FORECASTING ECONOMIC GAINS FROM INTENSIVE PLANTATION MANAGEMENT USING UNREALISTIC YIELD OVER INPUT CURVES

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Abstract—Some researchers claim that continuously increasing intensive plantation management will increase profits and reduce the unit cost of wood production while others believe in the law of diminishing returns. We developed four hypothetical production models where yield is a function of silvicultural effort. Models that produced unrealistic results were (1) an exponential curve and (2) a linear curve where the cost of growing a cubic foot of wood was inversely related to the discounted cost of intensive silviculture. Although increasing silvicultural effort will often result in producing more wood, the increase is sometimes not enough to prevent a reduction in net present value of the stand. Harvesting intensively managed stands at ages 14 to 16 years might not prove economical for a private, nonindustrial landowner if the costs of establishment are too high or if no local mills will purchase logs that contain a high percentage of juvenile wood.

INTRODUCTION

Intensive management can affect volume growth of loblolly pine (*Pinus taeda* L.) plantations (Borders and Bailey 2001; Haywood and Tiarks 1990; Miller and others 1991; NCSFNC 1996, 2000). Although there are a few exceptions (Miller and others 2003, South and others 1995), increasing inputs at time of establish ment typically increases volume production. Some believe that increasing silvicultural inputs will decrease the unit cost of wood production (Allen 2002). If this occurs, then increasing stand management inputs will result in greater profits (Yin and Sedjo 2001). Our concern is whether continuously increasing silvicultural inputs (e.g., soil tillage, fertilizers, herbicide applications, morphologically improved seedlings, improved genetics, irrigation, pest management, rooted-cuttings, container-grown stock, etc.) will result in enough additional yield to increase profits for a nonindustrial private forest landowner.

There are three schools of thought regarding the relationship between silvicultural inputs and wood yield. One school believes volume growth increases at an increasing rate (as silvicultural effort increases). For example, some believe increases in silvicultural inputs have increased volume growth by about 3 percent per year (Binkley 2003) and will continue to do so into the near future (Binkley and others 2005). This rate of increase might result in 1,000 percent gain in productivity when comparing the yield of natural stands in 1950 to intensively managed plantations in 2030 (Wallinger 1993). The second school believes volume gains are linearly related to inputs (Allen 2002, Larsen 1976). As a result, increasing inputs from $300 per acre to $350 per acre would equal gains achieved by increasing inputs from $200 per acre to $250 per acre. The third school follows the law of diminishing returns (Chapman and Meyer 1947, Spillman and Lang 1924). The point at which the diminishing returns begin to operate can be difficult to ascertain, which may explain why some believe in linear or exponential type relationships.

If the debate over these volume-over-input curve shapes were purely academic, there would be little need to examine potential economic outcomes. However, plantation managers sometimes invest in additional silvicultural practices without waiting for end-of-rotation research results. As a result, accountants sometimes ask managers to use short-term data to predict long-term gains. The managers might choose an optimistic volume-over-input curve in order to justify their prior expenditures.

PROCEDURES

Four contrasting models of loblolly pine merchantable volume-over-input curves were developed. All four models assume standing volume at age 15 years increases as silvicultural inputs increase (fig. 1). Model 1 assumes that yield increases at a decreasing rate as silvicultural effort increases. This model adheres to the law of diminishing returns. Model 2 assumes an exponential function, where yield increases at an increasing rate with increases in silvicultural effort. Models 3 and 4 assume yield is linearly related to the cost of silvicultural inputs. For model 3, the cost per unit of volume production increases as silvicultural costs increase. For model 4, the per-unit cost of volume production decreases as silvicultural costs increase. Graphically, the slope of the line for model 3 will be less than the slope for model 4.

Data from a paper by Borders and Bailey (2001) were used to develop the models. The moist site at Waycross, GA, was selected because it provided the greatest growth response to silvicultural inputs. Treatments at this site included: (1) a no chemical control; (2) treatment with annual fertilization; and (3) treatment with annual fertilization plus 3 years of herbicides to control herbaceous and woody vegetation.

