An Economic Evaluation of Fusiform Rust Protection Research

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ABSTRACT: *Fusiform rust is a widespread and damaging disease of loblolly pine* (P. taeda) *and slash pine* (P. elliottii) *in the South. Research has identified families of these pines with improved genetic resistance to the disease, allowing production and planting of resistant seedlings in areas at risk. This study cornpared the cost of fusiform rust research to the simulated benefits of rust resistant seedlings in plantations that have been or are projected to be established Southwide between I970 and 2020. Results showed that compounded fusiform rust research costs of $49 million in 1992 will return discounted benefits to plantation owners* of *between $108 and $999 million in 1992, at a 4% real discount rate. The most probable targeting of rust resistant seedlings would provide estimated discounted benefits of fusiform rust protection* of *about $200 to $300 million in 1992, or annual discounted benefits* of *$40 to $60 million. This would generate benefit-cost ratios of about 4:1 to 6:1 for fusiform rust research. Currently anticipated improvements in resistance will not eliminate all physical and financial damages from the disease; simulation results indicate substantial financial benefits yet remain for additional research and development. South. J. Appl. For. 24(2):77-85.*

Fusiform rust has long been recognized as the most damaging disease of southern pine forests. Occurring in a band across the heart of the South, the disease is prevalent in the most productive stands-loblolly pine (P. *taeda)* and slash pine *(P. elliottii)* plantations on higher quality sites (Anderson et al. 1986a, Borders and Bailey 1986). Galls on seedlings can cause early mortality, while survivors with resulting stem cankers are subject to breakage and are unsuitable for solidwood products (Geron and Hafley 1988, Holley and Veal 1977). The most effective means for reducing damage from this pathogen has been to plant genetically resistant seedlings.

Fusiform rust affects both the quantity and quality of timber produced per unit area, therefore increased rust resistance translates directly to increased economic value. To estimate the returns to fusiform rust research, we simulated timber production and merchandising processes at the stand level and then aggregated quantities and values across the region to estimate production and value functions. By comparing a base level scenario representing no investments in fusiform rust research with a variety of scenarios representing potential impacts of fusiform rust research, we estimated the aggregate production and value impacts of such research. Using data collected on research program costs, wc evaluated the economic returns from this research by computing a benefit-cost ratio for each of the potential outcomes. This article summarizes our research on this subject, drawing from a more detailed report by Pye et al. (1997).

The overall goal of this study was to evaluate the economic returns from past fusiform rust resistance programs. This research evaluation included the following specific objectives:

1. Estimate the aggregate growth and yield effects of fusiform rust resistance breeding programs.
2. Estimate the stand-level (microeconomic) impacts of fusiform rust on timber yields and timber growing investments.
3. Estimate the resulting aggregate increases in volume and value of southern softwood timber supply resulting from improved rust resistance.
4. Estimate the costs of fusiform rust research.
5. Compute benefit:cost ratios and discuss their implications for future research strategies.

Literature

Several studies have valued the impacts of fusiform rust, its control, or other issues related to the economic effectiveness of forestry research. Studies used a variety of empirical

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and simulation approaches, with some studies conducted at the stand level, and others evaluating regional impacts.

Powers et al. (1974) used 'Forest Inventory and Analysis (FIA, previously Forest Survey) data from South Carolina, Georgia, and Florida to extrapolate an estimated loss from fusiform rust of $28 million across the South in 1972. Gross volume losses to galls in plantations and natural stands were valued without explicit treatment of product shifts or mortality effects. The authors considered the estimated loss conservative because it excluded the costs of spraying protective fungicide in tree nurseries and replacing infected trees in seed orchards and did not separately account for losses of higher value products. Holley and Veal (1977) concluded that the major effect of rust-associated mortality is a reduction in yield. The lower quality of the infected stem also results in monetary losses. They speculated that damage from fusiform rust, on a Southwide basis, would run into the tens of millions of dollars annually and increase over time.

Anderson et al. (1986b) also used FIA data to estimate economic losses caused by fusiform rust. They estimated total losses for the South Central states (Texas and Oklahoma through Tennessee and Alabama) of $35 million per year based on a discounted cash flow. The harvest volumes estimated were gross volumes because they only merchandizcd individual stems into sawtimber and pulpwood products. Busby and Haines (1989) developed a model to estimate the damage of fusiform rust infection in slash pine stands. The model required the user to specify the percent reduction in sawtimber to account for degrade from fusiform rust, but this information was unobtainable, therefore, degrade was not included in their evaluation. Geron and Hafley (1988) used the North Carolina State University Managed Loblolly Pine Plantation Growth and Yield Simulator to examine the stand-level impacts of fusiform rust on loblolly yields using two different merchandising assumptions. They concluded that the majority of the stem galls occur below 8 ft, the most valuable portion of the stem. As the percent infection increased, so did solidwood losses.

Methods

To evaluate the benefits of genetically improved resistance one must contrast the values of Southern plantations *without* rust-resistant technologies against values *with* the improved rust resistance. The difference hetwcen plantation values for these two scenarios provides a measure of the benefit of the fusiform rust research program. Using our own routines and data from other sources, we designed a simulation model that projected the impacts of changing fusiform rust resistance on regional timber supplies.

Our models simulated the establishment of new plantations, growth to rotation age, harvesting, merchandising into products, and valuation. The sequence was simulated separately for loblolly pine and slash pine, and across a range of initial site qualities and early fusiform rust infection levels to reflect the diversity of plantation conditions across the region. Southwide production was calculated by multiplying the simulated per acre yields and values for each initial condition with that condition's corresponding area in the region and then summing across the South. This sequence provides the basis for the *without* scenario.

