EFFECT OF WEED CONTROL TREATMENTS ON TOTAL LEAF AREA OF PLANTATION BLACK WALNUT *(JUGLANS NIGRA)*

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Abstract.—Determining total tree leaf area is necessary for describing tree carbon balance, growth efficiency, and other measures used in tree-level and stand-level physiological growth models. We examined the effects of vegetation control methods on the total leaf area of sapling-size plantation black walnut trees using allometric approaches. We found significant differences in total tree leaf area and cross-sectional stem area at breast height between trees receiving 100 percent (pre-emergent and post-emergent) weed control treatment and those receiving pre-emergent control or no control. Additionally, neither branch height nor weed control treatment factored significantly in determining branch leaf area (BLA), allowing for the use of a universal equation for calculating BLA in young black walnut plantations.

INTRODUCTION

One of the key objectives for tree plantations is the rapid growth of timber volume over short periods of time. Meeting this goal is dependent upon a number of cultural factors; one of the most important of these factors is controlling the impact of competing herbaceous vegetation during early plantation development. Studies have shown that newly established afforested plantations benefit strongly from control of competing vegetation (Cogliastro et al. 1990, Fournier et al. 2007). For example, Willoughby (1999) examined the impact of five levels of herbaceous control, ranging from none to complete control (i.e., bare earth), on Corsican pine (*Pinus nigra* Arnold ssp. *laricio* Maire) and Norway maple (*Acer platanoides* L.). The bare earth treatment in Norway maple resulted in 19.9 percent higher average growth in stem diameter over the next closest treatment. Meanwhile, a 57.4 percent growth disparity occurred between the bare earth treatment and the untreated management.

Competition can affect trees in a number of ways. Although competition for belowground resources is important during plantation establishment (Ares and Brauer 2005, Burgess et al. 2010, Wagner et al. 2006), aboveground competition influences crown development, perhaps by changing the amount of leaf area displayed on branches or the number of branches a tree maintains (i.e., change in crown architecture). Development of total leaf area (TLA) allometric relationships can help to allude to this difference. This type of leaf area analysis has been used in many species of conifers, such as eastern hemlock (*Tsuga canadensis* (L.) Carriére) (Kenefic and Seymour 1999), balsam fir (*Abies balsamea* (L.) Mill.) (Coyea and Margolis 1992), and ponderosa pine (*Pinus ponderosa* C. Lawson) (O'Hara and Vallappil 1995), but has yet to be examined extensively in hardwood species.

In conifers, most leaf area models are based on either sapwood area or diameter (Kenefic and Seymour 1999). Sapwood area-based models, either for sapwood measurements taken at the base of the live crown or at breast height, have broad empirical support (Coyea and Margolis 1992, Long and Smith 1989) and are supported by the pipe model theory (Shinozaki et al. 1964). However, these sapwood-based models require destructive sampling to develop and are likely not significantly

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different from diameter-based models in young hardwood plantations, because a high proportion of cross-sectional area at breast height (CSA) is sapwood anyway.

We hypothesized that the relationship between TLA and CSA will vary by weed control treatment in black walnut (*Juglans nigra* L.). Additionally, we believe a relationship will exist between TLA and individual weed control treatments, with the highest TLA demonstrated in trees receiving "Full" treatment and the smallest TLA demonstrated in trees receiving no weed control.

STUDY AREA

The sample trees used for this study consisted of young, small-diameter (11.7 mm to 31.8 mm diameter at breast height[d.b.h.]) black walnut trees selected from plots demonstrating three different levels of herbaceous vegetation control on afforested farmlands. Trees ranged in age from 2 to 4 years old, had never been pruned, and all were first generation crosses from the Purdue #1 genotype (Beineke 1990). The first treatment, hereafter referred as "Full," consisted of 100 percent control of competing vegetation. This method involved the use of an initial pre-emergent inhibitor with subsequent use of glyphosate applications for control of emerging vegetation. Sample trees of this treatment were located at approximately 40˚22'51" N and 86˚59'22" W in the New 76 Plantation owned by ArborAmerica, Inc. (Westpoint, IN). The "Full" treatment trees from this plantation were used because the cross-sectional areas at breast height more closely resembled trees of the other two treatments; this would better isolate competition effects from tree size effects on leaf area display. The next treatment, "Pre," was application of the pre-emergent herbicide only. Any vegetation that emerged following this treatment was left to grow and compete. The final treatment, "No," involved no input for controlling competing vegetation. Sample trees of the "Pre" and "No" treatments were located on three different test plots within the Highlands plantation, 40˚23'23" N and 87˚02'53" W, also owned by ArborAmerica, Inc. Both the New 76 and Highlands plantations lie on the same large complex of Elston sandy loams and loams, although the Highland plantation does have some Coloma sands (NRCS 2011). Both plantations are sprayed annually in late May with azoxystrobin for walnut anthracnose that, if left untreated, would lead to early leaf abscission (i.e., in mid-August) within these plantations.

