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# PRELIMINARY BIOMASS EQUATIONS FOR EIGHT SPECIES OF FAST-GROWING TROPICAL TREES

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**DUDLEY, N.S. & FOWNES, J.H. 1992. Preliminary biomass equations for eight species of fast-growing tropical trees.** Biomass allometric equations and tested predictions were produced from previously published equations by harvest of 2-y-old tree plantations in Hawaii. Equations of the form $B = aDBH^b$, where B is total above ground biomass, were fitted to harvest data of *Acacia mangium, A. mearnsii, Casuarina equisetifolia, Eucalyptus grandis, E. robusta, E. saligna, E. urophylla,* and *Leucaena leucocephala.* Equations derived at Mountain View, Hawaii, were compared with independent data from Kilohana, Kauai. Regression of *ln* B *versus ln* DBH for 16 to 20 trees per species had $r^2$ ranging from 0.89 to 0.98. Height did not contribute significantly to biomass regression in seven of the eight species. Where estimates of mean total dry weight within 20% accuracy are sufficient, the published equations may be used. Equations from harvest of a relatively small number (*e.g.* 20) of trees can produce substantially better estimates for a given site, but these equations may not extrapolate to other sites any better than published equations.

Key words: *Acacia* - *Casuarina* - *Eucalyptus* - *Leucaena* - prediction equations - biomass - Hawaii

**DUDLEY, N.S. & FOWNES, J.H. 1992. Persamaan biojisim awalan untuk lapan jenis pokok cepat tumbuh tropik.** Persamaan alomer biojisim dan ramalan teruji dari persamaan-persamaan yang telah diterbitkan telah didapati daripada penebangan ladang pokok berusia 2 tahun di Hawaii. Persamaan dalam bentuk $B = aDBH^b$ dimana B ialah jumlah biojisim atas tanah telah dimasukkan dalam data penebangan *Acacia mangium, A. mearnsii, Casuarina equisetifolia, Eucalyptus grandis, E. saligna, E. robusta, E. urophylla,* and *Leucaena leucocephala.* Persamaan yang diperolehi dari Mountain View, Hawaii, telah dibandingkan dengan data tak bersandar dari Kilohana, Kauai. Regressi *ln* B melawan *ln* DBH untuk 16 ke 20 pokok setiap spesies, mempunyai $r^2$ diantara 0.89 ke 0.98. Ketinggian tidak memberi sumbangan bererti kepada regressi biojisim dalam 7 dari 8 species tebangan. Dimana ketepatan anggaran jumlah hitung panjang berat kering dalam lingkungan 20% adalah memadai, persamaan yang diterbitkan boleh digunakan. Persamaan dari jumlah penebangan pokok-pokok yang agak kecil (contohnya 20) dapat memberi anggaran yang lebih baik untuk sesuatu kawasan tetapi persamaan-persamaan ini mungkin tidak boleh menentukan luaran tapak-tapak lain dengan lebih baik berbanding dengan persamaan yang telah diterbitkan.

## Introduction

The accelerating rate of tropical forest use and destruction has generated much interest in Short Rotation Intensive Cultured (SRIC) forestry for pulp, energy, and other uses. Since SRIC biomass plantations are capital intensive, it is critical to monitor biomass growth accurately to optimize productivity. This work presents a preliminary set of biomass equations for eight fast-growing tropical tree species, compares their predictions with previously published equations, and tests both sets of equations against independent harvest data.

Allometric equations for estimating biomass or volume of tropical fast-growing trees have been developed, including those for *Acacia mangium* (Halenda 1989), *Eucalyptus saligna* (Whitesell *et al.* 1988), *E. grandis, E. robusta* and *E. urophylla* (Schubert *et al.* 1988), and *Leucaena leucocephala,* (Kanazawa *et al.* 1982, Van Den Beldt 1983, Brewbaker 1987, MacDicken & Brewbaker 1988). Specific gravity data are needed to convert from volume to biomass and can be obtained from published sources or from subsamples of harvested trees. The forms of the equations vary widely, including various polynomials and models incorporating $DBH^2H$, but the most common equation is the power function $B = aDBH^b$, where B is biomass and DBH is diameter at breast height (Parde 1980, Crow & Schlaegel 1988). The power function is most often fitted by linear regression on log-log transformed data for several reasons: (1) to linearize non-linear relationships for regression analysis (Neter & Wasserman 1974), (2) to homogenize the variance over the range of data (Meyer 1944, Baskerville 1972), (3) to compare with the wide body of literature using this equation, and (4) to test the independent contribution of height as a biomass predictor (Schubert *et al.* 1988).

For the present study, we derived biomass equations from a relatively small number of harvested trees to compare with published equations. Because equations from similar environments are often applicable over wide ranges (Satoo & Madgwick 1982, Crow 1983), we wanted to evaluate the published equations before investing in more extensive destructive harvests. We also wanted to evaluate the statistical significance of height as a predictor in addition to diameter. Finally, we tested both our preliminary equations against independent data from another site to see how far they could be extrapolated.

