Table 2. Volume and value losses in six stands of black walnut and probable cause of prior injury leading to decay.

| | Stand number | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| No. trees cut | 37 | 54 | 30 | 5 | 22 | 24 |
| No. trees with decay | 12 | 4 | 14 | 4 | 15 | 12 |
| % volume loss | 7 | 2 | 12 | 25 | 17 | 16 |
| % value loss | 42 | 14 | 21 | 45 | 45 | 48 |
| Probable cause of injury | livestock | livestock | flood | mechanical; lightning | fire | livestock; lightning |

feeder roots. Livestock, particularly swine, scrape and peel the bark at the base of trees, allowing decay to develop. If livestock must be confined in a woodlot, fence an area that does not include walnut trees. Injured trees can be harvested before decay develops. Very valuable trees may justify special protection. Floating ice also causes wounds in riparian areas during floods. Landowners should consider this when plantations are being established. By informing their clients of the relationship between injury today and loss in value due to decay in the future, foresters can provide information to growers, allowing them to make more intelligent management decisions. □

LITERATURE CITED

Hoffard, W. H., E. L. Heflin, and R. L. Anderson. 1977. Economic impact of defects in Missouri-grown black walnut. USDA For. Serv., Northeast. For. Exp. Stn., Impact Survey D-19-77.

# Economics of Red Pine Plantation Management in Wisconsin[1]

**Marie de Naurois** *and* **Joseph Buongiorno,**[2] *Department of Forestry, University of Wisconsin, Madison 53706.*

*ABSTRACT. It is more economical to manage red pine plantations in Wisconsin for pulpwood and sawlog combined rather than for pulpwood only, even on low quality sites. The most important factor influencing the economics of a plantation is land quality. On lands of site index 45 new plantations are unlikely to be economical, regardless of management regime. Lands of site index 60 to 75 have real rates of return of 4 to 5.5% per year and soil expectation values of $125 to $350 per acre at 3% interest. Planting densities of 8 by 8 ft followed by heavy thinnings at long intervals and short rotations are best, but rotations may be increased considerably with only small effects on the economics of the plantations.*

*North. J. Appl. For. 3:118–123, Sept. 1986.*

The demand for fiber for the pulp industry in Wisconsin creates a natural incentive to establish softwood plantations. Red pine is often the selected species, due to its excellent characteristics and good yields for pulp. Mature red pine also produces quality lumber (Weber 1984). There are currently some 1.2 million acres of red pine forests and plantations in the Lake States, and 6 million more acres are suitable for planting (Benzie 1982). In Wisconsin alone there are some 370 thousand acres of red pine plantations, close to 70% of all coniferous plantations. Nearly 60% of the red pine plantations are less than 20 years old (Wisconsin Dep. Nat. Resour. 1980). The interest in red pine management has been shown in recent symposia (Mroz and Berner 1982, Stier 1983), and considerable literature is available on the subject (Bassett 1984).

The purpose of this paper is to estimate the economics of red pine plantation management in Wisconsin. Given prevailing prices and costs it attempts, using simulation experiments, to foresee the soil expectation values and the rates of return that would be obtained under different management alternatives.

The management alternatives considered are defined in the first part of the paper. The second part compares the accuracy of two computer models, TWIGS and REDPINE, in predicting the growth of managed red pine plantations. We then discuss the criteria used to compare alternatives. The economic value of each alternative is presented in part three. This is followed by an analysis of the sensitivity of the predicted returns to assumptions on prices and costs. The paper concludes with a summary of the findings and comparisons of the results with those of other studies.

MANAGEMENT ALTERNATIVES

Each simulated alternative differed in terms of product goal, initial density, intermediate thinning, rotation, and site quality. The range of alternatives was such as to cover most of the current management practices in Wisconsin. Two product goals were considered: pulpwood, or pulpwood and sawlogs. Pulpwood was defined as timber 5 to 9 in dbh, no less than 4 in at the top. Sawlogs were at least 9 in dbh, no less than 7 in in top diameter.

Pulpwood Production

Pure pulpwood plantations were tested for site indices 45 and 60. On each site, they were planted at either 690 or 900 trees per acre, corresponding to square spacings of 8 and 7 ft, respectively. All plantations were then released at age 3.

Intermediate thinnings, when applied, were mechanical, removing every third row. For site index 45, the plantation was either thinned at age 30 and then clearcut at age 45, or clearcut at age 35 or 45 without intermediate thinning.

On site index 60 the plantation was thinned at age 25 and then clearcut at age 35, or clearcut at age 35 without thinning. No longer rotation was considered on site index 60, since it would have produced sawlogs. In total, 10 management alternatives were compared for pure pulpwood production.

