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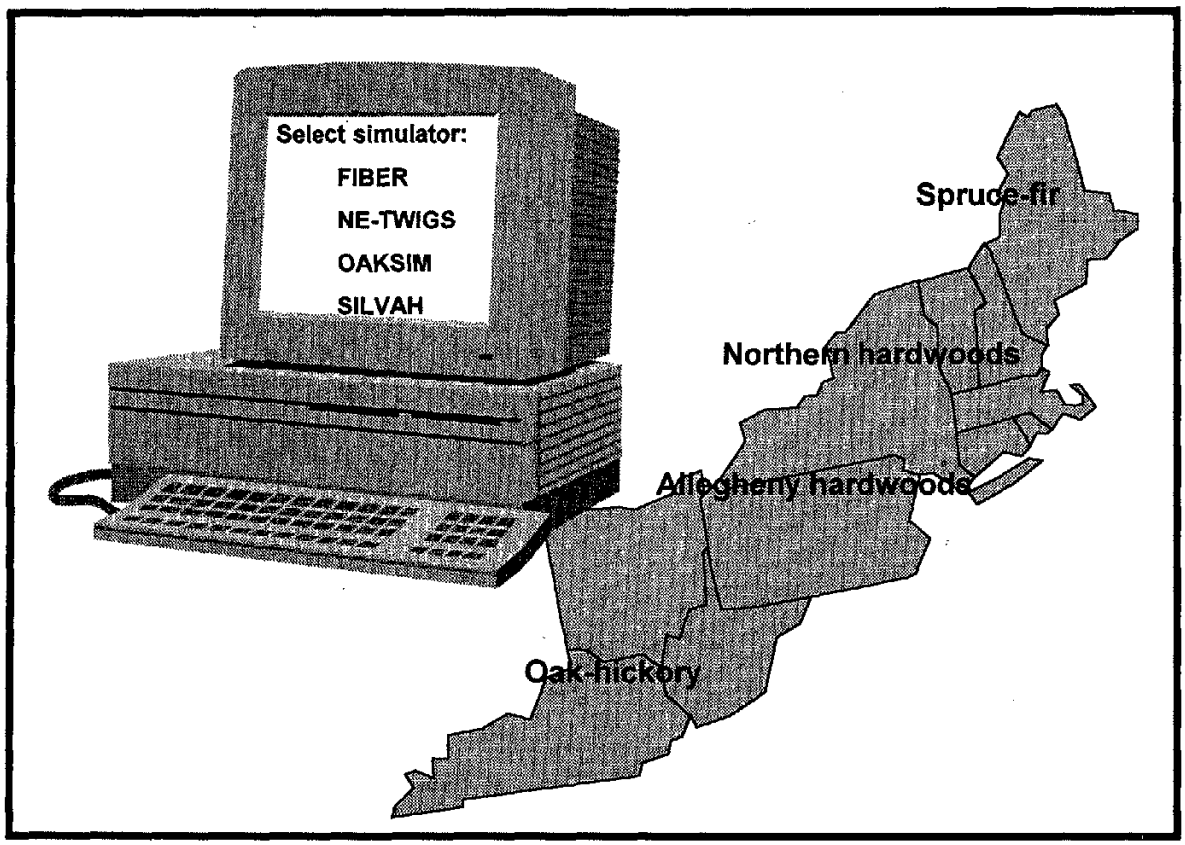
Test of Four Stand Growth Simulators for the Northeastern United States

Thomas M. Schuler
David A. Marquis
Richard L. Ernst
Brian T. Simpson



Abstract

SILVAH, FIBER, NE-TWIGS, and OAKSIM simulators, commonly used in the northeastern United States, were evaluated by comparing predicted stand development with actual stand development records for periods ranging from 15 to 50 years. Results varied with stand parameter, forest type, projection length, and geographic area. Except in the spruce-fir forest type where FIBER stands out as the best simulator, no single simulator is clearly superior to the others for all locations within a forest type. In general, FIBER, NE-TWIGS, and SILVAH performed best in the northern hardwood (beech-birch-maple) forest type; NE-TWIGS and SILVAH performed best in the Allegheny hardwood (cherry-maple) forest type; SILVAH and OAKSIM performed best in the oak-hickory forest type; and SILVAH was most suitable in the transition hardwood (mixture of northern hardwoods and oaks) forest type. The results give growth and yield model users more information for selecting the simulator most suitable for their particular needs. The results also can be used as a diagnostic tool for growth and yield model development.

The Authors

THOMAS M. SCHULER, research forester, received his bachelor's degree in forestry from Purdue University and a master's degree in silviculture from Colorado State University. In 1992, he joined the forest management research project at the U.S. Department of Agriculture, Forest Service, Timber and Watershed Laboratory, Parsons, West Virginia.

DAVID A. MARQUIS, (retired) coordinator for the Northeast Decision Model received his bachelor of science degree in forestry from Pennsylvania State University and his master's and doctoral degrees in forest ecology and silviculture from Yale University.

RICHARD L. ERNST, currently a mensurationist for the Washington Office in Fort Collins, Colorado, received his bachelor's and master's degrees in forest management and operations research from Pennsylvania State University.

BRIAN T. SIMPSON, currently a forester for the Northeastern Forest Experiment Station, Morgantown, West Virginia, received his bachelor's degrees in geology and forestry and his master's degree in forestry from West Virginia University.

The computer program described in this publication is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program. For cost information, write Northeastern Forest Experiment Station, 5 Radnor Corporate Center, Suite 200, P.O. Box 6775, Radnor, PA, 19087-8775. [FSM 6621.5].

Cover Figure—Range of geographic locations and forest types evaluated by the four growth and yield simulators included in this study.

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USDA FOREST SERVICE
5 RADNOR CORP CTR STE 200
PO BOX 6775
RADNOR PA 19087-8775

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Introduction

Forest land managers need reliable growth and yield information to manage the vast areas of forest land in the eastern United States. To provide this information, computer programs that simulate stand growth and yield have been developed and are widely available for use on microcomputers. Several stand growth simulators have been developed for forests of the northeastern United States. Although projection estimates are carefully evaluated during the development phase of each simulator, there is little information available to aid the potential user in selecting the best simulator for their particular circumstances when several simulators are available for a given area. The relative performance of various models and their suitability for use in a particular forest type and geographic area, in comparison to other simulators, is largely unknown.

