BIOMASS EQUATIONS FOR EVENAGED STANDS OF CARIBBEAN PINE (*PINUS CARIBAEA*) PLANTED AS AN EXOTIC IN NIGERIA

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KADEBA, O. 1989. Biomass equations for evenaged stands of Caribbean pine (*Pinus caribaea*) planted as an exotic in Nigeria. Allometric regression equations for biomass prediction were developed for trees of Caribbean pine from stands aged 14 years at three sites in the subhumid savanna region of Nigeria. Individual tree component weights (bole, branches, needles, roots and total aboveground) were regressed against DBH (stem diameter at breast height, 1.3 *m*) using 12 sample trees from each site. When statistical comparisons showed no significant differences ($P<0.05$) in regression models among sites, combined equations based on pooled data of 36 trees were developed. In every case the combined equations which had higher slopes than the individual site equations either underestimated or overestimated tree biomass depending on the site. The combined equations were thus considered inappropriate and the site specific equations were used to calculate the dry weight instead. Total tree biomass and net primary production varied with site but in all the sites, approximately 82% of tree biomass was in the aerial part and 18% in the roots. The bole, needles and branches constituted about 59, 13 and 10% of whole tree biomass respectively.The results showed that because of site quality there were differences in rates and magnitude of dry matter production.

Key words: Allometric regression - biomass - evenaged - Caribbean pine

Introduction

Studies of biomass production of evenaged plantations particularly when established as fast growing monocultures under intensive systems are of considerable interest. Biomass data are now being increasingly used in studies of primary productivity and nutrient distribution in forests (Koerper & Richardson 1980, Baker *et al.* 1984) and also in predicting the ecological impact of biomass removal in timber logging on stability of forest ecosystems (Alban & Laidly 1982).

A comprehensive review of different techniques for determining forest biomass has been compiled by Parde (1980). Dimensional analysis (Whittaker & Marks 1975) has gained wide acceptance for determining forest biomass. In this technique, allometric regression equations express biomass of tree components as a function of easily measured parameters such as stem diameter or basal area. Prediction of tree components biomass by means of such equations has also been generally preferred since the proportions of foliage, branches, bark and wood change with tree size (Van Lear *et al.* 1984).

Pinus caribaea Morelet var. *hondurensis* Barr. and Golf. is an important industrial timber tree for pulp production in Nigeria. In the Savanna region, it has proven adapted to a variety of sites particularly those at relatively low to medium elevation (600 - 1200 *m* above sea level) and where the mean annual rainfall is at least 1100 *m* (Jackson 1974). Despite its site adaptability and suitability for large scale planting (Ojo & Shado 1973), few data are available on the growth and biomass production of *P. caribaea* in the subhumid tropical savanna.

The first objective of this study was to develop allometric regression equations relating biomass of tree components to stem diameter of *P. caribaea* at three savanna sites that present contrasts in soil and climatic conditions. The second objective was to employ the regression equations to estimate biomass production of tree components at the three sites.

Materials and methods

The study areas

The study sites are located at Afaka, Miango and Nimbia, all in the subhumid savanna region of northern Nigeria. The sites represent a range in vegetation types, geologic substrates and climatic conditions.

Afaka (10°33'N 7°15'E) lies at an elevation of about 610 *m*. The relief is flat. The mean annual rainfall is 1250 *mm* but yearly totals show wide variations. Dry spells usually occur between November and March. The original vegetation before plantation establishment was classified as northern Guinea savanna (Keay 1959). The mean minimum temperature for the coldest month (December) is 14°*C* while the mean maximum is 35°*C* in April (hottest month) with a mean annual of 25°*C*. The soils are primarily loam to sandy loam in texture and classified as ferruginous tropical soils or plinthic cambisol as defined in units for the soil map of the world (Barrera & Amujo 1971) and have dominantly kaolinitic type of clay. The underlying rocks are mainly basement complex of the precambrian age buried under sandy drift material. The principal rocks of the complex are gneisses, migmatites, granites and schists.

