IS "COPPICE" A GOOD PREDICTOR OF RED OAK SPROUT GROWTH?

Robert Rogers and Paul S. Johnson[1/]

Abstract.--Overall, COPPICE'S (COPPICE is a computer-assisted growth simulator) predictions of diameter, height, and stem volume for a 10-year period are acceptably precise. However, although d.b.h. predictions are also acceptably accurate height and volume predictions are not--COPPICE overestimates height and volume of individual stems.

Part of this overestimation results from using COPPICE to predict responses for ages beyond those for which the simulator was developed, and partly because COPPICE does not fully account for the growth depressing effects resulting from inter-clump competition. Other contributing factors may be related to assumptions concerning stem form and the suitability of equations used to describe stem growth in the simulator.

Nevertheless, COPPICE generally provides accurate and reliable information about d.b.h. growth and although height and volume predictions are optimistic, forest managers can account for this when they make decisions concerning clump thinning operations.

Keywords: Oak coppice, growth simulation model, *Quercus rubra* L.

At the last Central Hardwood Forest Conference we presented a paper on "Predicting Growth of Individual Stems Within Northern Red Oak Sprout Clumps" (Johnson and Rogers 1980). Our predictions were based on a growth simulator called COPPICE that we developed from 5-year growth data collected from red oak coppice stems whose initial ages ranged from 4 to 22 years. At that time we were unable to test the simulator's accuracy and precision against data collected over a longer time interval. Since then, we have acquired data for comparing actual and simulated diameter, volume, and height growth of individual coppice stems for a 10-year period.

COPPICE can be used to identify the crop stems within clumps that have the highest growth potential. This is important because multiple stems commonly persist for 50 years or longer in northern red oak sprout clumps. Without thinning, growth rate of individual stems declines in these multi-stem clumps. COPPICE simulates the effects of intra-clump density on stem growth and predicts future d.b.h., height, and cubic foot volume. The methods for doing this are described in the earlier paper.

[1/] Respectively, Mensurationist and Principal Silviculturist, North Central Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Columbia, Missouri.

The growth simulator uses equations that were developed by multiple linear regression using 5-year growth data from a study of the effects of clump density on coppice stem growth. Three levels of density were created in this study by thinning clumps to one stem, two stems, or not thinning at all. Clump density is expressed in the model as relative basal area (RBA). RBA is the ratio of the basal area of an individual crop stem to total living clump basal area. Three other important growth determinants used in the model were initial d.b.h., clump age, and topographic site coefficient (TSC). TSC is an index of site quality that integrates the effects of soil depth, slope position, and aspect (Johnson 1975). COPPICE uses these variables in a 5-year iterative cycle to predict 25th-year diameter, cubic-foot volume, and height using any starting age younger than 25 years. Having done this for various starting ages, we observed that our predictions for 25-year-old stems seemed reasonable. However, we wanted to find out how close COPPICE's predictions were to actual stem growth. Because our study was only 10 years old, we could only compare actual versus predicted responses 10 years beyond starting ages, or one 5-year interval beyond the original 5-year interval used to construct the model.

METHODS

Stem Measurements

We remeasured stems initially measured 10 years ago and used these data to evaluate the accuracy and precision of COPPICE. The remeasurements included d.b.h. (nearest 0.1-inch--0.25 cm) and total height (nearest 1/10-foot--3.05 cm) of each surviving stem in each clump. Cubic-foot volume was calculated using these data and the equation of Gevorkiantz and Olsen (1955). Each remeasured stem was also "grown" for 10 years by COPPICE using its original d.b.h., stem age, relative basal area, and TSC measurements. This gave us 231 paired observations of actual and predicted d.b.h., height, and volume for the 10-year period.

Accuracy and Precision Criteria

We use the words accuracy and precision interchangeably in everyday conversation. But from the statistical viewpoint used here, their meanings are very different. Accuracy refers to the success of estimating the true value of a quantity, and precision refers to the clustering of sample values about their own average.

Growth estimates produced by COPPICE were considered inaccurate if the average discrepancy between observed and predicted responses were significantly different from zero at the 5 percent level as tested by Student's t statistic.

We estimated the precision of diameter, height, and volume predictions by constructing 95 percent confidence intervals around the average difference between observed and predicted values. Then we calculated decision intervals by multiplying actual 10th year average d.b.h., height, and volume by 10 percent. We called predictions precise if their confidence intervals fell within our calculated decision intervals; and conversely, those outside the decision limits were considered imprecise.

In addition to evaluating the overall performance of COPPICE, we looked at how well COPPICE predicted over different ages, topographic site coefficients, relative basal areas, and initial d.b.h.s.

