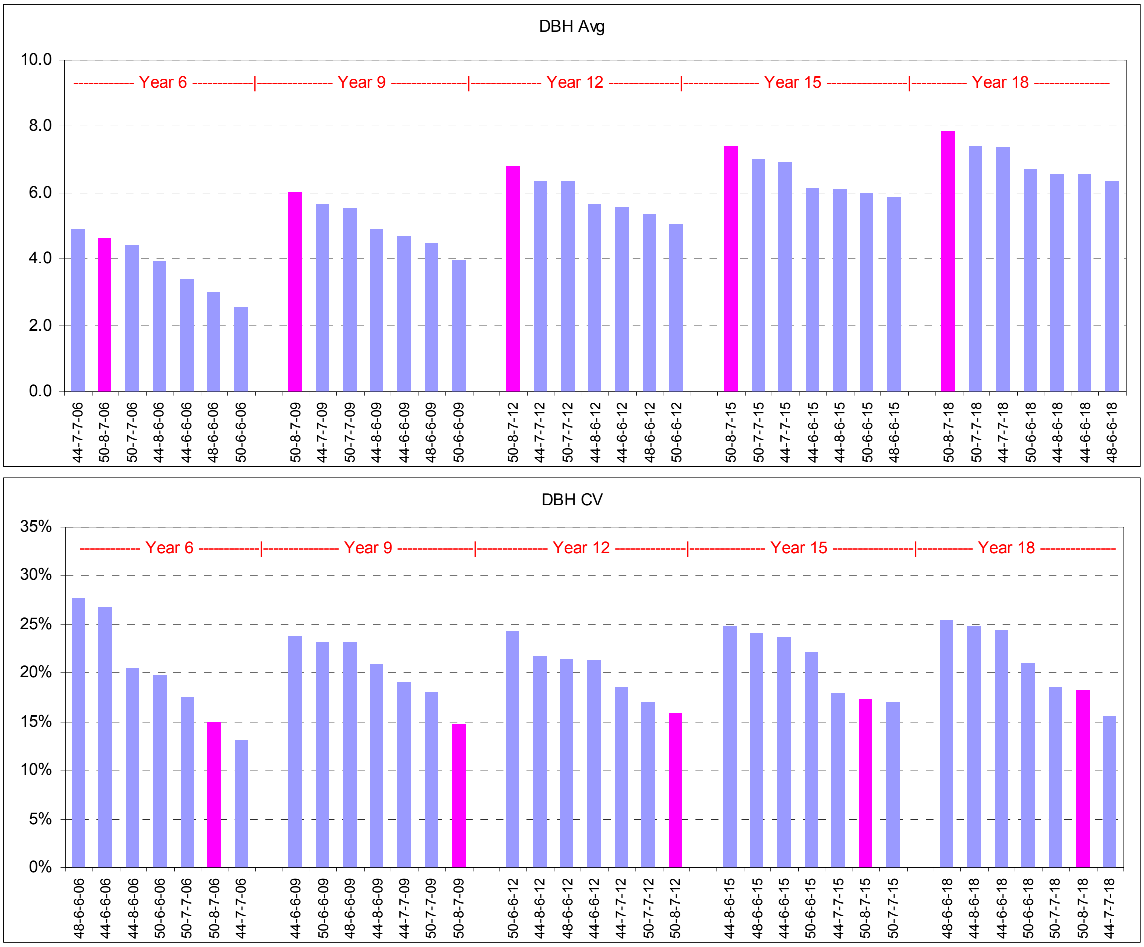

Figure 4.4. DBH Averages and DBH CVs by Plot, 7-056 Family, Georgia, over 18 Years

An overview of the PMRC data of the 7-056 family, Figure 4.5 shows the diameter distribution dynamics from age 6 through age 18. At age 18, treatment without vegetation control yields a Dq 6.7 inches and a volume of 120 ton/acre, while treatment with vegetation control yields a Dq 7.7 inches and a volume of 176 ton/acre.

Figure 4.6 summarizes the evolution of the diameter distribution for the clone in plot 19, and for the control at ages 4, 6, 7, 9, and 18 years. It also shows the diameter distribution for the 7-056 family from a different location at ages 6, 9, 12, 15, and 18 years. This figure provides a visual means for determining which of the analyzed trials is more concentrated or spread in

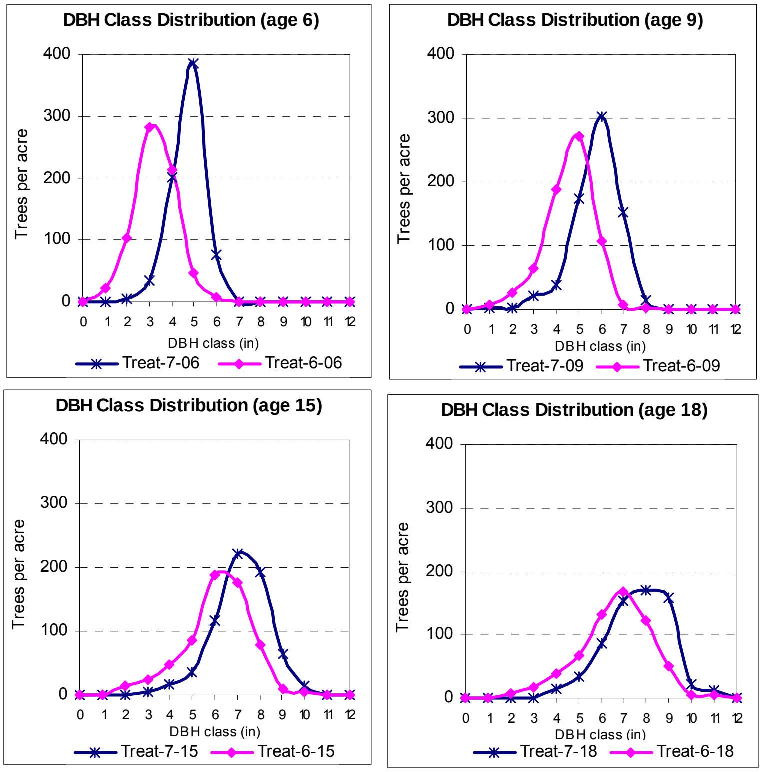

Figure 4.5. 7-056 Stand Dynamics: Under Two Different Silvicultural Treatments

distribution. It is especially important to recognize the increase in the number of diameter classes with increasing age for zygotic plots (from four to seven/eight), while the clonal plot seems to preserve fewer diameter classes over time. Thus, this evidence confirms that by selecting the right clone, it is possible to grow plantations with narrower diameter distributions than it is using seed lots at any level of genetic improvement. In addition, it is also important to note that for this particular clone (plot 19), the bars on the right site of the distribution taper differently than those on the left side. That is, this clone has negative skewness and a slight trend for shifting the diameter distribution to the right, which makes this clone more desirable. This accords with the observation of Carson and Hayes (1998) that as the seedlot stands aged, “frequency distributions tended to become flatter than a normal distribution (platykurtic) and more skewed to the right.”

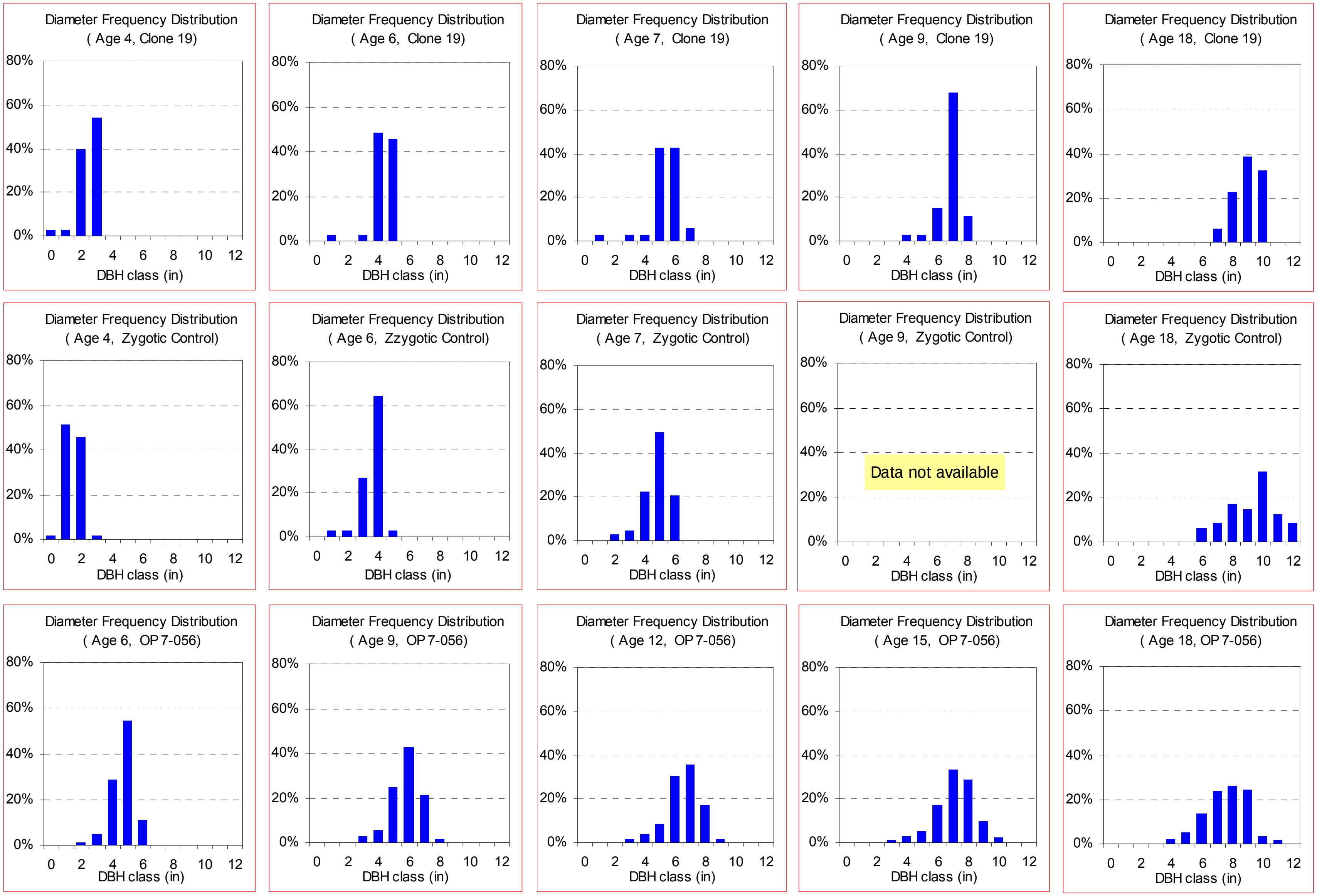

Figure 4.6. Diameter Distribution at Five Different Ages for One Clone and One Zygotic Control, and for Contrasting OP 7-056

Results and Discussion: Uniformity and Statistical Analyses

Although this analysis detailed many individual tree descriptive statistics (such as Mean (Avg.), Maximum, Minimum, Median, Mode, Quartiles, Interquartile Ranges, Standard Deviation, Coefficient of Variation (CV), Skewness, and Kurtosis, for stand parameters such as DBH, HT, HD, BA, Volume Index, Green Weight outside bark, (GWob), eight Crown classes, five Fusiform rust infection levels, and five Sawtimber rejection categories), the results presented cover few stand parameters and statistics, but enough to get a general picture of clonal plantations dynamics/structure and their implicit benefits.

Figure 4.7 shows that it is possible to confirm that good clones present narrower DBH Distributions and that the Dq shifts to the right. Although this is not true for all clones studied, the outperformers revealed an expected uniformity in almost all measures. The 17-year old clone A in South Georgia shows impressive qualitative results, specifically for sawtimber potential (98%), which outweighs, in financial outcomes, the volume attribute for seedling controls.

For the replicated studies, analyses of variance (ANOVA) were performed in order to examine differences among four stand parameters: DBH, HT, BA, Volume Index and/or GWob across installations and plots. The sources of variation, mentioned in the model description section, are installations, blocks nested within installations, clones/controls, and interaction between clones/controls by installation. Some of these outputs are discussed below, and the remaining are included in the Appendix I.

As for the replicated three-year old plots, one of the study objectives was to analyze the performance of commercial clones vs. the best half sib seedling source (7-056) under monitored operational management conditions. Thus, these sites resemble operational plantings rather than trial plantings. Figure 4 in Appendix C compares one clone to the control (7-056). The overall

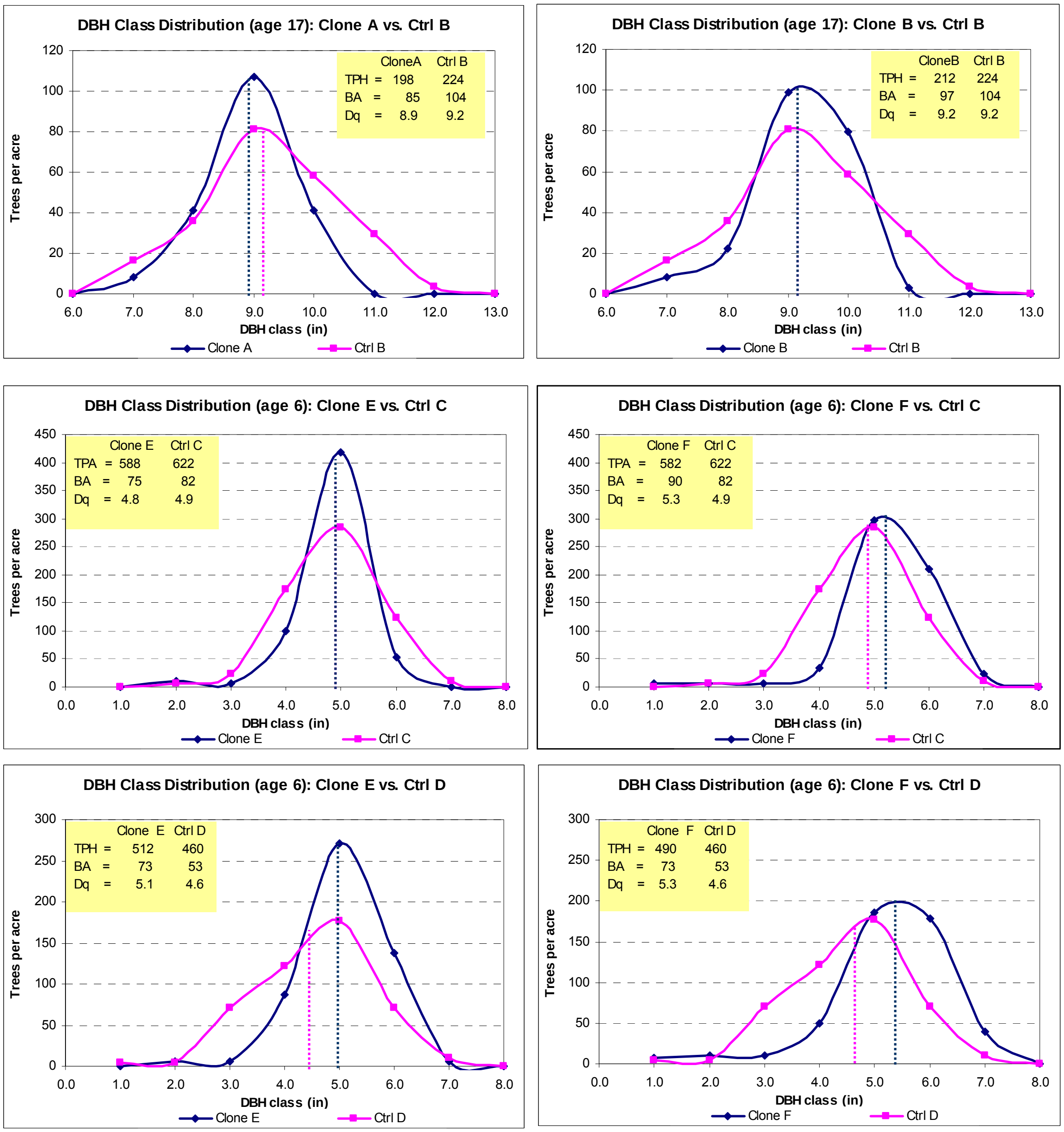

Figure 4.7. Narrower DBH Distribution in Clones vs. Controls (Related/Unrelated) Quadratic Mean Diameter (Dq) Shifts to Right with Good Clones

statistical analysis shows that 7-056 performed better here relative to the clones. While the best two clones show volume levels very similar to 7-056, some clones performed more poorly as indicated by the statistical differences identified in the various range tests performed. These undesirable clones have been discontinued, and the distinction between which clones might best match a particular region/area appears not to have been a consideration at planting time. For illustration in Appendix D, Figures 10 through 15 characterize, 7-056 and show a high timber production but a low sawtimber proportion due to the lack of uniformity and presence of rust incidence.

Figure 5 (6-year old demonstration plots in Mississippi) in Appendix C confirms one attribute of the determined best commercial clone from the three-year old plots: narrower diameter distributions in contrast to wider diameter distributions for zygotic seedlings (one full sib family, and two open pollinated families). This commercial line, at ages 3 and 6 years, shows gain in height increased over time compared to zygotic check lots, and the height CVs decreased significantly over time. In contrast, the check lots' CVs remained practically unchanged. In addition, this line, like others in the same study, was completely immune to rust susceptibility, while the check lot full-sib family, on the other hand, had 12% rust incidence, with 25% for the seed orchard bulk (PMRC analysis, unpublished).

Figure 6 in Appendix C shows the behavior of one clone in two different locations (NC and AL). The role of the environment is evident here: Clone 40 performed well, with height measures of uniformity, in NC, but not as well in AL.

Appendix D includes one sample of the uniformity analysis for DBH, GWob, and the description of timber quality for 58, 6-year old, loblolly pine plots with two replications per location (NC and AL). This data set included 50 clones and 8 controls, with diverse levels of improvement between wild seeds and second generation mass control pollinated seeds, as follows:

Check 01: 2nd generation, open pollinated
Check 02: Unimproved, wild seeds
Check 03: 2nd generation, open pollinated
Check 04: 1st generation x 2nd generation. Cross control (no pollen contamination)

Check 05: 2nd generation x 1st generation. Cross control (no pollen contamination)
Check 06: 1st generation, seed orchard mix
Check 07: 1st generation, open pollinated (7-056)
Check 08: 1st generation, open pollinated

At 5% level of significance, there are significant differences in the responses of the four parameters tested across the 58 seedling sources (treatments/labels) between locations, and within blocks in the same location. The site productivity is high in NC, but not as good in AL. Mortality rate was another important fact in these locations. At age 6-years old, the plot's mortality rate in Alabama was 24%, while in NC, 4%.

In general, 60% of the ten top performing clones, in volume, are common for all four blocks. The best check seed lot was Check 04 (1st generation x 2nd generation cross control pollinated), which, in one block, performed on a par with the ten top clones. The 7-056 check was the second best in the NC trials, but performed poorly in the AL trials. It appears that 7-056 needs higher SI for expressing its inherit growing potential

Figure 4.8 exhibits the average DBH for all 116 plots in the two blocks in NC. Taking as Check, the 7-056 for multiple comparisons. Using Dunnett's test at 5% level of significance, the average DBH for five clones is statistically different from the check in block 1, while in block 2, clones are not significantly different. On the other hand, the DBH CVs for the best clones in terms of total volume are the lowest, or among the lowest, in both blocks.

Figure 4.9, NC, depicts the DBH kurtosis, which is positive, and varies from 20 to -1. The DBH kurtosis of the best clone in block one is 5, the best clone in block 2 is close to zero. DBH skewness is negative and ranges from 0.9 to -4.0. DBH skewness of the best clone in block one is -1.5, and the best clone in block 2 is -0.4. These low kurtosis and skewness values, for the best clones at this age, suggest that the diameter distribution resembles a normal distribution. As

Figure 4.8. DBH Averages and DBH CVs by Plot, North Carolina

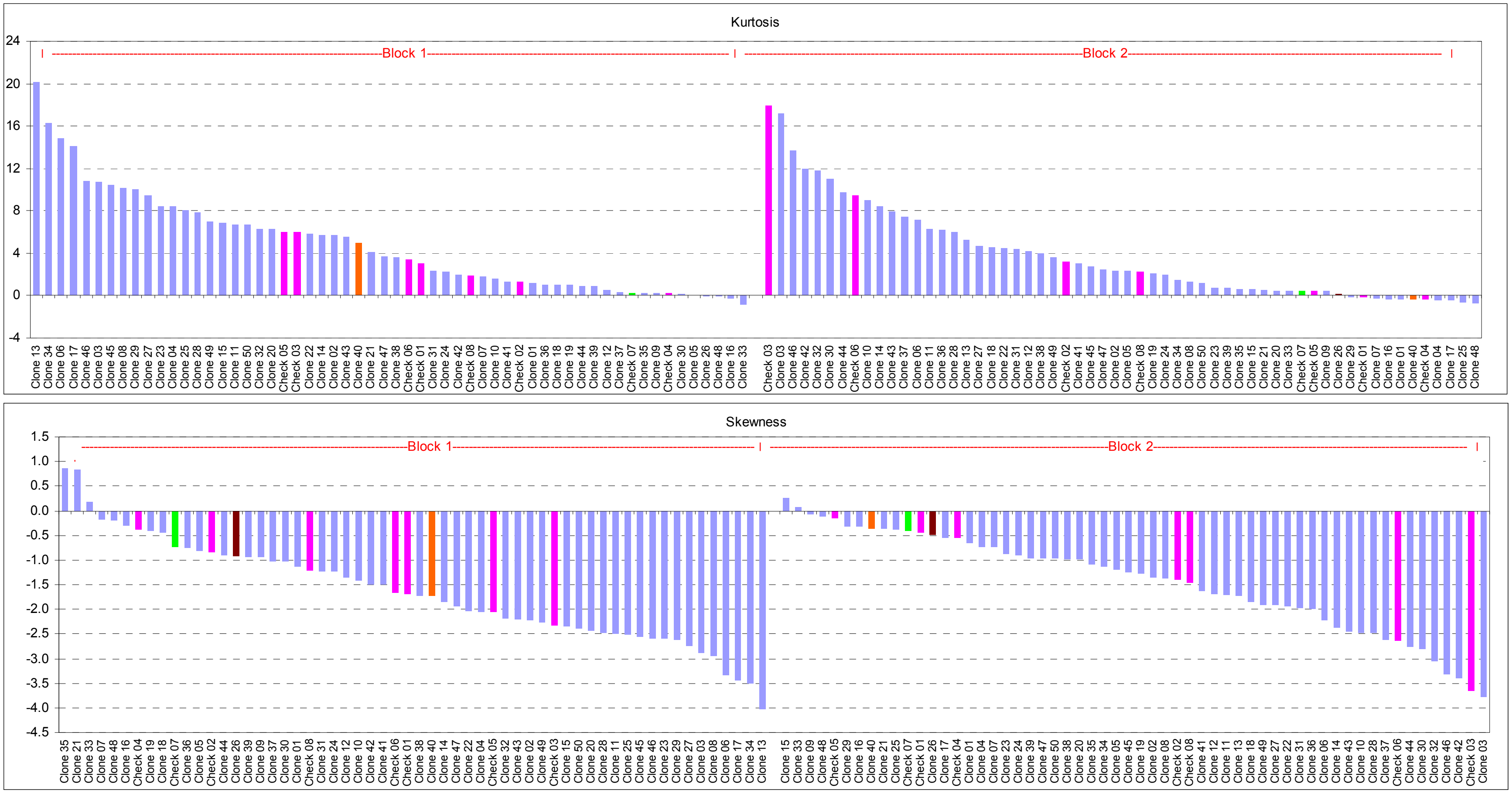

Figure 4.9. DBH Kurtosis and Skewness by Plot, North Carolina

per GWob, in Figure 4.10, NC, the best clone in block one outperformed the control 7-056 by 16%, and the best clone in block two, by 24%, and by 83% (block 1) and 107% (block 2) when the control is wild seed. Figure 4.11, NC, presents the proportion of sawtimber potential (STP) and rust incidence for both blocks. For STP, the best two clones in the first block are in the average bracket (20 to 40% STP), and in the second block, the same clones are in a superior bracket (40% to 60% STP). This superior STP range is consistent with ranges found in data collected for other 6-year old clonal plots. Rust incidence for both winning clones, in both blocks, is 90% plus rust-free. From Figures 18, 19, 21, and 23 in Appendix E, AL, similar analyses and conclusions can be derived.

Finally, data from eucalyptus plantations are depicted in Figures 24 and 25 in Appendix E. *E. tereticornis* clones show similar characteristics for uniformity in DBH as pine clones do. The trends for this eucalyptus clone, like a desirable pine clone, are that it has lower DBH CVs, positive kurtosis, and negative skewness. Eucalyptus seedlots *(E. pelltia)* show opposite kurtosis and skewness characteristics.

Additional Notes

- The initial impression, in selected softwood clones, was the narrower diameter distribution. However, not all clones show this uniformity relative to non-clonal plantings. See Appendix C.
- The qualitative results in the 17-year old plots are impressive for clones A and B, specifically for sawtimber qualifications. However, these plots give limited useful quantitative data because they were thinned and previous measurements were not available.