Combined Pulpwood and Sawlog Production

Alternatives that combined sawlog and pulpwood production were tested on lands of site index 45, 60, and 75. Three initial planting densities were studied: 440, 690, and 900 trees per acre. All alternatives involved a release when the plantation was 3 years old.

Three thinning alternatives were considered (Table 1). All but the mechanical thinnings were from below. The first one was a light thinning that started at age 25 by removing every third row. It proceeded with cuts at 10-year intervals leaving 90 to 110 ft² of basal area per acre.

The second alternative was a heavy thinning, corresponding to the minimum stocking level shown by Benzie (1977). The first cut removed every second row at age 25. This was followed by thinnings every 10 years that left 70 to 90 ft² of basal area.

The third alternative was also a heavy thinning, but starting at age 30 and cutting every 15 years.

The rotations tested varied between 45 and 75 years of age at 15-year intervals. The first mechanical thinning was not done when there were 440 trees per acre. In all, 78 management alternatives were evaluated for the sawlog-pulpwood production strategy.

GROWTH AND YIELD PREDICTION

The first step in determining the economic value of the alternatives defined above was to predict their physical production. Two computer models were used for that purpose, TWIGS (Belcher 1983) and REDPINE (Lundgren 1981). The former is a microcomputer version of the STEMS model that has been used extensively to predict the growth of various forest types, including red pine in the Lake States (Brand 1981). The programs and files for TWIGS can be obtained from the USDA Forest Service, North Central Forest Experiment Station. The programs are written in Pascal and run on Apple II computers. The REDPINE model was developed strictly for red pine. It has been used widely to predict the growth of plantations at different densities and under different cutting regimes (Bassett 1984).

Comparison of the two models on permanent sample plots in Wisconsin gave little reason for preferring one of these two models from a purely biometric point of view (Appendix A). In the end, the choice was dictated by practicality. The TWIGS model was used because *it includes procedures* that facilitate the economic evaluation of management alternatives.

Little is known about the growth of red pine plantations during the first years after establishment. TWIGS was developed with data on stands that were 15 years or older. Therefore, the growth simulations started at age 15, although the economic analysis started from bare land. The initial diameter distributions used for different spacings and site qualities were adapted from those observed on the Petawawa National Forest in Ontario (Stiell and Berry 1977). We assumed that the plantation density specified by each alternative represented the situation at age 15. This is consistent with the low mortality in young red pine plantations.

ECONOMIC CRITERIA AND PRICE AND COST ASSUMPTIONS

Two criteria were used in comparing the various management alternatives for red pine: first, the soil expectation value (SEV), the discounted value of returns, minus that of costs, over an infinite succession of rotations; and second, the internal rate of return (IRR), the interest rate that equates the present value of returns and costs on any given plantation.

Although they are closely related, the two criteria do not lead necessarily to the same ranking of alternatives. Alternative A may have a higher IRR than B, but a lower SEV at some interest rate.

Given an interest rate, the SEV criterion always leads to maximization of present value. The IRR may not do so. Another advantage of the SEV is that it provides an estimate of the value of bare land used to grow timber. But the choice of a proper guiding rate of interest is not always simple. For this reason, and because people find it easy to interpret and compare rates of return, we used both criteria.

From 1958 to 1984, the average real rate of return on Aaa corporate bonds was 2.5% per year, before tax (Appendix B). Therefore, after some allowance for risk, it would seem reasonable to use 3% as a real guiding rate of interest to evaluate plantations. Nevertheless, because interest rates are necessarily different for different decision makers, soil expectations were computed at interest rates of 2, 3, and 4% before tax.

These were real rates, net of inflation, in agreement with the fact that all alternatives were evaluated at prices and costs prevailing between 1980 and 1984. The stumpage prices assumed were $50 per mbf for sawlogs and $15 per cunit for pulpwood (Lothner et al. 1982). As stumpage prices they reflect costs of harvesting and transportation.

All other costs were average costs in 1982, determined mostly by interviews of managers of private and public forests throughout Wisconsin. They include:

- Site preparation: $75 per acre.
- Planting: $105 per thousand trees, including the cost of 3-year-old seedlings.
- Release: $40 per acre for all initial spacings and sites, except for 10 by 10 ft spacings on sites 60 and 75, in which case release costs are assessed at $60 per acre due to higher vegetative competition.
- Annual costs (administration and protection, but excluding taxes): $3 per acre.

The next section presents the economics of each alternative based on these prices and costs. This will be followed by a sensitivity analysis.

ECONOMICS OF PURE PULPWOOD PLANTATIONS

With the assumptions made above on pulpwood prices and management costs, the economics of plantations geared to pulpwood production only were not very good (Tables 2 and 3). The highest IRR obtained was 2.8% on site 60.