METHODS

We used stratified random sampling to collect all leaves from 38 branches across 32 sample trees from August 25 through September 5, 2010. Specifically, trees were randomly assigned to have branches sampled from the upper, middle, or lower third of the live crown. If branches were inadequate (i.e., damaged or missing leaves that had already senesced) or not available in the assigned third for a given tree, the tree was randomly reassigned to another strata. All trees had at least one branch sampled and a few had two branches sampled. In total, we sampled 15 branches from 13 trees in the "Full" treatment, 16 branches from 14 trees in the "Pre" treatment, and 7 branches from 5 trees in the "No" treatment. Collected leaves were kept refrigerated at 2˚C after collection. We then recorded two diameters at breast height perpendicular to one another with digital calipers and recorded tree height with a telescoping height pole. Attachment heights and basal diameters were recorded for every branch.

Leaf samples for each branch were scanned with an Epson 10000XL scanner. WinFolia 2009a (Regents 2009) was used to determine the leaf area to the nearest 0.01 cm^2 for each scanned image. To save time, subsamples of 20 leaves were collected from larger branches that held more than 30 leaves. Once scanned, leaves from each branch were oven-dried at 70 °C for 72 hours. Weights of the samples and subsamples were recorded to the nearest 0.01 g. Specific leaf area (SLA) was calculated for all samples or subsamples by dividing the total leaf area of each branch by the oven-dry leaf weight of the same branch. SLA from subsamples was used to estimate total branch leaf area by multiplication with total oven-dry weight of all leaves on those branches.

Analysis

Following the procedures of Kenefic and Seymour (1999), models were developed to estimate branch-level leaf area from branch cross-sectional area, branch height, and vegetation control treatment. The full model included all of these variables and their interactions to estimate the branch leaf area. Additional models were run that estimated branch leaf area with each of the variables separately.

The most parsimonious branch-level model was used to develop treatment-specific tree-level models by summing branch-level estimates across all branches on a given sample tree. Tree-level models included the response variables CSA, d.b.h., tree height, and weeding treatment. Models were simplified wherever possible by testing for common intercepts and slopes among weeding treatments.

The final branch-level and tree-level models were tested using standard procedures for normality, homoscedasticity, and independence (Zar 2010). All analysis was conducted using R 2.12.1 (R Development Core Team 2010). Significance was tested at $\alpha = 0.05$.

RESULTS

Branch Level

We found a mean of 15.7 branches per tree in the "Full" weed control treatment and means of 13.7 and 10.8 in the "Pre" and "No" treatments, respectively (Table 1). Overall, the average SLA across all three treatments was 105.2 $cm^2\ g^{-1}$. Individually, the "No" treatment displayed the highest average SLA value of 109.5 $cm^2\ g^{-1}$ the "Pre" and "Full" treatments had an SLA of 107.2 and 101.5 $cm^2\ g^{-1}$, respectively (Fig. 1). These differences were not significant, however ($F = 2.577$, $p = 0.091$).

Examination of branch-level models suggested that only branch cross-sectional area was needed to adequately predict leaf area. This finding was somewhat surprising as branch height, or one of its derivatives, has generally been found to be important in predicting branch-level leaf area (e.g., Kenefic and Seymour 1999). However, we found no evidence of its effect on the branch leaf area and branch cross-sectional area relationship ($F = 0.439$, $p = 0.512$).