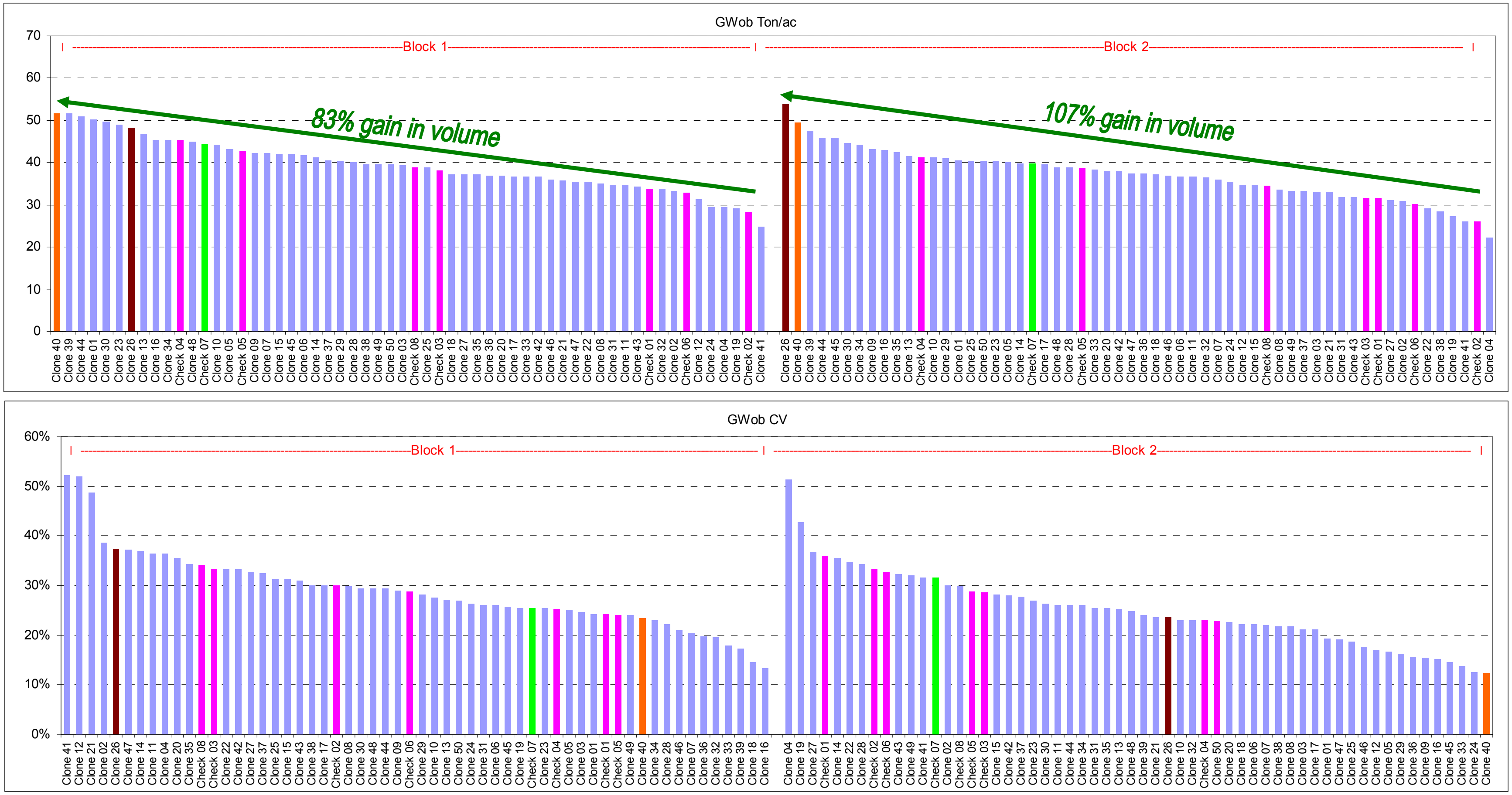

Figure 4.10. Green Weight outside Bark for 58 Plots Over 6 Year Period, and Individual Tree Coefficient of Variation for Growth over 6 Year Period, North Carolina

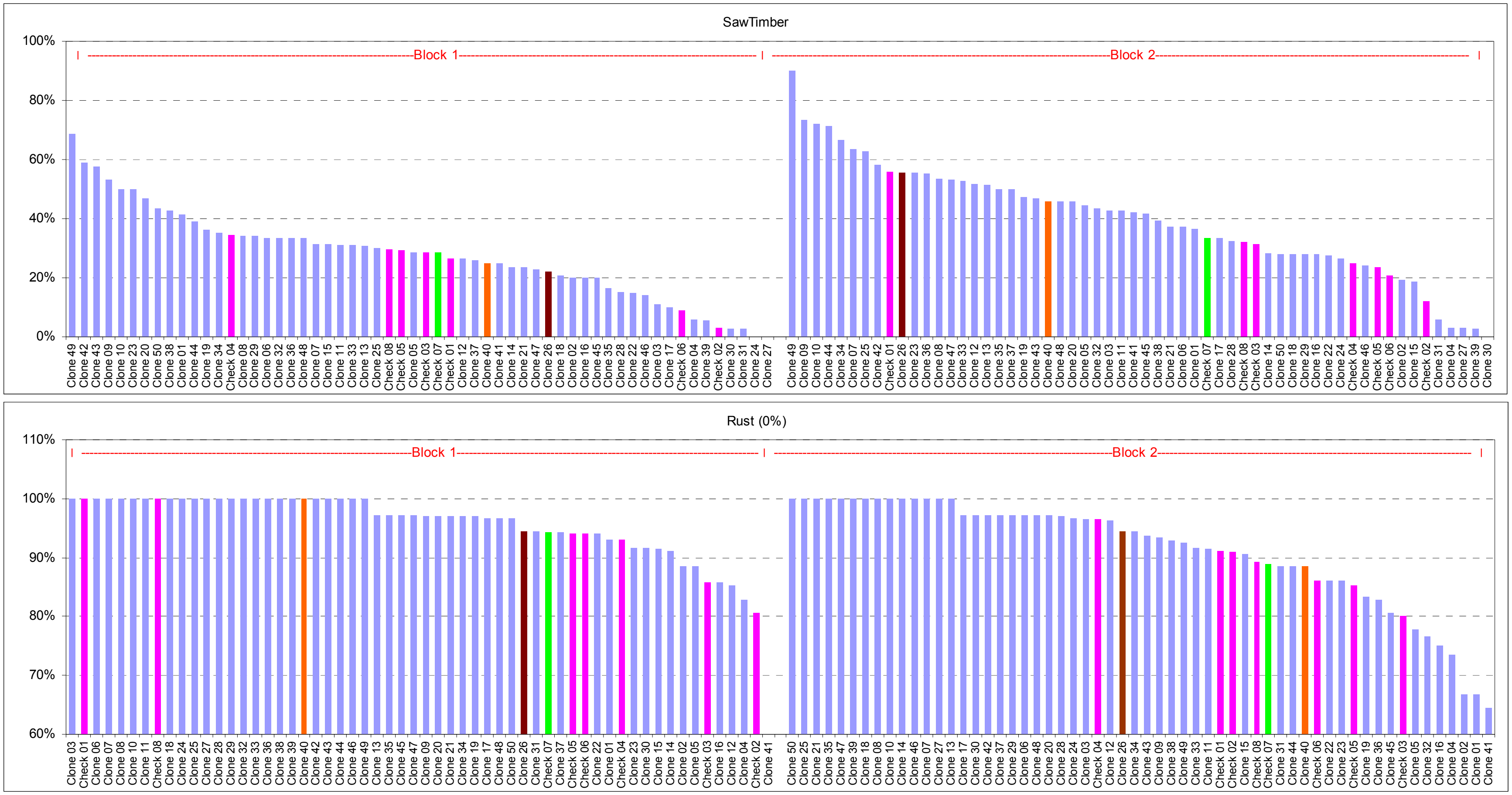

Figure 4.11. Sawtimber Potential and Rust-Free Averages, North Carolina

- Even though vegetatively propagated seedlings have complete genetic uniformity, clones may express GxE interaction[17]. For example, the same clones found across the study regions performed differently at two locations in terms of volume and quality. For instance, in general, clones were more susceptible to rust in NC than in AL.
- In addition to the GxE interaction, factors that may have affected this analysis were:
  - Storm damage in NC and SC: Hurricane Isabel (Sept. 2003), and Hurricane Charley (August 2004): broken tops, and leaning and fallen trees.
  - Flooding in one study area at an early age.
  - Intensive competition between clones and hardwoods (wax myrtle, oak, black gum), wild pine trees, underbrush (black berry briars), and grass in some trials.
  - Differences in soil types, and previous land uses/management regimes.
  - Differences in planting densities at all locations.

Statistical Analyses: Three-year-old Replicated Plots (Responses at Plot Level for Both Installations)

ANOVA for Diameter at Breast Height (DBH, inches), Total Height (HT, feet), Basal Area (BA, ft^2/acre), Volume Index (ft^3/acre) for seven replicated plots at three years old were computed (Appendix I, Tables 1 through 4).

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[17] The Genotype by Environment interaction can include a change of ranking of clones vs. controls on contrasting sites. It can also result from a change in variance among these genetic entries over sites. Clones will change their performance between sites, if those sites are different, but that alone does not prove there is any GxE interaction, in fact in both cases an interaction is only deemed significant if an analysis of variance shows the change to be large (significantly so) relative to the error variance of the experiment (R. Weir, pers. comm. 2007)

The overall means for DBH, HT, BA, and Volume Index were significantly different among the six clones and one control (labels), two locations (installations), and blocks (nested in installation), ($P < 0.05$). In contrast, differences in the interaction of clones/control x installations are not significantly different at 5% level for all four growth parameters (DBH, HT, BA, and Volume Index) for the two installations.

Statistical Analyses: Three-year-old Replicated Plots (Responses at Plot Level for Each Installation)

Given that differences between the two installations were found, ANOVA tables for the responses (DBH, HT, BA, and Volume Index) were computed separately for each installation.

ANOVA for Diameter at Breast Height (DBH, inches), Total Height (HT, feet), Basal Area (BA, ft^2/acre), and Volume Index (ft^3/acre) for seven replicated plots at three years old were computed. Six clones and one control (labels) were found not significant for the four growth parameters in Installation 1. In contrast, the clones/control were found to be significant for the four growth parameters in Installation 2, ($P < 0.05$).

Three comparison tests to the 7-056 family were performed (Dunnett, Duncan, and Tukey), but the ANOVAs, and Duncan and Tukey tests are not included in this chapter. In Installation 2, only clones 4 and 6 showed significant difference at 0.05 level when compared to the 7-056 family. See Appendix I, Tables 5 through 7 for Dunnett's test results.

Statistical Analyses: Six-year-old Replicated Plots (Responses at Plot Level for Both Installations)

ANOVAs of Diameter at Breast Height (DBH, inches), Total Height (HT, feet), Basal Area (BA, ft^2/acre), and Green Weight outside bark (GWob, tons/acre) for 58 replicated plots (50 clones and eight controls), at six years old were computed (see Appendix I, Tables 8 through 11).

The overall means for DBH, HT, BA, and GWob were significantly different among the 58 clones/controls (labels), two locations (installations), block (nested in installation), and interaction of clones/controls x installation ($Pr < 0.05$). There were two exceptions: the block (nested in installation), and the interaction of clones/controls x installation did not differ significantly in DBH ($Pr < 0.05$).

Statistical Analyses: Six-year-old Replicated Plots (Responses at Plot Level for Each Installation)

ANOVAs of Diameter at Breast Height (DBH, inches), Total Height (HT, feet), Basal Area (BA, ft^2/acre), and Green Weight outside bark (GWob, tons/acre) for 58 replicated plots (50 clones and eight controls), at six years old were computed (see Appendix I, Tables 12 through 19).

The overall means for DBH, HT, BA, and GWob were significantly different among the 58 clones/controls (labels), for each of the two installations ($Pr < 0.05$). The same results were found for blocks, with the exception of Installation 2 for the growth parameter DBH at 5% level.

Three comparison tests to both the 7-056 family and to the unimproved seedlings (wild seed) were performed (Dunnett, Duncan, and Tukey), but the ANOVAs, Duncan, and Tukey tests are not included in this chapter. In Installations 1 and 2, a Dunnett's test identified the clones compared to the 7-056 family and to unimproved seedlings that were significantly different at 0.05 level. See Appendix I, Tables 12 through 19 for Dunnett's test results.

Results and Discussion: Modeling

Results from stand and diameter distribution simulations are presented for Clone A and for the zygotic control (Figures 4.12 and 4.13) at age 17 years. Each figure has four graphs. The first set corresponds to clone A, which begins with the observed cruise stand table data at age 17, followed by the projection of eight years (harvesting age: 25 years) of diameter distribution, using the generalized stand table projection algorithm. The second pair of graphs shows the predicted stand table at age 17 (using the stand parameters derived from the observed cruised data), and its predicted stand table at age 25, using the diameter distribution recovery method (Weibull).

It seems clear that from the age of data collecting to the final harvest age of 25, that using the generalized stand table projection algorithm suggests a more realistic projection than using the diameter distribution recovery method (Weibull), which follows the original distribution for which it was created (for seed lot plantations).

In the same way, Figure 4.13 for the zygotic control, shows the results of testing the models using both approaches. As expected, the diameter distributions for both approaches, from year 17 to year 25, appear to follow the same patterns (no reduction of diameter classes and similar in range of diameter distributions). For seedlings (zygotics), in general, the standard deviations of diameter increase as stands age, and distributions become flatter.

The modeling results for Clone A are illustrative of desirable clones; the results for the control in Figure 4.13 are also typical.

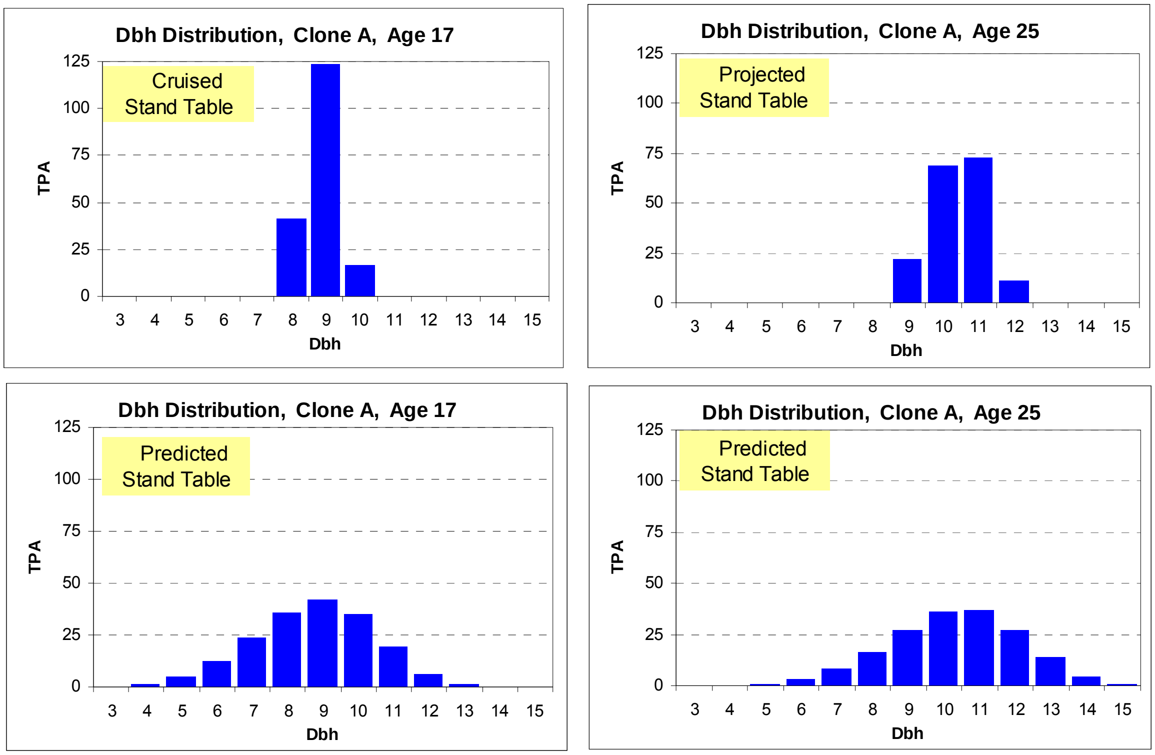

Figure 4.12. Descriptive Results for Selected Clone A (Generalized Stand Table Projection vs. Diameter Distribution Recovery Approach -Weibull)

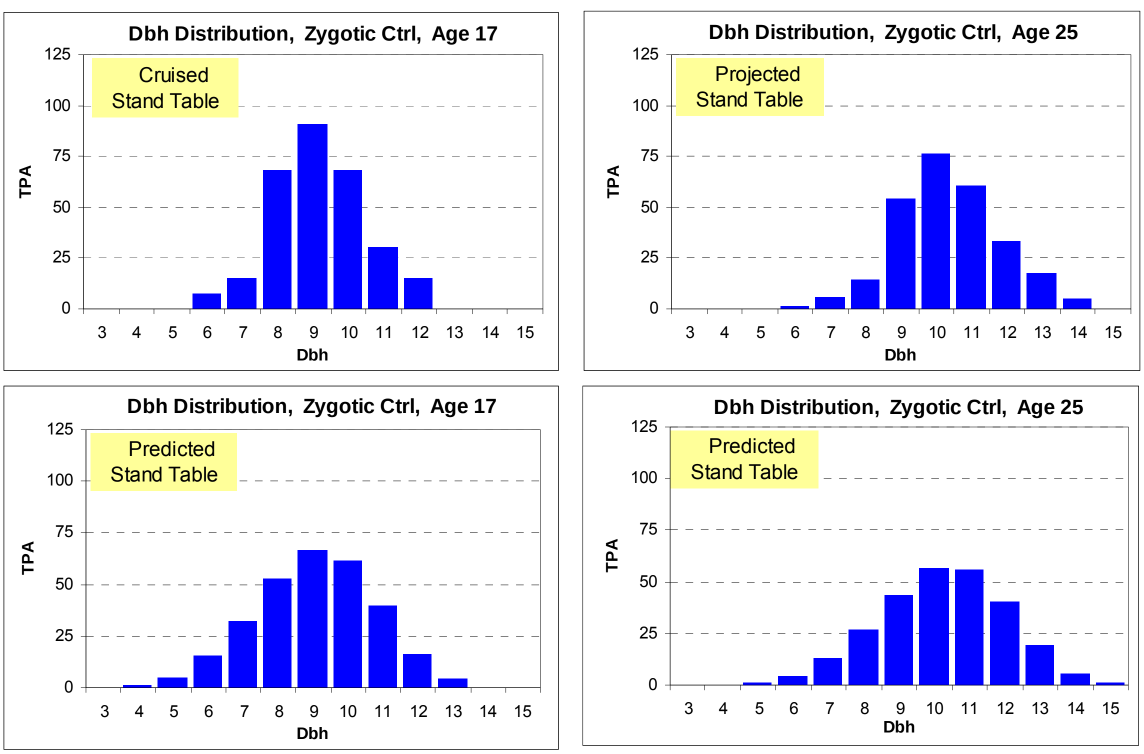

Figure 4.13. Descriptive Results for Selected Zygotic Control (Generalized Stand Table Projection vs. Diameter Distribution Recovery Approach -Weibull)

Appendix F includes four figures. Figures 28 and 29 represent the six-year old clone F and control C, with one projected thinning at year 14, and at final harvest at age 25. In spite of the longer projection (19-year prediction/projection) for clone F, the generalized stand table projection algorithm also produces more likely diameter distributions than using Weibull's approach. As for control C, both modeling methods produce diameter distributions similar to what is expected.

Growth simulations for clones using models developed for non-clonal material are extrapolations of the models, which can generate unrealistic results. Current diameter distribution recovery models do not seem appropriate for good clones. Thus, as more clonal stand data become available, the stand table projection algorithm (developed by L. Pienaar) should be used in conjunction with genetic gain estimates for height (used in the adjustment functions developed by Pienaar and Rheney, 1995) and stem quality information to develop more realistic projections for evaluating investments in clonal stands.

The use of one G&Y system for seedling forestry and another for clonal forestry would be impractical and unreliable. More reasonable would be one model that could accommodate both, such as those that model the diameter and height distributions for pine seedlots at various levels of genetic improvement. However, to make growth projections and stand valuations more realistic, regarding the planting and management of clonal pines in the Southern U.S., it is necessary to develop specific growth and yield functions capable of capturing clones' distinctive biological features.

Because of the newness of SE technology of mass clonal propagation for southern pines, the ability to obtain clonal block performance data has been limited. Thus, in lieu of real data, projections for clonal pine stands have been made by borrowing traditional models and simulating clonal stand growth increases/gains via site index. However, this temporary shortcut, must be taken with caution: traditional models were developed with data from plantations concentrated on 50 to 70 site index classes; beyond SI 70, these models weaken and begin to extrapolate. In addition, the mortality functions in traditional models usually kill more trees as site index increases, but clonal stands seem to show lower mortality rates than non-clonal stands do. Based on this tendency in the model, diameter distribution patterns for clonal stands may not accurately represent what is actually in the field.

In addition, the PMRC G&Y models, commonly used in the South, predict stands' basal area as a function of trees per acre, dominant height (SI), and age. Thus, gains in dominant height directly and proportionally affect gains in BA, which can lead to an overestimation because the maximum land carrying capacity[18] is not taking into consideration.

In light of limited data, and to overcome these weaknesses and produce more realistic projections of product yields, G&Y models need to be adjusted and made more flexible in order to reflect the clonal forest structure associated with stand tables. This can be done by taking the following steps of using evidence of clonal plantations in other parts of the world, including constraints consistent with biometric principles and educated hypotheses, and adjusting the models to be attuned to continually updated field data. Modeling improvement should be evaluated/validated by international clonal plantation experts. This would ensure that projections are as realistic as possible; and from such clonal pine plantation models we will be able to derive satisfactory financial analyses.

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[18] Carrying capacity is an ecological concept that expresses the relationship between a population and the natural environment on which it depends for ongoing sustenance. Carrying capacity assumes limits on the number of individuals that can be supported at a given level of consumption without degrading the environment and, therefore, reducing future carrying capacity. That is, carrying capacity addresses long-term sustainability. Available from http://www.mnforsustain.org/abernethy_v_carrying_capacity_policy_and_limits.htm

Results and Discussion: Financial Comparison of G&Y Models

Current diameter distribution recovery models are unrealistic for good commercial clones. For both clonal and non-clonal planting materials, the Generalized Stand Table Projection (GSTP) model generally generates narrower diameter distributions and lower NPVs and IRRs than the current diameter distribution recovery model (Weibull recovery); however, the discrepancy is wider for clones. Current diameter distribution recovery models do not seem appropriate for clones. Also, the results show how critical the log quality component is in the equation for the realistic valuation of any stand and demonstrate the importance of including quality in valuations of clonal plantations.

Table 4.5 and Figures 30 and 31 in Appendix G show, for the 17-year old plots, the financial results under three scenarios: using the Weibull recovery method, using the GSTP, and using the GSTP plus the effect of Tree Quality (TQI). TQI allows for identifying the quality and/or defects (e.g. rust incidence or forking) for each tree in its corresponding DBH class. Each tree is coded and projected to harvesting age at which time, it is automatically assigned to a product class based on its originally observed features.

Clone B-13 yielded the highest volume among clones (149 ton/acre using Weibull, and 151 ton/acre using GSTP at year 25), which generated an NPV ($1,390/acre) by using the Weibull model, $1,260/acre by using GSTP model, and $1,060 by accounting for stem quality (TQI) in the valuation process. Its IRRs were 11.3%, 11.1% and 10.7%, respectively.

On the other hand, Control 18 yielded the highest volume among controls (159 ton/acre using the Weibull, and 149 ton/acre using GSTP at year 25), which generated an NPV ($1,662/acre) by using Weibull model, $1,709/acre by using the GSTP model, but just $913/acre when TQI was considered. Its IRRs were 12.1%, 12.2% and 10.8%, respectively.

Table 4.5. NPVs and IRRs Comparison for 17-Year Old Plots

Source	NPV ($/acre)			IRR (%)		
	Weibull	GSTP	GSTP+TQI	Weibull	GSTP	GSTP+TQI
A 11	783	698	698	10.2%	10.0%	10.0%
A 12	937	898	863	10.5%	10.4%	10.3%
B 13	1,390	1,260	1,060	11.3%	11.1%	10.7%
B 14	1,085	924	617	10.8%	10.4%	10.3%
Ctrl 15	1,373	1,382	1,346	11.6%	11.7%	11.6%
Ctrl 16	1,143	1,137	677	11.2%	11.2%	10.2%
Ctrl 17	1,148	1,108	803	11.2%	11.2%	10.5%
Ctrl 18	1,662	1,709	913	12.1%	12.2%	10.8%
A 21	825	779	736	10.2%	10.1%	10.1%
A 22	669	721	686	9.9%	10.0%	9.9%
B 24	380	389	389	9.2%	9.2%	9.2%
B 25	233	249	124	8.8%	8.8%	8.4%
Ctrl 23	705	767	345	10.3%	10.4%	9.3%

Similar analyses for the 6 year-old plots were done, and the results can be seen in Figures 32 and 33 in Appendix G.

Selected examples are intended to emphasize the impact of sawtimber potential versus high volumes and the fact that stem quality is critical for realistic valuation of any stand.

Summary, Conclusions, and Implications

Data from clonal plantations at ages six, seventeen, and eighteen years old show that superior clones have narrower stand tables with left skew relative to non-clonal stand tables (which are broader and right skewed). This characterization, though seemingly subtle considered individually, is critical for contrasting these types of genetics for their final products, production in growth simulations, and financial returns.

In addition, it is clear that some clonal stands are practically immune or have a very low incidence of rust in contrast to stands from zygotic seedlings, even from the same pedigree.

In general, the clones reviewed herein tended to show more uniformity for all traits than seedling trees of any level of genetic improvement. However, the data also indicate that experimental clones sometimes perform just as poorly, or more poorly, than trees from zygotic seedlings. Perhaps some clones have more "plastic" phenotypes and are quite sensitive to environmental conditions, while others will perform more consistently across locations and management regimes. As a result, the same clones in different locations sometimes showed different developmental patterns due to environment. Thus, productivity is not just influenced by genotype and site, but also undoubtedly by their interaction in some clones.

With the recognition of some minor caveats for the data of the 7-056 family, such as the addition or omission of borderline trees at cruise time (which can lead to potential bias), and the subjectivity of sawtimber classification (the idea that the bigger the tree, the more apt to classify that tree as potential sawtimber), this analysis of the 7-056 family is appropriate as an industrial benchmark for comparing stand structures, yields, and quality traits to those of improved zygotic seedlings. This characterization of the 7-056 family, the industry standard, should also be useful for comparing its attributes to those of the most genetically advanced seedlings available on the market.

In general, the 7-056 family performed very well in the 3-year old trials relative to clones. The best clones showed production levels very similar to 7-056; however, some performed more poorly, as indicated by the statistical differences detected in the various range of tests performed. This family 7-056 is an excellent genetic resource, as shown in the Mississippi trials. A full-sib family that included 7-056 as one of its parents performed almost as well as the

Commercial Clone 1 (COMM1) in all measures. The 7-056 family responds remarkably well to complete vegetation control. Dqs shift to the right 1 inch compared to the Dqs of non-treated 7-056 stands over an 18-year period. Compared to a selected clone, the PMRC data show that the 7-056 family has a narrower diameter distribution at a younger age (5 DBH classes at year 6) than at an older age (8/10 DBH classes at year 18). However, there is evidence to suggest that well-screened elite varieties produce higher proportions of more valuable products like sawtimber as compared to 7-056. Therefore, selection and testing is critical for clones to be tailored to specific needs. This screening should include not only single tree plot design, but also block plantings for evaluation of diameter distributions, and to allow for model development/evaluation, realistic valuation, and financial analysis.

The G&Y model comparison shows that current diameter distribution models should not be used alone to simulate development trajectories for clones. In addition, generalized stand table projection models used in conjunction with appropriate genetic improvement gain adjustment functions, including TQI, should provide sound information and reasonably realistic analyses to evaluate the economic returns expected from clonal plantations.

Contrary to findings using traditional G&Y models that suggest that over time, diameter distributions tend to become flatter than a normal distribution, this study finds that for vegetatively propagated monoclonal plantations, with tested/selected clones, few diameter classes occur throughout the rotation. This result might not be expected in intimately-mixed polyclonal stands.

To improve G&Y predictions of clonal plantations under a balanced combination of the most typical management regimes and sites, reinforcement of conventional clonal test studies (single-tree plot design for early clonal testing), by using pure plots when clones are operationally planted in large stands, is recommended.

These monoclonal plot studies should include a significant number of clonal prospects as well as controls at all levels of genetic improvement, beginning with a reference line (unimproved seed lots), all of which will contribute to an understanding of the management of exceptional clones, incorporation of the most advanced silvicultural practices, and better preparedness for dealing with the increasingly aggressive global forest competition.

From the timberland investment point of view, clonal forestry, as opposed to any degree of improved seed lots, offers a powerful means of enhancing returns when planting a portfolio of clonal stands, and by buying well-characterized clones that minimize biological (diseases) and physical (weather) risks in hazard areas, and that can produce products in a predictable way. Clonal forestry should not only be growing more volume per area, but also shortening economic rotations without sacrificing wood quality (better value by matching clonal attributes to end products).

This study considers only one piece of the clonal forestry puzzle in that it defines a framework in which a forest investor could critically and confidently assess the value of selected traits offered by clones

Further Discussion and Research

The bank of data gathered (360 plots well-monumented in nine locations) by PMRC in this research should be exploited by maximizing its use through theoretical and applied research to improve the current knowledge of clonal forest plantations in the U.S. South, such as the derivation/adjustment of G&Y models, mortality functions, and taper functions (top diameters).

This bank of data should be used until data from more recently established, well-designed studies become available. Finally, there is a large potential and need for continuous and recurrent testing and screening for multiple attributes that need to be characterized and evaluated in order to exploit the true economic value and potential advantages of clonal forestry.

Jeff Tombleson (Past Manager Plantation Management Research Cooperative, New Zealand, Dec. 11, 2006 in personal communication) stated:

> "Clonal forestry is not only focused on growth but more importantly, tree and intrinsic wood quality. As such, production forestry based on clones is likely to contain some clones which have very high wood quality characteristics but may not be mega growth performers. And to use marathon terminology some runners are sprinters and some may be stayers thus conserving their energy for the final run. Trees that are slow starters do not want to be surrounded by sprinters because they suffer the penalty of shade, competition and lack of growth. New Zealanders have an example of a radiata pine genotype that was less than average for diameter up until age 13 years and then in the latter part of the rotation this tree grew to be the biggest, and in fact was selected for breeding. Today the tree has a volume of 23 m3! One can only speculate, but a likely explanation is that this genotype allocated to root growth versus shoot in its early years and then launched itself. Such clones will probably perform best in single clonal blocks/stands versus mixtures."