The *with* scenario modified the *without* scenario to reflect the deployment of genetically resistant seedlings. Resistant seedlings were assigned to particular site conditions and the resulting infection rates reduced to reflect their higher resistancc. The deployment of seedlings and establishment and growth of plantations were repeated across a range of years for the *with* and without scenarios to reflect the improving availability and resistance of genetically resistant seedlings over time and changing planting rates. The simulation encompassed loblolly and slash pine plantations that have been or are projected to be established throughout the South between 1970 and 2020.

Stand-Level Simulations

Impacts of infection at early ages were projected through to yields at various ages for a range of initial site conditions. The range of initial site conditions for loblolly and slash pine was represented by 3 site quality classes and 11 levels of rust infection at age 5.

Growth and Yield

To generate yield tables for the 33 initial conditions for slash pine, we used the University of Georgia GAPPS model (Burgan et al. 1989, Pienaar et al. 1988). The North Carolina Stale University (NCSU) Loblolly Yield Model (Hafley and Smith 1989) was used to produce a similar set of yield tables for loblolly pine. Both models project fusiform rust-associated mortality over time and infection rates of surviving stems through the life of the stand.

For the simulations, we specified no thinning and an initial planting density of 700 seedlings/ac. We assumed early survivorship varied with site quality: 75% survival for low quality sites; 80% for medium; 85% for high. Infection classes for the simulations were indicated as 0, 10, 20...90, 100% infection at age 5. The three site classes were termed low, medium, and high, defined for loblolly as site index 50, 65, and 80 ft at base age 25. Corresponding site indices for slash pine were 50, 60, and 70.

We estimated even-aged pine plantation yield tables for each species and each of the 33 initial conditions, calculating yield at 5 yr increments starting with stand age 10 and ending with stand age 35. For each age the model reported volume (ft^3) by diameter class (dbh) and overall percent of rust-infected trees. We applied this overall stand infection rate to the number of stems in each of the diameter classes to distribute infected stems to the different diameter classes.

Product Merchandising.--While both yield models incorporated mortality effects of rust, additional merchandising simulations were needed to capture how galls affected wood utilization on the surviving stems. Because empirical information was unavailable on logger responses to galls, we used four timber utilization scenarios to account for a range of possible merchandising intensities.

Case I ("poor utilization') assumed any tree with a stem gall is left in the woods. Case II ('pulpwaud utilization") assumed any tree with a stem gall is pulped. Case III ("sawtimber utilization") assumed the tree is pulped unless at least a 16 ft gall free log is present. Case IV ("full utilization") assumed optimal utilization of infected stems, pulping the cankered portions but otherwise merchandising infected stems to sawtimber, chip-n-saw, and pulpwood the same as uninfected stems.

Merchandising infected stems required information on where on the location and number of galls occurring on an individual stem. Geron and Hatley (1988) defined the probability of a gall occurring at a given height on the stem. To account for occurrences of more than one gall segment on a stem we used a 0.75 probability of one segment, 0.15 for two segments, and 0.10 for three segments on any given infected tree (Charles Walkinshaw, USFS, Pineville, LA, October 1992, personal communication). We used a uniform variate random number generator combined with these frequency distributions to determine the number of galls and their heights on any given stem.

The slash pine merchandiser incorporated the yield and taper equations used by GAPPS (Pienaar et al. 1988). We used the same assumptions for the loblolly pine merchandiser, with two exceptions. The number of gall segments on a slash stem was based on research by Belanger et al. (1985) and their height on the stem was based on research by Webb and Patterson (1984).

Product Prices.-We used three product classes: pulpwood, chip-n-saw, and sawtimber. Base product prices were computed using 1992 average prices from Timber Mart-South for the southern states and substate regions where fusiform rust is prevalent: Alabama, Arkansas (region 2), Florida, Georgia, Louisiana, Mississippi, North Carolina (region 2), South Carolina, and Texas. State product prices were weighted by removal rates to compute a weighted average price per cubic foot: (1) pulpwood = $0.32/ft3, (2) chip-n-saw = $0.66/ft3, and (3) sawtimber = $0.94/ft3. Timber prices were maintained in constant 1992 dollars throughout the analyses.

We adjusted sawtimber values for various log lengths using reported prices (Random Lengths Price Report 1993) for kiln-dried southern yellow pine lumber averaged over the West, Central, and East reporting regions for dimensions ranging from 2 x 6 to 2 x 12 and lengths ranging from 8 ft to 24 ft. The relative lumber prices were applied to the base stumpage prices to estimate log prices by length. This led to a range of derived stumpage values from $0.88 per ft3 for 8 ft log lengths to $1 .OO per ft3 for 16 ft log lengths.

Plantation Establishment Costs.--Regeneration costs were based on trends published by Belli et al. (1993). We assumed the costs of establishing loblolly and slash pine were equal; however, better quality sites required more intensive site preparation because they supported greater vegetative competition. With seedling costs included, plantation costs were $139, $155, and $197/ac for the low, medium, and high quality sites, respectively.

Economic Value Calculations.-We chose two financial measures of technological impact: soil expectation value (SEV) and net present value. SEV measures the long-term value of forestry operations under static technology (Jnhansscn and Löfgren 1985). We used SEV to compare individual or aggregate plantation values at specific times under *with* and *without* scenarios, similar to the approach used by others to evaluate the impacts of fire and insect outbreaks (Holmes 1991, Martell 1980, Reed 1983, Routledge 1980). These economic evaluations were essentially "comparative statics" analyses, measuring the effect of a technology-induced shift outward in the southern pine timber supply curve-or actually three separate curves, one for each product class.