Miango is situated on Jos Plateau (9°50'N 8°40'E) at an elevation of 1200 *m*. The relief varies from flat to gently sloping. The Jos Plateau is regarded as a highland variant of the northern Guinea savanna and because of its altitude, temperatures are generally lower. Diurnal variation of temperature is small compared to typical northern Guinea savanna. The monthly average of minimum and maximum temperatures are 16°*C* and 28°*C* respectively. The mean annual rainfall is 1560 *mm* with over 180 rain days in the year. The study site at Miango is a grass fallow of *Andropogon gayanus* and *Hyparrhenia* grasses. The soils, classified as eutrophic brown soils or eutric cambisol (soil map of the world) developed from volcanic rocks or newer basalt (Barrera 1971). The soils are deep, rich in organic matter and plant nutrients and possess 2:1 clay (montmorillonite).

Nimbia (9°26'N 8°30'E) lies within the derived savanna at an elevation of 600 *m*. Derived savanna refers to areas of savanna woodland, often outlying patches of closed forest, that have apparently been derived from continuous closed forest mainly through clearing land for farming. The mean annual rainfall is 1800 *mm* and the length of the rainy season is about 220 days. The mean maximum temperature for the hottest month (February) is 36°*C* while the mean minimum temperature for the coldest month (November/December) is about 12°*C*. The soils developed from weathered olivine basalt and are classified as eutrophic brown soil or eutric cambisol. Nimbia soils are well drained deep soils with an A horizon rich in organic matter and a clay loam to sandy loam texture. The clay fraction is predominantly montmorillonite.

Field measurements

Three stands of *P. caribaea* aged 14 *y*, one each at Afaka, Miango and Nimbia were selected for this study. The stands were established from container raised seedlings at a spacing of 2.74 x 2.74 *m*. The seed source was Mount Pine Ridge in Belize. Plantation history, establishment techniques and cultural practices were uniform for the stands but differing mortality rates has led to different tree stocking (Table 1).

Table 1. Characteristics of 14-*y*-old *Pinus caribaea* stands

Site	Afaka	Miango	Nimbia
Mean DBH (*cm*)	19.2	22.2	20.8
Mean height (*m*)	15.1	18.5	16.2
Basal area (m^2 ha^{1})	31.18	46.91	36.02
Stocking (trees ha^{1})	1063	1206	1050

A 50 x 50 *m* sample plot was centrally located to avoid side effects in each of the stands. Stem diameters (DBH) at breast height of 1.3 *m* of all trees in the plot were measured.

Twelve trees per site and proportionately distributed over the range of diameters found in the sample plots were harvested at ground level. Stem diameter and height of every felled tree were recorded. The sample trees were then subdivided into bole, branches and foliage. After branch removal, the bole of each tree was cut into one-metre logs to facilitate determination of their fresh weights in the field prior to subsampling for moisture content. Total fresh weights of the foliage and all the branches were similarly determined. Roots ($\geq$ 1.0 *cm* diameter) of three sample trees were excavated manually at each site to estimate root biomass. Samples of all fresh components were taken to the laboratory and dried to constant weight at 70°*C*. Ratios of dry weight to the corresponding fresh weight were used to obtain estimates of total dry weights.

Litterfall data were mean values for three years obtained in an earlier study (Kadeba & Aduayi 1985a).

Data analysis

Allometric regressions of biomass (*kg*) of tree components (roots, bole, branches, foliage and total aboveground) upon DBH (*cm*) were derived using the model: Log_e (biomass) = a + b Log_e (DBH) or natural logarithmic transform of the allometric equation: Biomass = $e^a(DBH)^b$ where **a** and **b** are constants and **e** is the base of natural logarithm. Both **E**, an estimate of relative error, and R^2, coefficient of determination were computed as estimators of accuracy for the regression lines. **E** is the antilog of the standard error of estimate of a logarithmic regression and provides a simple and direct comparison of the relative accuracy of an equation as a model of sample data (Whittaker & Woodwell 1968).