CHAPTER 5

CONCLUSION

As a response to meeting domestic and international demands for wood, and to compete in highly demanding capital markets, forest management practices are in constant flux. Forest investors pursue opportunities for diversification, capital preservation, real returns, risk mitigation, tax management, and financial gain through new technology. Properly managed forests should produce trees with higher growth rates and better quality. One important means of improving forests is through forest biotechnology, which can achieve substantial gains to boost productivity by enhancing growth and yield rates, improving wood quality, and ensuring product predictability. The three studies included in this dissertation are linked by the common thread of forest biotechnology.

Chapter 2 considers the profitability of current and potential biotechnological advances. Although it is difficult to make general statements about an "ideal" forest management regime, the findings from this study show that it is possible for investors to improve their competitiveness with best-suited intensive management, the best genetic seedlings available, balanced harvesting systems, and stands located close to receiving mills. The economic valuations for the two southern pine cases analyzed (thinned and unthinned regimes) demonstrate that volume gains through highly intensive silviculture increase marginal returns. However, intensive silviculture is not enough. Tested vegetatively propagated trees are also key to achieving the full potential of tree characteristics like desirable stem features and improved wood properties. For instance, given heritability, the deployment of clones that are immune to fusiform rust is a cost-effective means for planting in medium and high fusiform rust incidence areas. Another practice that increases profitability is to propagate a tree with both exceptional growth rate and high wood density. These are only two of the multiples traits that need to be characterized and evaluated in order to exploit the true economic value and potential advantages of clonal forestry. When clonal attributes are incorporated and translated into the financial terms, the economic findings in Chapter 2, which account only for growth gains, are apt to appear underestimated.

In fact, the breakeven estimates in the Chapter 2 case study, for the 8% discount rate, two management regimes, three site indices, and five levels of gain in volume, show enough room to accommodate investments of $100 to over $600/acre in biotechnogy products, or any other forest management practice able to push growth limits and improve wood quality, as well as for the opportunity of forest biotechnology research, development, and implementation. The importance of thinking strategically about landholdings and thinking holistically about the role of fiber in profitability shows that intensively managed, high-site-index land near a mill in the U.S. Southeast Lower Coastal Plain can be competitive on a delivered-to-mill cost basis with most areas in the world. Compared with the broad range of global delivered-to-mill costs that others have found, the estimates of a delivered production cost of $27/ton to $37/ton are clearly competitive.

Advances in biotechnology have promoted the creation of intellectual property (IP) assets, which have increased returns to research, motivated private firms to invest in biotechnology, and promoted market concentration in the U.S. seed industry. As a result, several legal options for protecting plant-based technology have evolved. Forest biotechnology companies face the same dilemma as agricultural biotechnology companies do in terms of how producers can protect their inventions and recoup their significant investments in research and development.

Plant patent protection through the Plant Patent Act is ideal for forest biotech companies as it applies, specifically, to clonal plants. It does not protect plants bred from seeds. Once a patent is issued, a specific clone will be recognized as a variety protected from unauthorized propagation. Vegetatively propagated seedlings are independent from genetic engineering. The latter is regulated to demonstrate that its implementation does not represent risks to health, safety, or environment.

Developers (vegetatively propagated seedling suppliers) tend to strictly control not only their technology, but also their decision-making approaches. Understandably, there is a high perception of business risk associated with sharing internal information. Therefore, Chapter 3 provides insights into what may be a guarded process: how to compute royalties for biotech forest products that are in their early stages. It should contribute to creating a firm foundation for comparing other valuation techniques as information improves.

Chapter 3 determines a royalty price premium, such that a seedling developer can remain financially indifferent to selling clonal seedlings for direct forest deployment, or for selling the seedlings (mother plants) and transferring a propagation right to multiply them through rooted cutting technology. From the buyers' perspective, the decision is whether to pay the premium or continue with a business as usual policy (buy seedlings at list price for forest establishment). If buyers are confident in their ability to propagate elite varieties despite the associated risks, they will be willing and able to pay the royalty, which other payment variants, would range from

$11/seedling when a single up-front payment is considered, to $2.7/seedling each year for five years, when constant royalty payments are selected.

Clonal forestry focuses not only on growth, but more importantly on wood quality. In general, the clonal trees analyzed for Chapter 4 tend to show more uniform traits than trees from any level of genetic improvement. At the forest level, reduction in variation across forest landscapes can be achieved simply by planting single clones in stands rather than in mixed clonal stands. However, in contextualizing the role of uniformity, it is important to define the scale for measuring variance, e.g., small plot, one acre plot, 100 acre plot, and to understand that even if genetic variation is eliminated, environmental effects can not be eliminated.

Although vegetatively propagated seedlings have complete genetic uniformity, clones express E x G interaction. For example, the same clones across the study regions performed differently, in terms of volume and quality, in different locations. For instance, in general, clones were more susceptible to rust in NC than in AL. It is likely that some clones have more "plastic" phenotypes and are quite sensitive to environmental conditions, while others will perform more consistently across locations and managements. Nevertheless, the same clones in different locations also sometimes showed different developmental patterns. Thus, productivity is not just influenced by genotype.

There is evidence to suggest that well-screened elite varieties produce higher proportions of more valuable products, like sawtimber. However, data indicate how critical field-testing is in the process of developing new varieties to ensure that the desired traits will perform under operational conditions. This screening process should include not only single-tree plot design, but also block plantings to evaluate diameter distributions; it should also allow for G&Y model development/evaluation, realistic valuation, and financial analysis. Individual clones may perform just as poorly, or more so, than trees from zygotic seedlings when misidentification or improper clonal evaluation occurs. For example, it is possible to find clonal stands that are practically immune, or have a very low incidence of rust in contrast to stands from zygotic seedlings, even when the clonal and zygotic seedlings share the same pedigree.

Data from clonal plantations of ages six, seventeen, and eighteen years old show that superior clones have narrower stand tables, with left skew, relative to non-clonal stand tables, which are not only broader, but also show right skew. This characterization is critical for defining products, production in growth simulations, and financial analyses. In future cruises, in addition to measuring DBH, it may also be important to measure the diameters of small-end stems.

The characterization of the OP 7-056 family in Chapter 4 could be used as an industry benchmark for comparing its stand structures, yields, and quality traits to those of improved zygotic seedlings, and to the most genetically advanced seedlings available on the market.

The G&Y model comparison in Chapter 4 shows that current diameter distribution models should not be used alone to simulate development trajectories for clones. In addition, generalized stand table projection models used in conjunction with appropriate genetic improvement gain adjustment functions, including TQI, should provide sound information and reasonably realistic analyses to evaluate the economic returns expected from clonal plantations.

Contrary to findings using traditional G&Y models, which suggest that over time, diameter distributions tend to become flatter than the normal distribution, this study finds that for vegetatively propagated plantations, with tested clones, fewer diameter classes occur through the rotation. If a golden rule could be inferred from this work, it would be that good clones show substantial uniformity improvement of at least 30% over controls. In fact, the clone characterized “the best” in this study showed uniformity improvement exceeding 50% CVs on the main growth parameters over the control.

Also in Chapter 4, some recommendations for improving G&Y predictions of clonal plantations are addressed although I have not developed a new G&Y model for clonal plantations nor included all possible uniformity analyses. However, I hope that the modeling discussion will stimulate interest in biometricians to revisit the current G&Y models with an eye for the advent of the biotech forest era.

From the timberland investment point of view, clonal forestry, as opposed to any degree of improved seed lots, offers a powerful means of enhancing returns when planting a portfolio of clonal stands, and when buying well-characterized clones that minimize risk and produce predictable products. Clonal forestry is not only growing more volume per area, but also shortening economic rotations without sacrificing wood quality. In addition, a producer will be able to tailor well-screened clones to a grower’s needs and to specific end products.

Horticulturists adopted clonal techniques a century ago to ensure the uniformity consistently demanded by the market. In contrast, high and low quality trees have been processed and reprocessed, as needed, to solve quality deficiencies. Progressive wood processors believe that in the future, wood technologies will not efficiently transform poor-quality raw material into high value final products at low costs; thus, high wood quality is necessarily the driver of future forest products, such as those required by the sensitive do-it-yourself and millwork markets (Sorensson, 2007)).

As intensive silvicultural practices continue to evolve, and better genetics becomes available, any vision of modern forestry must include clonal plantations. Clonal plantations will serve as a catalyst between land owners and end-product manufacturers for maximizing returns on both sides of the financial equation, even for products of unknown future markets (Shelbourne, 1997). As the industry and forest biotechnology proceed, products will continue to be developed, and producers will likewise be faced with protecting their discoveries, processes, and inventions.

This dissertation directly addresses a means, clonal forestry, which will increase the competitiveness of the U.S. South in a global market. My intention has been to discuss the current state of forest biotechnology and its associated value creation, and to prepare the ground for further research. In addition, the extensive data compiled, region-wide, from major growers should seed future studies of, for example, GxE interaction, clonal plantation development, variability in uniformity, and internal wood characteristics.

REFERENCES

Alig, R. J., D. M. Adams, B. A. McCarl, and P. J. Ince. 2000. *Economic Potential of Short-Rotation Woody Crops on Agricultural Land for Pulp Fiber Production in The United States*. Forest Products Journal. 50(5): 67-74.

Amateis, R.L., H.E. Burkhart, H.L. Allen, and C. Montes. 2001. *A Stand-Level Growth and Yield Model for Fertilized and Thinned Loblolly Pine Plantations. FASTLOB.* The Loblolly Pine Growth and Yield Research Cooperative at Virginia Polytechnic Institute. Blacksburg, VA. 27p.

American Soybean Association. 2003. *ASA Urges Adoption of Royalty System for Brazilian Exports Containing Pirated Soy*. Press release. URL: http://www.soygrowers.com/newsroom/releases/2003%20releases/r052103.htm. Accessed on February 16, 2007.

Bailey, R.L. and T.R. Dell. 1973. Quantifying diameter distributions with the Weibull function. Forest Science 19:97-104.

Baltunis, B., H. Dudley, T. White, B. Goldfarb, and H. Stelzer, 2007. *Genetic Gain from Selection for Rooting Ability and Early Growth in Vegetatively Propagated Clones of Loblolly Pine.* Tree Genetics and Genomes. 3(3):227-238.

Baltunis, B., H. Dudley, T. White, B. Goldfarb, and H. Stelzer, 2007. *Genetic Analysis of Earl Field Growth of Loblolly Pine Clones and Seedlings from the Same Full-Sib families*. Can. J. For. Res. 37:195-205.

Baltunis, B., J. Davis, T. Martin, E. Jokela, D. Huber, T. White, G. Kayihan. 2004. *Comparing Clonal Lines on Experimental Sites (CCLONES).* In Proceedings: IUFRO Forest Genetics and Tree Breeding in the Age of Genomics: Progress and Future. Nov. 1-5, 2004. Charleston, SC. p.112.

Bell, D. 1981. *Components of Risk Aversion.* Operational Research '81, J-P Brans North-Holland, p235-242.

Bell, D., and M. Shelman. 2006. *Monsanto: Realizing Biotech Value in Brazil.* Harvard Business School Case N2-507-018. 35p.

Bell, D., R. Martin, and M. Shelman. 2006. *ViaGen: Revolutionizing the Livestock Industry.* Harvard Business School Case 9-507-021. 31p.

Borders, B. E., W. M. Harrison, B. D. Shiver, Y. Zhang, C. Cieszewski, M. Clutter, and R. F. Daniels. 2001. *Growth and Yield Models for Loblolly Pine Plantation in the Piedmont/Upper Coastal Plain of the Southeastern U. S.* School of Forest Resources PMRC tech Rep. (Unpublished) University of Georgia., Athens, GA. 36p.

Borders, B. E. and B. D. Shiver. 2001. *The New Silviculture. Short course manual*. Forestry Information Services. Watkinsville, GA. 164p.

Borders, B.E. and Robert L. Bailey. 2001. *Loblolly Pine - Pushing the Limits of Growth.* Southern Journal of Applied Forestry. 25(2): 69-74.

Borders, B. E., W. D. Greene, and M. L., Clutter. 1991. *Variable Bedding, Planting, Harvesting and Transportation Costs Impact Optimal Economic Management Regimes*. Southern Journal of Applied Forestry. 15(1): 38-43.

Brinker, D. S. 2000. *Unpublished Equipment Costs for Logging Operations*. Auburn University.

Bullard, S. H., and T. J. Straka. 1998. *Forest Valuation and Investment Analysis*. Preceda, Education and Training. Edition 2.2, Auburn, AL.

Burdon, R.D., and W.J. Libby. 2006. *Genetically Modified Forests: From Stone Age to Modern Biotechnology*. The Forest History Society. Durham, NC. 79p.

Caldwell, B. E. 1989. *Intellectual property rights associated with plants*. ASA Special Publication No. 52. Madison, WI. Crop Science Society of America. 206p.

Cao, Q.V. and V. C. Baldwin, Jr. 1999. *Projecting a Stand Table Through Time*. In proceedings: Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, Feb. 15-18. pp. 515-518.

Carroll, B., R. De La Torre, and E. Cox. 2006. *Strategic Implications of Clonal Plantation Deployment*. In: Proceedings IUFRO'06 Sustainable Forest Management with Fast Growing Plantations, 10-13 Oct. Charleston, South Carolina, USA.

Carson, S.D. 1996. *Greater Specialisation of Improved Seedlots in New Zealand: New Developments for Efficient Selection of Parents and Evaluation of Performance*. NZ Forestry, Reprint 2594. 6p.

Carson, S.D. and J. D. Hayes.1998. *Diameter and Height Distributions in Genetically Improved Pinus Radiate*. Canadian Journal of Forest Research 28(2):248-258.

Carson, S.D., M.O. Kimberly, J.D. Hayes, and M.J. Carson. 1999b. *The effect of Silviculture on Genetic Gain in Growth of Pinus Radiate at one-third Rotation*. Canadian Journal of Forest Research. 29:1979-1984.

Carson, S.D., O. Garcia, and J.D. Hayes. 1999a. *Realized Gain and Prediction of Yield with Genetically Improved Pinus Radiata in New Zealand*. Forest Science. 45(2):186-200.

Chang, S.J., 1982. *Rotation Age, Management Intensity, and the Economic Factors of Timber Production: Do Changes in Stumpage Price, Interest Rate, Regeneration Costs and Forest Taxation Matter?* Forest Science 29(2): 267-278.

Clark, A., III, R. F. Daniels, and J.H. Miller. 2006. *Effect of Controlling Herbaceous and Woody Competition Vegetation on Wood Quality of Planted Loblolly Pine*. Forest Products Journal Science 56(2): 40-46.

Clutter, M. 2003. *Financial impact of seedling sub-lines in Loblolly Pine plantations*. Cellfor, Atlanta, June 2003.

Clutter, M., M. Kane, B. Borders, P. Bettinger, and J. Siry. 2006. *A Method for Calculating the Internal Rate of Return on Marginal Silviculture Investments*. The University of Georgia. School of Forestry and Natural Resources. PMRC. Technical Report 2006-3. 11p.

Clutter, J. L., J. C. Fortson, L.V. Pienaar, G. B. Brister, and R. L. Bailey. 1983. *Timber Management: A Quantitative Approach*. Wiley, New York. 333 p.

Clutter, J.L, and E.P. Jones. 1980. *Prediction of Growth after Thinning in Old-Field Slash Pine Plantations.* Res. Pap. SE-217. Asheville, NC: USDA, Forest Service, Southeastern Forest Experiment Station. 14 p.

Cossalter Ch., and Charlie Pye-Smithl. 2003. *Fast-Wood Forestry, Myths and Realities.* Center for International Forestry Research. Jakarta. 52 p.

Cubbage, F.W., D. Wear, and Z. Bennadji. 2006. *Economic Prospects and Policy Framework of Forest Biotechnology in the Southern U.S.A. and South America.* Chapter 11, in C.G. Williams (ed.), Landscapes, Genomics and Transgenic Conifers. p191-207.

Davis, L. S., K. N. Johnson, P. S. Bettinger, and T. E. Howard. 2001. *Forest Management: To Sustain Ecological, Economic, and Social Values*. McGraw Hill, New York. 4th edition, 804 p.

Denton, F. Russell and P. J. Heald. 2004. *Random Walks, Non-Cooperative Games, and the Complex Mathematics of Patent Valuation*. Rutgers Law Review. 55(4): 1175-1288.

Dieters, M.J., D.A., Huber, and R. Peters. 2004. *Genotype x Environment Interaction in Clonal Tests of Slash x Caribbean Hybrid Pine*. In Proceedings: IUFRO Forest Genetics and Tree Breeding in the Age of Genomics: Progress and Future. Nov. 1-5, 2004. Charleston, SC. p.42.

Dougherty, Derek. 2006. *Financial Evaluation of MCP and Varietal Loblolly Pine Plantations on Private Forestland in the SE US.* Proceedings at the 66 Annual Forest Landowners Conference: Varietal Forestry and Progressive Silviculture. Charleston, SC. 24p.

Erker, B., and M. Brick. Revised 1/2006. *The Plant Variety Protection Act*. Colorado State University Cooperative Extension. Crop Series Production No. 0.301. 3p. URL: http://www.ext.colostate.edu/pubs/CROPS/00301.pdf. Accessed on February 21, 2007

Faustmann, M. 1849. *Calculation of the Value Which Forestland and Immature Stands Possess for Forestry. Republished with Permission from Commonwealth Forestry Association. University of Oxford, Institute Paper 42, 1968*. Journal of Forest Economics. 1:1 1995,150 p.

Fernandez-Cornejo, J. 2004. *The Seed Industry in U.S. Agriculture.* U.S. Department of Agriculture, Economic Research Service. URL: http://www.ers.usda.gov/publications/aib786/aib786.pdf. Accessed on February 16, 2007. 71p.

Fernandez-Cornejo, J. and M. Caswell. 2006. *The First Decade of Genetically Engineered Crops in the United States.* U.S. Department of Agriculture, Economic Research Service. URL: http://www.ers.usda.gov/publications/AboutPDF.htm. Accessed on June 22, 2007. 30p.

Food and Agricultural Organization of the United Nations (FAO). 2000. The state of the world's forests.

Food and Agriculture Organization (FAO). 2005. Global Forest Resources Assessment 2005. URL: http://www.fao.org/docrep/008/a0400e/a0400e00.htm. Last accessed on May 20, 2007.

Foster, G.S., F.E. Bridgwater, and S.E. McKeand. 1981. *Mass Vegetative Propagation of Loblolly Pine – a Reevaluation of Direction*. From Proceedings of the 16th Southern Forest Tree Improvement Conference. Virginia Polytechnic Institute and State University. p311-319.

Fox, T.R., E.J. Jokela, and H.L. Allen 2004. *The Evolution of Pine Plantation Silviculture in the Southern United States*. Chapter 8, in H.M. Rauscher and K. Johnsen (eds). Southern Forest Science: Past, Present, Future. USDA For. Ser. South. Res. Sta., Gen. Tech Rep. SRS-75. 408 p.

Fox, T.R., E.J. Jokela, and H.L. Allen 2004. *The Evolution of Pine Plantation Silviculture in the Southern United States*. Chapter 8, in H.M. Rauscher and K. Johnsen (eds). Southern Forest Science: Past, Present, Future. USDA For. Ser. South. Res. Sta., Gen. Tech Rep. SRS-75. 408 p.

Garcia, O. 2006. *Scale and Spatial Structure Effects on Tree Size Distributions: Implications for Growth and Yield Modeling*. University of Northern British Columbia. Canadian Journal of Forest Research. 19p.

Goldberg, R., and Ch. Tasker. 1997. *Delta & Pine Land: Measuring the Value of Transgenic Cotton*. Harvard Business School Case 9-597-005. 28p.

Goldberg, R., and J. Gourville. 2002. *Calgene, Inc.* Harvard Business School Case 9-502-041. 21p.

Goldberg, R., and T. Urban. 1996. *Monsanto Company: The Coming of Age of Bio-Technology.* Harvard Business School Case 9-596-034. 27p.

Goldberg, R., J. West, C. Knoop, and D. Pearcy. 1999. *Seminis Inc*. Harvard Business School Case 9-600-030. 32p.

Greene, D., J. Siry, T. Harris, B. Izlar, T. Tye, A. Hamsley, W. Shiver, K. Eason, and C. Hyldahl. 2006. *Status and Future Sustainability of the U.S. Wood Supply System* (for the Wood Supply Research Institute). Center for Forest Business, The University of Georgia. 285p.

Greene, W. D. and B. L. Lanford. 2001. *Logging Cost Analysis. Shortcourse Manual. Georgia Center for Continuing Education*. Univ. of Georgia, Tifton, GA. 130 p.

Greene, W. D., B. D. Jackson, and J. D. Culpepper. 2001. *Georgia's Logging Businesses, 1987 to 1997*. Forest Products Journal. 51(1): 25-28.

Greene, W. D., T. G. Harris, Jr., C. E. Deforest, and J. Wang. 1996. *Harvesting Cost Implications of Changes in the Size of Timber Sales in Georgia*. Southern Journal of Applied Forestry. 21(4): 193-198.

Hancock T. C. 2001. *The Relationship between Stand Characteristics and Investment Risk and Return in Loblolly and Slash Pine Plantations*. Thesis. University of Georgia. Athens, GA. 105 p.

Harrington, T. B., 2001. *Silvicultural Basis for Thinning Southern Pines: Concepts and Expected Responses.* Georgia Forestry Commission. Report # FSP 001. 13 p.

Harrington, T. B., 2002. *Silvicultural Approaches for Thinning Southern Pines: Method, Intensity, and Timing.* Georgia Forestry Commission. Report # FSP 002. 17 p.

Harris, T., J. Siry, and S. Baldwin. In press. *How competitive is the southern timber industry?* In Proceedings of 2004 SOFEW Conference, St. Augustine, FL, March 15, 2004. University of Florida.

Harrison, W. M. and B. E. Borders. 1996. *Yield Prediction and Growth Projection for Site-Prepared Loblolly Pine Plantation in the Carolinas, Georgia, Alabama, and Florida*. PMRC Technical Report 1996-1. D.B. Warnell School of Forest Resources. The University of Georgia. Athens, GA. 64 p.

Hornsby, B.S. 2006. *Clonal Variation In Wood Properties Of Pinus Taeda L.* Master's Thesis. The University of Georgia, Warnell School of Forestry and Natural Resources.

Huber, D.A. and G.L. Powell. 2004. *The Cooperative Forest Genetic Research Program: Breeding Pure Species and Hybrids.* In Proceedings: IUFRO Forest Genetics and Tree Breeding in the Age of Genomics: Progress and Future. Nov. 1-5, 2004. Charleston, SC. p.98-100.

Hyde, W.F. 1980. *Timber Supply, Land Allocation and Economic Efficiency*. Baltimore: John Hopkins University Press for Resources for the Future. 224p.

Hyde,W.F., D.H. Newman and Berry J. Seldon. 1992. *The Economic Benefits of Forestry Research*, Iowa State University Press, Ames.

Janssen, I.E., and P.T. Sprinz, 1987. *Modelling Distributions of Stem Characteristics of Genetically Improved Loblolly Pine.* In Proc. South. For. Tree Improve. Conf. 19: 367-375.

Jayawickrama, K. J. S. 2001. *Estimated Among-Family and Within-Family Variances and Heritabilities from Three Radiata Pine Clonal Trials.* Forest Genetics 8(3):247–257.

Jayawickrama, K.J.S. G.R. Johnson and T. Ye. 2004. *Cooperative Advanced-Generation Breeding and Testing of Coastal Douglas-fir and Western Hemlock – Strategy And Implementation.* In Proceedings: IUFRO Forest Genetics and Tree Breeding in the Age of Genomics: Progress and Future. Nov. 1-5, 2004. Charleston, SC. p.101-103.

Jondle, R. J. 1989. *Overview and Status of Plant Proprietary Rights*. Chapter 1, in *Intellectual property rights associated with plants*. ASA Special Publication No. 52. Madison, WI. Crop Science Society of America. p5-15.

Kjeldgaard, R. H. and Marsh, D. R. 1994. *Intellectual property rights for plants*. The Plant Cell 6(11):1524-1528.

Klemperer, W. D. 1996. *Forest Resource Economics and Finance*. McGraw-Hill Series in Forest Resources. 551 p.

Knowe, S.A., and G.S. Foster. 2007. *Adjusting Site Index and age to account for Genetic Effects in Yield Equations for Loblolly Pine*. Proceedings of the Southern Silvicultural Research Conference. USDA Forest Service and The University of Georgia. P34

Larson, P. R., D. E. Kretschmann, A. Clark III, and J. G. Isebrands. 2001. *Formation and Properties of Juvenile Wood in Southern Pines, a Synopsis.* Madison, WI: USDA Forest Service, Forest products laboratory. 42p

Li, Minghe, and G. A. Ritchie. 1999. *Eight hundred years of clonal forestry in China:*

I. Traditional Afforestation with Chinese Fir (Cunninghamia lanceolata (Lamb.) Hook.) New Forests (18):131–1142.
II. Mass Production of Rooted Cuttings of Chinese Fir (Cunninghamia lanceolata (Lamb.) Hook.) New Forests (18):143–159

Magretta, Joan. 1997. *Growth Through Global Sustainability: and Interview with Monsanto's CEO, Robert B. Shapiro*. Harvard Business Review. p77-88.

McFarlan, W., and M. Dailey. 1998. *Pioneer Hi-Bred: Turning Seeds into Factories*. Harvard Business School Case 9-399-095. 24p.

McKeand, S.E., R.C. Abt, H.L. Allen, B. Li, and G.P. Catts. 2006. *What Are the Best Loblolly Pine Genotypes Worth to Landowners?* Journal of Forestry. Oct-Nov: 352-358.

McNabb, Ken. 2006. Forest Tree Seedling Production in the South for the 2004/2005 Planting Season. Auburn Nursery Cooperative. Technical Note 05-02.

NCFA. 2003. *Issues Review of Northern Coastal Plain Forest Inventory Data*, Press Release, "North Carolina Sees Big Loss of Forestland Use in Northern Coastal Plain".

Nester, M.R. 2000. *Interim Summary of Experiment 315 GYM – Implications for Routine Deployment of Clones and for the Use of Single Tree Plot Designs in Genetic Testing*. CTD Project Report No. 315GYM-PEEPCH-G-5-2000-05. 38p.

Newman, D.H., 1988. *The Optimal Forest Rotation: A Discussion and Annotated Bibliography*. Ashville, NC: U*SDA Forest Service, Southeastern Forest Experiment Station*. 47p.

Newman, D.H., 2002. *Forestry's Golden Rule and the Development of the Optimal Forest Rotation Literature.* Journal of Forest Economics. 8, 5-27

Newman, D.H., Charles B. Gilbert and William F. Hyde. 1985. The Optimal Forest Rotation with Evolving Prices. Land Economics. 61(4): 347-353.

Peter, G. F. 2002. The Value of Forest Biotechnology to Vertically Integrated Pulp & Paper Manufacturing. IPST Executives' Conference Presentation. Atlanta.

Peter, G.F., White, D.E., Duncan, R.G., Newman, D. 2001. *Commercialization of Forest Biotechnology: Economic Targets for Enhanced Global Competitiveness of the US Pulp and Paper Industry*. CPBIS proposal, Atlanta.

Pienaar, L. V., B.D., Shiver and J.W., Rheney. 1996. *Yield Prediction for Mechanically Site-Prepared Slash Pine Plantations in the Southeastern Coastal Plain*. PMRC technical report 1996-3. University of Georgia, School of Forest Resources. Athens, GA. 57p.

Pienaar, L.V. and J.W. Rheney. 1995. *Modeling Stand Level Growth and Yield Response to Silvicultural Treatments.* Forest Science 41(3):629-638.

Pienaar, L.V., and W.M. Harrison. 1988. *A Stand Table Projection Approach to Yield Prediction in Unthinned Even-Aged Stands*. Forest Science. 34(3): 804-808.

Plant Patent Act (35 U.S.C. §§ 161-164, July 19, 1952, as amended 1954). URL: http://ipl.unm.edu/cwl/fedbook/plantpat.html. Last accessed on May 20, 2007

Redmond C.H., and F. Cubbage. 1985. *Capital Budgeting Practices in the Forest Products Industry*. Forest Products Journal. 35(9):55-60.

Reinhardt, F. 2001. *Agricultural Biotechnology and its Regulation*. Harvard Business School case 9-701-004. 31p.