A test of four simulators was undertaken to provide performance information needed in a multiple-resource, silvicultural decision model currently being developed by the Northeastern Forest Experiment Station, U.S. Department of Agriculture, Forest Service (Marquis 1991). The results of the test will be used by the decision model to aid in the selection of a simulator for a given projection where a specific simulator is not designated by the user. The results also can be used by individuals to evaluate various simulators as to their utility for particular situations.

Methods

There were four stand growth simulators included in the test: SILVAH V4.03 (Marquis 1986, Marquis and Ernst 1992), OAKSIM (Hilt 1985a, 1985b), NE-TWIGS V2.0 (Hilt and Teck 1989, Teck 1990), and FIBER V2.0 (Solomon and others 1987). All four simulators are distance-independent, individual tree, or stand table-projection types of simulators. They all begin with a list of trees by species and diameter at breast height (d.b.h.) and can generate similar tree lists or stand tables upon completion of the projection. All are available for public use on IBM-compatible microcomputers.

Brief Description of SILVAH Version 4.03

SILVAH was developed for use in hardwood forests of the Allegheny region of Pennsylvania, New York, West Virginia, Maryland, and Ohio. The SILVAH system is primarily an expert system used in making silvicultural decisions, but it also includes a stand growth simulator. Since this work was completed, SILVAH V4.5 has been released.

Growth data in SILVAH comes from two major sources. Data on the cherry-maple and beech-birch-maple types were generated from long-term research plots in northwestern Pennsylvania, some of which span 53 years of continuous record. Data on the oak-hickory type in SILVAH came from OAKSIM. The equations for oak were taken from that simulator and used for all oak species. Some growth equation adjustments included in OAKSIM are not included in SILVAH.

Variables used in SILVAH growth and mortality equations include species, d.b.h., relative diameter (d.b.h./stand diameter), relative stand density for all species except oak (Marquis and others 1992), total basal area for oaks, and site index for oaks. SILVAH is a modified stand table-projection simulator. Usual projection periods are 5 years, but periods as short as 1 year are permitted. Minimum tree size is 1.0 inch d.b.h.; maximum tree size is 40.0 inches d.b.h. SILVAH does not estimate ingrowth into the 1-inch d.b.h. class.

Brief Description of OAKSIM

OAKSIM was developed for use with oak-hickory forests of the upland central hardwood region. Growth and mortality data were obtained from 20-year records on 77 permanent plots in southern Ohio and southeastern Kentucky. A single growth equation is used for all species, but there are four mortality equations applied to the species groupings of black oak, white oak, hickory and other trees, and understory trees.

Variables used in OAKSIM equations include: d.b.h., quadratic mean stand diameter, total stand basal area, and species (mortality only). OAKSIM is a distance-independent, individual-tree simulator. It works from a tree list and treats each tree in the list as a single entity, either killing it or growing it in its entirety.

OAKSIM projects only in 5-year growth periods. The minimum d.b.h. is 2.6 inches and the maximum d.b.h. is 30.0 inches. OAKSIM does not estimate ingrowth.

Brief Description of NE-TWIGS Version 2.0

NE-TWIGS was developed for use throughout the northeastern United States. It utilized the large data base pertaining to the entire northeastern United States of the Forest Inventory and Analysis Unit, Northeastern Forest Experiment Station, USDA Forest Service. Growth records on these plots range in time from 8 to 14 years and include all forest types growing in the Northeast.

Variables used in NE-TWIGS to estimate growth and mortality include species, d.b.h., basal area in trees larger than the tree in question, and site index. NE-TWIGS is a distance-independent, individual-tree simulator that calculates potential growth, then reduces that growth by competitive position.

NE-TWIGS projects growth annually in cycles of 1 to 5 years. Minimum d.b.h. is 1.0 inch and maximum d.b.h. is 30.0 inches. NE-TWIGS allows the user to select ingrowth as an option, but requires the user to specify manually the ingrowth tree characteristics. The ingrowth function was not utilized for these tests. Since this work was completed, NE-TWIGS V3.0 has been released and has automatic ingrowth functionality.

Brief Description of FIBER Version 2.0

FIBER was developed for the spruce-fir and northern hardwood forest types of New England. It is based on data from 359 spruce-fir research plots in Maine and 48 northern hardwood plots in New Hampshire. In addition, some 2,500 growth plots primarily from forest industry were utilized. These plots are located throughout Maine, New Hampshire, Vermont, and northern New York.

Variables used in the FIBER growth and mortality equations include d.b.h., initial stand basal area, residual stand basal area, percent hardwoods, and percent species. FIBER is a two-stage matrix model. One stage is a set of linear regression coefficients that predict transition probabilities of tree growth and mortality as a function of stand density, tree size, and proportion of hardwoods. The predicted probabilities are the elements of stand projection matrices used to project the distribution of diameters over a 5-year period.

FIBER projects in 5-year increments only. Minimum d.b.h. is 5.0 inches and maximum d.b.h. is 30.0 inches. FIBER was the only simulator of the four tested that contained an automated ingrowth function. FIBER estimates ingrowth into the 5.0-inch class. The ingrowth function cannot be disabled and was used for these tests.

Test Data and Procedures

Actual stand growth records were obtained from permanent research plots in Maine, New Hampshire, Vermont, Massachusetts, New York, Pennsylvania, West Virginia, Ohio, and Kentucky. Forest types on these plots included aspen-birch, cherry-maple or Allegheny hardwoods, beech-birch-maple or northern hardwoods, oak-hickory, spruce-fir, transition hardwoods (mixtures of northern hardwoods and oaks), and several miscellaneous types.

After the data were assembled, we found that five forest types were well represented and could be included in the analyses. Forest type determinations were designated using the proportion of total stand basal area represented by a particular species. Quantitative algorithms defined by Marquis and Ernst (1992) were used to determine forest type during initial stand analysis.

All plots in the simulator test data set had a minimum of 15 years of actual growth record. Some had growth records as long as 50 years. Each growth record was categorized as either a short or long period. A short period was defined as 20 years and a long period as 40 years. Since remeasurements often did not coincide exactly with the 20- and 40-year periods, deviations of up to 5 years were permitted for the short period, and deviations up to 10 years were permitted for the long period. Thus, the 20-year period contained growth records of 15 to 25 years and the 40-year period contained growth records of 30 to 50 years. No stands were in the 26- to 29-year length.