Site Index 45

On site 45, the present value of all alternatives were negative or nil for guiding rates of interest of 2 to 4%. The highest IRR, 2%, was achieved by planting 690 trees per acre and clearcutting when they were 45 years old (Table 2). The same IRR was obtained by adding a thinning at age 30. Planting 900 trees decreased the IRR to 1.8%. Shortening the rotation by 10 years decreased it to 1.1%, other things being equal.

Site Index 60

On land of site index 60, red pine plantations would begin to produce sawlogs beyond age 35. For this reason, all alternatives considered rotations of 35 years (Table 3). Soil expectation value of all alternatives were

Table 1. Thinning alternatives for combined pulpwood and sawlogs production. Each thinning was tested with different initial densities and rotations.

| Age (yr) | 10-year interval: Light | 10-year interval: Heavy | 15-year interval: Heavy |
|---|---|---|---|
| 25 | every 3rd row | every 3rd row | |
| 30 | | | every 2nd row |
| 35 | 90* | 70* | |
| 40 | | | |
| 45 | 100* | 80* | 80* |
| 50 | | | |
| 55 | 110* | 90* | |

* Residual basal area in ft² per acre. All thinnings except the first one are from below.

[1] Research supported by the University Industry Research Program and the School of Natural Resources, University of Wisconsin-Madison, and by McIntire Stennis Grant No. 2855.

[2] Marie de Naurois' present address is CERNA, Ecole des Mines, 75272, Paris, France. Many people helped us in this study. We wish to thank especially G. L. Martin for providing his yield data, D. Bradley, C. Locey, R. Guries, C. Lorimer and J. Stier for technical advice, and the numerous growers of red pine in Wisconsin who answered our questions patiently.

Table 2. Internal rate of return (IRR) of red pine plantations managed for pulpwood on site 45.

| Thinning | Initial density (trees/ac) | Rotation (yr) | IRR (%) |
|---|---|---|---|
| None | 690 | 35 | 1.1 |
| | | 45 | 2.0 |
| | 900 | 35 | <1.0 |
| | | 45 | 1.8 |
| Age 30 | 690 | 45 | 2.0 |
| | 900 | 45 | 1.7 |

Note: Thinnings are mechanical, removing every third row.

Table 3. Soil expectation value (SEV) and internal rate of return (IRR) of red pine plantations managed for pulpwood on site index 60.

| Thinning | Initial density (trees/ac) | Rotation (yr) | SEV at 2% | IRR (%) |
|---|---|---|---|---|
| None | 690 | 35 | 106 | 2.8 |
| | 900 | 35 | 57 | 2.2 |
| Age 25 | 690 | 35 | 70 | 2.6 |
| | 900 | 35 | 24 | 2.0 |

Note: Thinnings are mechanical, removing every third row.

negative for interest rates of 3 and 4%. As on site 45, the best initial density was 690 trees per acre, yielding an IRR of 2.8%.

Relative to this optimum strategy, planting 900 trees per acre reduced the IRR to 2.2%. Doing a thinning at 25 years would have reduced the IRR to 2.6%, other things being equal.

## ECONOMICS OF COMBINED PULPWOOD AND SAWLOG PRODUCTION

The economic returns from managing red pine for pulpwood as well as sawlogs were higher than for pulpwood production alone on the same sites. The maximum IRRs were 2.8% on land of site index 45, 4% on site 60, and 5.3% on site 75 (Tables 4, 5, and 6).

### Site Index 45

On this site, all SEVs were negative at interest rates of 3 or 4%. The highest IRR was 2.8% (Table 4). This was achieved by planting 440 trees per acre, thinning lightly every 10 years, and clearcutting at age 75.

However, several of the alternatives analyzed produced the same IRR and similar SEVs. The worst alternatives combined the highest initial densities with heavy thinnings at short intervals.

### Site Index 60

On this site, SEVs were positive for all alternatives when interest rates of 2 and 3% were used (Table 5). At 4%, all alternatives had negative SEVs.

The best alternative was the same regardless of the criterion and interest rate used. It consisted in planting 690 trees per acre, thinning heavily at long intervals, and clearcutting at age 45. This produced $125 per acre for an SEV with a 3% interest rate and an IRR of 4.0%.

Other things being equal, planting only 440 trees per acre led to a decline in SEV at 3% of $84 per acre. This was due in part to the fact that vegetation control was more costly at this low density on sites 60 and 75. On the other hand, the rotation could be lengthened by 30 years while reducing the SEV by less than $30 per acre.

### Site Index 75

On lands of site index 75 all alternatives but one had positive SEVs at interest rates of 2 to 4% (Table 6). IRRs ranged from 4 to 5.3% per year.

The best management alternative was the same as on site 60; that is, planting 690 trees, thinning every other row at age 30, and clearcutting at age 45. The corresponding SEV at a 3% interest rate was $334 per acre, almost three times that obtained on site 60.