Net present value (PV) reports the value of a single rotation, and consists of the gross revenue at harvest less the costs of stand establishment discounted to regeneration date. We aggregated PV values from individual stands across the region and then, with appropriate discounting, across time to calculate the regional benefits of improved resistance. We used a 4% real discount rate in calculating present values, per Row et al. (198 1). This rate represented reasonable long-term returns. Returns to the stock market were higher in the 1990s, but bond and savings account returns were less.

Two rotation standards were evaluated in this study. The first standard assumed a fixed rotation length of 35 yr, referred to as the sawtimber rotation. The second standard used rotation lengths which maximize SEV, referred to as the optimal economic rotation.

Aggregate Benefit Simulations

Several data sources were needed to extrapolate harvest volumes and values from the 66 conditions at the stand level to the regionwide estimates for each of the years being evaluated. These data sources included information on the regionwide frequency of species, site quality, and early infection rate among plantations in the region, as well as past and projected planting activities by species. Must importantly it also included estimates of past and projected production of rust resistant seedlings and the gains in resistance in those seedlings for the various years in the evaluation.

Distribution of Conditions Across the Region.-We obtained data on the distribution of stand conditions and fusiform rust incidence from FIA units for the Southeastern (SEFIA-Asheville. NC) and Southern (SOFIA-Starkville, MS) regions. Plot-level information with appropriate area expansion factors was obtained for all FIA loblolly- and slash pine-dominated plots in the South collected since 1968 (Southeast) and 1974 (South) and described the three most recent complete cycles of measurement available at the time. Dates of data collection for the fourth survey were 1968-l 977; for the fifth, 1978-I 986; for the sixth 1986-l 993. The fourth and fifth cycles were assumed to reflect conditions prior to substantial effects of improved resistance. Thus the frequency distribution of site qualities and early infection rates from these plots made up the "without" fusiform rust research condition.

Pine Plantation Area--For the years 1970, 1975, 1980, and 1985, we estimated planted area using Forest Service Tree Planting reports (i.e., Mangold et al. 1991, USDA Forest Service 1981, 1982, Williston 1980), summing the acres reported planted in the 13 southern States: Alabama, Arkansas, Florida; Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia. Figures did not include seeded acres. For the years from 1990 to 2020, we used unpublished ATLAS/TAMM pine plantation projections provided by John Mills (USDA Forest Service, Portland, OR, July 1993, personal communication),

Southern pine plantation acres were apportioned to loblolly (74%) and slash (21%) based on preliminary results from a survey of Southwide seedling production, with the balance in other pines (Carey and Kelley 1993). Because FIA data indicated somewhat different amounts prior to this survey, for 1970 and 1975 we used 63% and 37% for loblolly and slash, the ratio found for young plantations in the fourth and fifth survey cycles.

Estimation of Rust Resistance Adoption.--FIA data from the fourth and fifth forest survey cycles provided the infection rates for the baseline without scenario. Simulating the changes in these infection rates under the *with* scenario required information on technology diffusion and selection gain. We collaborated with the major southern tree improvement cooperatives in surveying the principal producers of loblolly and slash seedlings-both state and industry-to estimate past and anticipated production of rust resistant seedlings and the gains in resistance anticipated for those seedlings.

We obtained gain estimales for a given species and year by calculating the average gain reported by the different producers for a given year, weighted by the number of resistant seedlings they reported for that year. Thus the averages represent all resistant seedlings as a share of the total for that species. Responses indicated increasing shares of seedlings to be resistant to rust, rising *by* the year 2020 to about one-quarter of *loblolly* pine seedlings and about three-quarters for slash pine. Resistance gains were also forecast to increase, from near zero in 1970 to about 40% for loblolly pine and 60% for slash pine by 2020.

Rust-Resistant Seedling Deployment.-The benefit of using resistant seedlings depends on the degree to which those seedlings are deployed in locations where their resistance will do the most good. We used the FIA plot level data for the last three forest survey cycles to determine the distribution of fusiform rust at the plot level throughout the South. Then we simulated three scenarios: (1) uniform-assumed no information on areas at risk, (2) optimal-assumed perfect knowledge of areas at risk, and (3) total resistance-assumed all plantations were free of infection. The uniform assumption just planted all seedlings randomly throughout the South; the optimal targeted all rust resistant seedlings to the highest risk areas based on the FIA data. These scenarios were chosen to bracket the forestry sector's abilities to target resistant seedlings effectively. The total resistance scenario was added to help delimit the maximum benefits possible in the future from complete fusiform rust resistance in these species, as well as the past losses caused by fusiform rust.

Benefits Calculations.--Benefits were calculated for each simulation year by subtracting the SEV for a *Without* base case from the SEV for one of its corresponding with deployment scenarios. 'These comparisons were possible for each of the three deployment scenarios in each of the eight utilization by rotation standards, and for each of the 11 simulation years. SEV provided a useful comparison for such "point in time" comparisons.

Research Costs

Research costs for the fusiform rust program evaluation were collected from seedling producers, research cooperatives, the Forest Service, and from other unpublished data sources. The survey canvassing the university cooperatives and principal producers of loblolly and slash pine seedlings included questions on past annual resources they expended on fusiform rust research or development in 1970, 1975, 1980, 1985, and 1990. To simplify this task, respondents could specify resources in either dollars or scientist-years. We used other sources to obtain expenditures for Forest Service research and to translate scientist-years into dollars. The Forest Service provided both full-time equivalents (FTEs) and total annual budgets for fusiform rust research from 1976 to 1993, based on a historical tally of the research work units and scientists in the South (Richard Smith, USDA Forest Service, Washington Office, February 1994, personal communication).