The actual records were categorized as either short or long so that model performance for each projection length could be evaluated. However, in all simulations, attempts were made to match the actual growth period as closely as possible. If the actual growth records covered 22 years, the simulation was done for 22 years if permitted by the model. FIBER and OAKSIM were structured to make growth projections in multiples of 5 years only. Thus, a 22-year period was projected as a 20-year period with FIBER and OAKSIM, but projected for the actual time period with SILVAH and NE-TWIGS.

The test data included both cut and uncut stands. About one-third of the observations were stands that had some form of cutting during a projection period. Removals from simulated tree lists duplicated actual cutting procedures as closely as possible. Procedures that could not be duplicated with the simulator interface were done manually. In such cases, stands were projected to the time of the cut and saved. The projected tree list was edited to reflect cut characteristics and submitted again to the simulator to finish the projection.

The stand summary procedures from SILVAH were used to tabulate and report stand parameters, such as basal area and number of trees per acre for all tests. The results of each simulator's projection and the actual, observed stand data, in the form of a tree list, were entered into a modified version of SILVAH that excluded all trees less than 5.0 inches d.b.h. from stand summaries. This eliminated variation in test results due to differences in individual model minimum acceptable diameters and permitted direct comparisons among simulators. Summary statistics were transferred by this modified version of SILVAH to a spreadsheet where the stand summaries from actual and simulated stands were accumulated.

In all, there were 185 separate stands included in the tests. These provided 186 short-period observations and 28 long-period observations. The largest number of observations were from the northern hardwood forest type. Allegheny hardwoods, oak-hickory, and spruce-fir types also were well represented. States with 20 or more observations included Maine, Vermont, Massachusetts, New York, Pennsylvania, and West Virginia. Table 1 lists the number of observations by period, forest type, and state.

Stand Parameters

All simulators were used in all forest types and geographic areas. These methods resulted in using some simulators in forest types for which their use was never intended. In all analyses, six key per-acre stand parameters were used to represent stand conditions. The stand parameters consisted of number of trees, basal area in the pole-size class (5.0 to 11.0 inches d.b.h.), basal area in the sawtimber-size class (12.0 inches d.b.h. and greater), total basal area (5.0 inches d.b.h. and greater), medial stand diameter calculated as Σ d.b.h.^{3}/Σd.b.h.^{2}, and percentage of the basal area in the

primary species group for the forest type being tested (Table 2). Medial stand diameter was chosen as an expression of stand diameter because it has been shown to approximate the average diameter of the dominant, codominant, and intermediate trees of the stand (Marquis 1991).

Table 1.—Number of observations by forest type, state, and projection period.

Forest type, projection period, state	No. of Observations
Spruce-fir	
Short period, all states	32
Short period, ME	28
Northern hardwoods	
Short period, all states	77
Short period, ME	20
Short period, MA	14
Short period, VT	30
Short period, PA	10
Long period, all states	15
Long period, NH	10
Long period, PA	5
Allegheny hardwoods	
Short period, all states	32
Short period, PA	24
Short period, WV	6
Long period, all states	8
Long period, PA	6
Transition hardwoods	
Short period, all states	12
Short period, WV	8
Oak-hickory	
Short period, all states	29
Short period, KY	5
Short period, OH	7
Short period, NY	14

Originally, a seventh parameter was included to represent the proportion of stand basal area in a secondary species group. This worked well in some forest types where there were two distinct species groups represented, such as transition hardwoods in which oaks and maple-beech groups were both prevalent. But the use of two species groups in forest types in which only one major species group exists, such as northern hardwoods, introduced a large error that was not meaningful. As a result, the secondary species group was dropped as a test parameter.

The six key stand parameters together represent major stand characteristics that a forest manager might want to simulate: stand density or stocking, stand structure, average tree size, and species composition. Stocking is represented by total basal area and number of trees. Structure is reprsented by the distribution of basal area between the pole- and sawtimber-size classes. The basal area in these two size classes also provides an indirect measure of pulpwood and sawtimber volumes as well as timber values. Average tree size of the dominant, codominant, and intermediate trees is represented by the medial diameter. And species composition is represented by the percentage of basal area in the primary species group.

Simulator Performance Measures

Methodology for simulator evaluation has been investigated (Reynolds and others 1981; Ek and Monserud 1979; Goulding 1979; Brand 1983; Buchman and Shifley 1983; Zuuring and others 1988) revealing problems in evaluating multiple simulators. After considerable analysis, we chose to rank simulator performance based on three separate measures. Each measure is described.

In order to evaluate simulator performance, we developed a procedure that generated several statistics in order to evaluate the goodness of fit of each simulator to the actual data. The procedure calculated the mean difference between the actual ending stand parameters and the simulated stand parameters. This difference was an estimate of bias. The closer the bias to zero, the better on average the model predicted across all stands in the test.

We also calculated a tolerance interval, which indicated the spread in the prediction or the variation in the difference among the individual stands. The tolerance interval parameters were set so that 75 percent of the stands would fall within the tolerance interval width 95 percent of the time. Thus, the smaller the tolerance interval width, the better the simulator. The tolerance interval and bias were computed using SYSTAT[1].

Both bias and tolerance interval are important. A simulator that overpredicts on half the stands and underpredicts on the other half may have a small average bias, but a large tolerance interval. A simulator that always underpredicts may have a small tolerance interval but a large average bias. The ideal simulator is one that has both a small average bias and a small tolerance interval.

[1]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Table 2.—The primary species group used for each forest type evaluated

Forest type	Primary species group
Northern hardwoods	Sugar maple (*Acer saccharum* Marsh), beech (*Fagus grandifolia* Ehrh.), and birch (*Betula* sp.)
Allegheny hardwoods	Black cherry (*Prunus serotina* Ehrh.), white ash (*Fraxinus americana* L.), yellow-poplar (*Liriodendron tulipifera L.*)
Transition hardwoods	All oaks (*Quercus* sp.)
Oak-hickory	All oaks (*Quercus* sp.)
Spruce-fir	All conifers (*Abies* sp., *Picea* sp., *Tsuga* sp.)