Rockwood, D. L. 2000. *Growth and Yield Predictions for Queensland Produced F1 Clones of Slash x Honduras Caribbean Pines*, Queensland Forestry Research Institute and Cooperative Research Centre – Sustainable Production Forestry. Gainesville, University of Florida, Fl. 26p.

Rogers, W. R., and I. A. Munn. 2003. *Forest Management Intensity: A Comparison of Timber Investment Management Organizations and Industrial Landowners in Mississippi.* Southern Journal of Applied Forestry. 27(2): 83-91

Samuelson, P.A., 1976. *Economics of Forestry in an Evolving Society. Republished with Permission from Economic Inquiry V14.* Journal of Forest Economics. 1:1, 1995. p.115-148

Schmidtling, R.C. T.L. Robison, S.E. McKeand, R.J. Rousseau, H.L. Allen, and B. Goldfarb. 2004. *The Role of Genetics and Tree Improvement in Southern Forest Productivity.* Chapter 10, in H.M. Rauscher and K. Johnsen (eds). Southern Forest Science: Past, Present, Future. USDA For. Ser. South. Res. Sta., Gen. Tech Rep. SRS-75. 408 p.

Sedjo, R. A., and K. S. Lyon. 1996. *Timber Supply Model 96: A Brief Overview*. Chapter 6 in *Models needed to assist in the development of national fiber supply strategy for the 21st century*: Report of a workshop. Pp: 84-99.

Sedjo, Roger. 1999. *Biotechnology and Planted Forests: Assessment of Potential and Possibilities.* Resources for the Future. Discussion Paper 00–06. 27p. URL: http://www.rff.org/rff/Documents/RFF-DP-00-06.pdf. Accessed on February 21, 2007.

Sedjo, Roger. 2001. *Biotechnology's Potential Contribution to Global Wood Supply and Forest Conservation.* Resources for the Future. Discussion Paper 01–51. 37p. URL: http://www.rff.org/rff/Documents/RFF-DP-01-51.pdf. Accessed on February 21, 2007.

Sedjo, Roger. 2004. *Transgenic Trees: Implementation and Outcomes of the Plant Protection Act.* Resources for the Future. Discussion Paper 04–10. 32p. URL: http://www.rff.org/rff/Documents/RFF-DP-04-10.pdf. Accessed on February 22, 2007.

Shelbourne, C.J.A. 1997. *Genetics of Added Value to the End-Products of Radiata Pine*. In: Proceedings of NZFRI-IUFRO Conference: IUFRO'97 Genetics of Radiata Pine, 1-4 Dec., Edited by R.D. Burdon and J.M. Moore. Forest Research Institute, Rotorua, NZ. Bulletin 203, pp. 129-141.

Simpson, R. D. 1999. *Productivity in Natural Resources. Improvement through Innovation*. Resources for the future, Washington, DC. 220p.

Siry, J., D. Greene, T. Harris, B. Izlar, A. Hamsley, K. Eason, T. Tye, S. Baldwin, and C. Hyldahl. 2006. *Wood Supply Chain Efficiency and Fiber Cost. What Can We Do Better?* Journal Forest Products. 56(10): 4-10.

Smidt, M., M. Dubois, B. Da Silveira. 2005. *Costs and Cost Trends for Forestry Practices in the South*. Forest Landowner. Atlanta, GA. 64(2): 25-31.

Smith, Gordon V. and Russell L. Parr. 2005. *Intellectual Property: Valuation, Exploitation, and Infringement Damages*. John Wiley & Sons. 864 p.

Sorensson, C. T. 2007. *Improving the Relevancy of Breeding for Wood Quality in Softwoods.* In Proceedings: Australasian Forest Genetics Conference Breeding for Wood Quality Apr. 11 – 14. 12p.

Sorensson, C.T. (2004): The GOT – *A Forest Industry Partnership Model that Helps the 'New Genetics' Deliver Results.* In "Profitable Wood Processing", Proceedings of NZIOF Annual Conference, Gisborne, 19-20 April 2004, pp. 147-158.

Sorensson, C.T. 2002. *Reflection on Radiata Pine Genetic Improvement by a Clonal Forester*. NZ Journal of Forestry. 47(3):29-31.

Sorensson, C.T. 2006. *Varietal Pines Boom in the US South*. NZ Journal of Forestry. August: pp.34-40.

Sorensson, C.T. and C.J.A. Shelbourne. 2005. *Clonal Forestry with Radiata Pine*. Chapter 5-7, 4th edition of NZ Institute of Forestry "Forestry Handbook", pp. 92-96. NZIOF, New Zealand (nzif@paradise.net.nz).

Sorensson, C.T. and J.T. Brawner. 2005. *Will Tree-Breeders Produce Cloned Pine Treestocks with Characterised Hemicellulose Composition and Structure?* The Hemicelluloses Workshop 2005 (eds. K.E. Entwistle and J.C.F. Walker), pp. 1-12. University of Canterbury.

Sorensson, C.T., R. Bian, B. Wellauer, and R. Alley. 2004. *Structural Lumber Conversion Potential of Clonal Radiata.* In "Wood Quality 2004", Proceedings of Innovatek Ltd. Workshop, Albury NSW Australia 5-6 August, 15 pp.

Spirek, F.J., L.G., Arvanitis, D.L., Rockwood, and R.C., Littell. 1981. *Modelling Diameters and Heights of Improved Slash Pine (Pinus eltiottii Engelm. var. elliottii) Using Weibull Distributions*. In Proc. South. For. Tree Improve. Conf. 16: 47-54.

Stanturf J.A., R. Kellison, F.S. Broerman, and S.B. Jones. 2003. *Productivity of Southern Pine Plantations. Where are we and how did we get here*? Journal of Forestry. April/May: 26-31.

Texas Forest Service**.** Reforestation Practices - Estimated Costs**.** URL: http://txforestservice.tamu.edu/main/article.aspx?id=1802. Last accessed Feb. 20, 2007.

The Market, Fertilizer News and Analysis. URL: http://www.fertilizerworks.com/html/market/TheMarket.pdf. Last accessed Feb. 20, 2007.

Tufts, R.A., B.L. Landford, W.D. Greene, and J.O. Burrows. 1985. *Auburn Harvesting Analyzer (AHA). A Spreadsheet Template to Analyze System Balance, Production Rates, and Costs.* The Compiler. 3(2): 14-15. Forest Resources Institute. Florence, AL.

U.S. Department of Agriculture. Agricultural Biotechnology. Glossary of Agricultural Biotechnology Terms. Accessed 03/19/2007. at URL: http://www.usda.gov/wps/portal/!ut/p/_s.7_0_A/7_0_1OB?navid=BIOTECH&parentnav=AGRICULTURE&navtype=RT. Accessed on February 21, 2007

United States Patent and Trademark Office. URL: http://www.uspto.gov/web/menu/intro.html, http://www.uspto.gov/main/patents.htm, and http://ipl.unm.edu/cwl/fedbook/plantpat.html. Last accessed on May 20, 2007

USDA, Agricultural Marketing Service. URL: http://www.ams.usda.gov/Science/PVPO/PVPindex.htm. Last accessed on May 20, 2007

Wagner, J. E., F. W., Cubbage, and C. H., Redmond. 1995. *Comparing the Capital Asset Pricing Model and Capital Budgeting Techniques to Analyze Timber Investments*. Forest Products Journal. 45(7/8): 69-77.

Weiler, D. 2004. *Valuing Your Intellectual Property for Strategic Alliances and Financing*. NJSBDC Presentation URL: http://www.njsbdc.com/SciTech/scitech120804weiler.ppt#256. Accessed on February 18, 2007.

Weir R. J., J. Romero, and G. Hay. 2006. *Elite Varieties of Pine Seedlings Yield Measurable Results.* Forest Landowner. 65(6):35-37.

World Wildlife Fund (WWF). 2001. *The Forest Industry in the 21st Century*. URL: http://www.wwf.org.uk/filelibrary/pdf/forestind21century.pdf. 24p. Accessed on February 21, 2007

Wright, Brian D. 2006. *Plant Genetic Engineering and Intellectual Property Protection.* University of California, Berkeley. Agricultural Biotechnology in California Series. ANR Publication 8186. 6p. URL: http://anrcatalog.ucdavis.edu/pdf/8186.pdf. Accessed on February 21, 2007.

Yin, R. 1998. *Industry Characteristics and Investment Decisions: An Alternative Approach to Pulp and Paper Production*. Tappi Journal. 81(1): 69-74.

Yin, R. and R.A. Sedjo. 2001. *Is This the Age of Intensive Management? A Study of Loblolly Pine on Georgia's Piedmont*. Journal of Forestry 99(12):10-17

Zhang, Y., B. Borders, and R. Bailey. 2002. *Derivation, Fitting, and Implication of a Compatible Stem Taper-Volume-Weight System for Intensively Managed, Fast Growing Loblolly Pine*. *Forest Science.* 48:545-607.

Zhao, D., B. Borders, and M. Wang. 2006. *Survival Model for Fusiform Rust Infected Loblolly Pine Plantations with and without Mid-Rotation Vegetation Control.* Forest Ecology and Management. 235, pp. 232-239.

APPENDIX A

FINANCIAL ASSUMPTIONS

Table 1. Base Case Prescription for the Unthinned Model

Year	Activity	$/acre
0 - Jul-Aug	Mechanical site preparation - Shear-rake-pile-bed	182
0 - Jul-Aug	Chemical site preparation	110
0 - Dec-Jan	Machine planting + Seedlings (TPA: 605, 6'x12')	55+30
1 - Mar-Apr	Herbaceous release - Banded – no grass	48
1	Fertilization with DAP - 250 lbs/ac (P:20% & N:18%)	52
6	Fertilization with DAP - 125 lbs/ac (P:20% & N:18%)	26
6	Fertilization - Urea 345 lbs/ac - (N:46%)	84
≥ 10	Final Harvest - Optimum rotation age (Maximum BLV)	
Total costs	**Regeneration costs - (w/o annuities)**	**538**

Table 2. Base Case Prescription for the Thinned Model

Year	Activity	$/acre
0 - Jul-Aug	Mechanical site preparation - Shear-rake-pile-bed	182
0 - Jul-Aug	Chemical site preparation	110
0 - Dec-Jan	Machine planting + Seedlings (TPA: 605, 6'x12')	55+30
1 - Mar-Apr	Herbaceous control, early release - Banded – no grass	48
1	Fertilization with DAP - 250 lbs/ac (P:20% & N:18%)	52
6	Fertilization with DAP - 125 lbs/ac (P:20% & N:18%)	26
6	Fertilization - Urea 345 lbs/ac - (N:46%)	84
10 to 20	Thinning 50% of TPA	
Thinning Age + 1yr	Herbaceous control, mid-rotation release	65
Thinning Age + 2yrs	Fertilization with DAP - 125 lbs/ac (P:20% & N:18%)	26
Thinning Age + 2yrs	Fertilization - Urea 345 lbs/ac - (N:46%)	84
≥ Thinning Age + 3yrs	Final Harvest - Optimum rotation age (Maximum BLV)	
Total costs	**Regeneration costs - (w/o annuities)**	**610**

Table 3. Additional Financial Assumptions

Item	$/acre
Land price	400
Annual tax & administration costs	7
Annual hunting lease	5
Appreciation rate	0%
Discount Rate	6% - 8%

Table 4. Silvicultural Costs Used to Determine BLV

TPA	Mech. S. Prep	Chem. S. Prep	Planting	Seedling	HWC 1	HWC2	HWC3	Fert. 1	Fert. 2	Fert. 3
300	167	110	50	15	42	44	65	52	110	110
400	167	110	50	20	42	44	65	52	110	110
500	182	110	55	25	42	48	65	52	110	110
600	**182**	**110**	**55**	**30**	**42**	**48**	**65**	**52**	**110**	**110**
700	200	110	60	35	42	53	65	52	110	110
800	225	110	68	40	42	60	65	52	110	110
900	225	110	68	45	42	60	65	52	110	110
1000	250	110	75	50	42	66	65	52	110	110
1100	250	110	75	55	42	66	65	52	110	110

Table 5. Product Definition and Stumpage Prices for Southern Yellow Pine (TMS, South-Wide Averages, 2006)

	ST	CNS	PW
Min DBH (in)	12.0	8.0	4.5
Max DBH (in)	40.0	12.0	8.0
Min Top (in)	7.0	6.0	3.0
Stumpage price ($/ton)	38.25	22.10	6.56

South-wide averages

Table 6. Harvesting System Configuration and Assumptions: Feller-buncher

HydroAx 511 Feller-buncher	**Final harvest**	**Thinning**
=IF(DBH<18 --> TPA= 0.11+0.29814*DBH*TPA^ -.5+0.38674*TPA^ .5/BA)		
=IF(DBH>=18 --> TPA= -.251+0.123*DBH+0.00168*DBH^2)		
BA per accumulation (Ft^2)	0.56	0.56
Availability (%)	65.0%	65.0%
Operator efficiency	100.0%	80.0%
Number of machines	1	2
Fixed costs ($/SMH)	30.02	30.02
Variable costs ($/PMH)	42.91	33.93
1 CORD = 2.675 Tons		

Table 7. Harvesting System Configuration and Assumptions: Grapple Skidder

Cat 518 Grapple skidder	**Final harvest**	**Thinning**
CYCLE = 2.7688+0.002631*DIST+0.5149*TON/2.675		
Skid distance	720.0	720.0
Cords	0.75	0.68
Availability (%)	69.0%	69.0%
Operator efficiency	100.0%	80.0%
Number of machines	3	3
Fixed costs ($/SMH)	23.10	23.10
Variable costs ($/PMH)	25.02	29.16
1 CORD = 2.675 Tons		

Table 8. Harvesting System Configuration and Assumptions: Loader with Delimber

Prentice 325 loader with CTR 314 Delimber	**Final harvest**	**Thinning**
Productive time per load (TPL) (1 = cold loading, 2 = hot loading)	36.23	36.23
TPL = 36.2+65.9964 *Trees/TreeWT		
Trailer load size (cord = 5,350 lbs/cord)	9.80	9.80
Prep. time (minutes)	11.83	11.83
Availability (%)	85.0%	85.0%
Operator efficiency	100.0%	100.0%
Number of machines	1	1
Fixed costs ($/SMH)	17.29	17.29
Variable costs ($/PMH)	20.75	29.98

Table 9. Harvesting System Configuration and Assumptions: Hauling

Hauling	**Final harvest**	**Thinning**
Payloads (tons)	26.2	26.2
Loading time (minutes)	30.0	30.0
Unloading time minutes)	36.2	36.2
Haul distance (miles)	30.0	30.0
Average speed (mph)	40.0	40.0
Unloading time (minutes)	30.0	30.0
Haul rate (one way, $/mile)	4.3	4.3
Availability (%)	90.0%	90.0%
Operator efficiency	100.0%	100.0%
Number of machines	5.4	4.0
Fixed costs ($/SMH)	13.68	13.68
Variable costs ($/PMH)	17.58	19.45

APPENDIX B

GROWTH PARAMETERS' TRENDS

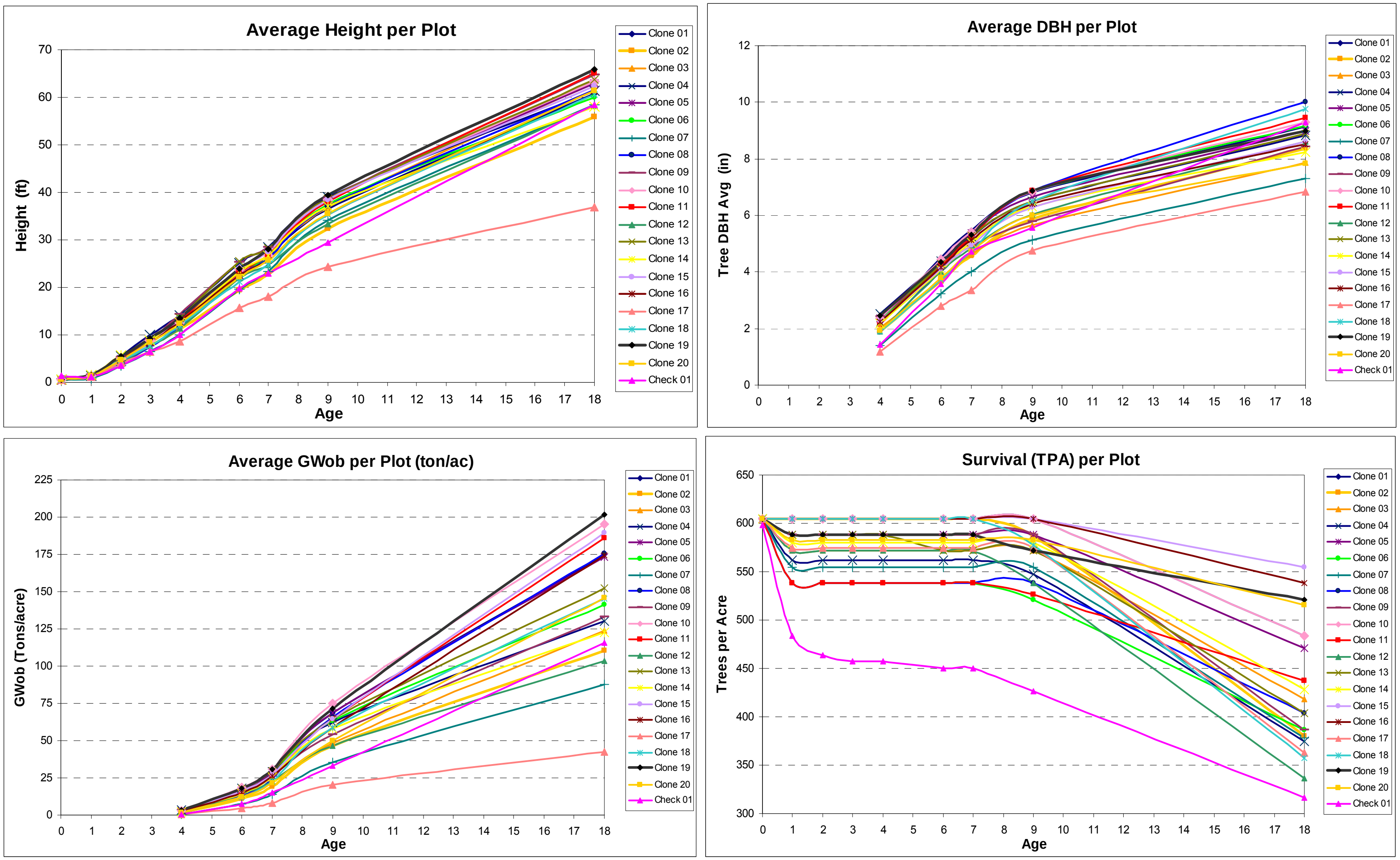


Figure 1. Trends for Average Height, DBH, GWob, and Survival/Mortality, Over 18 Years: Twenty Clones and One Control

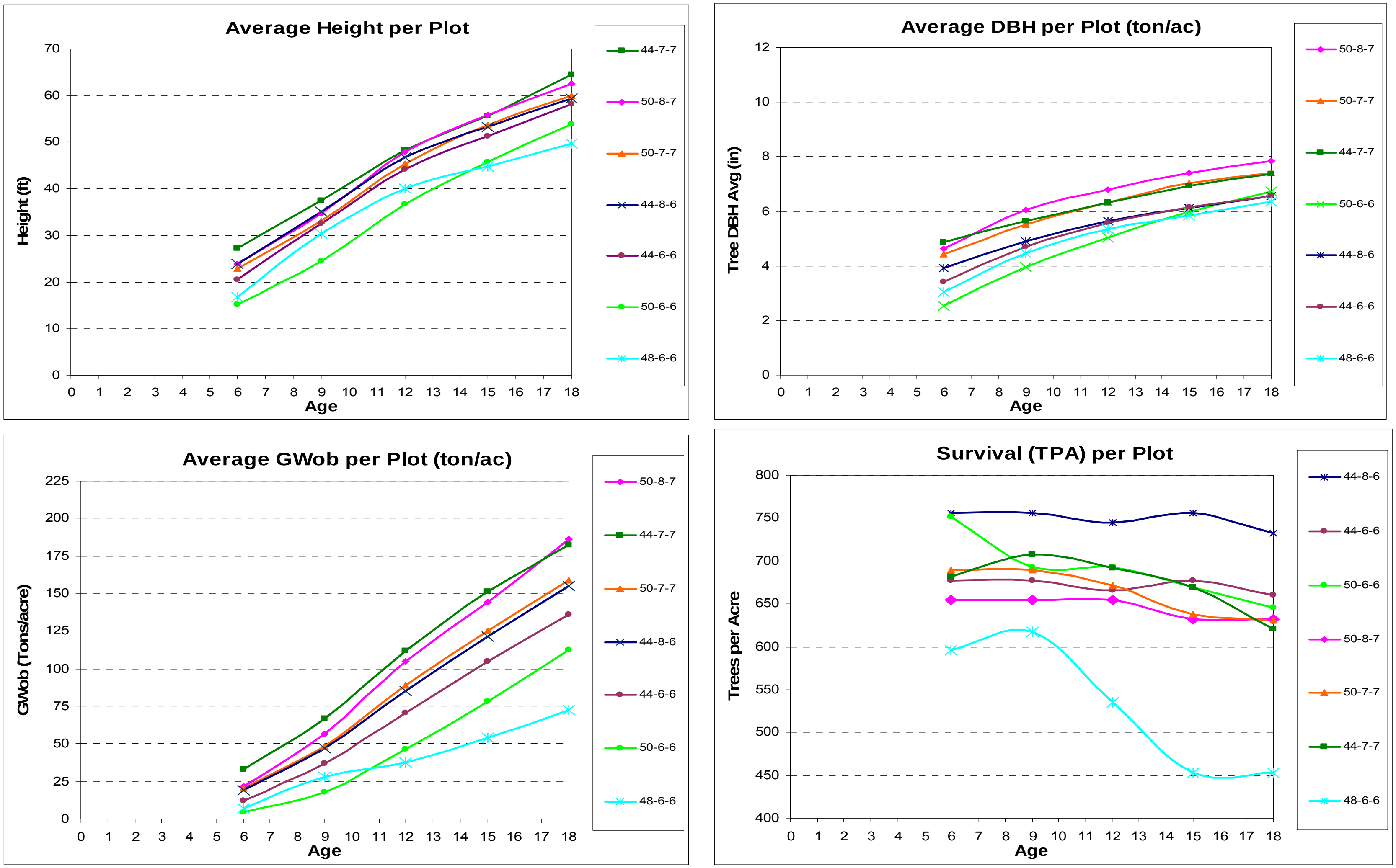


Figure 2. Trends for Average Height, DBH, GWob, and Survival/Mortality, Over 18 Years: Seven Plots, 7-056 Family

APPENDIX C

DIAMETER DISTRIBUTION

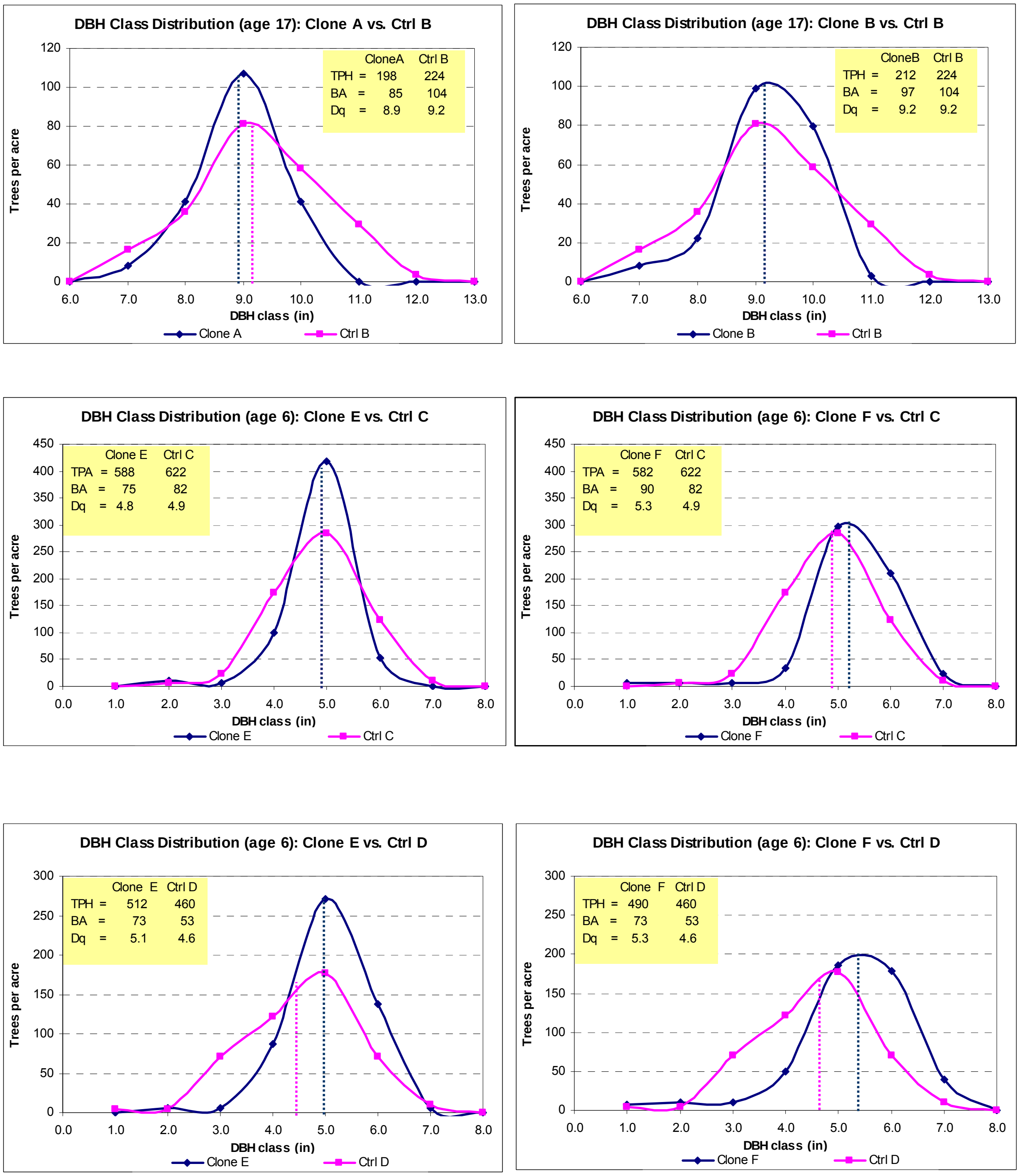


Figure 3. Narrower DBH Distribution in Clones vs. Controls (Related/Unrelated)
Quadratic Mean Diameter (Dq) Shifts to Right with Good Clones