Other things being equal, planting 900 trees per acre instead of 690 reduced the SEV at 3% by $61 per acre. Planting 440 trees reduced it by $140.

SEVs were more sensitive to rotation age on site 75 than on sites 60 and 45. Looking again at the best alternative, clearcutting the plantation at ages 60 or 75 instead of 45 reduced the SEV at 3% by $40 and $71 per acre, respectively.

It is interesting to observe that esthetic goals, which usually imply long rotations to obtain large trees, were not incompatible with economic objectives. On site 45, this was actually one of the most profitable way of managing a plantation, even though timber only was considered. On sites 60 and 75 lengthening the rotation to 75 years of age led to a loss with respect to the best alternative of $30 to $70 per acre.

## SENSITIVITY ANALYSIS

The previous results assumed costs and prices that prevailed between 1980 and 1985 for typical management situations described during the interviews. It is useful to determine how the results vary with different assumptions on prices and costs. The effect of the interest rates was shown above. Using an interest rate of 2% per year instead of 4% influenced SEVs considerably (see, for example, Table 6). The table shows also that small absolute variations in IRRs may correspond to substantial differences in SEVs.

The impacts of variations in other prices and costs were studied for site 60 only, using the ranges of values that were observed during the interviews. The following items were considered separately: stumpage price of pulpwood and sawlogs, costs of site preparation, planting and release, and annual costs. The results of the sensitivity of SEVs with respect to these items are summarized in Fig. 1 for pulpwood production and in Fig. 2 for pulpwood and sawlog production combined. In the two figures, the horizontal axis measures variations in prices and costs, in dollars, with respect to the prevailing figures that were used in Table 5. The corresponding variations in SEVs are measured along the vertical axis. Therefore, the slope of each segment in these figures indicates how sensitive the SEV of a red pine plantation is to variations in a specific price or cost.

For both final product objectives, it appears that the most important economic variables are the price of the final product and annual costs. Managers may have some influence on stumpage prices by choosing reforestation locations that are close to markets, thereby decreasing the transport costs of the buyer and increasing the residual stumpage value for the grower. Also, logging costs per unit tend to decline as the volume logged increases, thus growers should be able to secure higher unit prices by scheduling thinning and final harvests into large sales.

Annual costs are low for red pine, relative to other species. Nevertheless, given the large potential effect of even small changes in annual costs on SEV, growers should monitor this variable carefully. This suggests that on a private plantation the impact of taxes may be important.

Site preparation costs can also affect SEV considerably, especially because they vary so much in Wisconsin. Whether the silvicultural benefits are worth the cost is not known currently and is worth further study.

## SUMMARY AND CONCLUSIONS

Our general conclusion is that it is better to manage red pine plantations for pulpwood and sawlogs rather than pulpwood only, even on low sites. But on site index 45, new plantations are unlikely to be economical regardless of how they are managed.

The most important factor influencing the economic return of a plantation was site quality. The highest IRRs ranged from 2.8% per year on site index 45 to 5.3% per year on site index 75, in real terms. Assuming an average rate of inflation of 5% per year, this implies nominal rates of return of approximately 8 to 10% per year. This is somewhat lower than the rates of return found by Manthy et al. (1964) and Bradley and Lothner (1982), but similar to the me-

Table 4. Soil expectation value (SEV) and internal rate of return (IRR) of red pine plantations managed for pulpwood and sawlogs on site index 45.

| Thinning | Initial density (trees/ac) | Rotation (yr) | SE at 2% | IRR (%) |
|---|---|---|---|---|
| Light at 10 yr interval | 440 | 55 | 130 | 2.8 |
| | | 65 | 138 | 2.8 |
| | | 75 | 178 (b) | 2.8 (b) |
| | 690 | 55 | 113 | 2.7 |
| | | 65 | 123 | 2.7 |
| | | 75 | 124 | 2.7 |
| | 900 | 55 | 150 | 2.6 |
| | | 65 | 137 | 2.6 |
| | | 75 | 136 | 2.6 |
| Heavy at 10 yr interval | 440 | 55 | 87 | 2.7 |
| | | 65 | 98 | 2.7 |
| | | 75 | 98 | 2.7 |
| | 690 | 55 | 91 | 2.7 |
| | | 65 | 103 | 2.7 |
| | | 75 | 105 | 2.7 |
| | 900 | 55 | 79 | 2.5 |
| | | 65 | 69 | 2.5 |
| | | 75 | 61 (w) | 2.5 (w) |
| Heavy at 15 yr interval | 440 | 45 | 89 | 2.7 |
| | | 60 | 147 | 2.8 |
| | | 75 | 141 | 2.8 |
| | 690 | 45 | 150 | 2.7 |
| | | 60 | 137 | 2.8 |
| | | 75 | 136 | 2.8 |
| | 900 | 60 | 104 | 2.7 |
| | | 75 | 106 | 2.7 |

Notes: Thinning regimes are defined in Table 1; b and w are the best and worst alternative.

