DEVELOPING AN ALGORITHM TO PREDICT SINGLE-TREE BIOMASS WEIGHT FROM STEM DIAMETER MEASUREMENTS IN YOUNG HYBRID POPLAR ENERGY PLANTATIONS IN MICHIGAN.

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$$Stool\ Biomass\ \frac{OD\ lbs}{stool} = Sq.Ft.Basal\ area\ X\ 562.089$$

R^2= 0.968, Root Mean Square Error = 21%

INTRODUCTION

Poplar hybrids make excellent woody biomass crops in the Midwest and elsewhere around the world. They grow rapidly and are readily bred to adapt to various local conditions. Many hybrids are available and more are being developed all the time. The only way to identify elite varieties, however is to conduct local trials. It is useful to monitor the growth of trees in these trials using non-destructive sampling techniques. Similar monitoring of commercial plantations is needed to determine the appropriate timing for harvests.

The most convenient way to estimate standing-tree biomass is to use allometric equations that use easily measured tree parameters like diameter at breast height (DBH) a predictor variable. Tree height is so strongly correlated with DBH (r^2=0.862 in this case) that it adds little predictive ability. For this reason and because it is often difficult to measure precisely, it is rarely used in models. Attempts to develop regional biomass equations for poplar hybrids in the Lake States have been made recently. Netzer, *et. al.* (2002) developed an equation using a range of trees from many plantations in Minnesota. Wang (2012) developed an equation from a set of trees in a Michigan plantation. Here we attempt to improve on these two models.

Poplar hybrids frequently develop multiple stems from a single stump (or stool). These multiple stems are often pruned out of plantations where the desired product is pulpwood or sawtimber. In this way the remaining stem will grow large quickly. In biomass plantations multiple stems are often allowed to remain and develop independently because stem size is less important than total stool weight. Avoiding the pruning step also reduces the cost of managing these biomass plantations.

Multi-stemmed stool biomass can be estimated either through a process of summing individual stem weight estimates derived from their diameters or by estimating the entire stool's biomass based on a function of its basal area. Basal area is the total cross-section area of all the stems on the stool at a height of 4.5' (breast height). The latter method is favored by our group and so our equations require basal area as the independent variable.

Recognizing the need for a local poplar biomass equation, and having access to trees of various sizes and varieties, allometric equations were tested here to identify one that adequately predicted biomass weights of poplar stools. The process used to derive this equation along with a discussion of its limitations are provided here.

METHODS

Trees from two large-plot hybrid poplar yield trials at the Forest Biomass Innovation Center in Escanaba, MI were cut and measured to obtain the data needed to model whole tree weights. 159, eleven-year-old trees and 72, seven-year-old trees were cut from two plantations. Sampling was stratified to ensure relatively even representation from the five poplar varieties and the eight diameter classes present in these plantations.

DBH was recorded for each tree. Total tree green weight was also recorded. Each tree was subsequently chipped and a representative ten pound sample of these chips was oven dried at 220 degrees Fahrenheit until bone dry. Moisture content of the green chips was thus determined and this value was used to convert the whole-tree green weights to oven-dry weights.

Regression equations were developed using various model formats (Table 1). The models developed by both Netzer and Wang were compared with three models developed specifically from these field data. All three of the new models used basal area rather than diameter as the independent variable because it was felt this would be the better way to obtain stool weights when multiple stems were present. All new models were forced through the origin since a tree with zero basal area should have zero weight. Neither the Netzer nor the Wang models made this assumption.

Table 1: Comparison of five regression models attempting to predict single-stem, oven-dry biomass weight of hybrid poplar using stem diameter (or basal area) measurements. 233 sample trees representing 5 poplar varieites with stem diameters ranging from 1 to 8 inches were used in the modeling. (Weight is in oven-dry pounds, BA is in feet^2, and DBH is in inches.)

Model Name	Model	r^2	RMSE / $\overline{X}$
NEW Linear Model	Weight = 562.089*BA	0.968	21%
NEW Power Model	Weight = 658.679*BA^1.116	0.972	21%
NEW Quadratic Model	Weight = 487.488*BA + 322.284*BA^2	0.970	21%
Wang Power Model	Weight = 1.841 + DBH^2.3		53%
Netzer Quadratic Model	Weight = 13.58 - (12.487*DBH) + (5.021*DBH^2)		24%

RESULTS

All three new models (Table 1) fit the data very well as measured by the Coefficient of Determination (r^2= 0.97). All three models had similar prediction errors as measured by the Root Mean Square Error (RMSE) divided by the grand mean tree weight (21%). This error rate was better than predictions made by either the Netzer model (24% error) or the Wang model (54% error). The prediction error was similar among the five poplar varieties and among the larger diameter classes (Table 2). It was exceedingly difficult to predict the weight of especially small diameter (DBH less than 2 inches) stems with any of these models.

This large (~20%) overall prediction error is probably due to major differences in crown architecture among trees. Differences in branch diameters, number of branches, upper crown forking, etc. are not captured by simple measurements like DBH. Fortunately this prediction error is random; it overestimates as often as it underestimates. When the predicted weights of all 233 sampled trees were summed, the predicted total was within 2% of the actual total. So, this equation is more reliable when used to predict stand level biomass rather than for predicting the biomass of any one tree. However, since this equation is less accurate for small diameter stems, the stand-level error will be larger in stands with a high proportion of small stems (as might be the case with sprouts in a coppice rotation).

Table 2: Analysis of biomass weight prediction error by diameter class and variety among 233 sample poplar trees.

Error Analysis by Diameter Class				
DBH Class (inches)	*Ave Wt (pounds)*	*RMSE (pounds)*	*n*	*RMSE/Ave Wt*
1	3.4	1.6	12	47%
2	9.9	3.8	13	38%
3	25.6	6.9	26	27%
4	44.9	6.4	24	14%
5	75.4	11.5	46	15%
6	102.2	19.5	65	19%
7	161.8	30.5	37	19%
8	180.3	28.4	10	16%
Error Analysis by Variety				
Variety	*Ave Wt (pounds)*	*RMSE (pounds)*	*n*	*RMSE/Ave Wt*
D105	28.1	7.4	13	26%
DN34	60.7	10.8	57	18%
NE222	81.0	9.3	54	11%
DN5	81.3	21.8	52	27%
NM6	129.6	26.1	57	20%

The simplest of these three new models (the linear model) was chosen for use in subsequent analysis of Michigan poplar plantations. A plot of the data along with the predictor equation appears in Figure 1. Here, the random nature of the prediction error is obvious. Less obvious from this plot is the fact that prediction error for small diameter (Basal Area) trees is actually proportionally greater than for larger trees. This trend is more easily seen in Table 2.

LITERATURE CITED

Netzer, D.A. *et. al.* 2002. Growth, yield, and disease resistance of 7- to12-year-old poplar clones in the north central United States. USDA, Forest Service, North Central Research Station. GTR-NC-229. 31pp.

Wang, Z. 2012. Graduate student project. Developed biomass yield equations from data derived from poplar trees harvested from a plantation in Escanaba, MI.

Figure 1: 233 individual tree biomass values plotted against tree basal area showing best-fit predictor equation: **Biomass = 562.089*BA**.