To convert university and cooperative FTEs to dollar expenditures we used the Forest Service data plus information on university forestry research expenditures and research FTEs from the Southern National Association of Professional Forestry Schools and Colleges (NAPFSC) summaries (Arnett Mace, University of Georgia, Athens, March 1994, personal communication). We calculated cost per FTE for both the Forest Service and the academic forestry research data for the available years, and used simple linear regression as a function of year to estimate values for the evaluation years. The (lower) Forest Service costs and (higher) university costs were averaged to obtain the necessary FTE to dollars conversion figure.

Simple linear interpolation was used to estimate the annual research expenditures for both university cooperatives and seedling producers. For each sector, we used costs per FTE times the number of FTEs, plus research expenditures, to calculate the total research costs for each sector and for the South per year.

Benefit-Cost Computations

After estimating stand-level financial impacts, regional aggregate economic benefits, and regional research costs of fusiform rust research, the regional cost and benefits of fusiform rust research were computed. The benefit-cost (B/C) ratios and net benefits were calculated with all benefits and costs indexed to a common year. We compounded the research costs for the region to 1992--the base year used for the financial analyses--at the 4% real interest rate. Similarly, we discounted all the benefits of improved fusiform rust protection back to 1992 using a 4% real discount rate. For the B/C ratio, we divided the aggregated research benefits for the various scenarios by the single regional research cost term. For the net benefits, we subtracted aggregated regional rc-search costs from the aggregated research benefits for the various scenarios.

Results and Discussion

Stand-level Impacts:

Pye et al. (1997) provide details on sawtimber, chip-n-saw, and pulpwood yields, soil expectation value, and harvest age for the 528 site, utilization, and rotation conditions evaluated. The discussion here is limited to a few of the trends. In the absence of rust, the simulations showed markedly increased yields for higher site qualities, particularly for sawtimber volumes. The merchandising routines placed most of the timber in the chip-n-saw and sawtimber products, with relatively little volume going directly to pulp in uninfected stands. Economically optimal rotations were always shorter than the 35 yr assumed for the fixed rotation. Increasing levels of rust infection shifted volumes away from sawtimber and into pulp (Figure 1). Although high infection levels proved damaging, infection levels of around 10% to 20% sometimes resulted in increases in value compared with the no rust case. This generally occurred in slash plantations and particularly on high quality sites at high utilizations. Thus in slash pine plantations the economic benefits to reduced rust infection were often negative at low initial levels of i nfection. This finding suggests that firms or individuals were over-compensating for mortality at the assumed average planting rate of 768 trees/ac that prevailed in the 1980s. Lower planting rates would actually encourage faster slash pine volume growth, and indeed recent practices have moved in this direction.

As expected, utilization standard had a large effect on the magnitude of physical and economic damages from fusiform

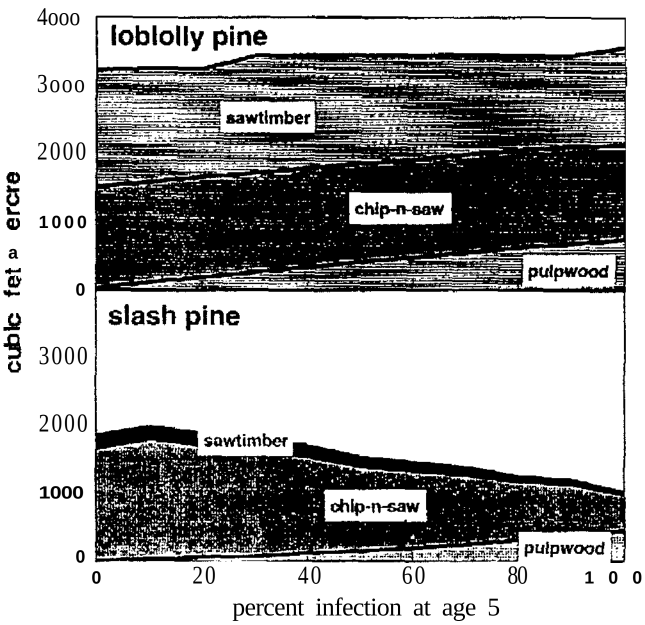

Figure 1. Simulated yield by product class for loblolly (top) and slash pine (bottom) under different levels of early rust infection, assuming full utilization of infected stems and economically optimal rotations growing on poor quality sites (SI 50).

rust infection. When **infected** stems are left in the woods (poor utilization), the absolute level of damage was generaIly higher for stands managed on short rotations than on long rotations; the opposite was true when infected sterns were utilized fully (full utilization).

The marginal benefits of reducing infection rates on loblolly and slash pine stands managed on short rotations with high utilization slandards generally increased with site index. Marginal benefits of reductions in infection rates increased with site index for Ioblolly stands with poor utilization standards, regardless of rotation length. The marginal benefits of reductions in infection rate were higher on short rotation stands than on long rotation stands, regardless of site index. The results indicate that managcmcnt and utilization also can have large impacts on stand-level returns, in addition to those reccivcd from deployment of rust-resistant seedlings.

Aggregate Benefits

Financial benefits by year.-Table 1 reports Southwide plantation SEVs over time for two utilization and two rotation standards. Results of the two utilization cases not detailed here-the pulpwood and sawtimber scenarios-were bounded by those shown in Table 1. Next to each base case value is the improvement over its base case due to uniform or optimal deployment of resistant seedlings or from total resistance to fusiform rust. The annual base case returns for all southern pine plantations varied over time by a factor of two, driven almost entirely by changes in planting activity across the region. The SEV results for a year's plantings generally exceeded $ 1 billion per year.