Merchantable cubic foot volumes per acre for each treatment were extrapolated to age 15 years. The estimated volumes were then plotted over the sum of discounted costs per acre (using a real interest rate of 6 percent) for each treatment. Functions were then developed for each site so they would approximate each of the four models (fig. 1). Costs for the treatments included: site preparation at $150 per acre, seedling and planting costs of $70 per acre, fertilization cost of $60 per acre per application, and herbicide costs of $60 per acre per application. Discounted costs per acre were used as a proxy for silvicultural intensity.

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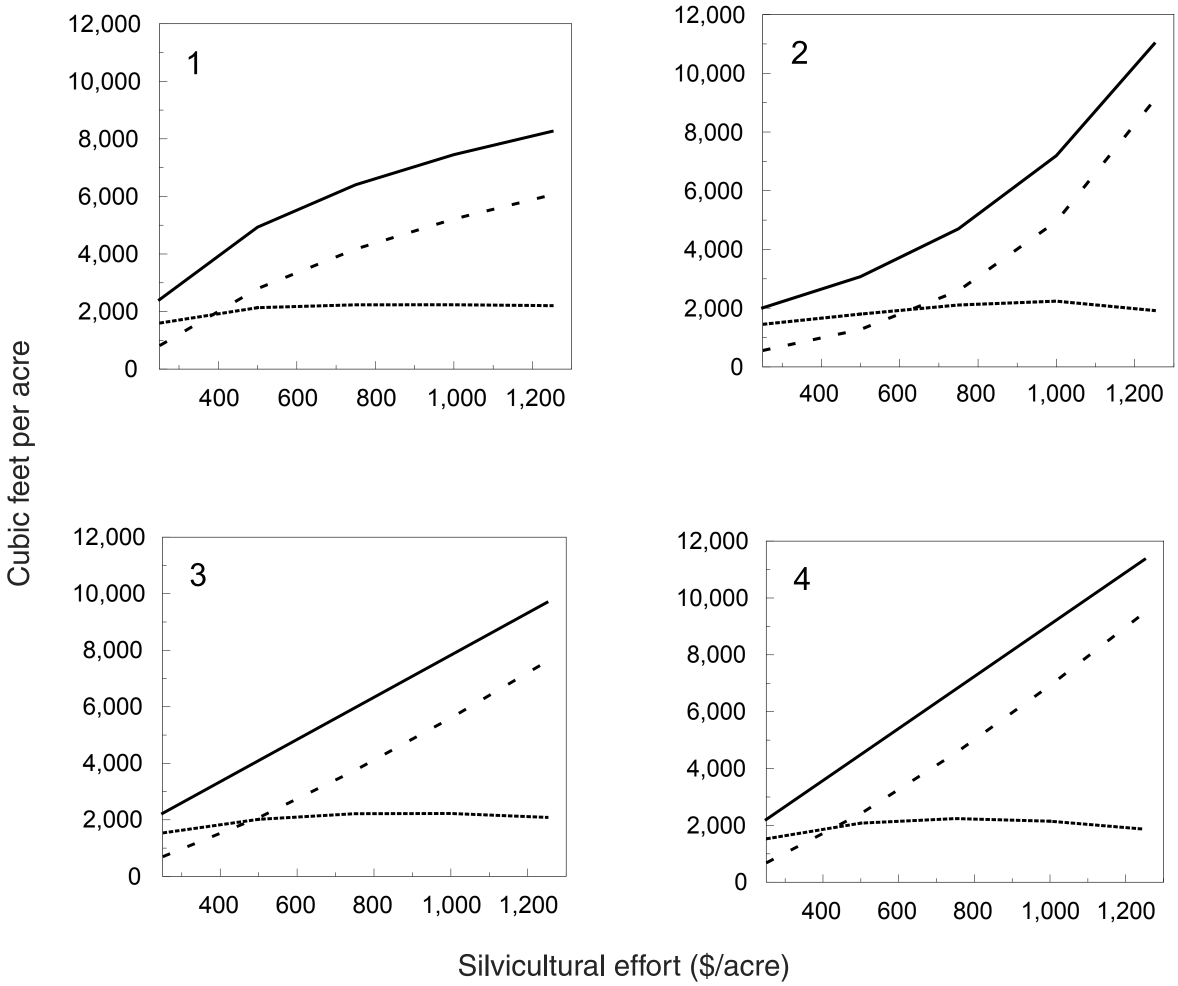