Table 5. Soil expectation value SEV and internal rate of return (IRR) on red pine plantations managed for pulpwood and sawlogs on site index 60.

| Thinning | Initial density (trees/ac) | Rotation (yr) | SEV 3% | SEV 2% | IRR (%) |
|---|---|---|---|---|---|
| Light at 10-yr interval | 440 | 55 | 50 | 272 | 3.5 |
| | | 65 | 43 | 269 | 3.4 |
| | | 75 | 33 | 259 | 3.3 |
| | 690 | 55 | 69 | 304 | 3.6 |
| | | 65 | 61 | 301 | 3.6 |
| | | 75 | 50 | 291 | 3.5 |
| | 900 | 55 | 39 | 266 | 3.4 |
| | | 65 | 33 | 267 | 3.3 |
| | | 75 | 24 (w) | 259 | 3.2 |
| Heavy at 10-yr interval | 440 | 55 | 46 | 250 | 3.5 |
| | | 65 | 41 | 248 | 3.4 |
| | | 75 | 33 | 240 | 3.4 |
| | 690 | 55 | 60 | 272 | 3.6 |
| | | 65 | 55 | 272 | 3.6 |
| | | 75 | 47 | 264 | 3.5 |
| | 900 | 55 | 48 | 271 | 3.5 |
| | | 65 | 44 | 271 | 3.5 |
| | | 75 | 37 | 264 | 3.4 |
| Heavy at 15-yr interval | 440 | 45 | 41 | 229 | 3.5 |
| | | 60 | 37 | 240 | 3.4 |
| | | 75 | 25 | 228 (w) | 3.2 (w) |
| | 690 | 45 | 125 (b) | 392 (b) | 4.0 (b) |
| | | 60 | 112 | 385 | 3.9 |
| | | 75 | 97 | 361 | 3.8 |
| | 900 | 60 | 107 | 380 | 3.5 |
| | | 75 | 85 | 354 | 3.4 |

Notes: Thinning regimes are defined in Table 1; b and w are the best and worst alternative.

Table 6. Soil expectation value (SEV) and internal rate of return (IRR) of red pine plantations managed for pulpwood and sawlogs on site index 75.

| Thinning | Initial density (trees/ac) | Rotation (yr) | SEV 4% | SEV 3% | SEV 2% | IRR (%) |
|---|---|---|---|---|---|---|
| Light at 10-yr interval | 440 | 55 | 45 | 176 | 450 | 4.6 |
| | | 65 | 31 | 166 | 453 | 4.5 |
| | | 75 | 16 | 150 | 441 | 4.3 |
| | 690 | 55 | 51 | 202 | 528 | 4.7 |
| | | 65 | 26 | 172 | 491 | 4.3 |
| | | 75 | 21 | 155 | 455 | 4.3 |
| | 900 | 55 | 39 | 193 | 524 | 4.4 |
| | | 65 | 25 | 175 | 504 | 4.3 |
| | | 75 | 14 | 159 | 480 | 4.2 |
| Heavy at 10-yr interval | 440 | 55 | 24 | 137 | 369 (w) | 4.3 |
| | | 65 | 14 | 131 | 378 | 4.2 |
| | | 75 | 5 | 121 (w) | 372 | 4.1 |
| | 690 | 55 | 49 | 174 | 428 | 4.6 |
| | | 65 | 39 | 167 | 619 | 4.5 |
| | | 75 | 29 | 157 | 424 | 4.4 |
| | 900 | 55 | 28 | 169 | 470 | 4.4 |
| | | 65 | 17 | 155 | 454 | 4.3 |
| | | 75 | 9 | 142 | 433 | 4.2 |
| Heavy at 15-yr interval | 440 | 55 | 44 | 194 | 520 | 4.5 |
| | | 65 | 126 | 163 | 488 | 4.2 |
| | | 75 | −3 (w) | 132 | 444 | 4.0 (w) |
| | 690 | 45 | 133 (b) | 334 (b) | 766 (b) | 5.3 (b) |
| | | 60 | 106 | 294 | 697 | 5.2 |
| | | 75 | 87 | 263 | 638 | 4.9 |
| | 900 | 55 | 83 | 273 | 681 | 4.5 |
| | | 65 | 63 | 243 | 629 | 4.6 |
| | | 75 | 47 | 217 | 580 | 4.8 |

Notes: Thinning regimes are defined in Table 1; b and w are the best and worst alternative.