Table 3.—Spruce-fir percent mean bias, percent tolerance interval, and percent of stands within 15 percent of the actual values by stand parameter, period length, and state

Projection period, states	SILVAH			OAKSIM			NE-TWIGS			FIBER			Best
	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	
							Basal area (total)						
Short period, all states	-25	33	22	-32	38	19	-17	28	25	-11	25	44	FIBER
Short period, ME	-26	34	18	-33	38	14	-17	29	25	-11	25	46	FIBER
							Basal area (saw)						
Short period, all states	18	22	28	-40	27	19	-20	23	22	-44	27	38	SILVAH
Short period, ME	17	22	32	-39	26	21	-17	23	25	-42	27	43	SILVAH
							Basal area (poles)						
Short period, all states	-37	45	19	-32	42	13	-25	40	22	-18	31	25	FIBER
Short period, ME	-39	45	18	-34	43	14	-27	41	21	-20	31	25	FIBER
							Medial stand diameter						
Short period, all states	13	20	66	0	10	81	9	15	72	1	10	91	FIBER,OAKSIM
Short period, ME	15	21	61	2	10	79	11	16	68	3	9	93	FIBER
							Number of trees						
Short period, all states	-36	47	22	-38	48	16	-31	45	28	-2	29	31	FIBER
Short period, ME	-41	48	14	-41	49	14	-35	46	21	-5	28	32	FIBER
							Percent basal area in primary Species Group						
Short period, all states	-6	17	72	-3	31	56	-2	12	81	3	12	84	TWIGS,FIBER
Short period, ME	-8	16	75	5	20	64	-4	10	86	2	11	89	FIBER
							Overall						
Short period, all states	-12.17	30.67	38.17	-24.17	32.67	34.00	-14.33	27.17	41.67	-11.83	22.33	52.17	FIBER
Short period, ME	-13.67	62	36	-33	48	35	-7	44	41	-9	33	55	FIBER

Finally, stand parameters after simulation were compared with actual stand values at the same age, and the proportion of stands estimated within 15 percent of the actual value was tabulated. These tabulations were made separately for each of the six stand parameters, then an average was calculated for all six parameters for each simulator. The results provide a measure of how well the simulators performed on the test data set.

Model Selection

The results from the bias, tolerance interval, and percent of stands within 15 percent of the actual values were tabulated. Both bias and tolerance interval width were converted to percentages of the average actual observations. An "overall" percent bias and percent tolerance interval for the six parameters was obtained simply by averaging the percentage estimates for the individual parameters. The simulator that performed the best in at least two of the three "overall" criteria--bias, tolerance interval width, and percent of stands estimated within 15 percent of the actual value--was selected as the simulator for the automatic simulator-selection algorithm for the Northeast Decision Model.

Results and Discussion

Spruce-fir

In the spurce-fir forest type, FIBER was the clear choice for the best performing simulator. This forest type was limited to Maine and an "all states combined" category. The "all states combined" category was dominated by the Maine observations as is evident by the similarity of the results of the tests for each of the six stand parameters and the "overall" averages presented in Table 3.

NE-TWIGS, FIBER, and SILVAH made reasonable estimates of the percent of basal area in the primary species group. FIBER predictions were closest to the actual observations for total basal area, basal area in pole-sized trees, and number of trees. SILVAH had the smallest bias and the narrowest tolerance interval for basal area of sawlog-sized trees.

All of the simulators underpredicted total basal area, pole-size basal area, and number of trees. This may be related to the large percentage of cut stands in the data set for this particular forest type. Although the cuttings were simulated within the stand projections, the reduced basal area in these stands may have resulted in changes in the rates of density-dependent mortality, growth rates of the residual trees, and ingrowth of new trees into measured size classes not accounted for by the simulators.

Northern Hardwoods

FIBER, NE-TWIGS, and SILVAH each provided the closest estimates for different categories (Table 4). FIBER projections were closest to the actual observations in the "overall" category for both the short and long projection periods of "all states combined," the short periods in Maine and Massachusetts, and the long period in New Hampshire. NE-TWIGS projections were closest in the "overall" category for both the short and long projection periods in Pennsylvania, while SILVAH projections were closest in the "overall" category for the short projection period in Vermont. The northern hardwood forest type was represented by more observations than any other forest type included in this evaluation. The northern hardwood test data included observations from five states and both short and long projection periods. SILVAH, NE-TWIGS, and FIBER were developed, in part, with data from the northern hardwood forest. The "overall" results reflect the calibration of these models for this forest type.

Individual parameter estimates of pole-sized basal area, number of trees, and the percent of basal area in the primary species group were estimated the closest by FIBER in the majority of the location and period length categories. The projections of sawlog-sized basal area exhibited considerable variability. SILVAH was closest to the actual observations for short projections in Vermont, Maine, and "all states combined." NE-TWIGS was closest for long projections in Pennsylvania and "all states combined." The results for other locations and projection periods were less clear, such as in sawlog-sized basal area estimates for the short period in Massachusetts and Pennsylvania and the long period in New Hampshire. Medial stand diameter estimates also showed considerable variability, with each of the models performing best in at least one category.

Allegheny Hardwoods

In most cases, growth and yield model users will be well served by using NE-TWIGS for this forest type. NE-TWIGS projections were closest to the actual observations in the "overall" category for the short and long projection periods in Pennsylvania and "all states combined" (Table 5). SILVAH projections were closest to the actual observations in the "overall" category for the short projection period in West Virginia. The results of the individual parameter estimates for total and sawlog-sized basal area projections clearly show that NE-TWIGS provided the best estimates. SILVAH generally provided the closest estimates for the percent of basal area in the primary species group, while OAKSIM generally had the best results for predicting number of trees and pole-sized basal area. All of the simulators provided reasonable estimates of medial stand diameter, and model differences were not clearly apparent for this parameter.