Location 1 **Location 2**

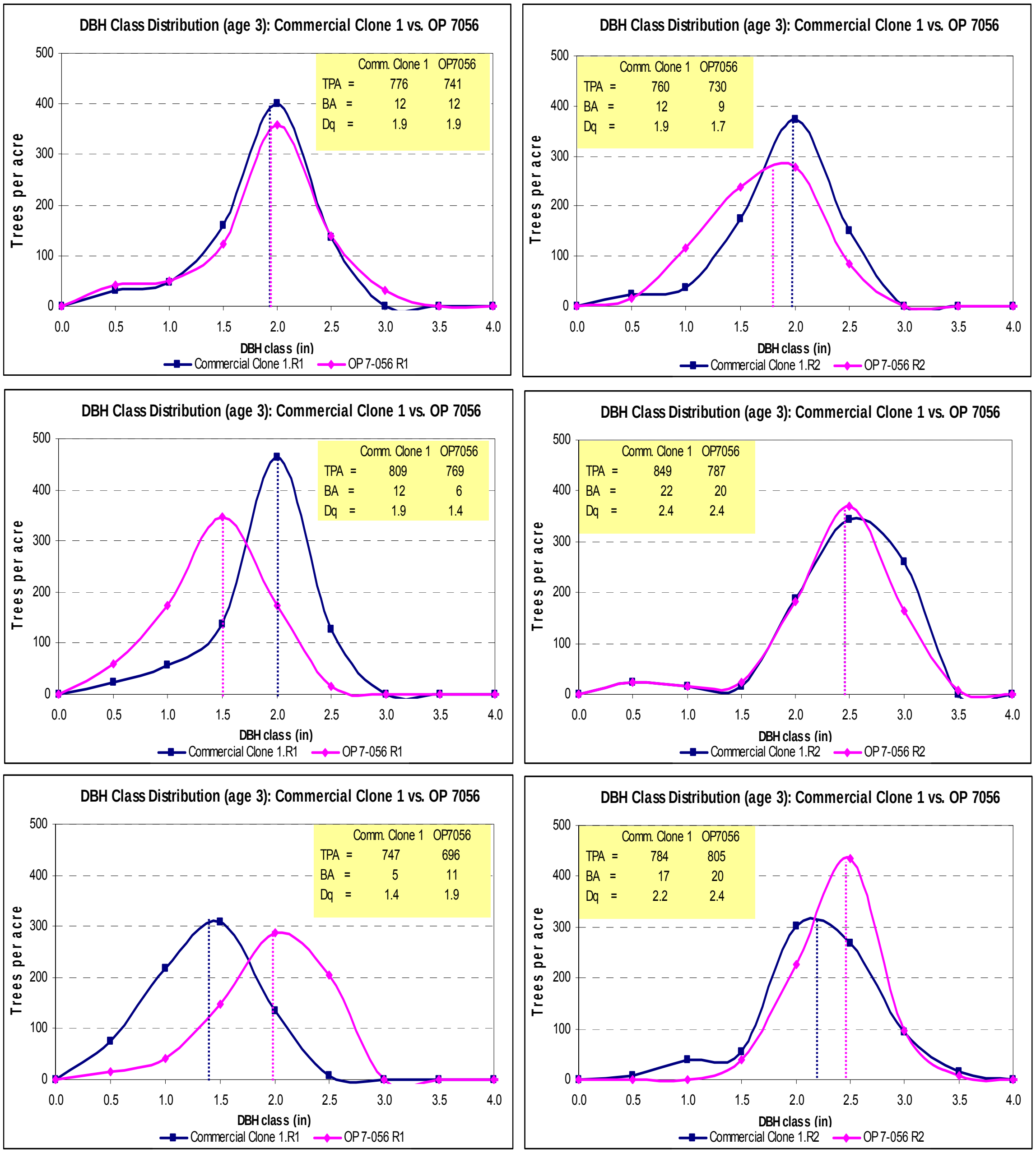


Figure 4. Commercial Clone vs. 7-056 Family, in Three Different Replications and Two Locations

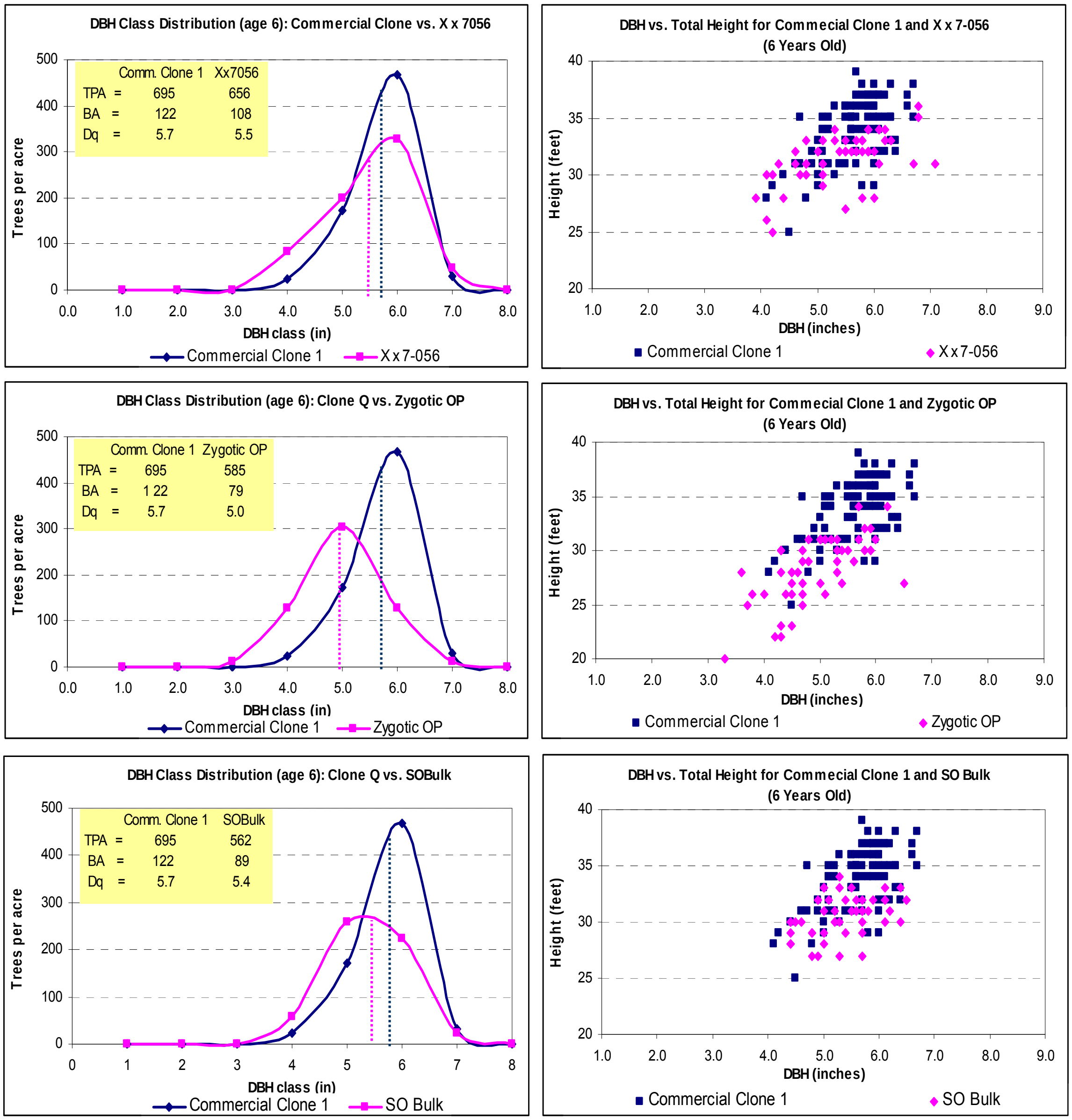


Figure 5. Commercial Clone vs. Three Different Controls

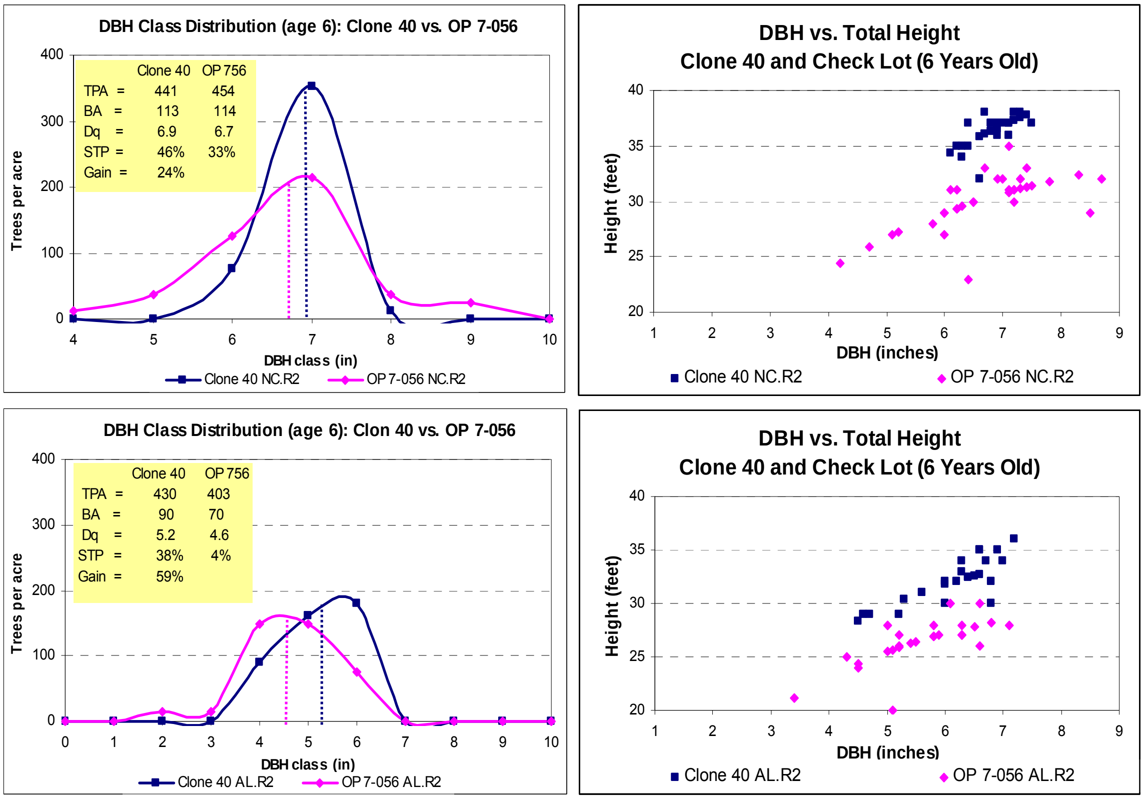


Figure 6. Quadratic mean diameter (Dq) Shifts to Right with Good Clones
Clones Tend to be More Uniform; H and DBH – But not True for all Clones

APPENDIX D

CLONES VS. NON-CLONES

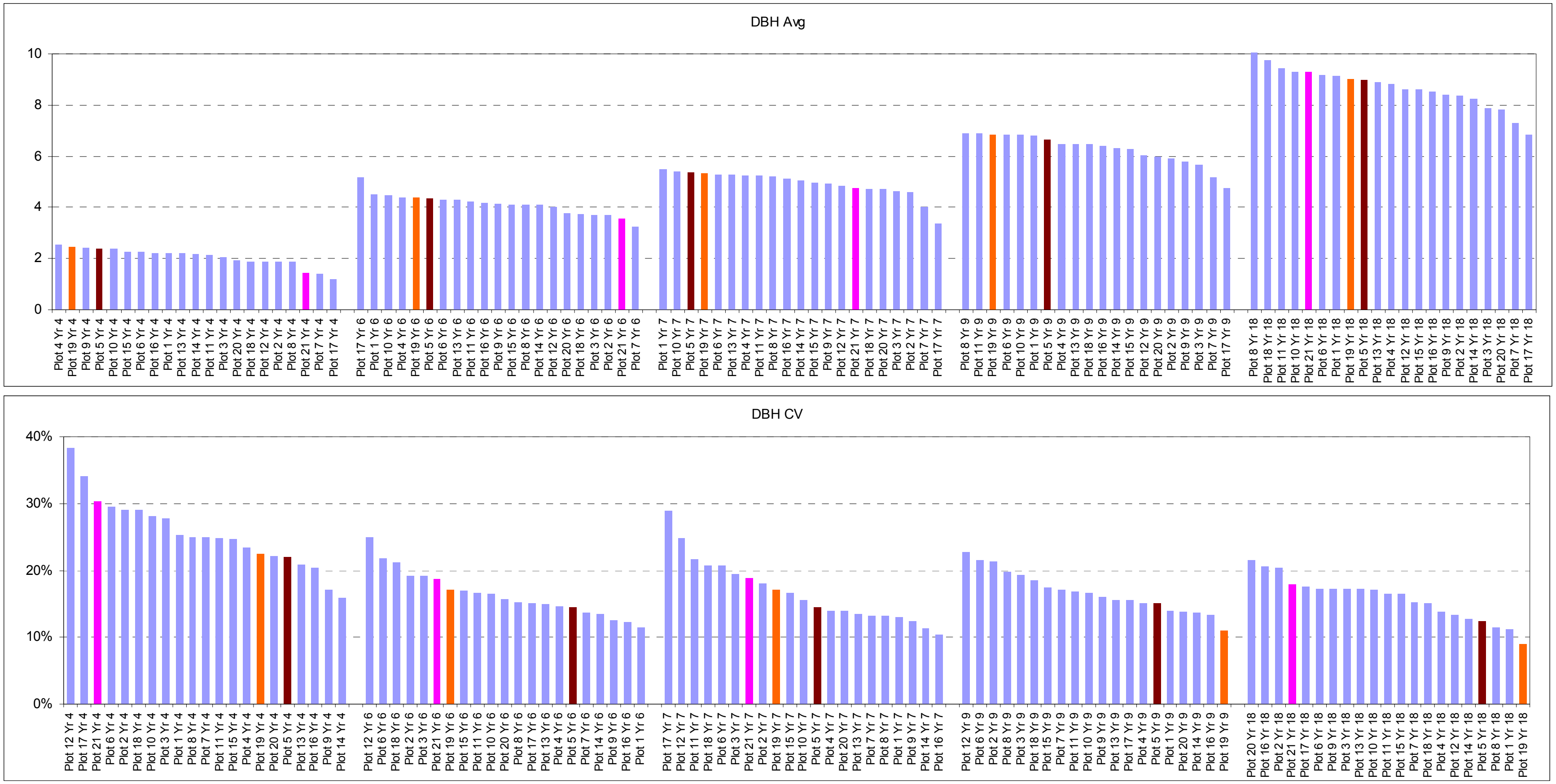


Figure 7. DBH Averages and DBH CVs by Plot, North Carolina: Twenty Clones, One Check, over 18 Years

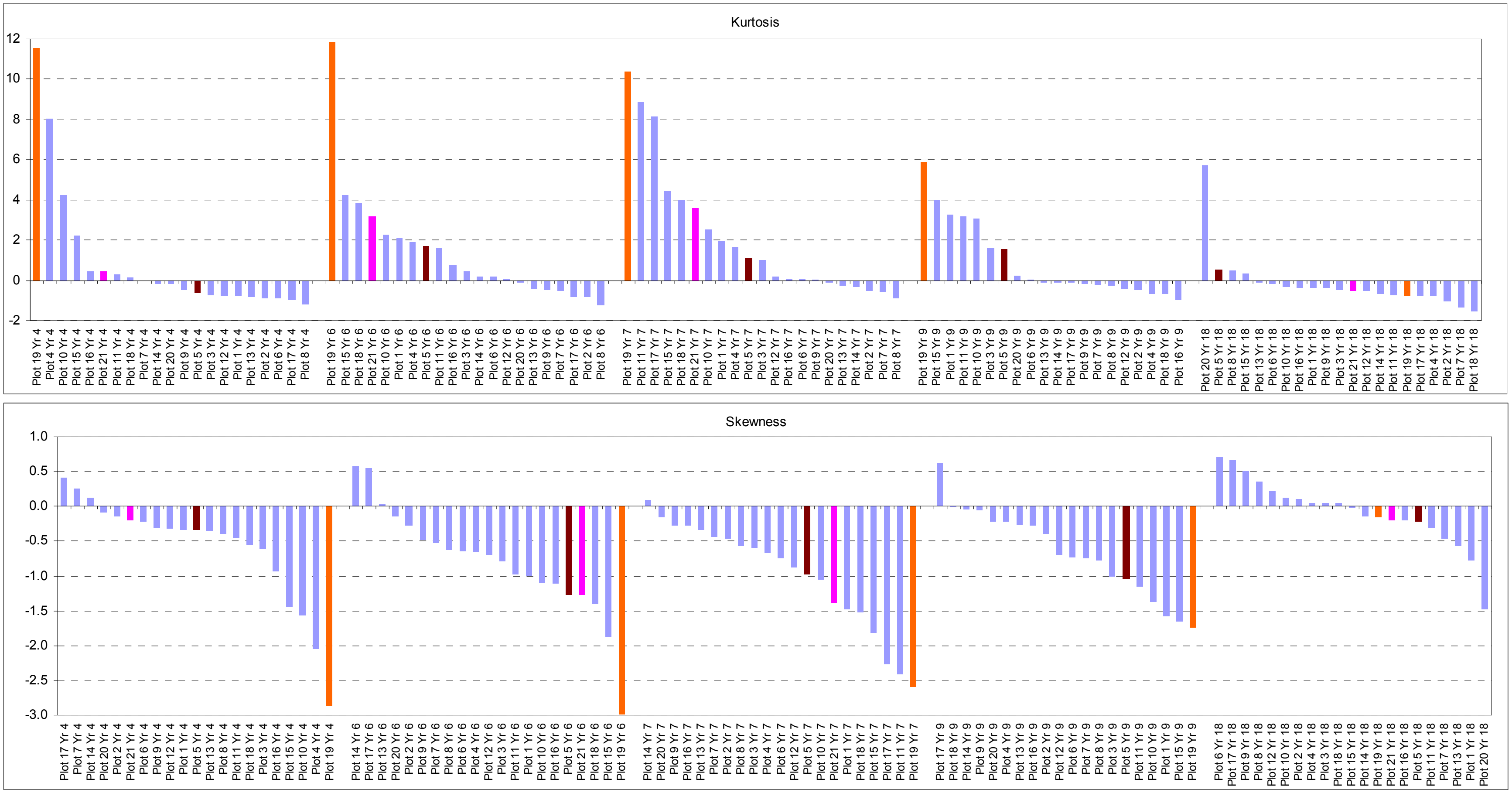


Figure 8. DBH Kurtosis and Skewness by Plot, North Carolina: Twenty Clones, One Check, over 18 Years

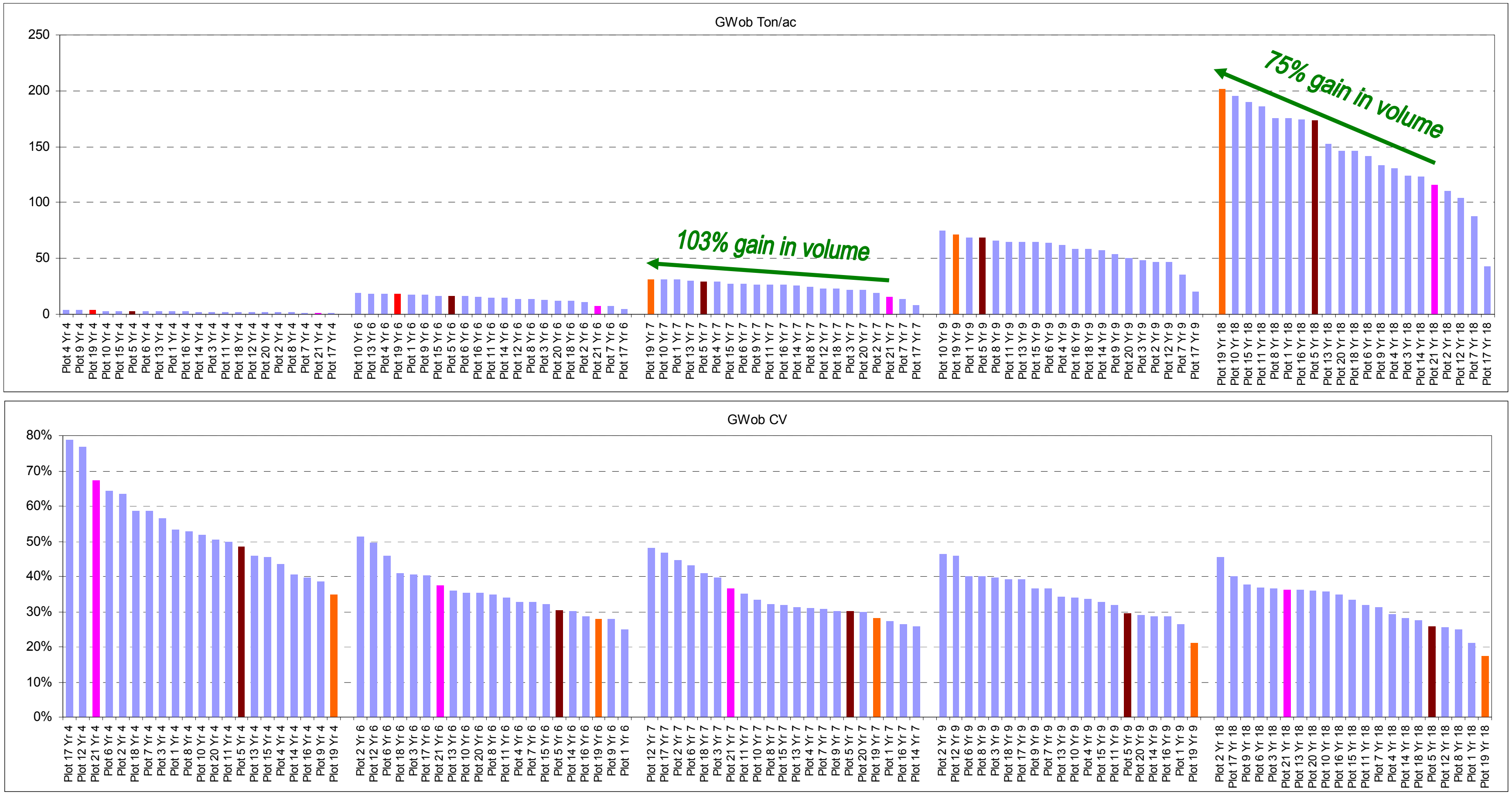


Figure 9. Green Weight outside bark and Individual Tree CV: Twenty Clones, One Check, over 18 Years

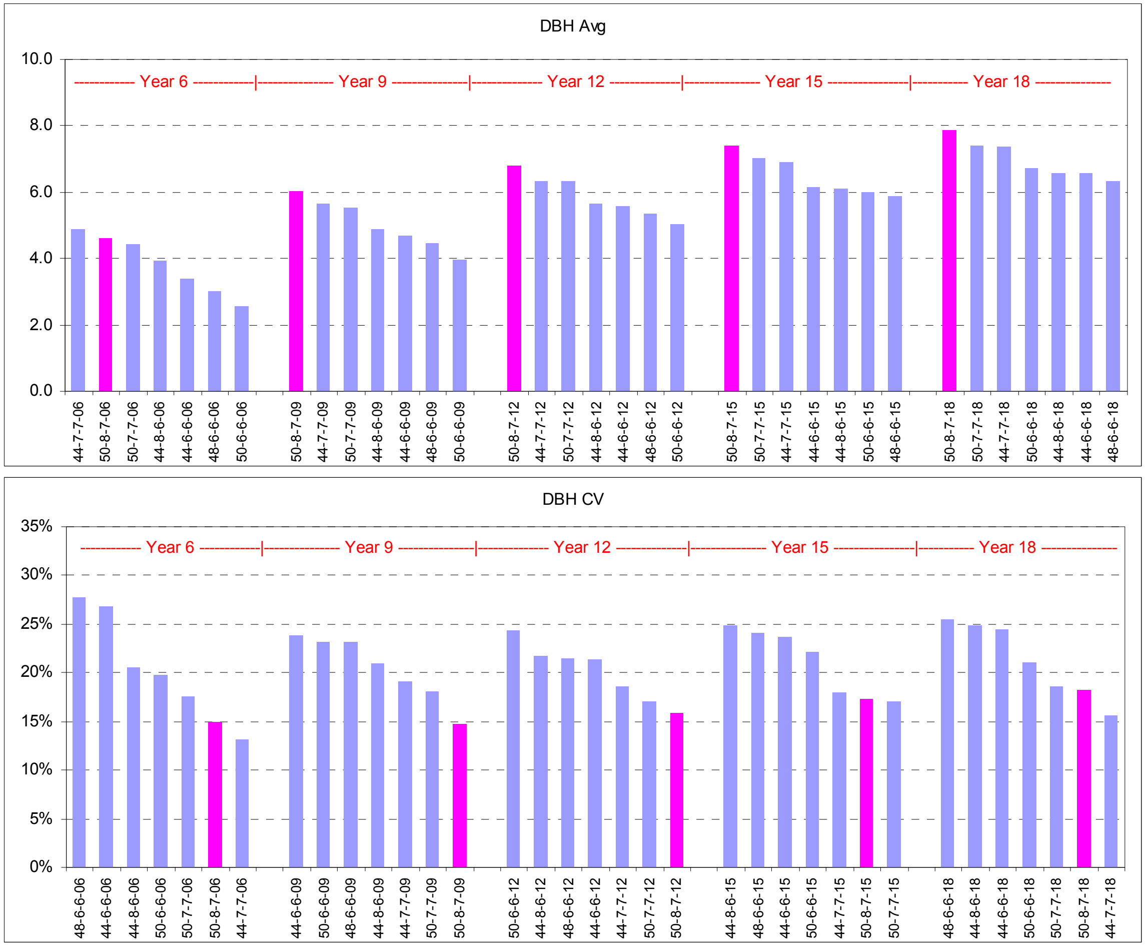


Figure 10. DBH Averages and DBH CVs by Plot, 7-056 Family, Georgia, over 18 Years

Figure 11. DBH Kurtosis and Skewness by Plot, 7-056 Family, Georgia, over 18 Years

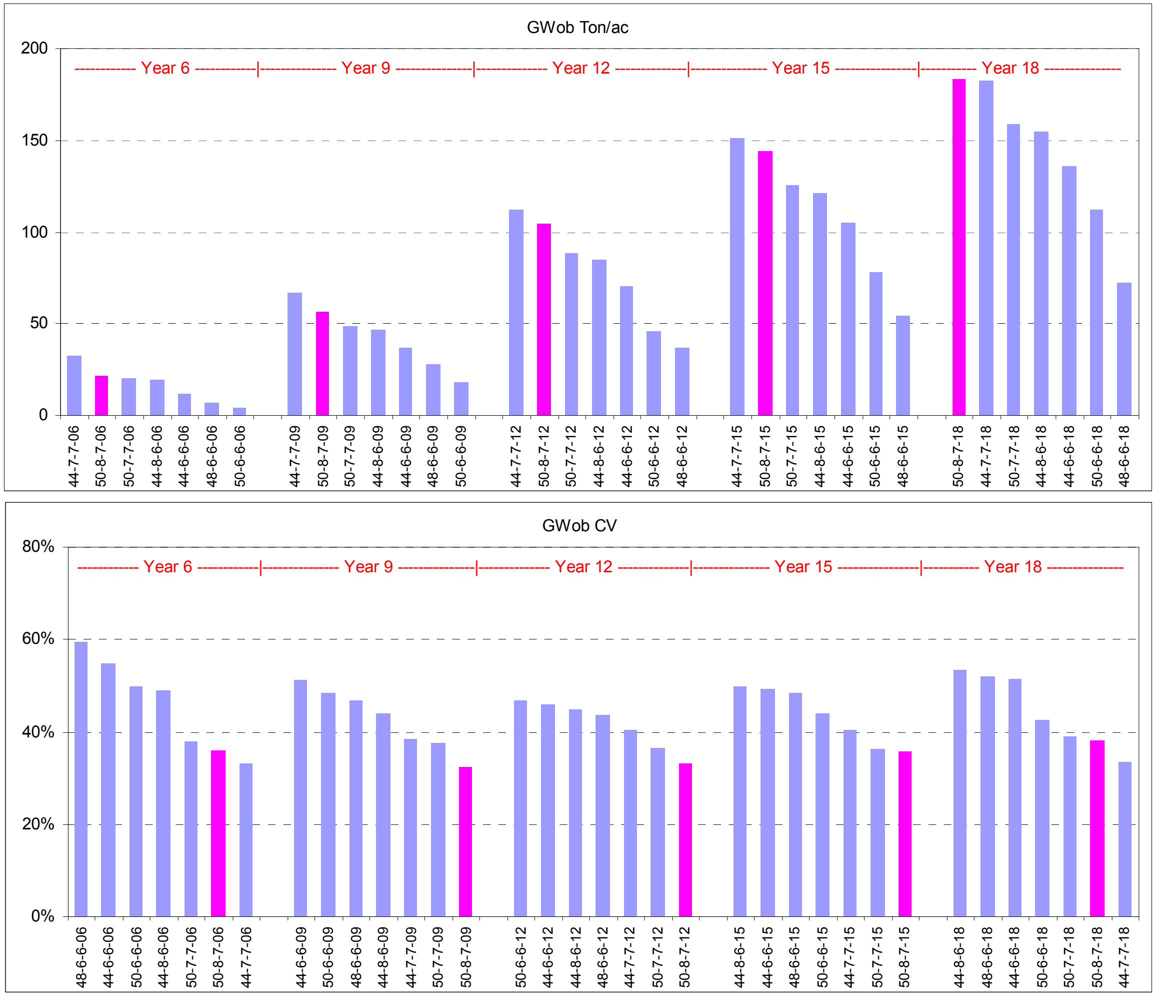


Figure 12. Green Weight outside bark Averages (Tons/acre), and CVs: 7-056 Family, Georgia, over 18 Years