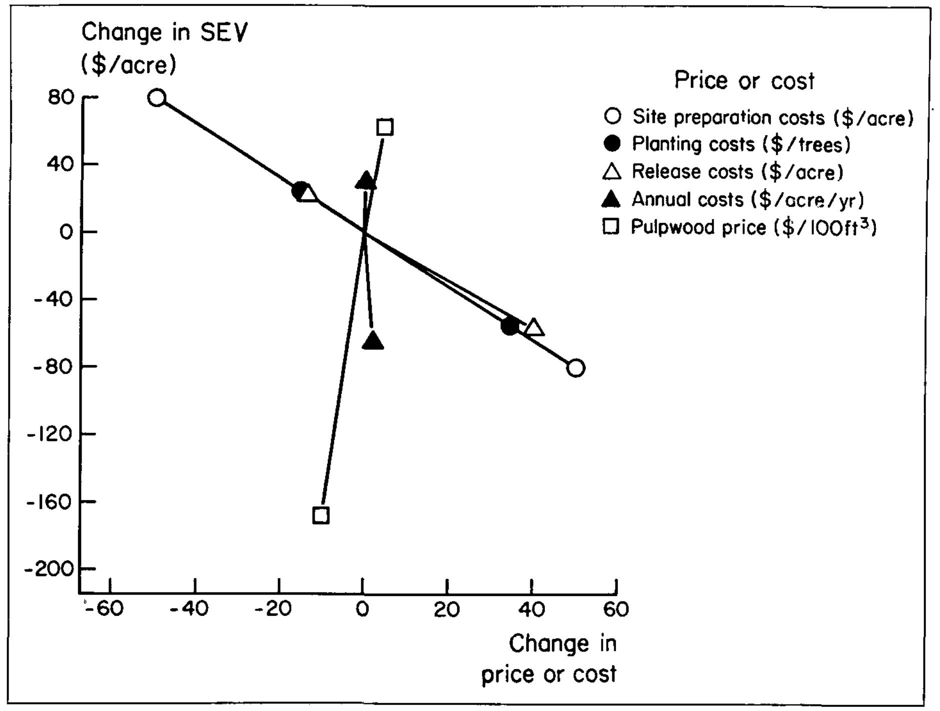


**Fig. 1. Changes in soil expectation value (SEV) due to changes in costs and price for red pine plantations managed for pulpwood production.**

dian returns reported by Lundgren (1966).

SEVs obtained by the best management alternative were negative on lands of site index 45, $125 per acre for site index 60, and $334 per acre for site 75, at 3% interest.

The best initial densities were 690 trees per acre on site indexes 60 and 75 and 440 trees per acre on site index 45. Bradley and Lothner (1982) recommended similar initial densities of 400 trees per acre.

On lands of site index 60 and 75 the best management regime consisted of a heavy thinning that would remove every other row at age 30 followed by cutting every 15 years to leave a residual basal area of 80 ft² per acre. The same residual basal area was found to be optimum by Bradley and Lothner (1982), although they used a 10-year cutting interval. On site index 45, lighter and more frequent thinnings were preferable.

Rotations of 45 years were found to maximize returns on site indexes 60 and 75. On site index 45 longer rotations were better. Bradley and Lothner (1982) recommended rotations of 55 to 65 years on sites 60 to 80. These differences do not seem crucial, given our finding that on a given site, the rotation could be lengthened at little reduction in soil expectation value. This implies that growers of red pine in Wisconsin who are interested in esthetic management could use long rotations that will lead to large trees. In the process they could reap benefits beyond those accounted for in this study.