Transition Hardwoods

Based on the results for "all states combined," we felt that SILVAH would be the most appropriate choice in this forest type for most situations. Although our test data included

Table 4.—Northern hardwood percent mean bias, percent tolerance interval, and percent of stands within 15 percent of the actual values by stand parameter, period length, and state

Projection period, states	SILVAH			OAKSIM			NE-TWIGS			FIBER			Best
	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	
							Basal area (total)						
Short period, all states	-6	21	53	-8	21	45	-7	22	45	-3	21	57	FIBER
Short period, ME	-17	25	30	-14	21	30	-17	23	25	-12	18	55	FIBER
Short period, MA	-11	14	71	-13	14	64	-10	18	50	-4	12	79	FIBER
Short period, VT	0	12	53	-1	24	40	-1	23	43	2	28	40	SILVAH
Short period, PA	9	12	80	-4	11	80	-2	10	80	1	15	80	TWIGS, FIBER
Long period, all states	6	17	53	-17	21	47	-2	18	53	0	4	60	FIBER
Long period, NH	8	17	60	-19	21	30	1	19	60	1	14	60	FIBER
Long period, PA	2	15	40	-12	16	80	-8	13	40	-3	18	60	NONE
							Basal area (saw)						
Short period, all states	2	18	44	-1	19	43	-1	21	38	-19	21	43	SILVAH
Short period, ME	-2	18	45	8	19	45	4	19	45	12	18	40	SILVAH
Short period, MA	-7	15	50	-6	15	50	2	19	36	-18	18	64	None
Short period, VT	-3	19	40	-3	20	30	-7	23	30	-26	23	33	SILVAH
Short period, PA	21	8	10	-2	7	20	-2	9	30	-15	9	20	OAKSIM,TWIGS
Long period, all states	10	19	27	41	17	33	77	16	40	-16	17	20	TWIGS
Long period, NH	88	23	10	-7	19	20	47	18	30	-25	17	20	None
Long period, PA	28	10	60	-14	11	60	7	9	60	-20	13	20	TWIGS
							Basal area (poles)						
Short period, all states	-12	38	32	-16	38	27	-15	40	29	2	34	38	FIBER
Short period, ME	-36	50	15	-42	53	0	-45	55	0	-28	42	30	FIBER
Short period, MA	-17	30	29	-22	30	14	-23	36	21	-6	22	57	FIBER
Short period, VT	2	27	43	0	25	37	3	26	40	21	32	37	OAKSIM
Short period, PA	19	29	50	13	24	70	13	22	60	30	29	30	OAKSIM,TWIGS
Long period, all states	-22	42	20	-23	45	27	-14	42	27	6	28	33	FIBER
Long period, NH	-31	39	20	-35	41	30	-19	41	20	-2	23	40	FIBER
Long period, PA	14	34	20	23	36	20	4	23	40	37	38	20	NE-TWIGS

Table 4.—continued

Projection period, states	SILVAH			OAKSIM			NE-TWIGS			FIBER			Best
	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	
							Medial stand diameter						
Short period, all states	1	10	87	3	11	86	3	12	82	-4	13	86	SILVAH
Short period, ME	3	10	80	8	12	75	9	14	75	0	0	80	FIBER
Short period, MA	2	8	86	5	10	86	6	15	64	-1	10	93	FIBER
Short period, VT	-1	10	90	0	10	90	-1	10	90	-8	15	83	OAKSIM
Short period, PA	2	5	100	-1	5	100	0	3	100	-6	7	100	TWIGS
Long period, all states	14	16	47	5	13	80	8	11	67	-4	9	87	FIBER
Long period, NH	21	20	20	13	14	70	13	14	50	0	7	90	FIBER
Long period, PA	1	6	100	-6	8	100	1	3	100	-11	9	80	TWIGS
							Number of trees						
Short period, all states	-10	33	38	-17	37	30	16	37	36	-5	32	39	FIBER
Short period, ME	-30	39	20	-34	41	10	-37	45	16	-6	27	50	FIBER
Short period, MA	-25	32	36	-34	38	7	-33	39	14	-14	25	57	FIBER
Short period, VT	12	24	40	5	23	43	3	19	47	31	28	20	TWIGS
Short period, PA	6	13	70	-6	13	70	4	14	80	13	18	40	TWIGS
Long period, all states	-20	27	27	-35	40	27	-14	26	40	-10	21	60	FIBER
Long period, NH	-24	26	30	-41	39	10	-16	25	30	-17	20	60	FIBER
Long period, PA	-5	20	20	-13	15	60	-6	19	60	11	19	60	TWIGS
							Percent basal area in primary species group						
Short period, all states	-1	15	68	-13	45	48	-4	15	68	-2	13	75	FIBER
Short period, ME	1	11	85	-6	27	50	-1	10	85	-1	9	80	SILVAH,FIBER
Short period, MA	3	13	50	-33	43	14	-1	13	71	0	9	79	FIBER
Short period, VT	-3	17	63	-5	54	53	-5	18	57	-3	16	67	FIBER
Short period, PA	-65	10	70	-17	24	70	-9	12	60	-2	9	80	FIBER
Long period, all states	-16	23	53	-23	28	47	-23	46	47	-8	21	60	FIBER
Long period, NH	-18	25	50	-35	50	50	-26	29	40	-13	23	50	FIBER
Long period, PA	-11	14	60	2	25	40	-15	18	60	4	12	80	FIBER
							Overall						
Short period, all states	-4.33	22.50	53.67	-8.67	28.50	46.50	-1.33	24.50	49.67	-5.17	22.33	56.33	FIBER
Short period, ME	-13.50	25.50	45.83	-13.33	28.83	35.00	-14.50	27.67	41.00	-5.83	19.00	55.83	FIBER
Short period, MA	-9.17	18.67	53.67	-17.17	25.00	39.17	-9.83	23.33	42.67	-7.17	16.00	71.50	FIBER
Short period, VT	-1.17	18.17	54.83	-0.67	26.00	48.83	-1.33	19.83	51.17	2.83	23.67	46.67	SILVAH
Short period, PA	-1.33	12.83	63.33	-2.83	14.00	68.33	0.67	11.67	68.33	3.50	14.50	58.33	TWIGS
Long period, all states	-4.67	24.00	37.83	-8.67	27.33	43.50	5.33	26.50	45.67	-5.33	16.67	53.33	FIBER
Long period, NH	7.33	25.00	31.67	-20.67	30.67	35.00	0.00	24.33	38.33	-9.33	17.33	53.33	FIBER
Long period, PA	4.83	16.50	50.00	-3.33	18.50	60.00	-2.83	14.17	60.00	3.00	18.17	53.33	TWIGS

Table 5.—Allegheny hardwood percent mean bias, percent tolerance interval, and percent of stands within 15 percent of the actual values by test parameter, period length, and state