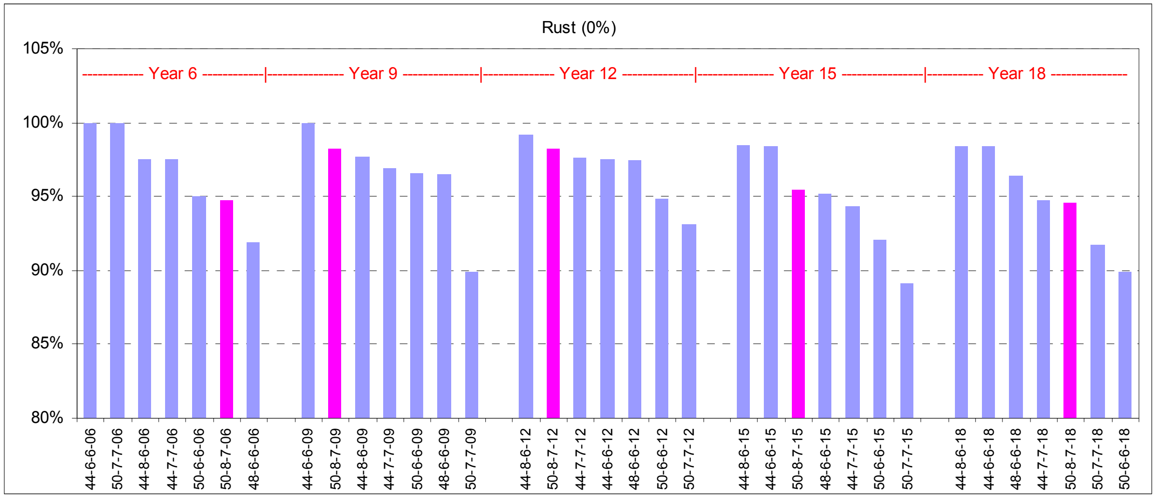


Figure 13. Rust-Free Averages per Plot, 7-056 Family, Georgia, over 18 Years

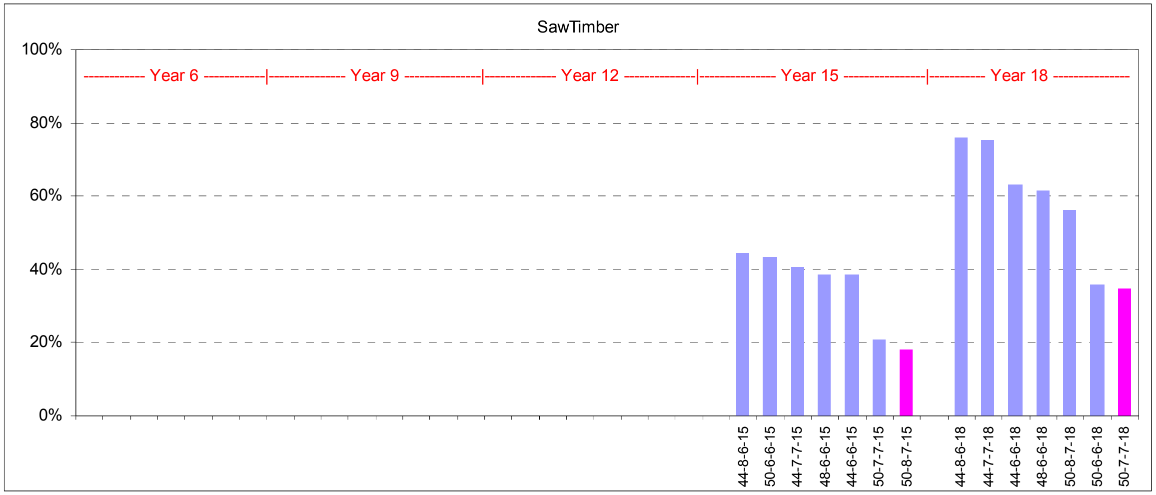


Figure 14. Sawtimber Potential per Plot, 7-056 Family, Georgia, Ages 15 and 18 Years

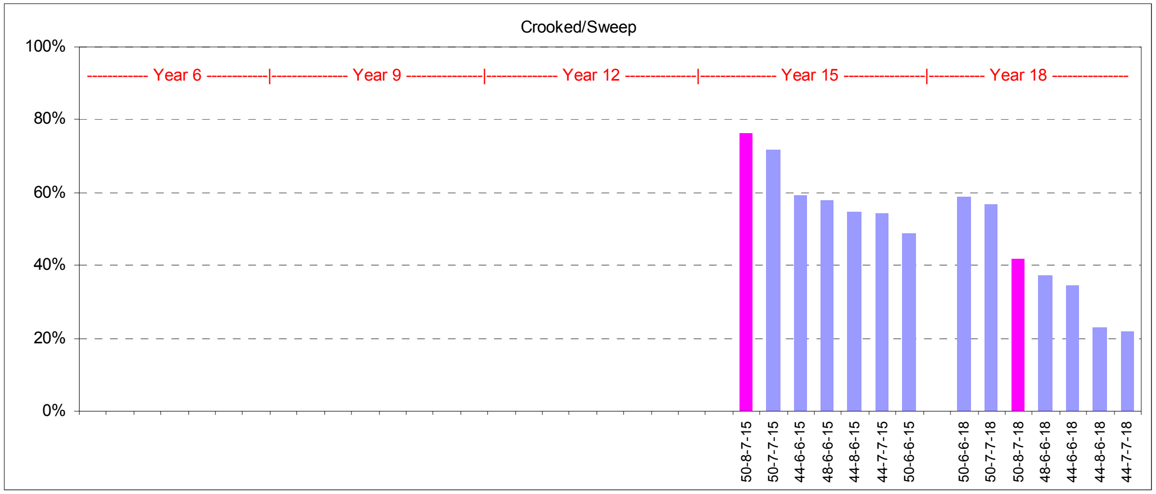


Figure 15. Crooked/Sweep as Sawtimber Rejection Factor per Plot, 7-056 Family, Georgia, Ages 15 and 18 Years

APPENDIX E

UNIFORMITY

Figure 16. DBH Averages and DBH CVs by Plot, North Carolina

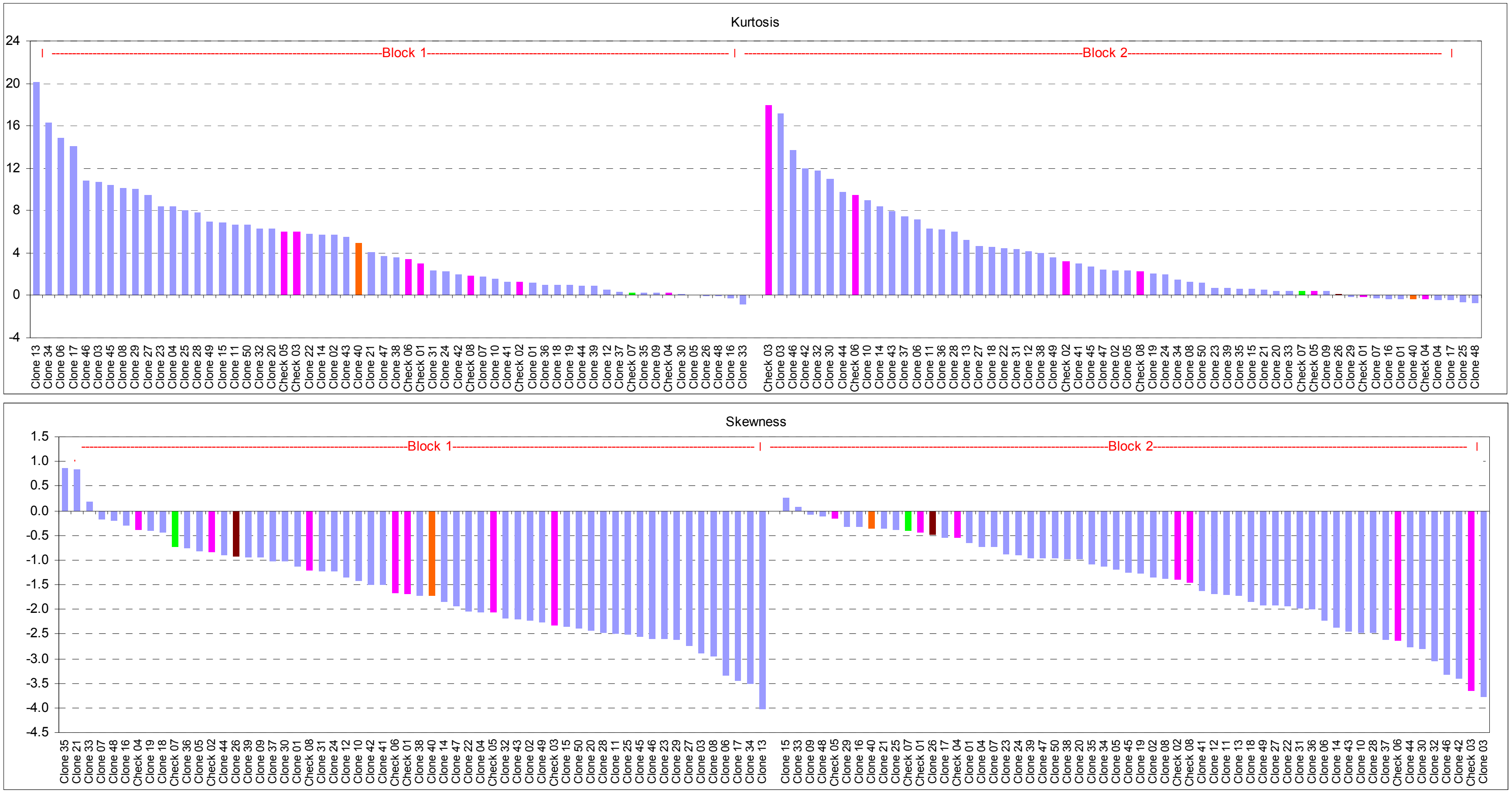


Figure 17. DBH Kurtosis and Skewness by Plot, North Carolina

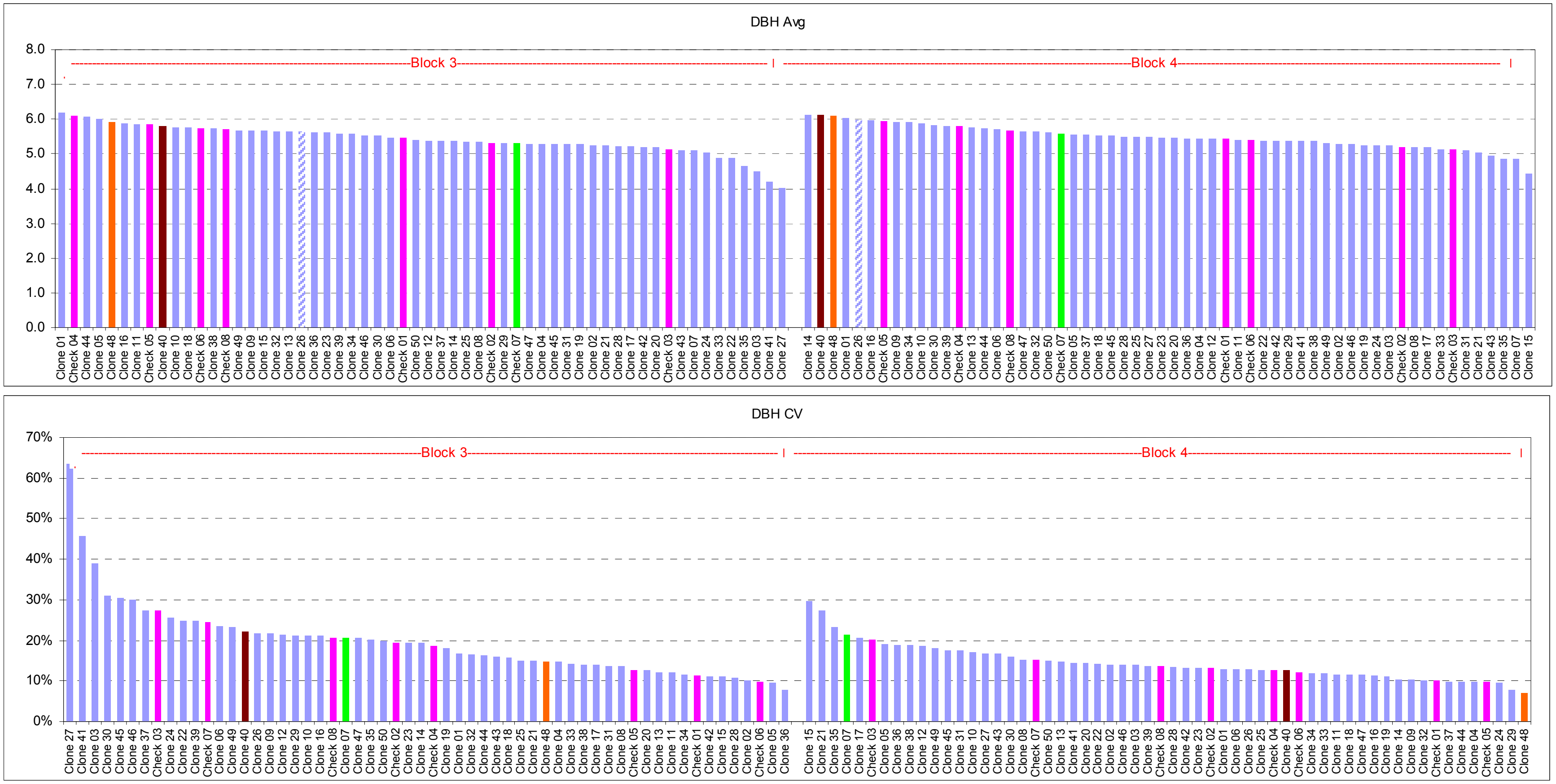
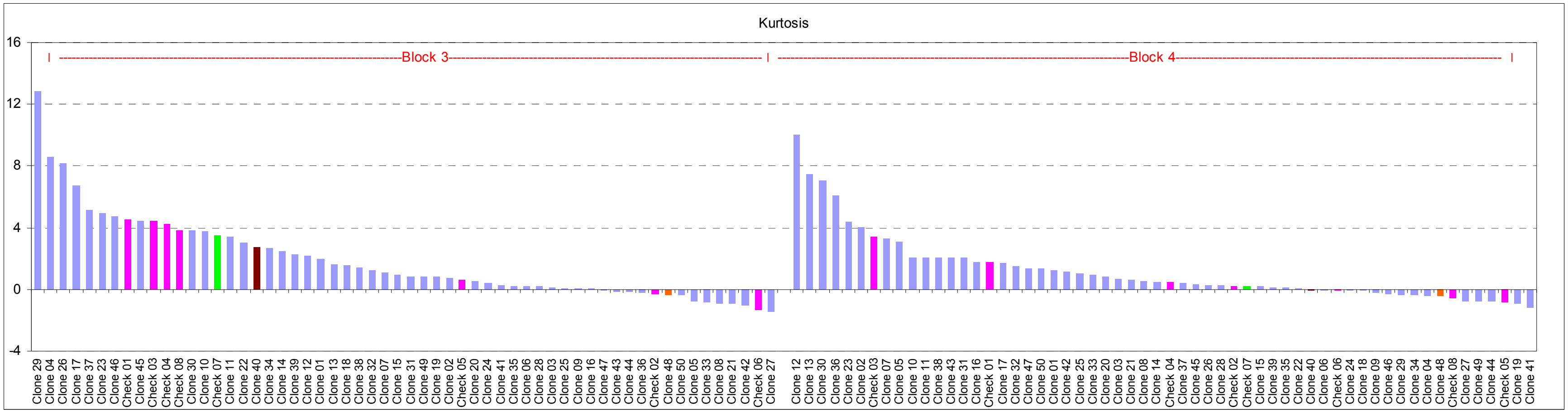


Figure 18. DBH Averages and DBH CVs by Plot, Alabama



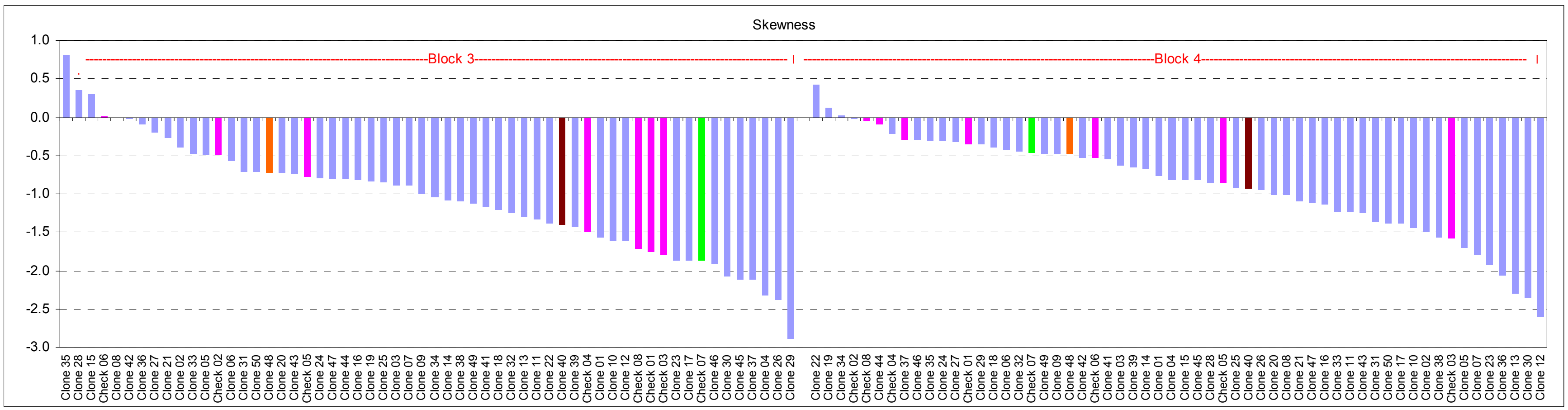


Figure 19. DBH Kurtosis and Skewness by Plot, Alabama

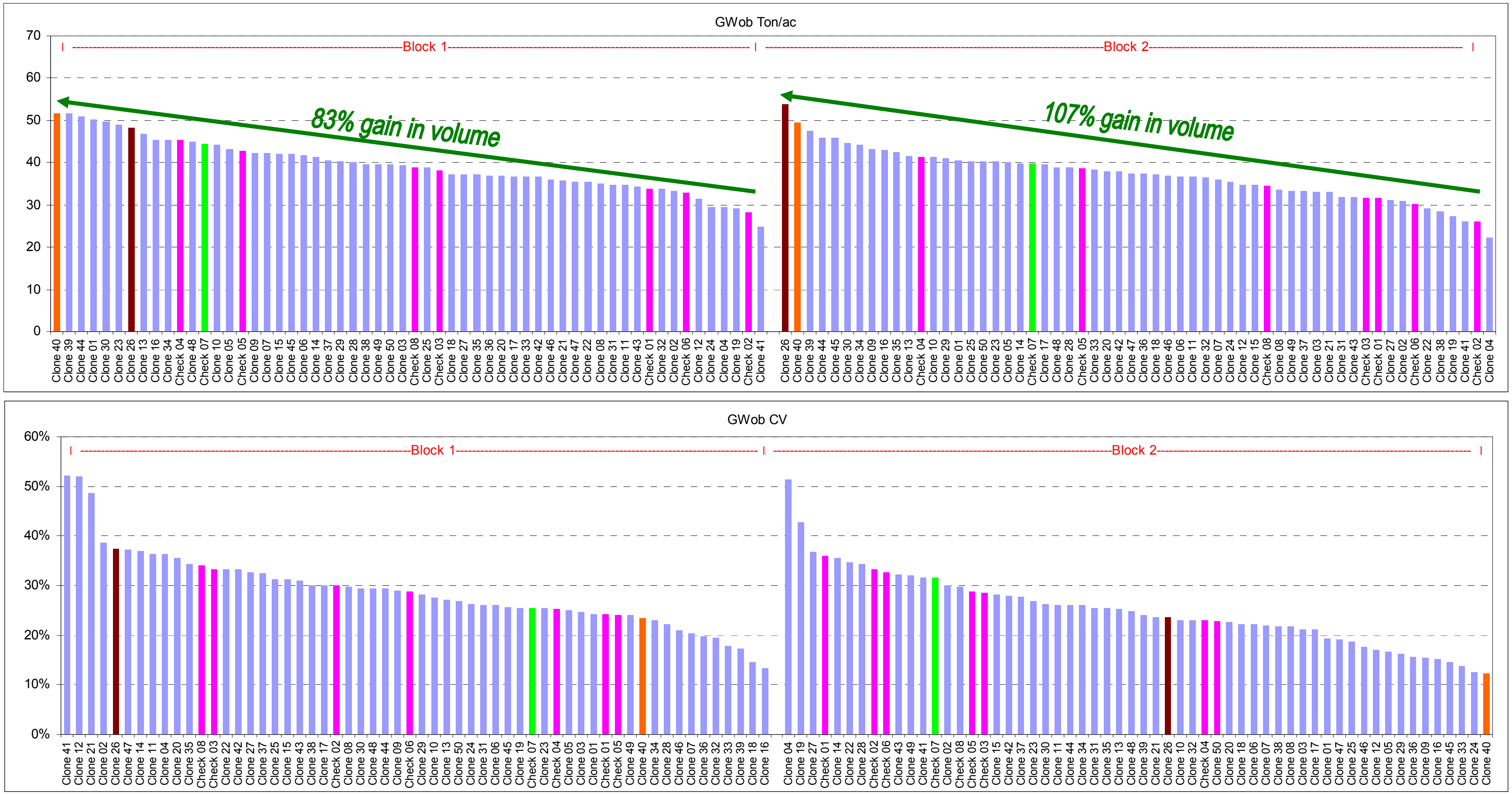


Figure 20. Green Weight outside Bark for 58 Plots Over 6 Year Period, and Individual Tree Coefficient of Variation for Growth over 6 Year Period, North Carolina

Figure 21. Green Weight outside Bark for 58 Plots Over 6 Year Period, and Individual Tree Coefficient of Variation for Growth over 6 Year Period, Alabama