SEVs were lower for fixed rotations and less intense utilization than under optimal rotation and full utilization; each of the base cases followed similar temporal dynamics. Loblolly pine made up most of these aggregate southern pine plantation values (about 80%/yr), in keeping with its dominant share of plantation area. Not surprisingly, base case values were higher under optimal rotations and more intensive utilization than fixed rotations or less intensive utilization.

Regardless of variations over time, several trends are clear. First, the deployment scenarios consistently ranked the same, *with* base cases (no rust protection) the least valuable followed by uniform and optimal, with total resistance the most valuable. Second, the uniform and optimal cases started out the same as the base case in 1970 but diverged over time as resistance technology was increasingly adopted by industry. Third, total resistance SEVs roughly paralleled those of the base case and provided a cap that the uniform and optimal values approached hut never reached (Figure 2). The differences between these scenarios were small relative to the overall value of plantations. For the full utilization and economic rotation scenario, resistant seedlings ultimately increased aggregate plantation values by only 0.6% under uniform deployment and 1.3% if deployment were optimal. Under these assumptions even total eradication of rust would only incrcasc plantation values by 2.1%, although under poor utilization total resistance could increase SEVs by as much as 12.7% Thcsc small percentage increases however, amount

Table 1. Annual soil expectation values (SEV) for all Southwide loblolly pine **and** slash pine plantations, without genetic fusiform rust resistance (base case), and with rust resistance (uniform. optimal, and total resistance seedling **targeting** scenarios), by utilization standard and rotation criteria (in million constant dollars, 1992)

	Economic rotation				Fixed rotation			
Planting year	Base case[a]	Uniform	Optimal	Total res.	Base case	Uniform	Optimal	Total res.
		(difference from base[b])				(difference from base)		
Poor utilization								
1970	733	0	0	89	549	0	0	64
1975	1,064	1	7	128	796	0	5	92
1980	1,210	3	13	154	902	2	10	110
1985	1,710	9	32	217	1.275	7	27	156
1990	1,372	13	55	174	1,022	10	42	125
1995	1.513	17	64	193	1,128	13	48	138
2000	1,064	16	51	135	794	12	3Y	97
2005	1,340	23	70	170	1,000	17	53	122
2010	1,242	25	70	158	926	19	53	113
2015	1,216	25	69	155	906	19	52	111
2020	1,175	24	67	149	877	18	51	107
Full utilization								
1970	804	0	0	18	601	0	0	12
1975	1,166	0	3	25	871	0	2	18
1980	1,335	1	4	28	999	1	4	14
1985	1,888	3	10	40	1,411	2	7	20
1990	1,514	4	14	32	1,132	4	12	15
1995	1,670	5	17	35	1,248	5	13	17
2000	1,175	5	12	25	878	5	11	12
2005	1,479	8	17	32	1,107	8	15	15
2010	1,370	8	17	29	1,025	8	14	14
2015	1,341	8	17	28	1,004	8	14	14
2020	1,298	8	17	27	971	8	15	14

a Base case values assume no genetic selection for fusiform rust resistance.
b "Difference from base" columns indicate increases in SEV from the base case given genetic selection assuming uniform or optimal targeting of resistant seedlings or complete ("Total resistance") in all seedlings.

to large total dollar benefits when applied across the whole South's plantation values.

As expected, benefits of rust protection were greatest if poor utilization were practiced (Table 1). If the industry fully merchandizcd all infected stems, the net benefits of fusiform rust protection would be smaller. The benefits of protection also would bc greater using economic rotations compared to fixed **rotations.** When resistant seedlings were distributed uniformly across sites, benefits were substantially lower,

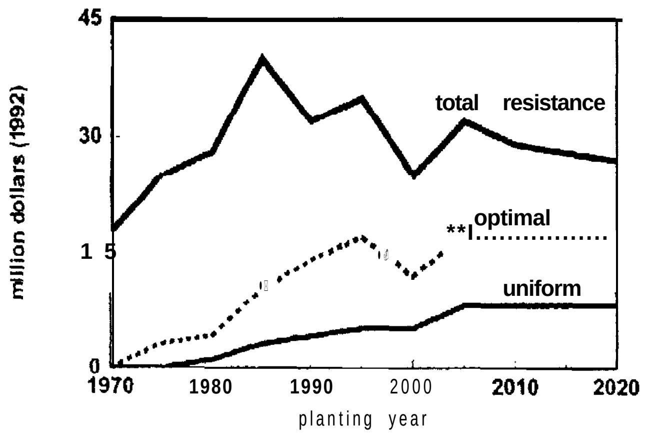

Figure 2. Increased soil expectation values from gradually **increasing production of seedlings** with improved genetic **resistance to fusiform rust, assuming** either uniformdeployment **of those resistant seedlings across plantation sites or optimal deployment of resistant seedlings to locations at** greatest risk, as **contrasted** with **the total** resistance scenario which estimates **gains from immediate and complete elimination of fusiform rust damage to loblolly pine and slash plantations.**

generally less than half those achieved if distributed first to the highest risk sites.

Benefits summed over time.--Southwide present values were discounted to 1992 and summed across years for loblolly pine and slash pine plantations separately and for both combined, and can be seen in Tables 2, 3, and 4. As with SEV, present values were greater for economic rotations than for fixed rotations within each merchandising scenario, and PV increased with improvements in the utilization and deployment standards.