Figure 1—Volumes at age 15-years as affected by four theoretical volume-over-input models. Model #1 adheres to the law of diminishing returns. Model #2 assumes an exponential relationship between volume and inputs. Model #3 assumes a linear relationship with an increasing cost of producing a unit of wood. Model #4 assumes a linear relationship but with a decreasing cost of producing a unit of wood. Silvicultural effort is measured by total discounted costs of all silvicultural inputs. The upper solid line represents total cubic foot volume production, the lower dotted line is pulpwood volume production, and the dashed line represents chip-n-saw volume production.

After volume-over-silvicultural input curves were developed, the total volume was divided into two product classes: pulpwood [diameter at breast height (d.b.h.) ≥ 4.5 inches but not > 9 inches] and chip-n-saw (d.b.h. > 8.9 inches). A growth and yield simulator (Acorm) developed in Georgia (Dangerfield and Moorhead 1996) was used to determine the product mix. The simulator estimates the product distribution for a given rotation age and site productivity.

We used two stumpage price scenarios. The first scenario assumed the landowner could sell pulpwood for $21 per 100 cubic feet (cunit) and could sell 15-year-old chip-n-saw for $104 per cunit. The second scenario assumed a mill would only pay $21 per cunit for juvenile wood, regardless of the d.b.h. We used a stand-level economic model rather than a forest-level economic model (e.g., Yin and others 1998), since the private landowner in our example only has one 40-acre stand. Since rotation age is the same in each case, we compared the models using before-tax, net-present-values (NPV).

After volume-over-input models were developed, realized 15-year data were obtained for the Waycross site and for the site at Tifton, GA. The Tifton site was selected because it was unresponsive to fertilization with diammonium phosphate and potassium chloride. These data were used to calculate before-tax NPVs for both sites.

RESULTS

When all wood was sold as pulpwood, the NPVs were generally negative (fig. 2a). In fact, at $21 per cunit, none of alternatives at the Waycross site produced a positive NPV (with silvicultural inputs < $1,250 per acre). However, with extrapolation past the data (and assuming no limit to carrying capacity), the exponential model (#2) will eventually produce a positive NPV.

Regardless of model selected, the NPVs obtained by selling pulpwood plus chip-n-saw increased with additional inputs (fig. 2b). However, the diminishing returns model (#1) appears close to reaching an optimal silvicultural effort near $1,250 per acre. The NPV curves for the remaining three models suggest that higher NPVs would be achieved when inputs are > $1,250 per acre.