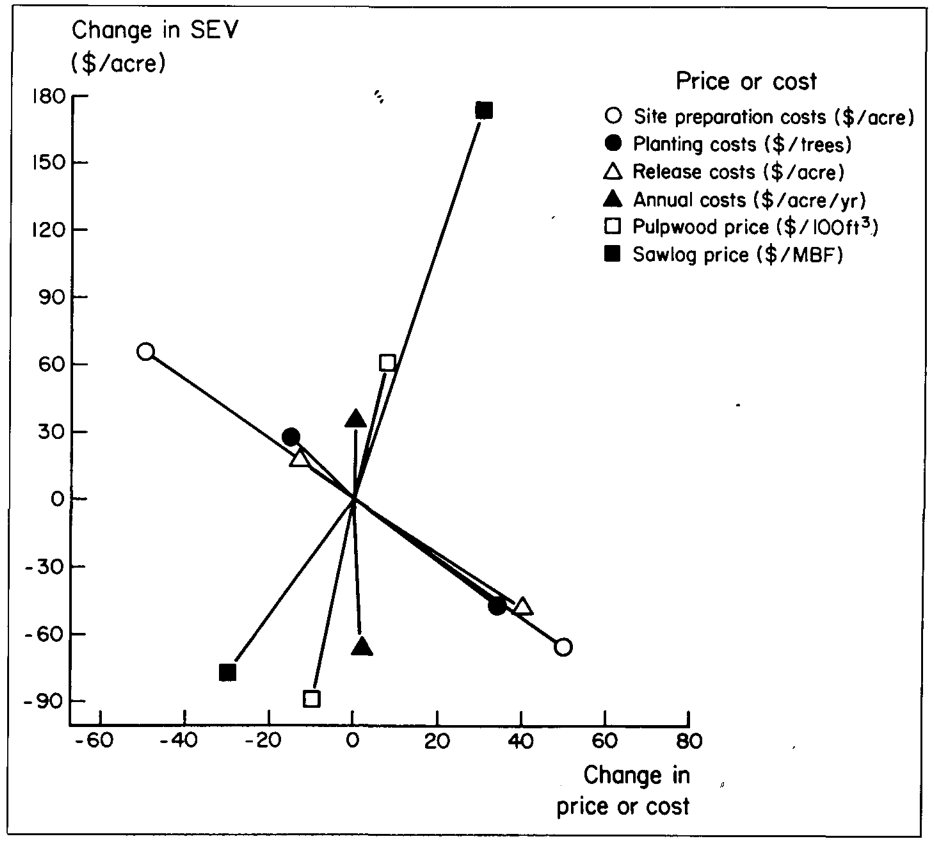


**Fig. 2. Changes in soil expectation value (SEV) due to changes in costs and price for red pine plantations managed for pulpwood and sawlogs combined.**

## APPENDIX A

We compared the ability of the TWIGS and REDPINE models to predict the past growth of 11 thinned and unthinned permanent plots located in Vilas, Oneida, Marinette, and Adams counties in Wisconsin. The site index of these plots varied from 55 to 79 ft, the age from 27 to 58 years, the basal area from 82 to 255 ft² per acre, and the density between 227 and 1073 trees per acre. [A detailed description of the plots is available in Martin (1978).] The stand characteristics that we compared were number of trees per acre, average diameter, and basal area.

**Table A1. Root mean square (RMSE), average (E), standard deviation (S), minimum (min) and maximum (max) of projection errors of TWIGS and REDPINE for various variables. All errors are in percent.**

| Variables | TWIGS | REDPINE |
|---|---|---|
| Density | | |
| RMSE | 7 | 16 |
| E | 3 | 11 |
| S | 6 | 12 |
| min | −1 | −3 |
| max | 23 | 36 |
| Average dbh | | |
| RMSE | 4 | 4 |
| E | 3 | 0 |
| S | 3 | 4 |
| min | −6 | −8 |
| max | 9 | 8 |
| Basal area | | |
| RMSE | 14 | 12 |
| E | 7 | 6 |
| S | 13 | 11 |
| min | −34 | −30 |
| max | 38 | 30 |

The main results of the analysis of errors are reported in Table A1. They include the root mean square error, average error, standard deviation, and minimum and maximum of errors for each one of the variable of interest and for each model. All data are in percentages and refer to an average projection length of 5.2 years, but no systematic relationship was found between the size of the error and the length of the projection.

Overall, the prediction errors of REDPINE and TWIGS were quite similar. Average diameter is the variable that was predicted best by each model, with a root mean square error of 4.4%. TWIGS predicted the number of trees better than REDPINE (6.7% error versus 15.8%), but in predicting total basal area REDPINE performed slighly better than TWIGS (11.8% error versus 14.5%).



**Table A2. Nominal and real rates of return on Aaa corporate bonds.**

| Year | Nominal Aaa returns | Changes in CPI | Real Aaa returns |
|---|---|---|---|
| 1958 | 3.8 | 1.8 | 2.0 |
| 1959 | 4.4 | 1.5 | 2.9 |
| 1960 | 4.4 | 1.5 | 2.9 |
| 1961 | 4.4 | 1.0 | 3.4 |
| 1962 | 4.3 | 1.1 | 3.2 |
| 1963 | 4.3 | 1.2 | 3.1 |
| 1964 | 4.4 | 1.3 | 3.1 |
| 1965 | 4.5 | 1.7 | 2.8 |
| 1966 | 5.1 | 2.9 | 2.1 |
| 1967 | 5.5 | 2.9 | 2.5 |
| 1968 | 6.2 | 4.2 | 1.9 |
| 1969 | 7.0 | 5.4 | 1.5 |
| 1970 | 8.0 | 5.9 | 2.0 |
| 1971 | 7.4 | 4.3 | 3.0 |
| 1972 | 7.2 | 3.3 | 3.8 |
| 1973 | 7.4 | 6.2 | 1.1 |
| 1974 | 8.6 | 11.0 | −2.6 |
| 1975 | 8.8 | 9.1 | −0.3 |
| 1976 | 8.4 | 5.8 | 2.5 |
| 1977 | 8.0 | 6.5 | 1.4 |
| 1978 | 8.7 | 7.7 | 0.9 |
| 1979 | 9.6 | 11.3 | −1.5 |
| 1980 | 11.9 | 13.5 | −1.4 |
| 1981 | 14.2 | 10.4 | 3.4 |
| 1982 | 13.8 | 6.1 | 7.3 |
| 1983 | 12.0 | 3.2 | 8.5 |
| 1984 | 12.7 | 4.3 | 8.0 |
| Average | | | 2.5 |