## Methods

The sample trees were located at two sites. The first site, Mountain View, was located in the Puna district 30 *km* southwest of Hilo at an elevation of 380 *m* on the windward slope of Mauna Kea on the island of Hawaii. The soil at this site was an extremely rocky muck derived from organic matter overlaying a'a lava rock (classified as dysic, isothermic Lithic Tropofolist). At Mountain View, rainfall averaged 4700 *mm* annually over a 40-year period. Generally, the rainfall was evenly distributed but it could vary greatly on a monthly basis. The second site, Kilohana, was located in the Lihue district 9 *km* northwest of Lihue at 337 *m* elevation on the windward slope of Kilohana crater on the island of Kauai. The soil was a gravely silty clay (classified as clayey, ferritic isothermic Typic Gibbsihumox). At Kilohana, rainfall, which historically averaged 2980 *mm* annually, was evenly distributed over the year.

Samples were selected from 2-*y*-old trees growing at both the Mountain View and Kilohana sites in small, replicated plots planted at 1 × 1 *m* spacing with 100 trees per plot. Five sample trees per plot were randomly selected from each of four replications for a total of 20 sample trees per site. Height and diameter at breast height were recorded for each sample tree before felling. Each sample tree was weighed whole in the field. Basal diameter of every living branch was measured, and a regression of branch diameter *versus* leaf biomass was used to estimate leaf and twig weight per tree. Two subsamples of leaves and twigs per tree were taken for dry weight (70°*C*) conversion. Stem specific gravity was determined from two disks per tree, one at the base and the other at the first live branch. Specific gravity was expressed as dry weight (70°*C*) per fresh volume of each section. Because no consistent difference in specific gravity or moisture content was observed between the sample locations within trees, an average was used. Species and size range of trees are given in Table 1.

**Table 1.** Regression coefficient and statistics of allometric equations relating B (total above ground biomass, *kg* dry weight) to DBH(*cm*). The regression model was *ln* B = c + b *ln* DBH. The allometric equation derived from the regression is B = a $DBH^b$ where a = exp $(c + S_{y.x}^2/2)$

| | n | Minimum DBH | Maximum DBH | c | b | $S_{y.x}$ | a | $r^2$ |
|---|---|---|---|---|---|---|---|---|
| *Acacia mangium* | 16 | 1.6 | 7.8 | -2.353 | 2.142 | .180 | .0966 | .97 |
| *A. mearnsii* | 20 | 1.5 | 8.6 | -2.863 | 2.729 | .224 | .0639 | .97 |
| *Casuarina equisetifolia* | 18 | 0.6 | 5.0 | -2.177 | 2.523 | .243 | .1168 | .93 |
| *Eucalyptus grandis* | 18 | 1.1 | 9.9 | -2.683 | 2.438 | .217 | .0700 | .94 |
| *E. robusta* | 18 | 1.6 | 7.9 | -3.060 | 2.756 | .129 | .0473 | .98 |
| *E. saligna* | 19 | 1.5 | 9.0 | -2.462 | 2.443 | .237 | .0877 | .96 |
| *E. urophylla* | 17 | 2.2 | 8.8 | -2.598 | 2.534 | .130 | .0750 | .98 |
| *Leucaena leucocephala* var. K636 | 18 | 0.6 | 5.2 | -2.337 | 2.391 | .279 | .1005 | .89 |

## Statistical analysis

Linear regressions were performed on transformed data, where the model was *ln* B = c + b *ln* DBH. To test for the significance of height, a multiple regression model was used, with *ln* DBH and *ln* H as the independent variables, and a t-test was performed on the slope coefficient for *ln* H. To transform the logarithmic regression back into the power function, the antilog of the intercept c was multiplied by a correction factor (cf) to account for the bias inherent in fitting the model to the geometric mean rather than the arithmetic mean (Meyer 1944, Baskerville 1972). The correction factor was calculated as cf = $\exp(S_{y.x}^2/2)$, where $S_{y.x}$ is the standard error of the estimate of the regression. The percentage of error of the equation predictions was calculated based on the mean of the measured dry weights *versus* the mean of the predicted dry weights of the 16 to 20 sample trees. Characteristics of sample populations and resulting equations from published sources are given in Table 2.

## Results

### *Regression equations*

The exponents of the allometric equations ranged from 2.14 for *Acacia mangium* to 2.76 for *Eucalyptus robusta* (Table 1). The correction factor ranged from 1.008 for *Eucalyptus urophylla* to 1.040 for *Leucaena leucocephala.* All regressions were highly significant ($p < 0.001$). Height did not significantly improve the regression in seven of the eight species, the exception being *E. urophylla* ($p = .036$). Because the improvement was slight, and for consistency with the other species, we used the *E. urophylla* equation based on DBH alone for the following comparison.