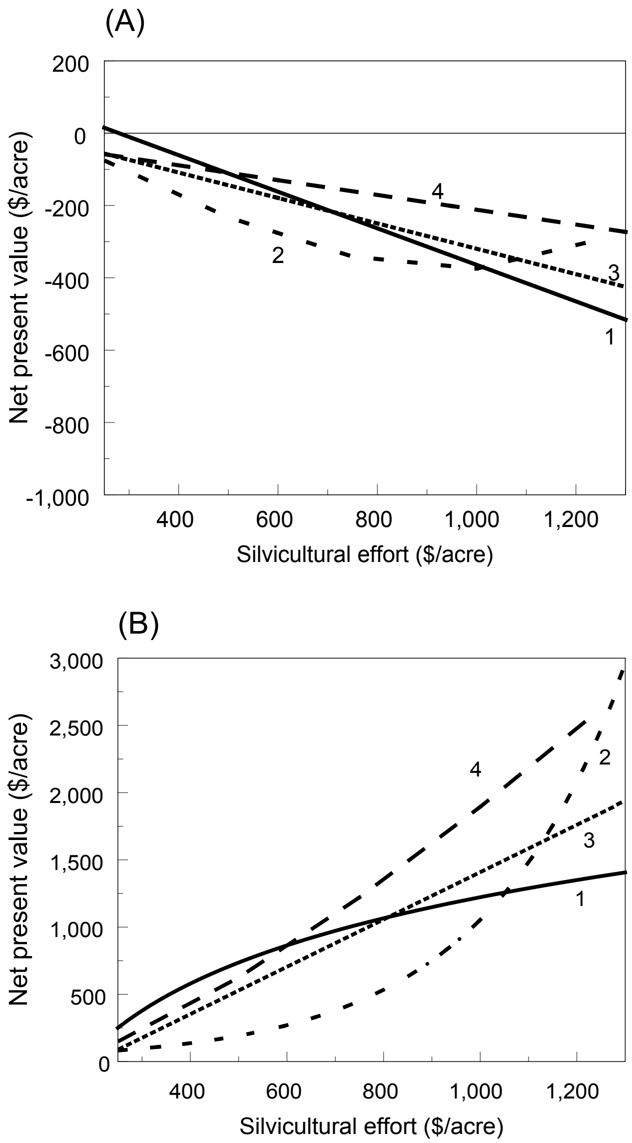

Figure 2—Net present value per acre for the four alternative models: 1 = diminishing returns; 2 = exponential; 3 = linear (increasing cost per cubic foot); 4 = linear (decreasing cost per cubic foot). In (A), all wood is sold as pulpwood at $21 per cunit. In (B), wood is merchandized and pulpwood is sold for $21 per cunit while chip-N-saw is sold for $104 per cunit. The level of intensive management increases as the discounted costs for the inputs (i.e silvicultural effort) increases.

The discounted cost per unit of wood produced at harvest is of interest to some plantation managers. In our examples, the cost per unit of wood tended to increase with models #1 and #3 (fig. 3). With the more optimistic models (#2 and #4), the discounted cost of wood was reduced as inputs increased.

Realized gains at age 15 years varied by site. Fertilization plus the use of herbicides increased volume growth by 28 cunits per acre at the Waycross site but the increase was only 9 cunits per acre at the Tifton site (table 1). At both sites, annual fertilization (with or without the use of herbicides) increased the discounted cost of a cubic foot of wood.

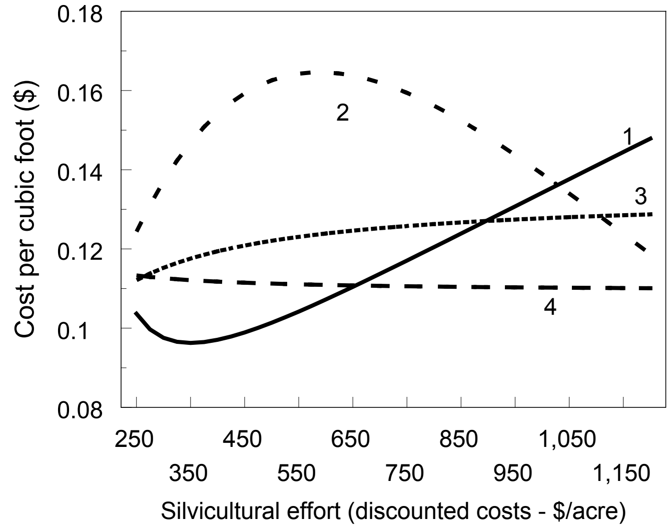

Figure 3—Discounted silvicultural costs (at a 6 percent interest rate to year zero) per cubic foot as affected by the amount of silvicultural effort for four alternative models: 1 = diminishing returns; 2 = exponential; 3 = linear (increasing cost per cubic foot); 4 = linear (decreasing cost per cubic foot). Of the models presented here, only two reduce the unit cost of wood production as silvicultural inputs exceed $600 per acre.

DISCUSSION

This paper does not present specific models to estimate growth response to intensive management. Instead, we are trying to make managers aware of the various outcomes that can result when predictions about future volume gains differ. Therefore, this paper takes a simplistic view of "intensive" plantation management. Our four hypothetical production functions (fig. 1) do not represent actual production curves but rather only a few examples of many shapes of curves that may exist. Although many curve shapes could be fitted to response data, we are only interested in the shape of "boundary layer" curves. Hopefully, this paper will shed light on how different schools of thought might affect projected NPVs.