Projection period, states	SILVAH			OAKSIM			NE-TWIGS			FIBER			Best
	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	
							Basal area (total)						
Short period, all states	-3	20	56	-19	22	41	-5	16	69	-6	18	69	TWIGS
Short period, PA	4	17	63	-18	21	46	-2	16	75	-3	17	75	TWIGS
Short period, WV	-30	26	33	-24	20	17	-15	14	50	-20	21	33	TWIGS
Long period, all states	-3	35	38	-33	29	0	-14	19	38	-16	20	50	None
Long period, PA	12	27	50	-30	25	0	-10	16	50	-12	17	67	TWIGS
							Basal area (saw)						
Short period, all states	-2	12	38	-32	16	9	-4	13	59	-24	14	50	SILVAH
Short period, PA	11	10	46	-28	15	8	-2	14	54	-17	14	50	TWIGS
Short period, WV	-35	13	0	-42	14	0	-10	7	67	-46	14	33	TWIGS
Long period, all states	38	19	13	-47	17	13	-15	10	38	-34	11	38	TWIGS
Long period, PA	55	17	0	-49	16	0	-18	9	67	-27	10	33	TWIGS
							Basal area (poles)						
Short period, all states	1	24	59	-5	18	50	-7	26	50	1	22	50	SILVAH
Short period, PA	4	23	58	-4	17	54	-2	23	58	3	21	50	TWIGS
Short period, WV	-17	26	50	-10	24	17	-31	39	17	-12	26	33	OAKSIM
Long period, all states	3	36	38	-8	26	50	-17	32	38	-16	27	25	OAKSIM
Long period, PA	15	32	50	5	14	67	-2	18	50	-15	27	33	OAKSIM
							Medial stand diameter						
Short period, all states	0	183	97	-6	7	97	3	6	97	-2	7	94	SILVAH,TWIGS
Short period, PA	2	5	100	-7	7	96	2	4	100	-1	7	96	TWIGS
Short period, WV	-5	6	83	-4	7	100	8	9	83	-6	8	83	OAKSIM
Long period, all states	0	11	75	-8	11	63	6	11	88	-2	9	88	FIBER
Long period, PA	5	7	83	-12	11	50	1	4	100	0	181	83	TWIGS
							Number of trees						
Short period, all states	2	22	56	-9	17	66	-4	20	66	-10	22	47	OAKSIM
Short period, PA	6	20	58	-6	14	75	1	16	71	-11	21	46	OAKSIM
Short period, WV	-27	28	33	-29	29	17	-35	34	33	-17	22	50	FIBER
Long period, all states	2	40	38	-20	27	38	-12	31	25	-22	27	13	SILVAH,OAKSIM
Long period, PA	17	35	50	-10	18	50	1	23	33	-22	27	17	OAKSIM

Table 5.—continued

Projection period, states	SILVAH			OAKSIM			NE-TWIGS			FIBER			Best
	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	
							Percent basal area in primary species group						
Short period, all states	2	13	75	-20	43	47	14	18	50	-20	43	44	SILVAH
Short period, PA	3	12	75	0	12	63	11	16	63	4	15	54	SILVAH,OAKSIM
Short period, WV	-3	12	83	-100	82	0	25	22	17	43	38	17	SILVAH
Long period, all states	6	20	50	-21	43	38	26	28	25	11	28	25	SILVAH
Long period, PA	9	22	33	2	19	50	21	24	33	6	20	33	OAKSIM
							Overall						
Short period, all states	0.00	45.67	63.50	-15.17	20.50	51.67	-0.50	16.50	65.17	-10.17	21.00	59.00	TWIGS
Short period, PA	5.00	14.50	66.67	-10.50	14.33	57.00	-1.33	14.83	79.17	-4.17	15.83	61.83	TWIGS
Short period, WV	-19.50	18.50	47.00	-34.83	29.33	25.17	9.67	20.83	44.50	-9.67	21.50	41.50	SILVAH
Long period, all states	7.67	26.83	42.00	-22.83	25.50	33.67	-4.33	21.83	42.00	-13.17	20.33	39.83	TWIGS
Long period, PA	18.83	23.33	44.33	-15.67	17.17	36.17	-1.17	15.67	55.50	-11.67	47.00	44.33	TWIGS

stands from West Virginia, Massachusetts, and Vermont, only West Virginia had adequate representation to allow independent performance evaluations. The similarity of the results for "all states combined" and West Virginia reflect the proportion of West Virginia stands in this category.

FIBER projections were closest to the actual observations for total basal area and basal area of sawlog-sized trees (Table 6). SILVAH was the closest to the actual observations of pole-sized basal area, while both SILVAH and FIBER were nearly equal in estimates of medial stand diameter. FIBER was the best at projecting number of trees for West Virginia, although there were no clear distinctions for the "all states combined" category. SILVAH and NE-TWIGS were the best predictors of species composition. In this category, FIBER's performance was adversely affected by model design that did not include a category for oak species comprising the primary species group category as designated by our tests. For the FIBER simulations, we converted all oak species to white ash, which was one of the FIBER species categories. Thus, FIBER projections did not include the oak species component and, consequently, somewhat biased the results. SILVAH had the best results for the "overall" category for "all states combined." The "overall" results for West Virginia did not exhibit any clearly superior simulators, according to our ranking technique.

Oak-hickory

In the oak-hickory forest type, SILVAH, OAKSIM, and NE-TWIGS had similar results. There were no long observation periods in this forest type. OAKSIM was the best predictor of total basal area and also proved to be the best "overall" simulator for New York. SILVAH predictions resulted in the best "overall" performance for Ohio and the "all states combined" categories. The "overall" results for Kentucky did not exhibit any clearly superior simulators, according to our ranking techniques. OAKSIM clearly provided the best predictions of total basal area for all locations (Table 7). SILVAH, NE-TWIGS, and OAKSIM all provided reasonable estimates of basal area of sawlog-sized and pole-sized basal area, medial stand diameter, and number of trees. Most notable from these results was the absence of FIBER, which overpredicted all measures of basal area and medial stand diameter and underpredicted number of trees. SILVAH and NE-TWIGS provided the best estimates of species composition. The species composition estimates provided by OAKSIM also were adequate in most cases. However, as stated earlier, the design of OAKSIM requires that species be grouped into four categories. Once species of the same category are combined, it is not possible with OAKSIM to identify the trees within a group as to their individual species designations. This design feature reflects the intent of the developers to limit the use of OAKSIM to upland oak stands where combining similar species did not compromise growth and yield projections. Similarly, the inadequate estimates of species composition obtained from FIBER reflect the use of the simulator beyond its scope of applicable forest types.