RESULTS

Overall, COPPICE is acceptably precise for predicting d.b.h., height, and volume and is acceptably accurate for predicting d.b.h. However, it is not accurate for predicting height and volume. On the average, heights were overestimated by almost 20 percent (9 feet (2.7 m)) and volumes by 27 percent (1.3 cubic feet (0.037 m^3)) (Figure 1).

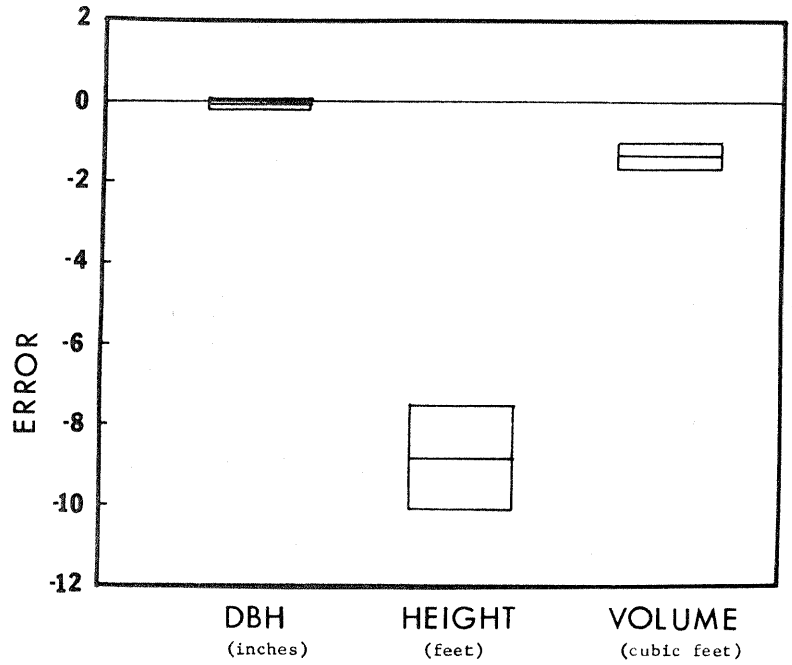

Figure 1.--Discrepancy between predicted and measured d.b.h., height, and volume of stems after 10 years growth. (The midline in each box represents the average discrepancy (error) and the outer lines the limits for the 95 percent confidence interval for each mean difference. Boxes that do not overlap the zero line are biased, i.e., inaccurate. Negative errors indicate an overestimate by the model; positive errors indicate an underestimate.)

When we examined COPPICE's predictions by the number of stems retained in a clump, the pattern just described did not change except that heights and volumes of single stems were overestimated more than those in multiple-stem clumps.

It was not until we examined COPPICE's predictions by initial clump age (age at the time of initial measurement) that we discovered an anomaly in height and volume estimation (Figure 2). COPPICE's overestimation increased gradually with increasing stem age up to age 21. At that point error almost tripled for stems 21 years old or older. If we eliminated these stems from consideration, COPPICE's estimates improved (Figure 3). Volume estimates were then within our acceptance criteria; however, height estimates were not--they were overestimated by an average of almost 4 feet. Although this was an improvement over the 9-foot discrepancy noted earlier, it still did not meet our accuracy requirement. A discrepancy of no greater than 1 foot would be needed to satisfy the requirement.

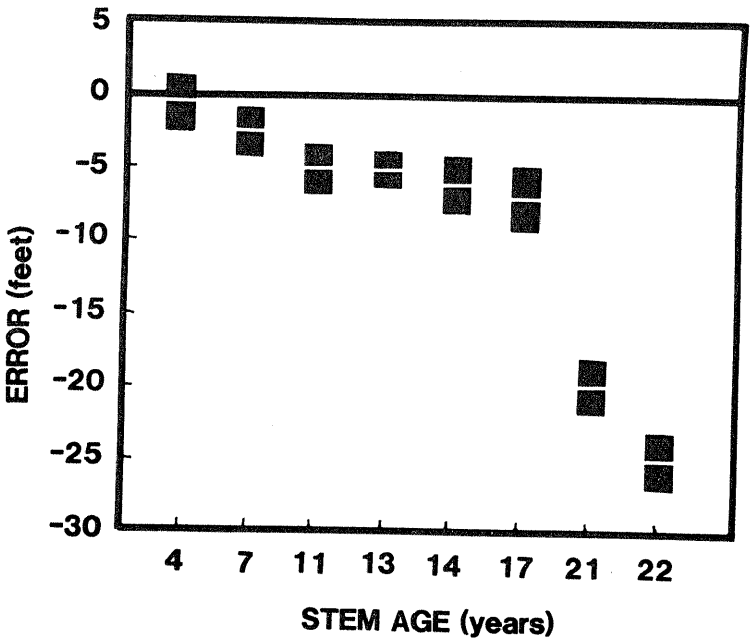

Figure 2.--Differences between predicted and observed heights after 10 years by initial stem age. (Means and limits represented by the boxes are the same as defined for Figure 1.)

