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Development and validation of aboveground biomass estimations for four *Salix* clones in central New York

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Abstract

Commercial and research scale plantings of short-rotation woody crops require reliable and efficient estimations of biomass yield before time of harvest. Biomass equations currently exist but the accuracy and efficiency of estimation procedures at the level of specificity needs to be quantified for clones being used in North America. Diameter-based allometric equations for aboveground biomass for four clones of willow (*Salix discolor*, *Salix alba*, *Salix dasyclados*, and *Salix sachalinensis*), between two sites (Canastota and Tully, NY), and across four years (1998–2001), were developed using ordinary least-squares regression (OLSR) on log-transformed variables, weighted least squares regression (WLSR) on log-transformed variables, and nonlinear regression (NLR) methods and validated using independent data sets. Biomass estimations derived from clone, age, and site (Specific) using OLSR equations had highest R^2 and lowest percent bias (<2.3%) allowing for accurate estimations of standing biomass. Values for specific equations using WLSR were similar, but bias was higher for NLR (0.7–12.5%). However, the amount of time and effort required to develop specific equations, is large and in many situations prohibitive. Biomass estimates derived from clone and age, regardless of site (Intermediate), resulted in small increases in prediction error and a small increase in percent bias using OLSR (<0.4%) and WLSR (<1.7%). The increase in percent bias was larger (1.1–5.7%) for NLR equations. Intermediate models correspond to the loss of only a small amount of accuracy while gaining more efficiency in estimating standing biomass. Estimates of biomass derived from clone alone (general) equations, considering neither age nor site, had the weakest prediction abilities that may lead to large errors for biomass estimations using OLSR (7.0–9.5%), WLSR (1.1–21.7%) or NLR (31.9–143.4%).

Keywords: Allometric equations; Bioenergy crops; Biomass estimation; Internal validation; Willow; Salix

1. Introduction

Renewed interest and increasing attention is being directed towards the need to use woody biomass as a feedstock for bioenergy and bioproducts [1]. Relative to the current fossil fuel feedstocks, biomass production systems can meet the growing raw material and fuel needs, create less pollution, have positive environmental impacts, revitalize rural economies, and maintain national energy security [2]. In the future, short rotation woody crops (SRWC) will be a significant source of biomass as more bioenergy and bioproducts are produced [3]. In addition, SRWC can be used to address an array of nutrient management, phytoremediation and other environmental problems across the landscape [4,5]. Willow biomass crops are being studied and developed as a SRWC in northern Europe [6] and northeastern USA [1,7] because of the many environmental benefits and rural development opportunities they offer.

At an operational or commercial level, willow biomass crops in the northeastern USA are expected to be ready for harvest three years after the first coppice or four years after planting [8]. In some cases biomass yield may not be optimal after three years due to unexpected external factors related to weather conditions, pests and/or weed competi-

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Nomenclature

W	stem dry weight (g)
D	stem diameter at 30 cm height (cm)
Specific equation	uses clone, age and site-specific data
Intermediate equation	uses clone and age data generalized across sites
General equation	uses clone data generalized across site and age
OLSR	ordinary least-squares regression
WLSR	weighted least-squares regression
NLR	nonlinear regression
R^2	coefficient of determination
%RMSE	percent root mean square error
%Bias	positive bias indicates underestimation, negative bias indicates overestimation
%RMSE_V	percent root mean square error for validation data

tion. Since harvesting costs account for about 40% of the cost of willow biomass [7], landowners or SWRC managers will benefit from conducting non-destructive, accurate, and cost-efficient biomass estimations [9,10]. This data will allow for appropriate decisions about the crop to be made (i.e. delaying harvest by a year or two) to ensure a steady supply of biomass to power plants or other processing facilities without compromising profitability.

Researchers studying SRWC require very accurate, non-destructive estimates of aboveground biomass production. However, the level of accuracy required and the investment of time for this work are greater than for commercial operations. In order to assess the impact of different treatments on crop development, researchers need to be able to estimate biomass production after each year of growth. In contrast, commercial level operations will primarily be interested in estimates at the end of the rotation.

Biomass estimates can be derived using various estimation procedures following methods described by Verwijst and Telenius [11]. These include using regression analysis to develop allometric relationships, such as between dry weight and diameter. While allometric equations facilitate the estimation procedure, varying levels of accuracy result depending on whether the equations are specific to clone, age, and/or site. In Sweden, Telenius and Verwijst [9] analyzed allometric data derived from 2 to 4 year-old shoots from 124 stands of *Salix viminalis* and *Salix dasyclados*, using a two-parameter nonlinear model. They concluded that equations should be age specific and species specific, but can be generalized across sites and clones from the same species with the estimates resulting in less than a 10% bias. In contrast, a study of *Salix* clones in Sweden and Finland concluded that equations generalized across species and clones were as accurate as clone specific, although estimates of error associated with these more generalized equations were not provided [12]. In the northeastern USA, Ballard et al. [13] compared clone-specific and clone-generalized allometric regression equations for one poplar and five willow clones from three sites, using logarithmic, two-parameter nonlinear, and three-parameter nonlinear models. Clone-specific logarithmic regression models were better than generalized equations (for the poplar, NM6, and one willow clone, SV1), although the predictive improvements of the clone-specific models over the generalized equations were small. Verwijst [14] examined biomass estimation procedures with *S. viminalis* grown on two sites. He found that models developed using logarithmic transformations resulted in biased estimates. Deviations resulted in an overestimation of 12.7% and an underestimation of 10% when D^2H or D was used as an independent variable, respectively. He suggested that linear weighted least-squares and iterative nonlinear regression methods were reasonable alternatives to avoid biased estimations caused by logarithmic transformations.

From the literature, it is clear that the choice of the allometric regression model and specificity included in the data (species or clone, age, and site) may affect the accuracy of the models and efficiency of biomass estimation procedures. Results from one set of clones generally cannot be transferred to other unrelated clones [9,12]. This study is therefore aimed to determine the level of specificity of the data and the most suitable regression method to accurately and efficiently estimate aboveground biomass for a suite of *Salix* clones that are being used for biomass production, agroforestry applications, and phytoremediation purposes in the northeastern USA.

2. Methodology

2.1. Site preparation

This study was replicated at two sites in central New York, Canastota and Tully. Soil at the Canastota (43°03′10″W, 75°46′16″W, elevation 198 m) site is classified as a Cazenovia silt loam (Glossic Hapludalf) with a 3–8% slope. It is a deep, moderately well drained to well-drained soil formed from glacial till [15]. The soil at the Tully site (42°47′30″N, 76°07′30″W, elevation 391 m) is a well drained to somewhat excessively well-drained Palmyra gravelly silt loam (Glossoboric Hapludalf) with a slope of 0–3% [16]. The climate is temperate humid and cold. Thirty-year averages for annual precipitation across the sites ranged from 973 to 1017 mm.

The sites were in grass (Tully) and hay (Canastota) in 1997. Site preparation involved mowing both sites during the summer of 1997 and application of glyphosate (2.25 kg ai ha^{-1}), plowing and cross disking several weeks later. A final pass with a cultipacker (Canastota) or disk (Tully) was conducted one to three days prior to planting.