Model Comparisons

By design, three of the models predict a harvest volume of 70 to 80 cunits per acre with $1,000 of silvicultural effort (fig. 1). However, at this level of input, model 4 predicts over 90 cunits per acre, but this is because a steep slope was required to maintain a declining cost of wood production (fig. 3). Therefore, model #4 is the most liberal in predicting volume production and produces the highest NPVs (with inputs ranging from $750 to $1,250). Since this model does not fit the Waycross data well, we believe this model is unrealistic. It seems unlikely that the unit cost of wood production will continue to decline as silvicultural inputs are increased (as some have suggested).

The exponential model predicts that once $600 per acre is expended, the unit cost of wood production will also decline with additional inputs (fig. 3). In fact, when extrapolating to an input level of $1,500 per acre, this model produces the highest NPV and cheapest wood cost. However, realized gains at both the Waycross and Tifton sites show an increase in the unit cost of wood with increasing treatment costs (table 1).

Table 1—Effect of increasing silvicultural inputs on volume yields and mean annual increment (MAI) at age 15 years at a wet site at Waycross, GA and a site near Tifton, GA (Borders and Bailey 2001). A Yield-Cost Index (YCI) is provided in green tons per acre per year (g). Discounted treatment costs and net present values per acre (NPV) are provided (at 6 percent interest rate; $21 per cunit of pulpwood; $104 per cunit of chip-n-saw)

Location	Treatment	Yield	MAI	YCI_{15}	Discounted costs/acre	Discounted costs/cunit	NPV pulpwood only	NPV
		- - - - ft^3 /acre - - - -			- - - - - - - - - - - - - - - - $ - - - - - - - - - - - - - - - -			
Waycross	No fertilization; no herbicides	2,869	191	6g-2	220	7.67	31	490
	Annual fertilization	6,454	430	13g-7	693	10.74	-127	1,474
	Annual fertilization plus three herbicide applications	7,007	467	15g-9	854	12.19	-240	1,547
Tifton	No fertilization; no herbicides	4,380	292	9g-2	220	5.02	164	1,157
	Annual fertilization	4,151	277	9g-7	693	16.69	-329	585
	Annual fertilization plus three herbicide applications	5,299	353	11g-9	854	16.12	-390	885

Results from slash pine (*Pinus elliottii* Engelm.) plantations also indicate the unit cost of wood production can increase as silvicultural inputs increase (Yin and others 1998). In addition, an exponential model inherently assumes no "carrying-capacity" limit. For these reasons, we conclude an exponential model is also unrealistic.

This leaves two models: the diminishing return model (#1) and a linear model (#3). Both models predict similar volume gains (fig. 1.1 versus 1.3), but they differ in their unit cost curves (fig. 3). Although both models show a general trend of increasing unit costs with increasing inputs, the diminishing return model shows an initial decrease in unit costs. The "diminishing return" curve (#1) not only fits the realized gains well (table 1), but it also is similar to the curve reported by Crutchfield (1991). We predict that in the long-run, a "diminishing return" curve will prove to be more appropriate than a linear model. Yields per acre per year tends to level off after the leaf-area index reaches a maximum level.

Stumpage Price

Costs and stumpage prices are the major factors determining whether increases in silvicultural inputs will be worth the investment for a private landowner. For example, when stumpage prices for pulpwood are expected to rise to $55 to $110 per cunit (Abt and others 1995), intensive management becomes attractive. However, at $21 per cunit, an investment of $800 per acre to produce 15-year-old pulpwood is not attractive (table 1; fig. 2a). In the second quarter of 2003, regions paying less than $21 per cunit for pine pulpwood included Arkansas, and parts of South Carolina, Tennessee, and Texas. For chip-n-saw, the only region with stumpage more than $104 per cunit was in south Mississippi (Norris Foundation 2003).