Inspecting COPPICE's performance, including all initial ages 17 years or younger by the number of stems retained in the clump, we found that d.b.h. and volume are overestimated in 1-stem clumps (7 and 25 percent respectively) and underestimated in multiple-stem clumps (7 and 6 percent respectively) (Figure 4). Overestimates of height tend to be greater in 1-stem (19 percent) than in multiple-stem clumps (4 percent). But, precision is acceptable in all cases.

With the exception of a border line overestimate of volume at age 13, d.b.h. and volume estimates are acceptably accurate over initial clump ages from 4 to 17 years. Height is overestimated across all ages except age 4--but estimates are nevertheless precise.

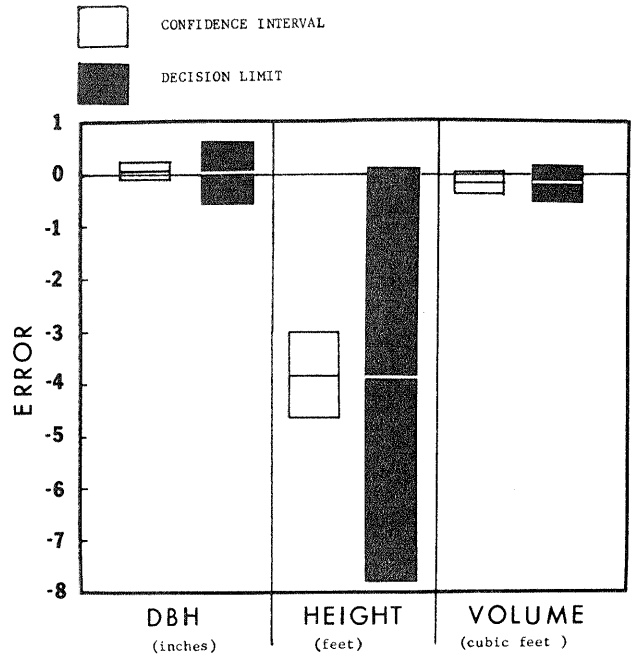

Figure 3.--Confidence intervals (95 percent) and decision limits of 10 percent of average observed response for d.b.h., height, and volume. (If the height of the open box is less than the height of the solid box, the estimate for that response is acceptably precise. The zero line must intersect the open box for the estimate to be acceptably accurate. Initial stem ages greater than 17 are not included.

We did not detect any nonrandom behavior in discrepancies between actual and observed responses associated with either initial d.b.h. or topographic site coefficient.

DISCUSSION

Overall, COPPICE predicts 10-year d.b.h. growth with acceptable accuracy and precision. The average discrepancy between measured and predicted diameters after 10 years' growth was less than 0.1-inch (.25 cm), with the true discrepancy being between plus or minus 0.15-inch (.38 cm) with 95 percent confidence. D.b.h. estimation is thus both accurate and precise and COPPICE can confidently be used to estimate future d.b.h.

Although COPPICE's height estimates were acceptably precise, they were too inaccurate by our standards. Therefore, be cautious in using COPPICE to estimate height because estimates are likely to be too high. Be particularly cautious in accepting estimated heights of stems in clumps thinned to one stem

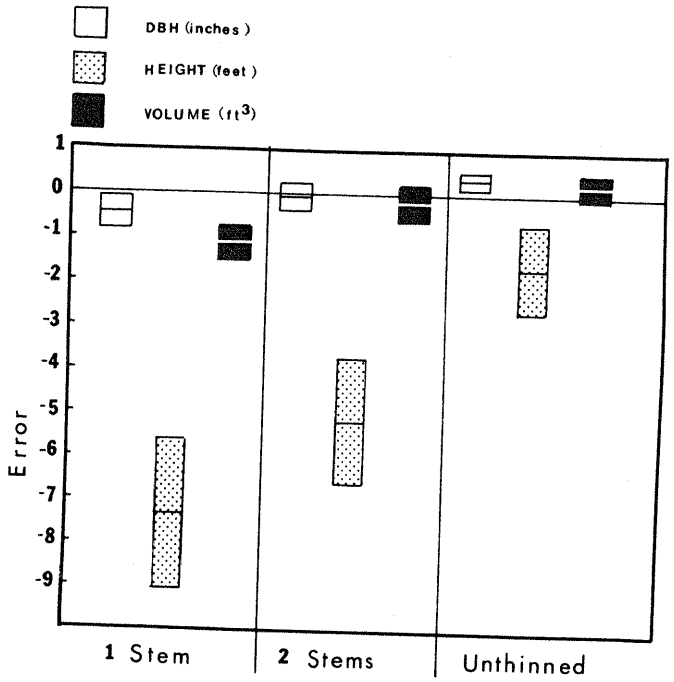

Figure 4.--Discrepancy between predicted and measured d.b.h., height, and volume for 1-stem, 2-stem, and unthinned clumps. (Boxes are defined as in Figure 1. Initial stem ages greater than 17 years are not included.)