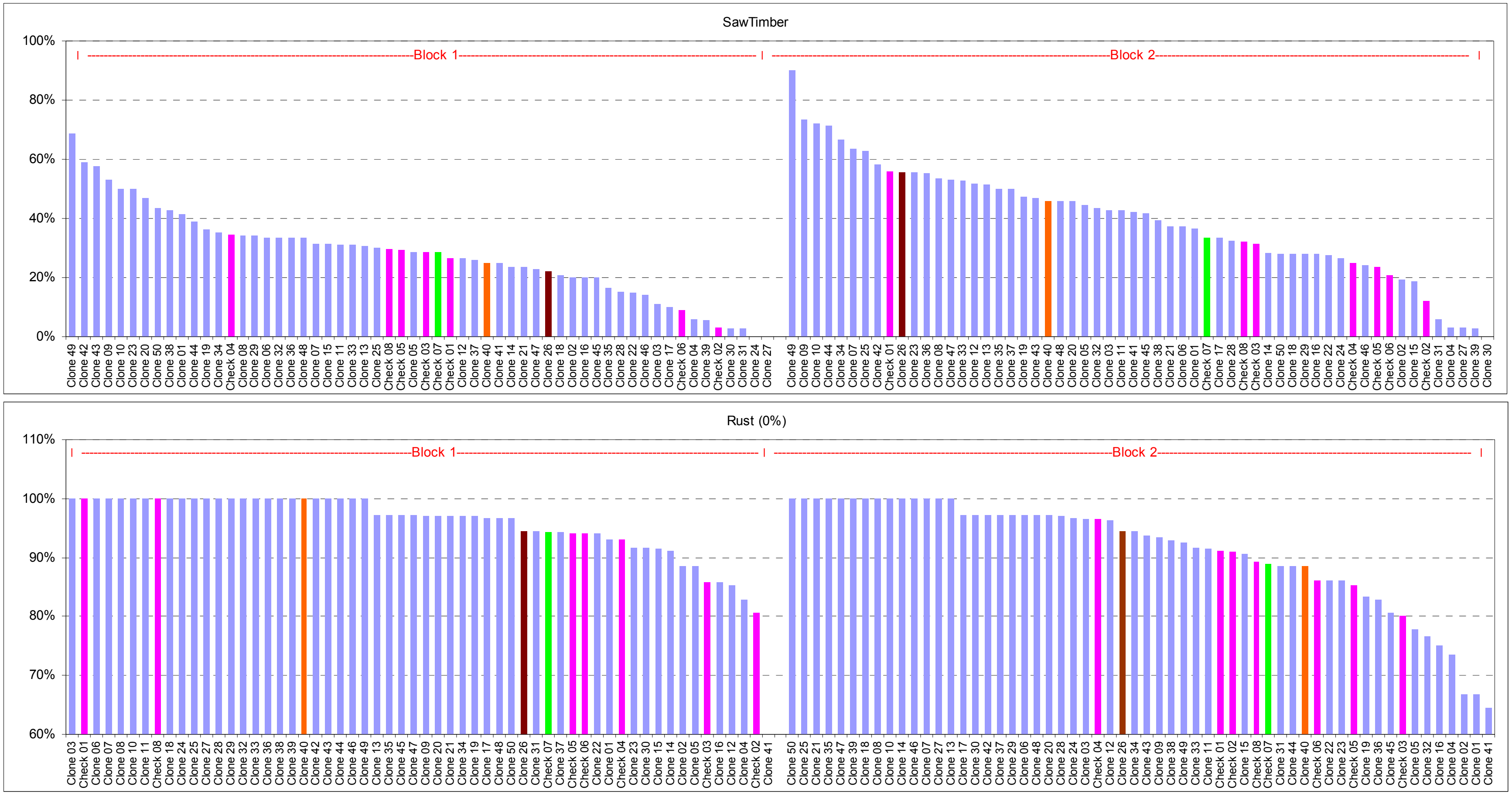


Figure 22. Sawtimber Potential and Rust-Free Averages, North Carolina

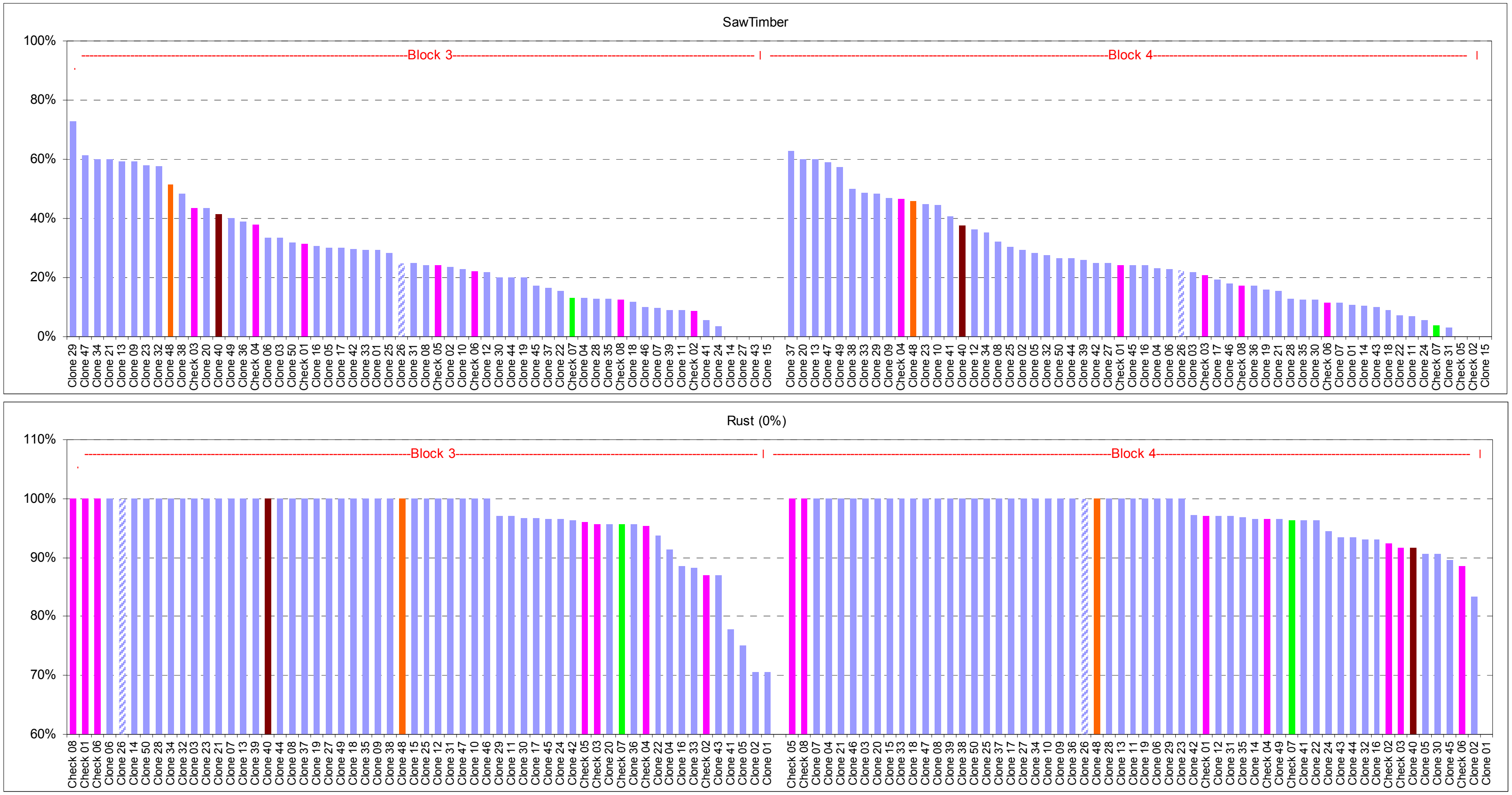


Figure 23. Sawtimber Potential and Rust-Free Averages, Alabama

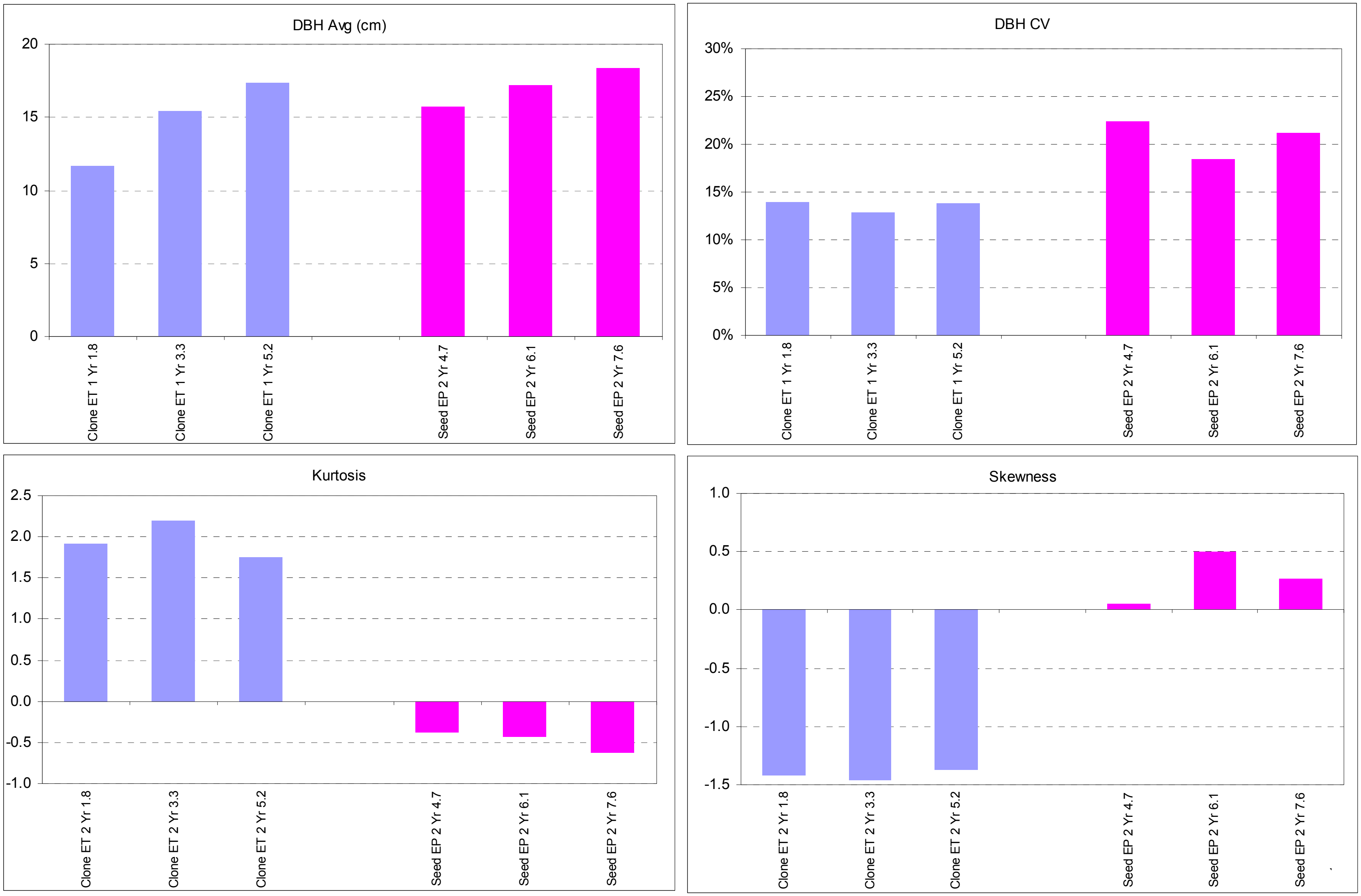


Figure 24. DBH Averages and DBH CVs by Plot, for *Eucalyptus tereticornis* (Clone) and *Eucalyptus pellita* (Seeds, Control), at Different Ages (Refocosta, Colombia)

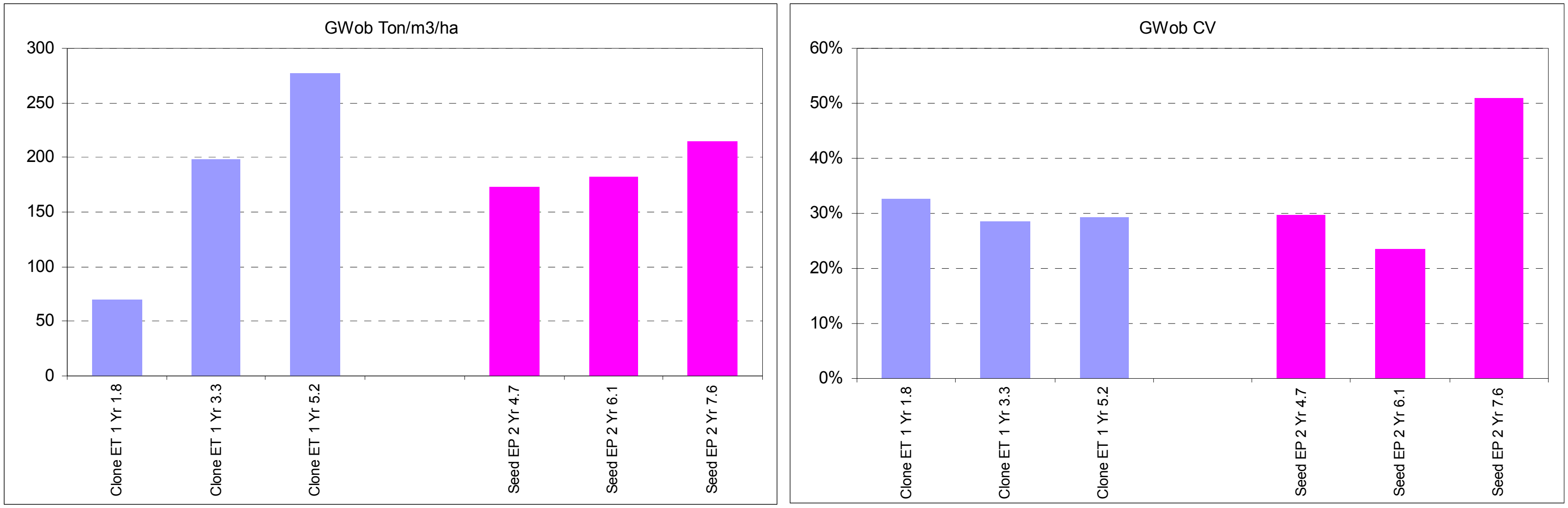


Figure 25. Volume and Volume CVs for *Eucalyptus tereticornis* (Clone) and *Eucalyptus pellita* (Seeds, Control), at Different Ages (Refocosta, Colombia)

APPENDIX F

MODELING

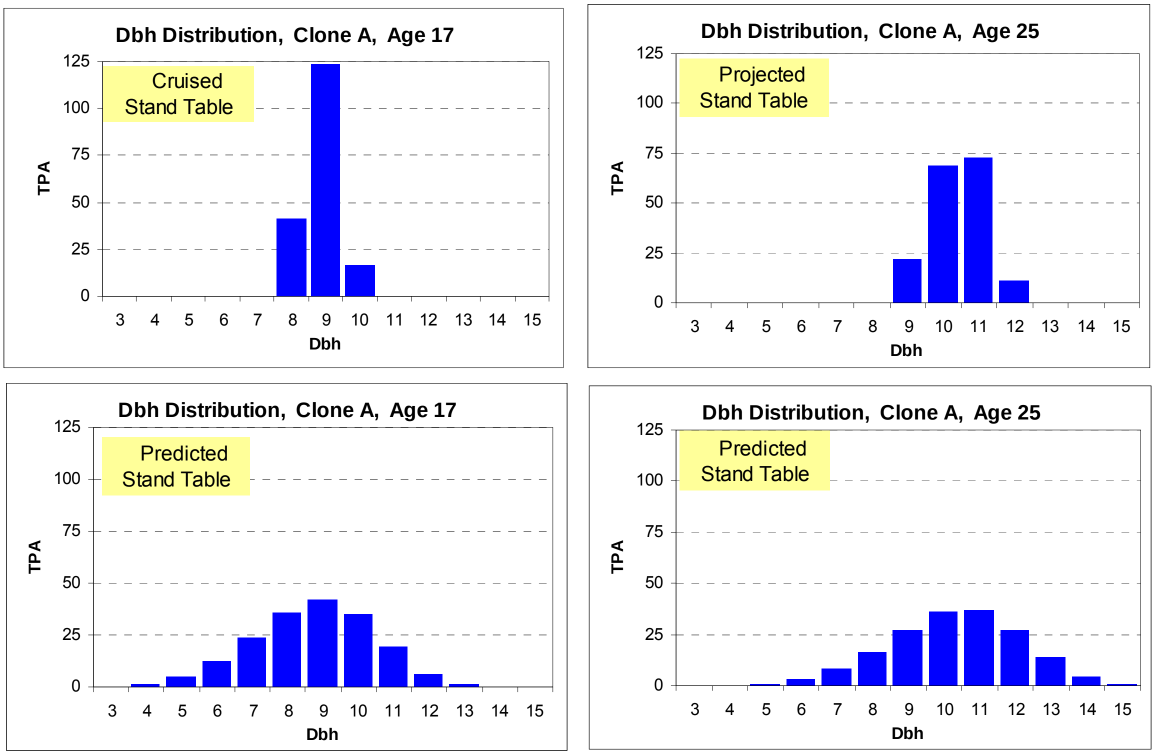


Figure 26. Descriptive Results for Selected Clone A (Generalized Stand Table Projection vs. Diameter Distribution Recovery Approach -Weibull)

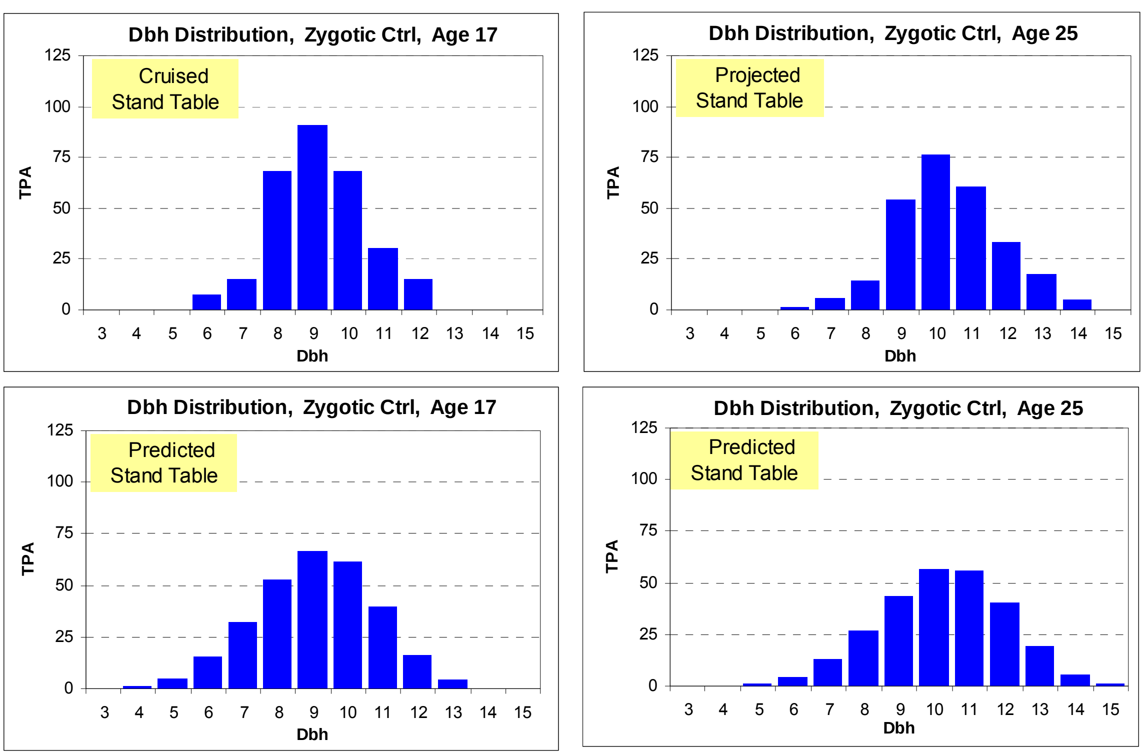


Figure 27. Descriptive Results for Selected Zygotic Control (Generalized Stand Table Projection vs. Diameter Distribution Recovery Approach -Weibull)

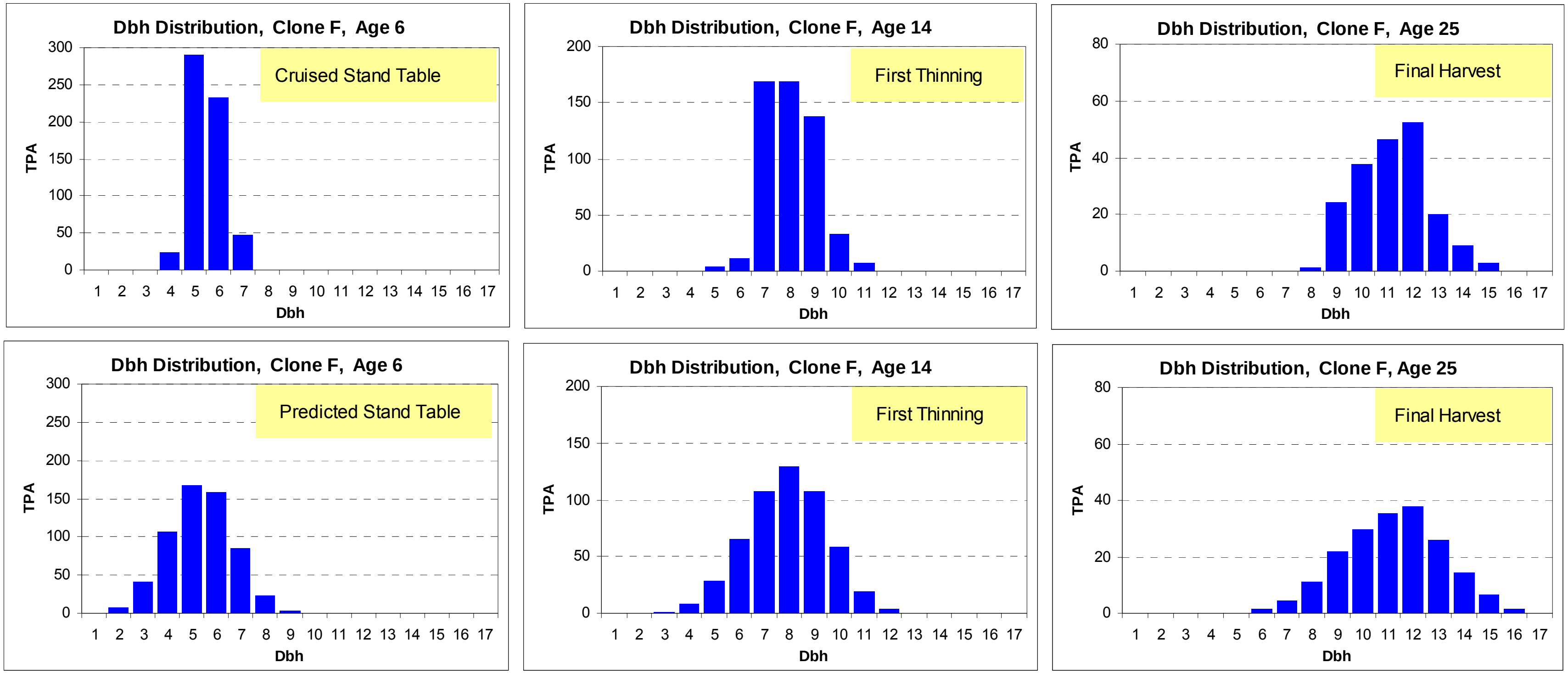


Figure 28. Descriptive Results for Selected Clone F (Generalized Stand Table Projection vs. Diameter Distribution Recovery Approach -Weibull)

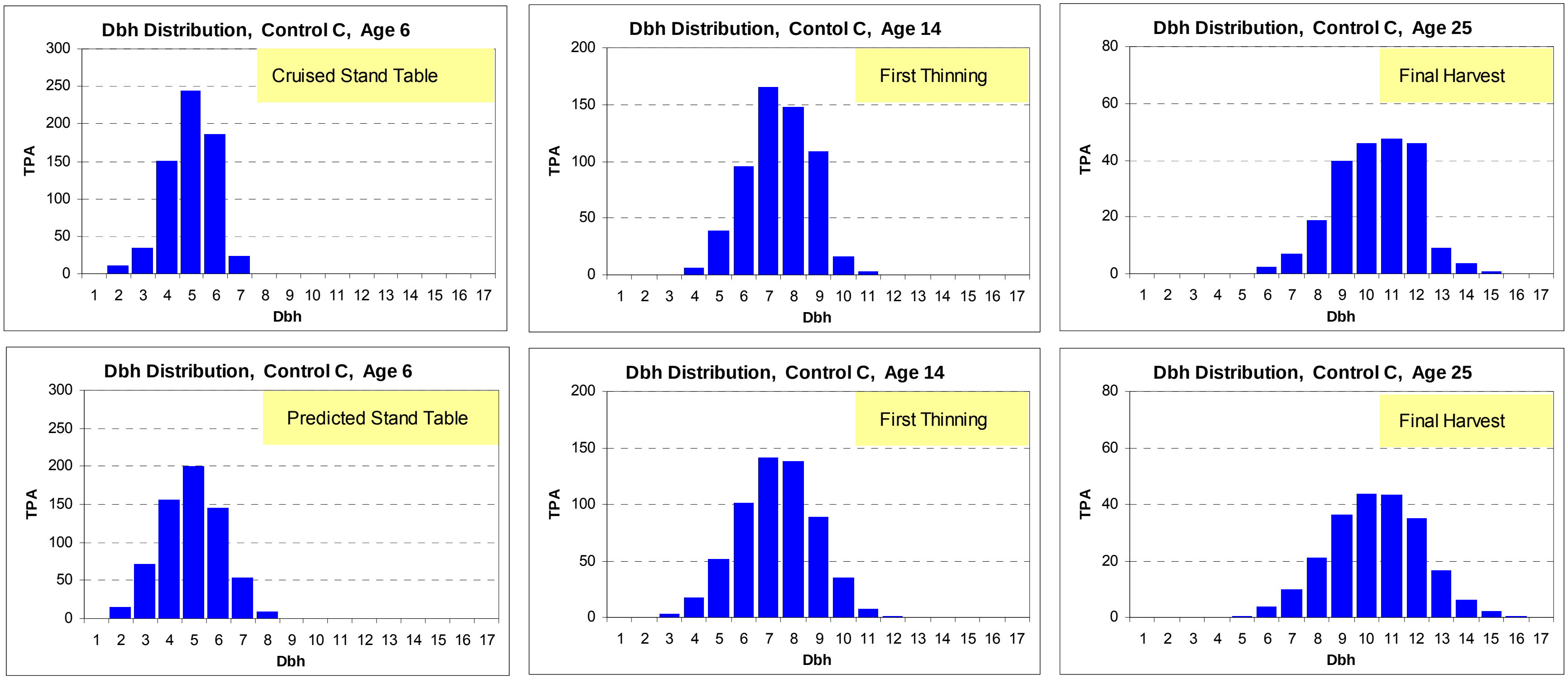


Figure 29. Descriptive Results for Selected Zygotic Control (Generalized Stand Table Projection vs. Diameter Distribution Recovery Approach -Weibull)