The benefits of improved resistance to fusiform rust were obtained by subtracting the PV of a particular base case from the PV of one of the three "with resistance" scenarios on the same row. For example, the total benefit of improved resistance assuming uniform deployment, poor utilization and a fixed rotation age for loblolly pine was (29683 - 29547 ≈) \$137 million (Table 2). For a different combination of utilization and rotation type (i.e., full utilization and an economic rotation age), the benefit was (36887 - 36872 ≈) \$18 million. Despite loblolly pine's greater share of total plantation area and annual SEVs, the computed research *benefits were cm-*sistently greater for slash pine than loblolly pine (Table 3). This result occurred because slash pine fusiform rust losses were greater, and more stands were found in high rust incidence areas.

Research benefits for the two species combined are shown in Table 3 and ranged from \$108 to \$999 million depending on rotation length and utilization and deployment standards. In most cases, economic damages were higher for economic

Table 2. Aggregate present value of the net revenues from all loblolly pine plantations Southwide, planted 1970-2020, without and with genetic fusiform rust resistance, by utilization standard and rotation criteria (in million constant dollars, 1992)

			Deployment		
Utilization type	Rotation type	Base	Uniform	Optimal	Total resist.
Poor	Economic	33,276	33,417	34,008	37,553
	Fixed	29,547	29,683	30,259	33,379
Pulpwood	Economic	34,794	34,883	35,25 I	37,450
	Fixed	31,152	31,236	3 1,592	33,379
Sawtimber	Economic	36,785	36,804	36,879	37,450
	Fixed	32,991	33,015	33,116	33,379
Full	Economic	36,872	36,887	36,949	37,450
	Fixed	33,197	33,215	33,288	33,379

Table 3. Aggregate present value of the net revenues from all slash pine plantations Southwide, planted 1970-2020, without and with genetic fusiform rust resistance, by utilization standard and rotation criteria (in million constant dollars, 19921.

			Deployment		
Utilization type	Rotation type	Base	Uniform	Optimal	Total resist.
Poor	Economic	7,514	7,642	7,773	7,857
	Fixed	6,817	6,961	7,103	7,379
Pulpwood	Economic	8,191	8,316	8,442	8,571
	Fixed	6,878	7,004	7,125	7,379
Sawtimber	Economic	8,247	8,342	8,434	8,555
	Fixed	6,932	7,042	7,144	7,379
Full	Economic	8,302	8,395	8,486	8,575
	Fixed	6,947	7,052	7,149	7,379

Table 4. Aggregate present value of the combined net revenues (net research benefits) from all slash pine and loblolly pine plantations Southwide, 1970-2020, by utilization standard and rotation criteria (in million constant dollars, 1992).

			Incremental deployment present value		
Utilization type	Rotation type	Base	Uniform	Optimal	Total resist.
Poor	Economic	40,790	269	991	4,619
	Fixed	36,363	282	999	4,394
Pulpwood	Economic	42,985	214	708	3,037
	Fixed	38,030	211	687	2,728
Sawtimber	Economic	45,032	114	281	973
	Fixed	39,923	134	337	835
Full	Economic	45,174	108	261	850
	Fixed	40,144	123	294	614

rotations than under the longer, fixed case. The one exception was for slash stands with high utilization standards-here damages were higher for long rotations. The potential total resistance benefits were much greater than the uniform or optimal benefit estimates.

The values in Table 4 represent benefits relative to the base case for combined loblolly pine and slash pine planted stands and are thus the total present value for net research benefits. Caution should be exercised when making comparisons across scenarios. For example, a comparison of the combined research benefit for the poor utilization standard with a fixed rotation age and uniform deployment ($282 million) with the research benefit for the full utilization standard with an economic rotation age given optimal deployment ($261 million) does not suggest that the former scenario is more desirable from an economic perspective because each is based on a different assumption about logging practices. However, our results indicate that efficiency gains associated with the introduction of genetically improved planting stock would be greatest for producers with the lowest utilization of infected stems, and lowest for those producers who utilize infected stems as completely as possible with the highest utilization standards.

Genetic Improvement, Rotation Age, and Utilization Contributions.--The aggregate simulation analyses also provide a means of comparing relative economic contributions of stand management, utilization, and genetic improvement. Again, these arc compared to different bases, so they cannot be considered absolute quantities, but different magnitudes bear mention. Protection from fusiform rust, optimal targeting, and improvements from the worst to the best utilization combined could generate incremental (1992) benefits of about $108 million to $999 million for the uniform and optimal scenarios, depending on the rotation and utilization type. The differences between fixed 35 yr rotations and optimal (about 25 yr) rotations within any given utilization type ranged only from only $3 million (pulpwood utilization, uniform deployment) to $56 million (sawtimber utilization, optimal deployment) in 1992 dollars. Large differences could occur in present values depending on poor to full utilization, ranging from $159 million given uniform seedling distribution and fixed rotations to $730 million for optimal targeting and economic rotations.

One can also compare these management, utilization, and rust protection effects on a percentage basis for the total present value of all southern pine plantations. Moving from a fixed, 35 yr rotation to an optimal economic rotation, within any given utilization level and on the base case, increases aggregate plantation present values 11-13% (about $4-$5 billion) based on the combined loblolly and slash pine base case values. Utilization has a slightly smaller effect on the total southern pine plantation prcscnt values, with the plantations collectively worth about 10% more under full utilization than under poor. Fusiform rust protection effects, were almost an order of magnitude smaller ($123 million to $1 billion), but still large for all plantations. Depending on the utilization assumption, plantation values with fusiform rust resistance were worth as little as 0.2% more than the base case for full utilization and uniform targeting to 2.7% more for poor utilization and optimal targeting. Total resistance to fusiform rust, however, could generate returns that could approach the financial selection of the optimal rotation age or the fullest utilization practices ($614 million to $4.6 billion).