**Table 2.** Charateristics of sampled trees and resulting equations from published sources

| | n | Average DBH (*cm*) | Average Ht. (*m*) | Spacing (*m*) | Harvest age (*y*) |
|---|---|---|---|---|---|
| *Acacia mangium* | 54 | - | 19.7 | - | 6-7 |
| | 29 | 18.7 | - | - | 6-7 |
| *Eucalyptus grandis* | 21 | 13.2 | 16.8 | 2 × 2 | 3-6 |
| *E. robusta* | 16 | 9.5 | 17.5 | 1.5 × 1.5 | 6 |
| *E. saligna* | 286 | 9.7 | 17.5 | 1.5 × 1.5 | 2-6 |
| *E. urophylla* | 15 | 9.4 | 13.1 | 1.5 × 1.5 | 6 |
| *Leucaena leucocephala* | 77 | 4.4 | 8.6 | 1 × 1 | <5 |
| | | | | 2 × 2 | |

The following published biomass equations were used:

| | | |
|---|---|---|
| a. | *Acacia mangium* | $\ln SW = -3.212 + 0.905 \ln (D^2H)$ (Halenda 1989) |
| b. | *Eucalyptus grandis* | $Y = 0.069413 * (D^{2.1472}) * (H^{0.3129})$ (Schubert *et al.* 1988) |
| c. | *E. urophylla* | $Y = 0.119931 * (D^{2.3610})$ (Schubert *et al.* 1988) |
| d. | *Leucaena leucocephala* | $Y = 0.5 (DBH^2) \times HT \times SG$ (Kanazawa *et al.* 1982) |

SW = stem weight; Y = Total above-ground biomass; SG = Specific gravity

### *Equation comparison*

The mean dry weight of sampled trees ranged from 2.3 *kg* for *Leucaena leucocephala* to 8.0 *kg* for *Eucalyptus urophylla* at Mountain View, and from 3.9 *kg* for *Casuarina equisetifolia* to 11.3 *kg* for *Acacia mearnsii* at Kilohana (Table 3). Equations derived from harvest at Mountain View predicted mean dry weight well, as expected; the published equations ranged from a 16% underestimate of *L. leucocephala* to a 14% overestimate of *E. grandis* and *E. urophylla* (Table 3). At Kilohana, the equation based on data from the Mountain View harvest underestimated the biomass of *A. mangium* by 19% and overestimated the biomass of *A.*

*mearnsii* by 7% (Table 3). Mean biomass estimates from the published equations were better for *A. mangium* and *E. grandis* but worse for *E. urophylla* (Table 3).

**Table 3.** Measured *versus* estimated mean total dry weight per tree (*kg*). Measured trees at Mountain View were those used in determining regressions. Measured trees at Kilohana are independent of the derivation of the equation

| | Equation Type | | |
|---|---|---|---|
| | Measured | $aD^b$ | Published |
| Mountain View: | | | |
| *Acacia mangium* | 2.69 | 2.69 | 2.99 |
| *A. mearnsii* | 7.65 | 7.61 | - |
| *Casuarina equisetifolia* | 2.90 | 2.65 | - |
| *Eucalyptus grandis* | 6.26 | 6.03 | 7.14 |
| *E. urophylla* | 7.98 | 7.89 | 9.06 |
| *Leucaena leucocephala* | 2.26 | 2.06 | 1.89 |
| Kilohana: | | | |
| *Acacia mangium* | 5.95 | 4.81 | 6.24 |
| *A. mearnsii* | 11.27 | 12.17 | - |
| *Casuarina equisetifolia* | 3.93 | 3.47 | - |
| *Eucalyptus grandis* | 11.02 | 9.39 | 11.07 |
| *E. urophylla* | 11.19 | 10.94 | 12.26 |

## Discussion

Our findings suggest that where estimates of mean total dry weight within 20% accuracy are sufficient, using published equations would be satisfactory and certainly the most cost effective alternative. Sampling of a relatively small number of trees (such as 20) may improve estimates considerably at one site, but small sample equations may not predict biomass at another site any better than the published equations.

In seven out of eight species, tree height did not significantly improve biomass prediction over diameter-based equations alone. The time spent in field inventory could therefore be greatly reduced by eliminating height measurements in these relatively uniform stands. In previous studies, height did explain significant variation in addition to diameter (Schubert *et al.* 1988). It is likely that height becomes more important as the population sampled included more sites and ages, hence more variation in the height-diameter relationship. The increase in precision must still be compared to the increased field time and cost of height measurement.

The most important consideration in using allometric equations is that the sampled population be representative of the target population. Extrapolation of exponential equations beyond the range of fit may result in substantial errors. We found that published equations can give estimates within 20% of measured values, but that a relatively small number of sample trees can greatly improve biomass estimated at a given site.

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