APPENDIX G

FINANCIAL COMPARISON OF G & Y MODELS

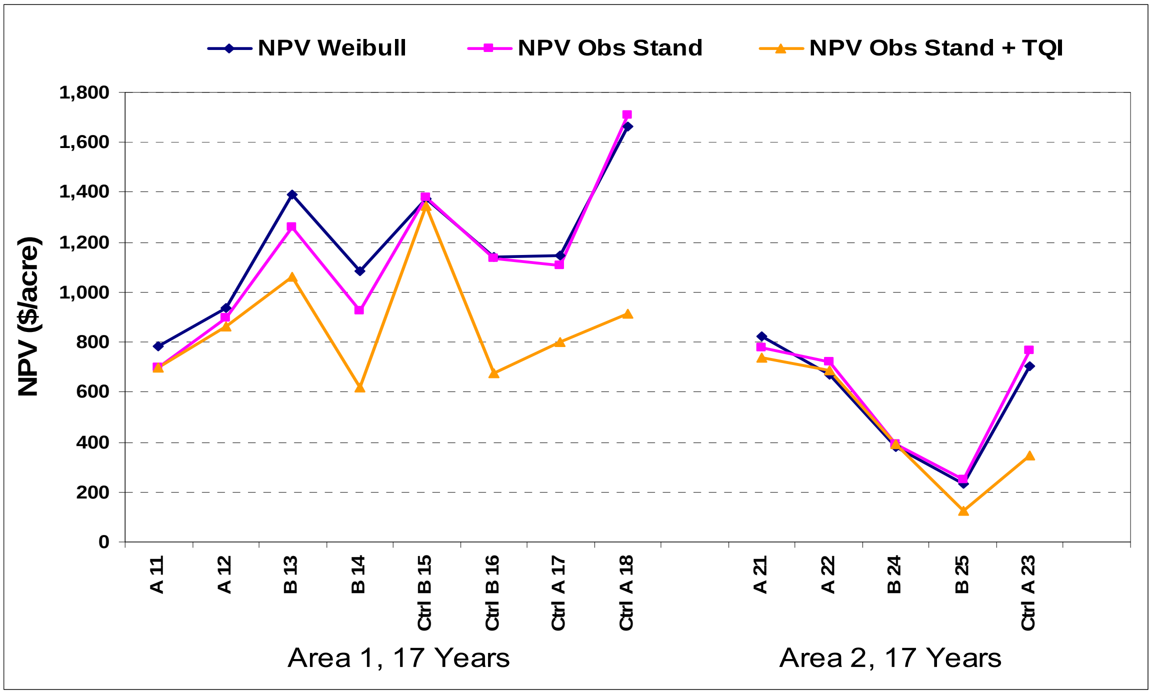


Figure 30. NPV Comparisons for 17 Yr. Plots

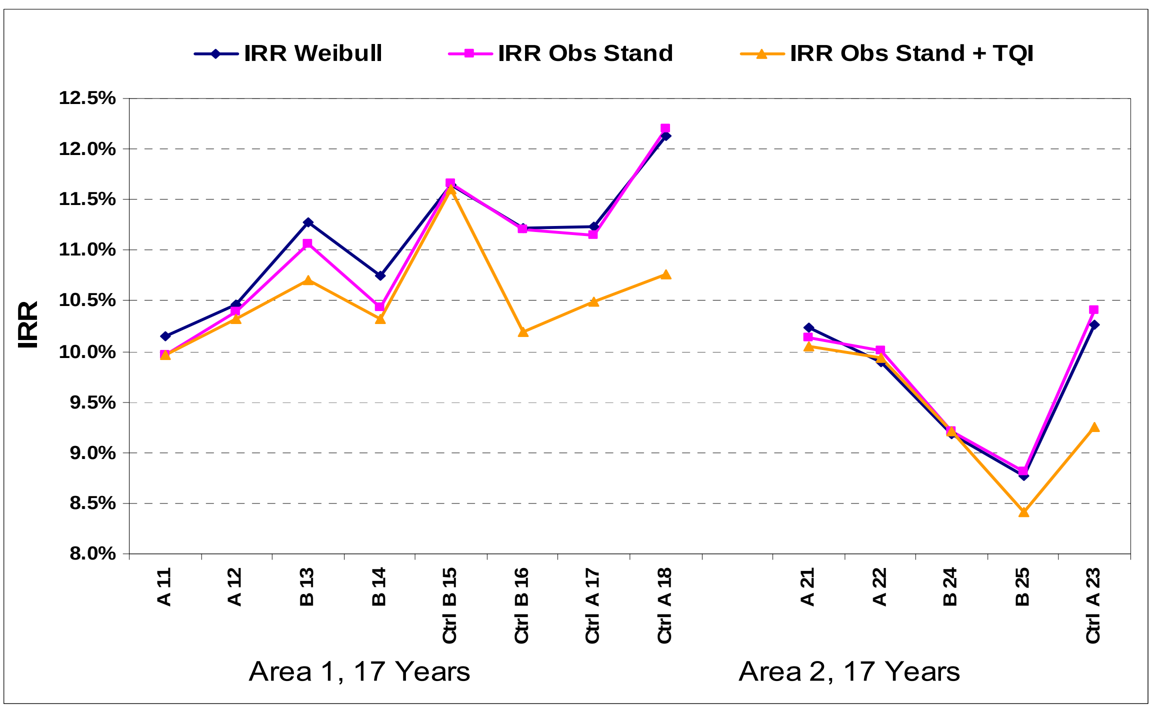


Figure 31. IRR Comparisons for 17 Yr. Plots

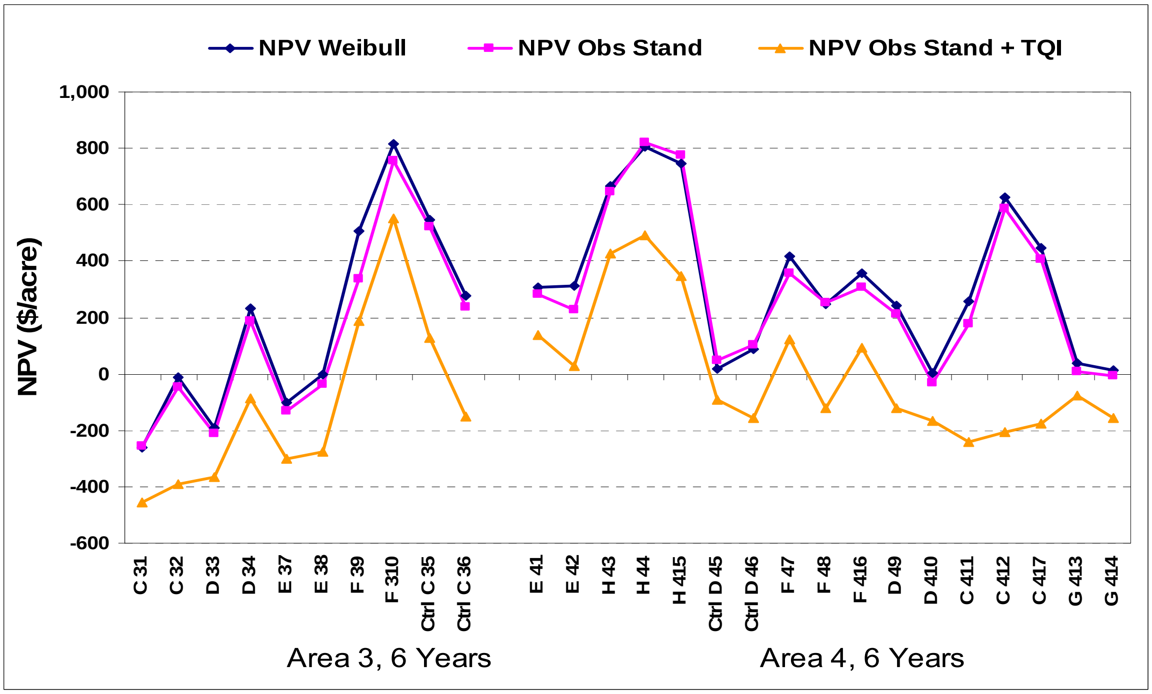


Figure 32. NPV Comparisons for 6 Yr. Plots

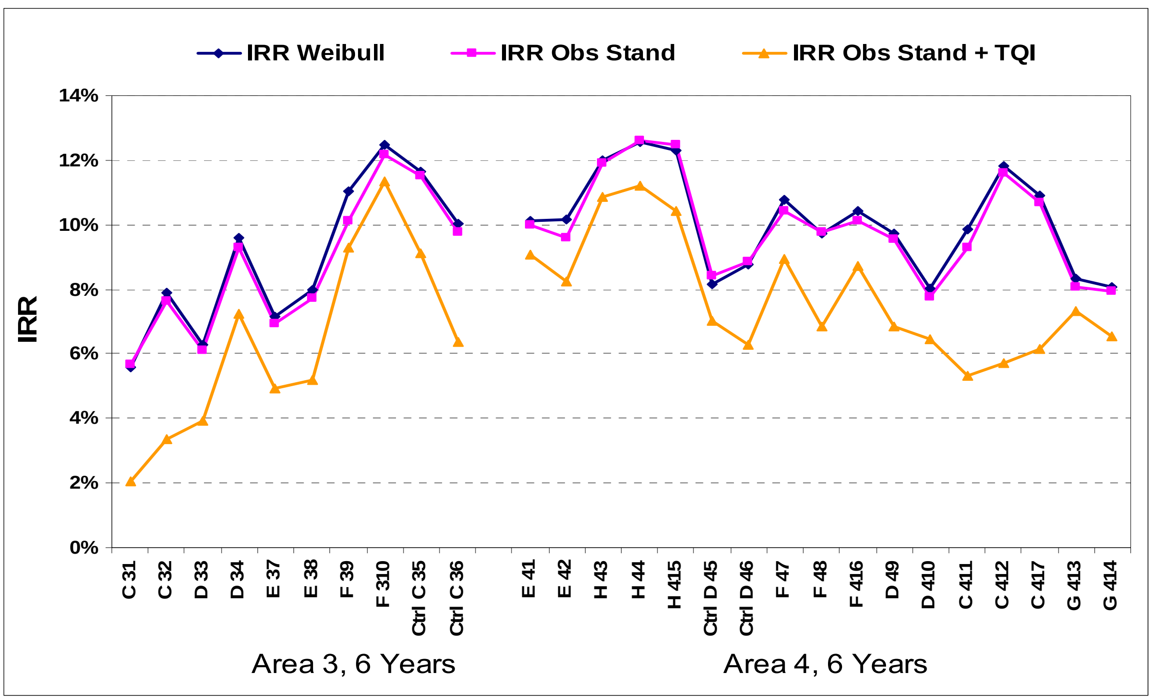


Figure 33. IRR Comparisons for 6 Yr. Plots

APPENDIX H

MANAGEMENT REGIMES

MANAGEMENT REGIMES

Company 1, Three Locations: Management Regime

Pure clonal loblolly pine blocks from rooted cuttings or SE seedlings were established early in 1989 and 1999 in the lower coastal plain of Georgia and South Carolina. Related and unrelated seedling control blocks were also planted adjacent to the clonal blocks at this time. None of the clones were selected with respect to growth. The purpose of establishing these blocks was to compare clonal and non-clonal stands for uniformity.

The first set of two clonal demo blocks were propagated from rooted cuttings, clones A and B; and two seedling demo blocks, seedling A (clone A parent, half sib) and seedling B (Clone B parent, full sib) were included as controls and planted by hand (8' x 10') in Georgia. The blocks were 5th row thinned and selected within at age 12. The management schedule consisted of weed control for the first two years, and tip moth control for the first three years.

The second set of four clonal demo blocks from somatic embryogenesis containerized seedlings, clones C, D, E, and F; and one bare root seedling demo plot (clones C, D, E, and F half sib), included as control, were planted by machine (6' x 12') in Georgia in late 1999. Clonal trees were derived from a single open-pollinated family, the same family of the non-clonal trees (same genetic background as clones). Site preparation included chopping and bedding; herbicide (3 oz of Oust + 48 oz of Velpar per acre), fertilizer (125 lb/ac of DAP in year 0). Insecticide (3.3 gm/tree of Furadan at planting time) was applied with ground equipment. Soil type is moderately to well-drained. First year survival rate was higher than 90%; currently the trees are growing relatively well without weed pressure.

The third set of six clonal demo blocks from somatic embryogenesis containerized seedlings includes clones C, D, E, F, G, and H (clones G and H have the 7-056 family in their pedigree). One bare root seedling demo block (unrelated to clones) was also included as control. These demo blocks were planted by hand (7' x 11', each block, 6 x 50 trees per row) in South Carolina in early 2000. Soil type was somewhat poorly drained (Blayden); site was bedded prior to planting. First year herbaceous weed control (3 oz of Oust + 48 oz of Velpar per acre) was applied in this spring after planting. First year Tip Moth control (Pounce, 3 sprays), and second year briar control (Escort 1 oz/ac and Arsenal 6 oz/ac) were applied; neither fertilization, nor other treatments, were applied. First year survival rate was + 90% in spite of intensive weed and hardwood competition at early growth age.

Company 2, Three Locations: Management Regime

Pure loblolly pine blocks from SE seedlings and zygotic seedlings were established early in 2001 in the lower coastal plain of Mississippi. None of the elite varieties were selected with respect to growth or performance. The purpose of establishing these blocks was to monitor their development and uniformity. The uniformity of ten 6-year-old elite variety blocks to three 6-year-old improved seedling blocks (full-sib, half-sib, and seed orchard bulk, a mix of seedlings from a well-rogued 1.5 generation orchard) were compared.

The site was disked and subsoiled (cross-hatched) prior to hand planting; Tip Moths were controlled by ground spraying until a majority of the trees were above head-height (eight applications). Herbaceous competition (there were no hardwoods) was almost completely controlled (some grass grew) within the tree rows until crown closure (3 oz of Oust + 48 oz of Velpar by hand). Currently, the trees are growing without weed / hardwood competition. DAP was applied at a common rate (~250 lbs/ac) at age 3. Spacing was 6' x 10'. Non-spodosol soil type is moderately well-drained.

Company 3, Three Locations: Management Regime

Pure elite variety loblolly pine blocks from SE seedlings were established in the lower coastal plain of Georgia in two locations and three replications per location, in January 2004. The performance of six commercial clones vs. the best half sib seedling source under monitored operational management conditions was analyzed. For both installations, the previous land use was slash pine plantation.

The management regime in location 1 was chopping, spot-raking, and bedding. The regime in location 2 was spot raking and bedding. Herbaceous weed control was applied to both installations the following spring at the rate of 13 oz/acre Oustar banded. Neither site received chemical site prep due to the late timing of mechanical site prep. Both installations were mechanically planted for an intended density of 605 TPA (6’x12’), but TPAs actually vary. These sites resemble operational plantings rather than trial plantings.

There was no fertilization at planting time. Future management of these trials includes a first fertilization at year 3-5, then at year 8-10 (60 lb DAP, + 238 lb Urea, + 87 lb potassium sulfite, and + 20 lb boron), and finally mid-rotation fertilization (91 lb DAP, + 356 lb Urea, 87 lb potassium sulfite, and + 20 lb boron). Company 3’s standard regime is a single thinning. Thinning age is usually between 14-16 yrs; typical optimized rotation age is at ~25 yr. Surrounding the clonal blocks, the control 7-056 was also established. In total, 42 permanent plots were established and marked.

In the first installation, the three trial blocks are located on Olustee (Ultic Alaquod) and Pelham (Arenic Paleaquult) series soils. Both soils are poorly drained. Olustee soils occur on broad flats and are slightly better drained than the Pelham soils, which occur in depressions. Both soils have low fertility and are often bedded and P fertilized at plantation establishment.

In the second installation, two of the three trials are also located largely on Olustee series soils. The third trial is located on Olustee, which extends into an area mapped as Rutledge. Rutledge soils are very poorly drained soils that occur in depressions or on floodplains. They have a water table at/or near the surface for long periods of the year. Ponding is common. They do not have a B horizon, and they are sandy textured throughout the profile.

Company 4, Three Locations: Management Regime

Pure elite variety loblolly pine blocks from rooted cuttings were established in May 1990 and in November 2000 in the lower coastal plain of North Carolina and Alabama. The purpose of establishing these demonstration blocks was to compare, quantitatively, clonal and non-clonal plantations. The first trial installation includes 20 clones and one selected family as control. For the youngest trials, two replications were established, per location, of 50 clones and eight controls, with diverse levels of improvement between wild seeds and second generation mass control pollinated seeds.

For both locations in North Carolina, the previous land use was loblolly pine plantation. These wet areas were improved with drainage or water control by raising beds. Site preparation included shearing, piling, bedding, and raking. For herbaceous weed control, Oust and glyphosate were applied, and mechanical weed control included brush chopping by machete and ax when needed. Fertilization with phosphorus at planting was applied. For both tracks, containerized rooted cuttings were planted by hand for an intended density of 605 TPA (6’x12’) for the oldest trial, and 454 TPA (8’x12’) for the youngest.

For the demo blocks in Alabama, site preparation was by a single-pass ripper to 12-16 inches (no bedding). Arsenal (four ounces) and Oust (two ounces) were applied by backpack, one per year for four years, and one application of Round Up was applied. One hundred per cent Tip Moth control was applied (April, June, July, August, and September) during the first four years, using 3.8 lb. of Orthene each time. No fertilization was applied. Containerized rooted cuttings were planted by hand for an intended density of 538 TPA (9' x 9'). Briars were mowed as needed.

In total, 137 permanent plots in the three locations, which were systematically well-monumented, were recorded. As a planting standard in all locations, lateral buffer rows were established, except in front of, at the back of, and in-between replications. Thus, for this analysis, the final database excluded the trees with border effect

The NC study sites are located on very poorly drained soils; whereas, the AL site is located on a well-drained soil. The Wasda series that occurs on the NC site is characterized by an O horizon ranging from 0" to more than 12" in depth, over low chroma (gray), sandy clay loam, to clay loam Bg horizon. The combined thickness of the O, A and B horizons is less than 60" deep and is underlain by a sand to sandy clay loam C horizon. The very poorly drained Belhaven series mapped at the NC site is an organic soil with 16" to more than 50" inches of black O horizon materials overlaying low chroma sandy loam to clay loam sediments. In contrast, the AL site is located on deep, well-drained Ruston series soils. These soils are characterized by sandy loam A and E horizons, overlying a yellowish to reddish loam to sandy clay loam Bt horizon. The depth of the A, E, and Bt horizons is more than 80".

APPENDIX I

STATISTICAL ANALYSES: THREE-YEAR- AND SIX-YEAR-OLD PLOTS

Statistical Analyses: Three-year-old Replicated Plots (Responses at Plot Level for Both Installations)

Table 1. ANOVA Table for Three-year-old Replicated Plots, Variable: DBH

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Label	6	1.02255734	0.17042622	7.28	0.0146
Installation	1	1.68861532	1.68861532	72.10	0.0001
Block(Installation)	4	0.76409020	0.19102255	5.28	0.0034
Label*Installation	6	0.14052177	0.02342029	0.65	0.6917

Comments:
1. There is a significant difference in the response (average DBH) across the seven labels (six clones and one control) at 5% level.
2. There is a significant difference in the response across the two installations (1% level).
3. There is a significant Block (nested in installation) effect at 1% level.
4. There is a non-significant interaction Installation*Label effect (p-value=0.6917).

Table 2. ANOVA Table for Three-year-old Replicated Plots, Variable: HT

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Label	6	21.673264	3.612211	8.34	0.0104
Installation	1	29.598437	29.598437	68.34	0.0002
Block(Installation)	4	14.413208	3.603302	5.80	0.0021
Label*Installation	6	2.598774	0.433129	0.70	0.6546

Comments:
1. There is a significant difference in the response (average HT) across the seven labels (six clones and one control) at 5% level.
2. There is a significant difference in the response across the two installations (1% level).
3. There is a significant Block (nested in installation) effect at 1% level.
4. There is a non-significant interaction Installation*Label effect (p-value=0.6546).

Table 3. ANOVA Table for Three-year-old Replicated Plots, Variable: BA ft^2/ac

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Label	6	157.134632	26.189105	7.69	0.0127
Installation	1	348.524598	348.524598	102.33	<.0001
Block(Installation)	4	190.851785	47.712946	8.62	0.0002
Label*Installation	6	20.434589	3.405765	0.62	0.7158

Comments:

1. There is a significant difference in the response (average BA ft^2/ac) across the seven labels (six clones and one control) at 5% level.
2. There is a significant difference in the response across the two installations (1% level).
3. There is a significant Block (nested in installation) effect at 1% level.
4. There is a non-significant interaction Installation*Label effect (p-value=0.7158).

Table 4. ANOVA Table for Three-year-old Replicated Plots, Variable: D^2H $ft^3/acre$

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Label	6	61854	10309	5.98	0.0235
Installation	1	113114	113114	65.56	0.0002
Block(Installation)	4	70889	17722	9.65	<.0001
Label*Installation	6	10352	1725.293645	0.94	0.4858

Comments:

1. There is a significant difference in the response (average D^2H $ft^3/acre$) across the seven labels (six clones and one control) at 5% level.
2. There is a significant difference in the response across the two installations (1% level).
3. There is a significant Block (nested in installation) effect at 1% level.
4. There is a non-significant interaction Installation*Label effect (p-value=0.4858).

Statistical Analyses: Three-year-old Replicated Plot (Responses at Plot Level for Each Installation)

Multiple Comparisons for Three-year-old Replicated Plots

Table 5. Dunnett's t Tests for DBH

------------- DBH Inst 1----------------/-------------- DBH Inst 2------------------

Label Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		Label Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
COMM1 - OP7056	-0.0778	-0.6534	0.4978	COMM1 - OP7056	0.0229	-0.2871	0.3330	
COMM3 - OP7056	-0.1126	-0.6882	0.4630	COMM2 - OP7056	-0.2077	-0.5177	0.1024	
COMM2 - OP7056	-0.1393	-0.7149	0.4363	COMM5 - OP7056	-0.2612	-0.5713	0.0488	
COMM4 - OP7056	-0.3448	-0.9204	0.2308	COMM3 - OP7056	-0.2668	-0.5768	0.0432	
COMM6 - OP7056	-0.3963	-0.9719	0.1793	COMM4 - OP7056	-0.3570	-0.6671	-0.0470	***
COMM5 - OP7056	-0.4911	-1.0667	0.0845	COMM6 - OP7056	-0.4454	-0.7555	-0.1354	***

Comparisons significant at the 0.05 level are indicated by ***

Table 6. Dunnett's t Tests for HT

--------------- HT Inst 1----------------/--------------- HT Inst 2----------------

Label Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		Label Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
COMM1 - OP7056	-0.3322	-2.6309	1.9665	COMM1 - OP7056	-0.0277	-1.4625	1.4072	
COMM2 - OP7056	-0.3439	-2.6426	1.9548	COMM2 - OP7056	-0.9679	-2.4027	0.4670	
COMM3 - OP7056	-0.5896	-2.8884	1.7091	COMM3 - OP7056	-1.2321	-2.6669	0.2027	
COMM4 - OP7056	-1.5953	-3.8940	0.7035	COMM5 - OP7056	-1.2842	-2.7190	0.1506	
COMM6 - OP7056	-1.6282	-3.9270	0.6705	COMM6 - OP7056	-1.9394	-3.3743	-0.5046	***
COMM5 - OP7056	-2.0615	-4.3602	0.2373	COMM4 - OP7056	-2.1332	-3.5680	-0.6983	***

Comparisons significant at the 0.05 level are indicated by ***

Table 7. Dunnett's t Tests for D^2H ft^3/acre

-----------D2H ft^3/acre Inst 1-------------/------------D2H ft^3/acre Inst 2------------

Label Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		Label Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
COMM1 - OP7056	-6.88	-104.91	91.16	COMM1 - OP7056	12.77	-97.23	122.76	
COMM2 - OP7056	-36.50	-134.53	61.53	COMM2 - OP7056	-59.11	-169.11	50.88	
COMM3 OP7056	-40.35	-138.38	57.69	COMM5 - OP7056	-80.78	-190.78	29.21	
COMM4 - OP7056	-57.73	-155.76	40.31	COMM3 - OP7056	-90.15	-200.14	19.85	
COMM6 - OP7056	-67.71	-165.74	30.33	COMM6 - OP7056	-125.00	-234.99	-15.00	***
COMM5 - OP7056	-77.77	-175.80	20.27	COMM4 - OP7056	-129.09	-239.08	-19.09	***

Comparisons significant at the 0.05 level are indicated by ***

NOTE: This test controls the Type I experimentwise error for comparisons of all treatments against a control.

Statistical Analyses: Six-year-old Replicated Plots (Responses at Plot Level for Both Installations)

Table 8. ANOVA Table for Six-year-old Replicated Plots, Variable: DBH

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Label	57	20.411131	0.358090	5.38	<.0001
Installation	1	66.191115	66.191115	994.92	<.0001
Block(Installation)	2	0.327525	0.163763	2.83	0.0630
Label*Installation	57	3.792153	0.066529	1.15	0.2607

Comments:

1. There is a significant difference in the response (average DBH) across the 58 labels (50 clones and eight controls) at 5% level.
2. There is a significant difference in the response across the two installations (1% level).
3. There is a non-significant Block (nested in installation) effect at 5% level (p-value=0.0630).
4. There is a non-significant interaction Installation*Label effect (p-value=0.2607).

Table 9. ANOVA Table for Six-year-old Replicated Plots, Variable: HT

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Label	57	599.238054	10.512948	3.26	<.0001
Installation	1	1182.305445	1182.305445	366.74	<.0001
Block(Installation)	2	43.314702	21.657351	11.26	<.0001
Label*Installation	57	183.758334	3.223830	1.68	0.0101

Comments:

1. There is a significant difference in the response (average HT) across the 58 labels (50 clones and eight controls) at 5% level.
2. There is a significant difference in the response across the two installations (1% level).
3. There is a significant Block-nested-in-Installation effect at 1% level.
4. There is a significant interaction Installation*Label effect (p-value=0.0101).

Table 10. ANOVA Table for Six-year-old Replicated Plots, Variable: BA ft^2/ac

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Label	57	22457	393.988305	2.79	<.0001
Installation	1	56481	56481	400.28	<.0001
Block(Installation)	2	3989.345579	1994.672790	29.67	<.0001
Label*Installation	57	8042.897948	141.103473	2.10	0.0004

Comments:

1. There is a significant difference in the response (average BA ft^2/ac) across the 58 labels (50 clones and eight controls) at 5% level.
2. There is a significant difference in the response across the two installations (1% level).
3. There is a significant Block (nested in installation) effect at 1% level.
4. There is a significant interaction Installation*Label effect (p-value=0.0004).

Table 11. ANOVA Table for Six-year-old Replicated Plots, Variable: GWob ton/acre

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Label	57	5138.469863	90.148594	3.38	<.0001
Installation	1	13407	13407	502.51	<.0001
Block(Installation)	2	626.173763	313.086881	27.85	<.0001
Label*Installation	57	1520.807974	26.680842	2.37	<.0001

Comments:

1. There is a significant difference in the response (average GWob ton/ac) across the 58 labels (50 clones and eight controls) at 5% level.
2. There is a significant difference in the response across the two installations (1% level).
3. There is a significant Block (nested in installation) effect at 1% level.
4. There is a significant interaction Installation*Label effect (p-value=0.0001).

Statistical Analyses: Six-year-old Replicated Plots (Responses at Plot Level for Each Installation)

Installation 1

Table 12. ANOVA Table for Six-year-old Replicated Plots, Variable: DBH

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Label	57	11.703096	0.205317	5.40	<.0001
Block	1	0.158849	0.158849	4.18	0.0455

Comments:

1. There is a significant difference in the response (average DBH) across the 58 labels (50 clones and eight controls) at 5% level.
2. There is a significant difference in the response across the two installations (5% level).

Multiple Comparisons: Dunnett's t Tests for DBH: Control 7-56 and Control Wild Seed

Comments: Dunnett's t Tests for DBH

1. At 5% level of significance, the average DBH for the Clones 02, 19, 08, 04, and 41 is statistically different from the Control Check 07 (OP 7-56).
2. At 5% level of significance, the average DBH for the Clones 01, 45, 14, 16, 30, 26, 40, 39, 44, 09, and 34, and cChecks 04, 05, and 07 is statistically different from the Control Check 02 (wild seed).

Table 13. ANOVA Table for Six-year-old Replicated Plots, Variable: HT

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Label	57	475.257070	8.337843	5.38	<.0001
Block	1	13.388653	13.388653	8.64	0.0047

Comments:

1. There is a significant difference in the response (average HT) across the 58 labels (50 clones and eight controls) at 5% level.
2. There is a significant difference in the response across the two installations (5% level).

Multiple Comparisons: Dunnett's t Tests for HT: Control 7-56 and Control Wild Seed

Comments: Dunnett's t Tests for HT

1. At 5% level of significance, the average HT for the Clones 40, 41, 19, and 04, and Check 02 is statistically different from the Control Check 07 (OP 7-56).
2. At 5% level of significance, the average HT for the Clones 40, 39, 26, 44, 10, 13, 28, 34, 23, 15, 35, 05, 30, 29, 48, 09, 08, 25, 33, 16, 37, 07, and 43 and Checks 07 and 04, is statistically different from the Control Check 02 (wild seed).

Table 14. ANOVA Table for Six-year-old Replicated Plots, Variable: BA ft^2/ac

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Label	57	13209	231.729851	8.67	<.0001
Block	1	197.362374	197.362374	7.39	0.0087

Comments:

1. There is a significant difference in the response (average BA ft^2/ac) across the 58 labels (50 clones and eight controls) at 5% level.
2. There is a significant difference in the response across the two installations (5% level).

Multiple Comparisons: Dunnett's t Tests for BA ft^2/ac: Control 7-56 and Control Wild Seed

Comments: Dunnett's t Tests for BA ft^2/ac

1. At 5% level of significance, the average BA ft^2/ac for the Clones 38, 31, 02, 24, 12, 08, 19, 43, 04, and 41, and Checks 01 and 02, is statistically different from the control Check 07 (OP 7-56).
2. At 5% level of significance, the average BA ft^2/ac for the Clones 1, 30, 26, 45, 39, 16, 44, 40, 14, 34, 23, 50, 06, 48, 13, 18, 05, 36, 49, 10, 03, 29, 46, 17, 25, 11, and 35, and Checks 04, 05, 07, 03, 09, and 08 is statistically different from the Control Check 02 (wild seed).

Table 15. ANOVA Table for Six-year-old Replicated Plots, Variable: GWob ton/ac

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Label	57	3812.920291	66.893338	8.75	<.0001
Block	1	142.067375	142.067375	18.58	<.0001

Comments:

1. There is a significant difference in the response (average GWob ton/ac) across the 58 labels (50 clones and eight controls) at 5% level.
2. There is a significant difference in the response across the two installations (5% level).

Multiple Comparisons: Dunnett's t Tests for GWob ton/ac: Control 7-56 and Control Wild Seed

Comments: Dunnett's t Tests for GWob ton/ac

1. At 5% level of significance, the average WGob ton/ac for the Clones 12, 24, 22, 02, 19, 04, and 41, and Checks 01, 06 and 02, is statistically different from the Control Check 07 (OP 7-56).
2. At 5% level of significance, the average GWob ton/ac for the Clones 26, 40, 39, 44, 30, 01, 34, 23, 16, 13, 45, 10, 09, 48, 05, 29, 14, 50, 35, 25, 28, 06, 07, 15, 17, 33, 20, 42, 36, 18, 37, 47, 46, 49, and 03, and Checks 04, 07, 05, and 08 is statistically different from the Control Check 02 (wild seed).

Installation 2

Table 16. ANOVA Table for Six-year-old Replicated Plots, Variable: DBH

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Label	57	12.500187	0.219302	2.83	<.0001
Block	1	0.168677	0.168677	2.17	0.1459

Comments:

1. There is a significant difference in the response (average DBH) across the 58 labels (50 clones and eight controls) at 5% level.

2. There is a non-significant difference in the response across the two installations (5% level).

Multiple Comparisons: Dunnett's t Tests for DBH: Control 7-56 and Control Wild Seed

Comments: Dunnett's t Tests for DBH

1. These results indicate that the average DBH for all clones compared to the Control Check 07 (OP 7-56) is not significantly different at a 5% level in this installation.
2. These results indicate that the average DBH for all clones compared to the Control Check 02 (wild seed) is not significantly different at a 5% level in this installation.

Table 17. ANOVA Table for Six-year-old Replicated Plots, Variable: HT

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Label	57	307.739317	5.398935	2.35	<.0008
Block	1	29.926048	29.926048	13.03	0.0006

Comments:

1. There is a significant difference in the response (average HT) across the 58 labels (50 clones and eight controls) at 5% level.
2. There is a significant difference in the response across the two installations (5% level).

Multiple Comparisons: Dunnett's t Tests for HT: Control 7-56 and Control Wild Seed

1. At 5% level of significance, the average HT for Clone 40 is statistically different from Control Check 07 (OP 7-56).
2. At 5% level of significance, the average HT for Clone 40 is statistically different from the Control Check 02 (wild seed).

Table 18. ANOVA Table for Six-year-old Replicated Plots, Variable: BA ft^2/ac

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Label	57	17292	303.361927	2.82	<.0001
Block	1	3791.983205	3791.983205	35.19	<.0001

Comments:

1. There is a significant difference in the response (average BA ft^2/ac) across the 58 labels (50 clones and eight controls) at 5% level.
2. There is a significant difference in the response across the two installations (5% level).

Multiple Comparisons: Dunnett's t Tests for BA ft^2/ac: Control 7-56 and Control Wild Seed

Comments: Dunnett's t Tests for BA ft^2/ac

1. At 5% level of significance, the average BA ft^2/ac for Clone 48 is statistically different from Control Check 7 (OP 7-56).
2. At 5% level of significance, the average BA ft^2/ac for Clone 48 is statistically different from the Control Check 02 (wild seed).

Table 19. ANOVA Table for Six-year-old Replicated Plots, Variable: GWob ton/ac

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Label	57	2846.357546	49.936097	3.37	<.0001
Block	1	484.106388	484.106388	32.63	<.0001

Comments:

1. There is a significant difference in the response (average WGob ton/ac) across the 58 labels (50 clones and eight controls) at 1% level.
2. There is a significant difference in the response across the two installations (5% level).

Multiple Comparisons: Dunnett's t Tests for GWob ton/ac: Control 7-56 and Control Wild Seed

Comments: Dunnett's t Tests for GWob ton/ac

1. At 5% level of significance, the average WGob ton/ac for the Clones 48, 40, and 13 is statistically different from the Control Check 7 (OP 7-56).
2. At 5% level of significance, the average WGob ton/ac for the Clones 48, 40 and 13 is statistically different from the Control Check 02 (wild seed).