Individual site equations were first derived using the data of 12 sample trees of each site. The site equations were tested for (1) equal variance, (2) equal slopes,and (3) equal intercepts (Steel & Torrie 1960). When there were no significant differences between the site equations, combined equations based on the grouped data of 36 trees from the three sites were developed. The variability of the prediction using the combined equation relative to the individual site equations was further tested by means of three statistics: (1) the coefficient of determination, R^2; (2) the estimate of relative error, **E**; (3) the mean percentage difference between predictions by the combined equations and the individual site equations (Pastor *et al.* 1984). The last statistic was calculated by selecting five trees of different diameters per site and solving both the site and combined equations for each tree. Differences in biomass estimates predicted by both sets of equations were expressed as percentage of the corresponding biomass estimates from the site equations and the results averaged for the five trees.

Stand biomass calculations

Four 20 x 20 *m* subplots were randomly located in each of the stands. All trees within each subplot were measured for stem diameter (DBH). The dry weights of tree components were estimated via the site specific regression equations and the results summed for each subplot. The stand biomass was calculated in *kg* ha^{-1} from the mean of dry weight totals for the subplots and expanding to hectare basis. The standard error of means for the estimates of stand biomass was calculated from the dry weight data of the four subplots. The effect of correction for bias resulting from logarithmic transformation of variables (Mountford & Bunce 1973) on the estimates was marginal and was therefore ignored.

Results and discussion

Comparison of regression equations

Statistical tests showed that there were no significant (5% level) differences among the sets of allometric equations for the three sites. So equations based on all 36 trees (9 trees only for roots) were calculated (Table 2). The **E** values were highest for needles and roots thus implying that the estimates of these two components are most subject to error (Table 2). For example, an **E** value of 1.15 indicates a 15% standard error around the mean **Y** value.

Table 2. Regression coefficients of biomass equations for tree components of *Pinus caribaea* (equation form: $Log_e Y = a + b \log_e DBH$ where Y is component dry weight in *kg* and DBH is in *cm*)

Dependent Variable (Y)		Individual sites				Combined			
		a	b	E	R^2	a	b	E	R^2
1.	Bole:								
	Afaka	-2.9283	2.4944	1.08	0.96	-3.5095	2.7031	1.08	0.95
	Miango	-3.1363	2.6015	1.07	0.95				
	Nimbia	-3.0395	2.5408	1.06	0.97				
2.	Branches:								
	Afaka	-3.5739	2.1049	1.04	0.97	-4.1547	2.3188	1.09	0.92
	Miango	-2.7309	1.8821	1.06	0.92				
	Nimbia	-4.1564	2.3133	1.08	0.93				
3.	Needles:								
	Afaka	-3.5446	2.1919	1.06	0.96	-4.0691	2.3979	1.13	0.86
	Miango	-3.3784	2.2035	1.13	0.80				
	Nimbia	-2.8414	1.9901	1.12	0.83				
4.	Total aboveground:								
	Afaka	-2.3094	2.3960	1.06	0.97	-2.8856	2.6054	1.08	0.95
	Miango	-2.3144	2.4432	1.05	0.97				
	Nimbia	-2.3076	2.4061	1.07	0.94				
5.	Root					-3.6125	2.3221	1.15	0.96

The similarity between the sets of regression equations derived for each of the three sites tends to suggest that combined equation based on the pooled data of all the sites can be used to estimate biomass production of *P. caribaea.* Such a conclusion assumes that height-diameter relations are similar for the sites, an assumption that may not be valid from data of Table 1.