Table 6.—Transition hardwood percent mean bias, percent tolerance interval, and percent of stands within 15 percent of the actual values by stand parameter, period length, and state

Projection period, states	SILVAH			OAKSIM			NE-TWIGS			FIBER			Best
	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	
							Basal area (total)						
Short period, all states	-14	19	50	-5	6	50	-10	18	42	-1	19	58	FIBER
Short period, WV	-22	21	38	-21	19	25	-19	18	38	-12	15	75	FIBER
							Basal area (saw)						
Short period, all states	-35	13	17	-154	40	8	-28	9	33	19	11	58	FIBER
Short period, WV	-39	11	0	-53	10	13	-32	7	38	-27	7	63	FIBER
							Basal area (poles)						
Short period, all states	0	17	75	2	20	58	-6	28	50	-1	26	58	SILVAH
Short period, WV	8	15	75	-8	20	50	-21	27	50	-12	16	75	SILVAH
							Medial stand diameter						
Short period, all states	-2	5	100	-3	6	100	4	6	92	3	6	92	SILVAH
Short period, WV	-2	5	100	-3	5	100	4	6	88	1	3	100	FIBER
							Number of trees						
Short period, all states	2	22	33	-9	17	33	-4	20	25	-10	22	67	None
Short period, WV	-27	28	25	-29	29	13	-35	34	0	-17	22	75	FIBER
							Percent basal area in primary species group						
Short period, all states	5	20	67	-19	24	42	-9	17	67	-100	100	0	SILVAH,TWIGS
Short period, WV	17	22	63	-16	16	50	-2	10	75	-100	89	0	TWIGS
							Overall						
Short period, all states	-7.33	16.00	57.00	-31.33	18.83	48.50	-8.83	16.33	51.50	-15.00	30.67	55.50	SILVAH
Short period, WV	-13.50	17.00	50.17	-21.67	16.50	41.83	-17.50	17.00	48.17	-27.83	25.33	64.67	None

Table 7.—Oak-hickory percent mean bias, percent tolerance interval, and percent of stands within 15 percent of the actual values by stand parameter, period length, and state

Projection period, states	SILVAH			OAKSIM			NE-TWIGS			FIBER			Best
	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	Bias	Tol. Int.	15%	
							Basal area (total)						
Short period, all states	5	16	66	0	12	83	7	19	48	28	38	24	OAKSIM
Short period, KY	-1	9	80	-6	8	100	3	20	60	14	27	20	OAKSIM
Short period, OH	-8	8	100	-2	7	100	1	11	71	40	39	14	OAKSIM
Short period, NY	17	19	36	6	11	79	19	19	36	33	38	21	OAKSIM
							Basal area (saw)						
Short period, all states	9	15	41	-10	14	38	8	17	41	66	37	17	TWIGS
Short period, KY	-1	5	60	-17	8	40	0	9	20	211	25	0	SILVAH
Short period, OH	-20	11	43	-10	11	57	15	8	86	189	28	14	TWIGS
Short period, NY	40	20	29	6	14	29	51	26	29	76	39	14	OAKSIM
							Basal area (poles)						
Short period, all state	5	15	62	10	23	59	0	22	48	-8	28	38	SILVAH
Short period, KY	-2	9	80	4	8	80	2	17	40	-35	35	20	SILVAH,OAKSIM
Short period, OH	16	21	43	31	42	14	10	24	57	-7	22	29	None
Short period, NY	5	11	79	6	11	79	0	19	50	-2	22	50	SILVAH,OAKSIM
							Medial stand diameter						
Short period, all states	2	9	93	-2	8	93	4	8	93	12	14	48	OAKSIM
Short period, KY	0	5	100	-6	7	80	2	3	100	18	14	20	SILVAH,TWIGS
Short period, OH	-7	6	100	-8	8	100	-1	3	100	12	11	71	TWIGS
Short period, NY	6	7	93	0	5	100	9	11	86	15	14	43	OAKSIM
							Number of trees						
Short period, all states	7	27	62	4	19	66	4	25	55	-10	25	52	OAKSIM
Short period, KY	21	47	0	10	30	20	4	36	40	-32	32	0	TWIGS
Short period, OH	2	5	100	10	15	71	6	18	57	-3	18	57	SILVAH
Short period, NY	7	16	64	3	9	86	7	17	71	-6	19	57	OAKSIM
							Primary species group						
Short period, all states	3	5	100	-9	17	69	6	3	100	-100	97	0	SILVAH,TWIGS
Short period, KY	5	5	100	-1	9	80	2	3	100	-100	77	0	TWIGS
Short period, OH	3	4	100	-25	24	29	0	3	100	-100	82	0	TWIGS
Short period, NY	2	3	100	-5	10	86	0	2	100	-100	87	0	TWIGS
							Overall						
Short period, all states	-5.17	14.30	70.67	-1.17	15.50	68.00	4.83	15.67	64.17	-2.00	39.83	29.83	SILVAH
Short period, KY	-3.67	13.33	76.00	-2.67	11.67	66.67	2.17	14.67	60.00	12.67	35.00	10.00	None
Short period, OH	-2.33	9.17	81.00	-0.67	17.83	61.83	-5.17	11.17	78.50	21.83	33.33	30.83	SILVAH
Short period, NY	12.83	12.67	66.83	2.67	10.00	76.50	14.33	15.67	62.00	2.67	36.50	30.83	OAKSIM

Table 8.—Simulators that will be selected by the automatic selection algorithm used by the Northeast Decision Model