## APPENDIX B

The interest rate selected in evaluating forest plantations should reflect the fact that these are long-term investments. Although different procedures have been suggested to arrive at an appropriate rate (Row et al. 1981), one of the simplest uses the average rate of return on moderately risky private investments over a long period of time. For example, the second column in Table A2 shows the nominal rates of return on Aaa corporate bonds before taxes, R, between 1958 and 1984, as reported in the 1985 Economic Report of the President (U.S. Gov. Print. Off.). $R$ varied between 3.8 and 14.2% per year. During the same period, the annual rate of inflation, $f$, measured by changes in the consumer price index (CPI) varied between 1.1 and 13.5%. For each year, the real rate of return on Aaa bonds was: $r = (1 + R)/(1 + f) - 1$. The results of the computation appear in the third column. They show that the real rate of return on Aaa bonds, before taxes and net of inflation, varied between −2.6 and 8.5% per year during that period and averaged 2.5% per year. □

## LITERATURE CITED


BASSETT, J. R. 1984. Red pine management in the Lake States: a review. Sch. Nat. Res., Univ. Mich. Intensive For. Syst. Proj. Pap. 3. 327 p.

BELCHER, D. M. 1983. TWIGS: the woodsman's ideal growth projection system. A description paper. USDA For. Serv. North Central For. Exp. Stn. 26 p.

BENZIE, J. 1977. Managers handbook for red pine in the Lake States. USDA For. Serv. Tech. Rep. NC-33. 22 p.

BENZIE, J. 1982. Red pine. P. 134–41 *in* G. D. Mroz and J. F. Berner, eds. Proc. Artificial regeneration of conifers in the Upper Great Lakes Region. Mich. Tech. Univ., Houghton. 435 p.

BRADLEY, D., and C. LOTHNER. 1982. Financial returns from growing red pine and loblolly pine using yield evidence. P. 345–57 *in* Proc. Artificial regeneration of conifers in the Upper Great Lakes Region. Mich. Tech. Univ., Houghton. 435 p.

BRAND, G. J. 1981. Simulating timber management in Lake States forests. USDA For. Serv. Gen. Tech. Rep. NC-69. 26 p.

LUNDGREN, A. L. 1966. Estimating investment returns from growing red pine. USDA For. Serv. Res. Pap. NC-2. 48 p.

LUNDGREN, A. L. 1981. The effect of initial number of trees per acre and thinning densities on timber yields from red pine plantations in the Lake States. USDA For. Serv. Res. Pap. NC-193. 25 p.

LOTHNER, D., E. KALLIO, and D. DAVIS. 1982. Minnesota and Wisconsin forest product prices: a historical review 1950–1980. USDA For. Serv. North Central For. Exp. Stn. 114 p.

MANTHY, R. S., C. D. RANNARD, and V. J. RUDOLPH. 1964. The profitability of red pine plantations. Mich. State. Univ. Agric. Exp. Stn. Res. Rep. 11. 12 p.

MARTIN, G. L. 1978. A dynamic network analysis of silvicultural alternatives for red pine. Ph.D. Diss. Univ. Wis., Madison. 189 p.

MROZ, G. D., and J. F. BERNER, eds. 1982. Artificial regeneration of conifers in the Upper Great Lakes Region. Mich. Tech. Univ., Houghton. 435 p.

ROW, C., H. F. KAISER, and J. SESSIONS. 1981. Discount rate for long-term forest service investments. J. For. 79:367–76.

STIELL, W. M., and A. B. BERRY. 1977. A 20-year trial of red pine planted at seven spacings. Can. For. Serv. For. Manage. Inst. Info. Rep. FMR-X-97. 24 p.

STIER, J. C., ed. 1983. Silviculture of established stands in North Central forests. First Soc. Am. For. Reg. V Tech. Conf. Dep. For., Univ. Wis., Madison. 265 p.

WEBER, S. 1984. Red pine management: a resource for the future. The Timber Producer. (June):42–46.

WIS. DEP. NAT. RESOUR. (MADISON) 1980. Wisconsin's forest assessment. 83 p.