While the contributions of various components to aggregate economic returns depends on the scenario examined, an illustration is useful. For a "representative" scenario of sawtimber utilization and optima1 deployment, the net present value of improved rust-resistant seedlings would be $281 million in 1992 dollars. Selecting the optimal rather than the fixed rotation would contribute a much greater $5,109 million to the total incremental return. Increasing utilization from sawtimber to full utilization would add about $142 million to total southern pine plantation returns.

Timber Supply and Price Impacts.--This research was performed as a comparative statics analysis, assuming constant prices for inputs and outputs over several decades. Large changes in timber production costs, timber supply, or stumpage prices could change the results. Increases in timber produced due to rust resistant seedlings could increase volumes enough to drive timber prices down, reducing net benefits, On the other hand, timber prices could have incrcascd in real terms since 1992, or planting costs decreased, which would increase the net benefit calculations, all else being equal. In fact, probably both of these events have occurred and will continue.

If the optimal rust protection benefits and largest difference in utilization scenarios occurred, the greatest net amount of new timber volumes over the production period would be about 2.7%; in the least amount of improvement, it would be 1.1%. Given an average southern pine price to inventory elasticity of -0.4%, the net change in stumpage prices would be small. A modified price elasticity calculation could illustrate the cumulative effect of this added volume, assuming it occurred at one point in time. Given the increased quantity, and solving for the new price, indicates that this would lead to net price reduction from the base of $0.62/ft3 to a new equilibrium of $0.616 to $0.602/ft3, for the least and most amounts of added rust resistance. This relatively small drop in prices would have little effect on the results presented here. Timber prices, however, have probably increased from 25% to 50% since 1992, depending on the region of the South, and are still projected to have significant real price appreciation (Cubbage and Abt 1998). Thus the benefits we calculated should actually be fairly conservative compared to current price levels.

Research Costs

Investments in research reported by the Forest Service, seedling producers, research cooperatives and universities were converted to 1992 constant dollars and summed. Research costs by these groups from 1970 through 1992 totaled $49 million, with annual expenditures ranging from a low in 1970 of $1.3 million to a high of $3.2 million reported for 1986.

Benefit-Cost Analysis

Table 5 summarizes benefit-cost (B/C) ratios and net benefits results. If a B/C ratio is greater than 1, then the benefits are greater than the costs, implying the program was economically acceptable at the given discount rate. All the B/C ratios were greater than 1. Research costs could double and, in some scenarios, increase by a factor of 10, and net benefits would remain positive.

Table 5. Benefit-cost ratio and net benefit of fusiform rust research in loblolly pine and slash pine, by utilization standard, rotation type, and targeting scenario, 1992.

Utilization & rotation type	Benefit measure	Deployment: Uniform	Deployment: Optimal
Poor			
Economic	B/C	5.51	20.29
	Net benefit	220.36	942.47
Fixed	B/C	5.17	20.44
	Net bencfit	232.80	949.68
Pulpwood			
Economic	B/C	4.31	14.49
	Net benefit	164.79	659.07
Fixed	B/C	4.31	14.06
	Net benefit	161.74	638.18
Sawtimber			
Economic	B/C	2.33	5.75
	Net benefit	64.95	232.13
Fixed	B/C	2.74	6.89
	Net benefit	85.03	287.03
Full			
Economic	B/C	2.21	5.33
	Net benefit	58.93	211.68
Fixed	B/C	2.53	6.02
	Net benefit	74.55	245.03

NOTE: B/C is defined as the benefit cost ratio; Net Benefits in $1992 million.

Conclusions

Our analysis indicates that the benefits of increased resistance to fusiform rust are substantial. The exact amount of benefits depends on how well industry merchandises cankcred logs, and how well rust resistant seedlings are successfully targeted to rust-prone sites. At a minimum, planting of rust-resistant seedlings could save millions of dollars per year by preventing product losses and degrades. At best, it could save tens of millions per year.

Summed over the decades from first introduction of rust-resistant seedlings until those planted in 2020, the discounted net present value of benefits ranged from $108 million to $999 million depending on the assumptions used. We believe that more rust-resistant seedlings were probably targeted to high-rust sites (optimal targeting), and that industry probably was fairly good at cutting out defective portions of logs and then aggressively merchandising the remainder. This suggests total discounted rust resistance benefits in the $200 to $300 million range, representing $40 million to $60 million of discounted benefits per year. With total research costs of less than $50 million, the benefit-cost ratio would approach 4:1 to 6:1. These returns support the merits of past investments.

Comparing the uniform versus optimal scenario values shows that the ability to target resistant seedlings to high risk areas is extremely important to their economic effectiveness, easily doubling or tripling their net benefit. Even with perfect allocation of seedlings and aggressive utilization, the failure to eradicate fusiform rust from plantations still costs the industry millions each year. As the bottom left section of Table 1 indicates, even in the evaluation's last years, eradication of fusiform rust would still add $10 million per year to plantation values in the South (assuming plantation landowners are harvesting their stands near optimal rotation lengths and merchandizing infected stems efficiently). More aggressive production of resistant seedlings or development of newer resistance technologies can still yield substantial additional benefits to the industry. Achieving total resistance seemed unlikely a decade ago, but. is not so unthinkable today, now that at least one gene that confers fusiform rust resistance in loblolly pines has been identified (Wilcox ct al. 1994).

There are of course limits to improved resistance, including the potential for increased virulence in the disease itself. Our results show, however, that investments in tree improvement technologies can yield large benefits to the industry, and suggest that opportunities exist for substantial returns to future research and dcvclopmcnt investments.