Forest type Projection period, state	Model selection	Also suitable	Not suitable
Spruce-fir			
Short period, all states	FIBER	None	SILVAH,NE-TWIGS,OAKSIM
Short period, ME	FIBER	None	SILVAH,NE-TWIGS,OAKSIM
Northern hardwoods			
Short period, all states	FIBER	NE-TWIGS,SILVAH	OAKSIM
Short period, ME	FIBER	NE-TWIGS,SILVAH	OAKSIM
Short period, MA	FIBER	NE-TWIGS,SILVAH	OAKSIM
Short period, VT	SILVAH	NE-TWIGS,FIBER	OAKSIM
Short period, PA	NE-TWIGS	FIBER,SILVAH	OAKSIM
Long period, all states	FIBER	NE-TWIGS,SILVAH	OAKSIM
Long period, NH	FIBER	NE-TWIGS,SILVAH	OAKSIM
Long period, PA	NE-TWIGS	FIBER,SILVAH	OAKSIM
Allegheny hardwoods			
Short period, all states	NE-TWIGS	SILVAH	OAKSIM,FIBER
Short period, PA	NE-TWIGS	SILVAH	OAKSIM,FIBER
Short period, WV	SILVAH	NE-TWIGS	OAKSIM,FIBER
Long period, all states	NE-TWIGS	SILVAH	OAKSIM,FIBER
Long period, PA	NE-TWIGS	SILVAH	OAKSIM,FIBER
Transition hardwoods			
Short period, all states	SILVAH	NE-TWIGS	OAKSIM,FIBER
Short period, WV	SILVAH[1]	NE-TWIGS	OAKSIM,FIBER
Oak-hickory			
Short period, all states	SILVAH	OASKIM,NE-TWIGS	FIBER
Short period, KY	SILVAH[1]	OAKSIM,NE-TWIGS	FIBER
Short period, OH	SILVAH	OAKSIM,NE-TWIGS	FIBER
Short period, NY	OAKSIM	SILVAH,NE-TWIGS	FIBER

[1]Because simulator performance measures yielded inconclusive results, the simulator selection was based on the "all states combined" category.

Recommendations for the Northeast Decision Model

The simulator that ranked the best on the basis of the three "overall" evaluation criteria used will be the recommended simulator for that forest type and state in the Northeast Decision Model. These designations are shown in Table 8. Table 8 also lists growth and yield simulators that should not be used with particular forest types. Suitability determinations were made by a combination of test results and the intended use of the simulator by the developers. In no case do we recommend that a particular growth and yield simulator be used where the developers recommend otherwise.

FIBER proved to be the most reliable simulator for spruce-fir and was the only choice in that forest type. FIBER also proved to be the best choice for most locations in the northern hardwood forest type, although NE-TWIGS and SILVAH also were selected as the best simulators for Pennsylvania and Vermont northern hardwoods, respectively. NE-TWIGS had the best results for most locations in Allegheny hardwoods, although SILVAH was the chosen simulator for Allegheny hardwoods in West Virginia. In transition hardwoods, SILVAH was selected as the best simulator for the "all states combined" category. Based on the results from the "all states combined" category, SILVAH also was selected as the most appropriate simulator for West Virginia transition hardwoods in which conclusive results from our simulator performance measures were not obtained. In the oak-hickory forest type, OAKSIM was selected as the best simulator for New York, while SILVAH was selected for Ohio and "all states combined." Again, based on the results from "all states combined," SILVAH also was selected as the most appropriate simulator for Kentucky oak-hickory forests in which conclusive results were not obtained.

The Northeast Decision Model will include all four simulators tested here, and users will be free to select any of these four, and possibly others, to use in any forest type or geographic area. If users select a simulator that has given poor results in these tests for a particular type or region, a warning will be issued, but the user will be free to employ the simulator of their choice.

In addition, the Northeast Decision Model will include an automatic simulator selection algorithm, based on forest type and ecological land type or geographic region. When the user chooses automatic simulator selection, the decision model will select the growth and yield simulator that performed best in these tests.

Conclusions

As we evaluated the results in a continuum of forest types from north to south, certain general trends were observed. Most notable was the performance of FIBER. FIBER projections clearly provided the best estimates for the spruce-fir stands of Maine and Vermont; provided the best estimates for most, but not all, applications in the northern hardwood stands found throughout the New England states to Pennsylvania; and was replaced by other simulators as the most suitable in the Allegheny hardwood stands of Pennsylvania and West Virginia and the oak-hickory stands of Ohio and Kentucky.

All models generally performed better in the geographic region and forest type for which they were developed. This validates regional growth and yield modeling efforts that have been undertaken. However, several simulators performed reasonably well in types and geographic areas in which they were never intended to be used. While it seems appropriate to recommend the simulator designed for a particular forest type and geographic area over another that works as well there but was not built with data from that situation, it also seems reasonable to extend the geographic range of the better performing simulators when there is not a simulator available designed for that locale.

Except in the spruce-fir forest type, no individual simulator stands out as clearly superior to the others for all locations. There are always at least two, and often more that logically could be used.

All simulators that proved suitable for use in particular forest types and geographic regions seem to do a good job, on the average. That is, when run on numerous stands of a particular type, they provide reasonable estimates of stand parameters. But all the simulators can produce very large errors on individual stands. Errors of the magnitude of 30 to 50 percent occurred even on 20-year projections. This primarily was a consequence of some large individual trees within a small sampling unit dying during the projection period. Thus, these simulators probably are best used for development of yield tables and for general management and planning purposes where they can be run on multiple stands and the averages are used to characterize that class of stand. Caution should be exercised when using these simulators to determine the future value or appropriate management for an individual stand.

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Evaluates SILVAH, FIBER, NE-TWIGS, and OAKSIM, simulators commonly used in the northeastern United States, by comparing predicted stand development with actual stand development records for periods ranging from 15 to 50 years. Results varied with stand parameter, forest type, projection length, and geographic area. Except in the spruce-fir forest type where FIBER stands out as the best simulator, no single simulator is clearly superior to the others for all locations within a forest type. In general, FIBER, NE-TWIGS, and SILVAH performed best in the northern hardwood (beech-birch-maple) forest type; NE-TWIGS and SILVAH performed best in the Allegheny hardwood (cherry-maple) forest type; SILVAH and OAKSIM performed best in the oak-hickory forest type; and SILVAH was most suitable in the transition hardwood (mixture of northern hardwoods and oaks) forest type. Results give growth and yield model users more information for selecting the simulator most suitable for their particular needs and the results also can be used as a diagnostic tool for growth and yield model development.

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Keywords: Growth and yield, SILVAH, FIBER, NE-TWIGS, OAKSIM, predicted stand development

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