Table 1.—Treatment-specific mean specific leaf area (SLA; ± 1 standard error), average height of first branch (AHT), average number of branches per tree (Nbr), and average number of branches found below breast height (NbrBH)

Treatment	SLA ($cm^2\ g^{-1}$)	AHT (cm)	Nbr (no.)	NbrBH (no.)
Full	101.5 ± 1.8	53.4	15.7	9.7
Pre	107.2 ± 2.8	59.5	13.7	6.6
No	109.5 ± 2.7	53.9	10.8	6.1

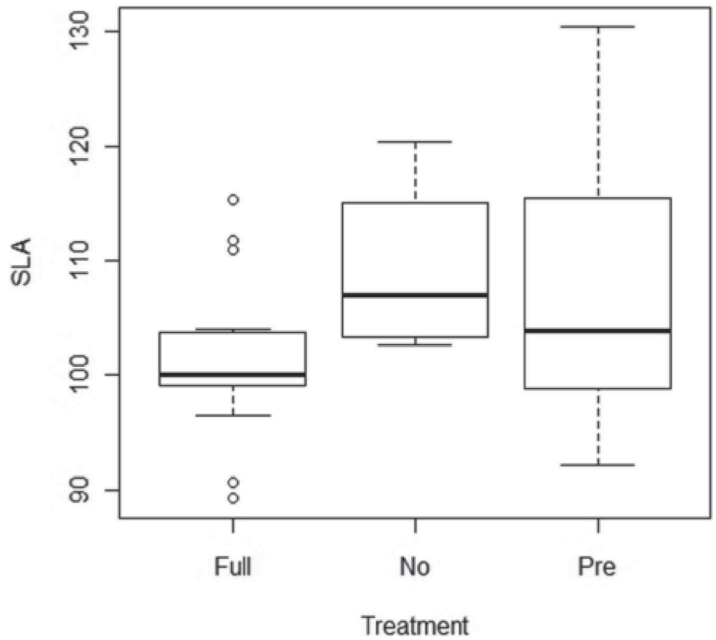

Figure 1.—Boxplot of specific leaf area (SLA) in cm^2 per oven-dry g for the three weed control treatments.

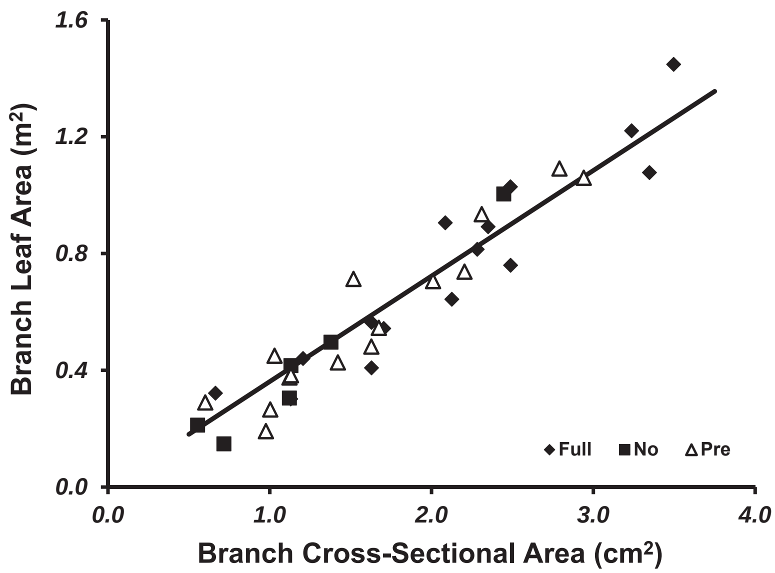

Figure 2.—Relationship between the branch leaf area and the branch cross-sectional area for all trees across all weeding treatments. Treatment-specific models were not significantly different at $\alpha = 0.05$.

We also did not observe a difference among the three vegetation control treatments on the branch-level leaf area relationship through an effect on either the slope or intercept of the model (all models p > 0.678). Therefore, the most parsimonious branch-level model was:

$$BLA = 3614.5 \times BSA \quad (1)$$

where BLA is the branch-level leaf area in cm^2 and BSA is the cross-sectional area of the base of the branch in cm^2. This relationship was quite significant (F = 42.4, p < 0.001) and had an adjusted R^2 of 0.91 (Fig. 2).