Literature Cited

Anderson, R.L. N.D. COST. J.P. McClure AND G. RYAN. 1986a. Predicting severity of fusiform rust in young loblolly and slash pine stands in Florida, Georgia. and the Carolinas. South. J. Appl. For. 10(1):38-41.

Anderson, R.L., J.P. McClure N.C. Cost, AND R.J. Uhler 1986b. Estimating fusiform rust losses in five southeastern states. South. J. Appl. For. 10 (4):237-240.

BELANGER, R.P.,T. MILLER, J.F. Godbee, AND R.S. WEBB. 1985. Rust in slash pine plantations. P. 43-51 in Proc. of the Rusts of Hard Pines Working Party Conference, Barrows- Broaddus, J., and H.R. Powers (eds.). University of Georgia, Athens, GA.

Belli, M.L., T.J. STRAKA, M. DUBOIS, AND W.F. WATSON. 1993. Cost and cost trends for forestry practices in the South. For. Farm. 52(3):25-31.

BORDERS, B.E., AND R.L. BAILEY. 1986. Fusiform rust prediction models for site-prepared slash and loblolly pine plantations in the southeast South. J. Appl. For. 10:145-151.

Burgan, T.M., K.L. BAILEY, AND J.R. BROOKS. 1989. Georgia pine plantation simulator. vers. 3.0. School of For. Resour., University of Georgia, Athens, GA.

BUSBY, R.L., AND T.K. Haines 1989. Determining the value of a fusiform rust infected stand. USDA For. Serv. Res. Pap. S0-245. 5 p.

CAREY, W.A., AND W.D. KELLEY 1993. Seedling production trends and fusiform rust control practices at Southern nurseries, 1981-1991. South. J. Appl. For 17(4):207-211.

CUBBAGE, F.W. AND R.C. ABT. 1998. Southern timber supply implications for the pulp and paper sector. PaperAge 114(2):31-33.

Geron, C.D., AND W.L. Hafley. 1988. Impact of fusiform rust on product yields of loblolly pine plantations. South. J. Appl. For. 12(4):226-231.

Hafley, W.L., AND W.D. SMITH. 1989. North Carolina State University Managed Pine Plantation Growth and Yield Simulator. N.C. State Univ. Coll. of For. Resour. Raleigh, NC.

Holley, D.L., AND M.A. Veal. 1977. Economic impact of fusiform rust. P. 39-50 *in* Management of fusiform rust in southern pines, Dinus, R.J., and R.A. Schmidt (eds.). University of Florida, Gainesville, FL.

HOLMES, T.P. 1991. Price and welfare effects of catastrophic forest damage from southern pine beetle epidemics. For. Sci. 37:500-516.

JOHANSSEN, P.O., AND K.G. LOFGREN. 1985. The economics of forestry and natural resources. Basil Blackwell, Oxford, United Kingdom. 292 p.

MANGOLD. R.D., R.J. MOULTON, AND J.D. SNELLGROVE. 1991. Tree planting in the United States: 1990. USDA For. Serv., State and Private For., Coop. For. Washingron, DC. 18 p.

MARTELL, D.L. 1980. The optimal rotation of a flammable forest stand. Can. J. For. Res. 10:30-34.

PIENAAR, L.V., W.M. HARRISON, T. BURGAN. AND J.W. RHENEY. 1988. Yield prediction for site-prepared slash pine plantations in the coastal plain. Tech. Rep. No. 1988-1 Plantation Manage. Res. Coop., School of For. Resour, University of Georgia, Athens, GA.

POWERS, H.R.,Jr., J.P. McCLURE H.A. KNIGHT, AND G.F. DUTROW 1974. Incidence and financial impacts of fusiform rust in the South. J. For 72(7):398-401.

PYE, J.M., J.E. WAGNER, T.P. HOLMES, AND F.W. CUBBAGE. 1997. Positive returns from investment in fusiform rust research. USDA For. Serv. Res. Pap. SRS-4. 55 p.

RANDOM LENGTHS PRICE REPORT. 1993. January 8 Report. Jon P. Anderson, Publisher, Eugene, OR. 12 p.

REED, W.J. 1983. The effects of the risk of fire on the optimal rotation of a forest. J. Environ. Econ. Manage. 11:180-190.

ROUTLEDGE, R.D. 1980. The effect of potential catastrophic mortality and other unpredictable events on optimal forest rotation policy. For. Sci. 26:389-399.

Row, C.H., F. KAISER, AND J. SESSIONS. 1981 Discount rates for long-term Forest Service investments. J. For. 79(6):367-369,376.

USDA FOREST SERVICE. 1981. Forest planting, seedling, and silvical treatments in the United States 1980 Report. Rep. No. FS-368. USDA For. Serv., Washington, DC. 15 p.

USDA FOREST SERVICE. 1982. I98 1 U.S. Forest Planting Report. Report No. FS-379. USDA For. Serv.. Washington, DC. 15 p.

WEBB, R.S., AND H.D. PATTERSON. 1984. Effect of stem location of fusiform rust symptoms on volume yields of loblolly and slash pine sawtimber. Phytopathology 74(8):980-983.

WILCOX, P.L., H.V. AMERSON, E.G. KUHLMAN, D. O'MALLEY, AND R.R. SEDEROFF. 1994. Genetlc dlssection of fusiform rust resistance in loblolly pine. Contributed paper and abstract. IUFRO Molecular Genetics Workshop.

WILLISTON. H.L. 1980. A statistical history of tree planting in the South: 1925-1979. USDA For. Serv. Misc. Rep. SE-MR 8. State and Private Forestry, Atlanta. GA. 36 p.