because they are likely to be even more inaccurate than those in multiple-stem clumps. Moreover, inaccuracies in height estimates increase as clump age increases. Other minor difficulties include a slight diameter overestimation in 1-stem clumps, underestimation in multi-stem clumps and volume overestimation in single-stem clumps.

Why is COPPICE a poor predictor of the responses just mentioned? Three reasons are plausible: (1) the assumptions concerning stem form factors in the model may not be correct; (2) the assumptions concerning competition from outside the clump may not be correct; or (3) the "age" terms in the original model equations may not adequately describe growth of red oak sprout stems for a 10-year growth interval.

The overestimation of height we observed may be due to incorrect assumptions about tree form in thinned northern red oak clumps. Height growth is estimated as a by-product of COPPICE's simulation of diameter and volume growth. We considered and tried to develop an equation to predict height growth directly using the variables we studied but were unable to account for enough variation in height growth. On the other hand, we were able to

describe volume growth very well. So we derived height from predicted volume and diameter using Gevorkiantz and Olsen's (1955) form factors to compensate for stem taper. Although form factor could influence the observed discrepancy in height, the discrepancy is too large to be solely accounted for by form factor. As such, it would account for only 2.2 feet (.7 m) of the 7.4 foot (2.3 m) deviation observed in 1-stem clumps.

Another potential source of error involves the assumption that competitive influences of adjacent trees remain the same after the first 5-year growth period. If clumps are not thinned every 5 years, this assumption is violated and the model may underestimate the growth-depressing effects of crown closure in subsequent growth periods. In fact, clumps in our study were not thinned after the initial thinning. In the absence of rethinning, departures from estimated values are likely to be greatest where competing trees of about the same size and vigor as the crop stems occur near the periphery of the initial clump thinning radius and where clumps have been thinned to leave one stem. Intra-clump competition in multistem clumps is likely to be as great or greater than inter-clump competition so encroaching crown closure is not likely to greatly alter future stem growth. On the other hand, growth depressing effects of crown closure on a single stem, initially thinned to be free from competition, are not accounted for by the model beyond the first 5 years. Therefore, COPPICE's predictions for growth periods greater than 5 years are more likely to correspond to actual stem growth in unthinned clumps than in clumps thinned to leave one stem.

The effect of age in the model is also a possible source of prediction errors. This variable is a highly significant predictor in all regression equations used in COPPICE. The coefficients in these equations were developed from 5-year growth data collected from clumps spanning initial ages from 4 to 22 years. Thus we might expect 10-year growth projections to overestimate stem height in clumps older than 17 years. A 10-year growth period would make stems that were 18 years old or older at initial measurement more than 27 years old at the end of the period, which is beyond the oldest age used to develop the model. Therefore, the model should not be faulted for failing to predict responses beyond the age for which it was originally constructed. Thus we recommend that COPPICE only be used to predict d.b.h., height, and volume of coppice stems up to age 27.

We developed COPPICE using data from the Driftless Area of southern Wisconsin. Because we have not tested the simulator outside that region, it should be used cautiously in other areas. Furthermore, COPPICE uses a site quality expression, TSC, whose efficacy outside that area is unknown.

Mindful of the comparisons and comments just made, we believe COPPICE can be profitably used as an aid in making decisions about thinning young red oak sprout clumps. Specific gains in d.b.h., height, and volume of stems in thinned versus unthinned clumps of course, will depend on clump age, size of the stem selected, length of growth period, and site quality--all of which are easily handled by COPPICE. Evaluation of these gains can lead to decisions involving the time of first and subsequent thinnings, the number of stems to leave in a clump, minimum site requirements, and minimum size requirements at the time of thinning.

SUMMARY

The growth simulator "COPPICE" overestimates 10-year growth of height and volume. Nevertheless, d.b.h. can be estimated with confidence.

In order to avoid large inaccuracies, estimates of d.b.h., height, or volume should be made on stems whose ending ages will not exceed 27 years. Beyond age 27, we found COPPICE overestimated actual 10-year growth.

COPPICE can be used to estimate individual stem d.b.h., height, and volume in clumps located in the Driftless Area of Wisconsin and adjacent states. Caution should be exercised in using COPPICE elsewhere.

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