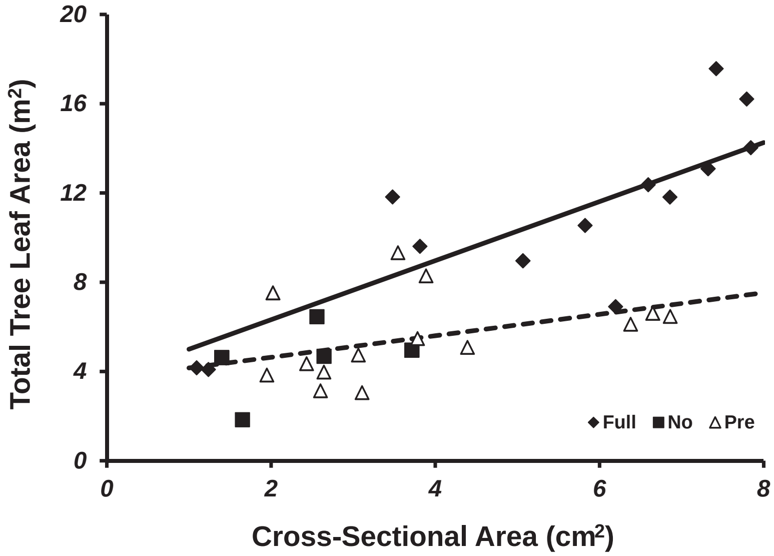

Figure 3.—Treatment-specific relationships between cross-sectional area at breast height and total tree leaf area. The “Full” treatment model (equation 2) is shown as the solid line. The “No” and “Pre” treatments were not significantly different from one another at $\alpha = 0.05$ (equation 3) and are shown as the dotted line.

Tree Level

Total tree leaf area was strongly related to CSA ($F = 44.11$; $p < 0.001$) with an adjusted R^2 of 0.538. Adding vegetation control treatments improved fits considerably ($F = 8.10$; $p < 0.001$). After testing linear models for common intercepts and common treatments among the treatments, we found that the most parsimonious model included a shared intercept among all treatments and a different slope for only the “Full” treatment (Fig. 3). This model was ($F = 58.29$; $p <0.001$):

$$TLA = 3.675 + 1.323 \times CSA \qquad (2)$$

for the “Full” treatment, and:

$$TLA = 3.675 + 0.481 \times CSA \qquad (3)$$

for the other two treatments, where TLA is in m^2 and CSA is in cm^2. The model had an adjusted R^2 of 0.756.

DISCUSSION

In young black walnut plantations that have not reached crown closure, cross-sectional area appears adequate to predict TLA if plantations are under the same cultural regime. If plantations differ in the level of herbaceous control, plantation-specific relationships may need to be developed. Our results suggested that only the “Full” vegetation control required a separate model; however, we recognize that the small sample size of the “No” vegetation control treatment (n = 5) likely limited the statistical power to separate from the “Pre” treatment. This was unavoidable in our sample because most walnuts under this cultural regime had died or shed leaves much earlier in the growing season due to the intense competition for light from surrounding taller weeds. Walnut has been shown to be extremely sensitive to competition (Ares and Brauer 2005); for example, after five growing seasons, Fournier et al. (2007) observed significant improvement in height and diameter growth for trees in young plantations with chemical release treatments over mechanical release treatments, largely because the mechanical treatments resprouted and acted as strong competitors with the walnut for both light and belowground resources.

Branch-level leaf estimates did not differ by cultural treatment or by height of the branch, allowing for use of a universal branch level equation. Likely, branch height was not as important as we initially thought because the trees were not large or old enough for that factor to become significant. However, Gilmore and Seymour (1997) observed even in mature trees that branch height may not be important to modeling BLA; their study of crown architecture of balsam fir used a generic branch level formula within four crown positions (open-grown, codominant, intermediate, and suppressed) with only minimal sacrifice to the overall accuracy of the model.

This disparity in effects of weed control on the tree-level and branch-level leaf area equations demonstrate that treatment-level differences are not a function of differing leaf area display on the same size branches across treatments, but instead a change in the crown architecture in response to vegetation control. In this study, the presence of herbaceous vegetation likely influenced the number of branches that develop per tree, which in turn influenced the depth of the live crown. This conclusion is consistent with Marino and Gross (1998) on willow species planted in southwest Michigan. They observed that trees grown in the presence of weeds initiated fewer branches and had fewer living branches than those grown in weed-free conditions.

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