Some justify the added expense of intensive silviculture by assuming the stumpage price paid to private landowners for 14- to 16-year-old logs is the same as that paid for logs (with the same large-end diameter) that are 24- to 30-years-old. But in the real world, mill managers know that harvest age affects the juvenile to mature wood ratio. Some pulpmills pay 9 to 13 percent less per cunit for juvenile pulpwood because they know that young logs with more juvenile wood have higher moisture contents than older logs. Others limit their wood acquisitions to ages 15 to 18 years because the price is lower than larger 24-year-old logs, and their product favors the use of juvenile wood. In fact, "juvenile wood chips will pulp more rapidly and produce higher yields at a given kappa number compared with the heavier cellulose yielding mature wood" (Zobel and Sprague 1998). Although an inherent relationship between growth rate and specific gravity does not exist for loblolly pine (Megraw 1985), harvesting at younger ages will lower specific gravity. Since lumber cut from the center of a 15-year-old tree might not meet design requirements due to the amount of juvenile wood, some sawmills pay less for young logs while others do not even purchase logs that are < 17- to 23-years-old. Therefore, if private landowners plan to invest heavily in silviculture and harvest at 15 or 16 years, they should make sure the local mills are willing to pay a decent price for logs with a high percentage of juvenile wood.

Site Differences

Site selection is very important if a landowner decides to invest $800 per acre in silvicultural treatments. Although volume gains can be expected with annual fertilization and weed control, some sites will show a reduction in NPV. For example, intensive silviculture at the Tifton site reduced NPV even when wood was merchandized and large-diameter trees were sold for $104 per cunit (table 1). Since there is an interaction between site and NPV response to silvicultural treatments, one company (located in east central Alabama) has decided to restrict the application of certain silvicultural practices to only medium sites. Therefore, they do not apply intensive silviculture on their best sites.

Economic Approach

Some economic approaches used to justify intensive silviculture are different from the one presented here. Others have used a reduction in rotation age and a reduction in acreage managed to justify the added expense of intensive silviculture. In our example, we assumed a landowner had 40 acres of land and plans to harvest the trees in 15 years. Therefore, we used a fixed rotation of 15 years and did not use a "forest-level" economic model (Yin and others 1998). We did not consider volume production past age 15 years because we did not want to predict trends more then 4 years past the observed data. Therefore, we are not suggesting that the rotation age or management scenarios presented here are optimal.

YCI Terminology

The term "intensive plantation forestry" is often poorly defined. Since it represents a wide range of meanings, it has become an almost meaningless term. For example, one reference states that "Intensive plantation forestry is practiced by industry on 14.0 million ha in the southeastern United States." The authors assumed that all pine plantations in the Southeast are intensively managed by "industry." Of course this claim is not true since (1) industry only owns about 7.7 million ha in the "southeast"; (2) only about 63 percent of industry land is in plantations; and (3) not all pine plantations owned by industry are managed intensively (Siry 2003). Without definitions, terms like "superior" and "high-yield" are not very informative when discussing increasing silvicultural effort. A more professional method of communication is needed.

Some simply use mean annual increment as a measure of silvicultural effort, but this can be misleading since some sites produce more than 3 cunits per acre per year with very little silvicultural effort (South and others 1985). Therefore, to improve communication, we have proposed a "yield-cost index" (YCI) that combines both mean annual increment and inputs (discounted costs of silvicultural treatments) for a given base-age (South 2004). For example, if a yield of 4 cunits per acre per year resulted from an investment of $540 per acre (i.e. $540 is equal to the costs of all silvicultural inputs discounted to year 0), the YCI (base age 15 years) would be 4u-5. Likewise, if a yield of 5 green U.S. tons per acre per year was expected from an investment of $360, the YCI15 would be 5g-4 (discounted dollar values are rounded to the nearest hundred dollars to encourage use by industry). Examples of YCI15 values are presented in table 1. Since providing site index values (e.g., 80 feet – base age 25 years) is better than saying the site is "very productive", providing a YCI15 value (e.g., 12g-5) will be more informative than saying the management intensity is "superior."

CONCLUSIONS

Due to advances in silviculture, plantation managers can produce more than 8 green tons per acre per year on sites where 1940 plantations produced only 3 green tons per acre per year (Stanturf and others 2003). Despite this ability, it must be understood that certain sites and certain economic situations will not justify large capital investments in silviculture. Yield-over-input models that follow the law of diminishing returns will produce results that indicate a limit in NPV. Models that follow an exponential form or certain linear models might produce no NPV limit.

Employing intensive silviculture can increase the mean annual increment of a stand, but in some cases, a reduction in NPV can result. Therefore, intensive silviculture should be thought of as a tool that should be applied to certain sites; it is not a panacea that will produce attractive economic returns on all sites and all markets.

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