The suitability of the combined equations relative to the separate site equations was further tested by comparing the biomass of tree components as predicted by the two sets of equations. The fact that the percentage differences in biomass estimates (Table 3) were in the range of estimates of relative error (Table 2) does not necessarily establish the suitability of the combined equations for predicting biomass at the three sites. For example, in every case the combined equations have higher slopes than the separate site equations (Table 2). It should also be noted that the taller stand at Miango had all weights underestimated by the combined equation while the reverse is true for the other sites. This would thus suggest that a generalized equation incorporating a combined variable of diameter and height such as $(DBH)^2$ x Height would be more appropriate if one equation is to be used to predict biomass at different sites.

Table 3. Comparison of means of tree component biomass (*kg*) of *Pinus caribaea* estimated from individual site and combined regression equations

Tree component	Biomass predicted		Difference (%)	
	Site	Combined	Mean	Range
		Afaka (n = 5)		
Bole	81.0	85.6	5.8	3.9 - 7.5
Branches	13.4	14.2	5.8	3.2 - 8.8
Needles	17.9	19.6	7.2	0.0 - 12.4
Total aboveground	113.2	118.9	5.5	3.9 - 7.8
		Miango (n = 5)		
Bole	154.5	146.0	5.7	4.8 - 6.6
Branches	23.9	22.8	5.3	1.5 - 9.3
Needles	34.4	31.8	7.9	6.2 - 9.7
Total aboveground	212.1	199.5	6.0	4.5 - 7.6
		Nimbia (n = 5)		
Bole	110.6	115.7	4.5	3.7 - 5.3
Branches	18.3	18.6	1.9	1.7 - 2.2
Needles	25.3	25.8	2.8	0.0 - 6.3
Total aboveground	154.2	159.3	2.9	1.2 - 5.3

An earlier work in Nigeria by Egunjobi (1976) had shown that for a given evenaged stand of *P. caribaea* diameter alone is adequate to accurately estimate tree component weights. Biomass estimates (Table 4) were thus calculated using the site specific equations.

Table 4. Estimates of biomass production ($kg\ ha^{-1}$) and net primary production ($kg\ ha^{-1}\ y^{-1}$) of *Pinus caribaea* plantations at three savanna sites

Tree component	Site					
	Afaka	%	Miango	%	Nimbia	%
Bole	90,600 ± 2,870[a]	58.4	166,000 ± 4,370	59.6	112,000 ± 2,910	59.1
Branches	15.000 ± 430	9.5	26,800 ± 483	9.5	18.500 ± 436	9.7
Needles	20,000 ± 586	13.5	37.900 ± 826	13.2	25,700 ± 529	13.3
Total aboveground	126,000± 3,880	81.4	231,000 ± 5,670	82.3	155,000 ± 3,810	82.1
Roots	25.600 ± 783	18.4	46,400 ± 1,090	17.7	34,800 ± 833	17.9
Whole tree	152,000± 3,960		277,000 ± 5,770		190,000 ± 3,900	
Annual litterfall	4,520 ± 233		6,080 ± 343		5,050 ± 146	
NPP[b]	13,500 ± 362		22,600 ± 531		16,100 ± 309	

[a] Standard error of mean
[b] NPP is net primary production of total aboveground material

Estimates of stand biomass and net primary production

Standing biomass production was highest at Miango and least at Afaka (Table 4). Biomass estimates excluded weight of forest floor and biomass losses due to pruning. The data showed that site conditions strongly influenced stand dry matter yields (Table 4). Biomass distribution amongst tree components was, however, not so much influenced by site conditions (Table 4). Approximately 82% of the whole tree biomass was in the aboveground part in contrast to 18% in the roots. The bole, needles, and branches constituted about 59, 13 and 10% of tree biomass respectively.

Net primary production (NPP) was estimated from the sum of mean annual biomass production and annual litterfall. The estimated aboveground net primary production of *P. caribaea* in the study areas was 13.5, 22.6 and 16.1 $t\ ha^{-1}\ y^{-1}$ at Afaka, Miango and Nimbia respectively (Table 4). These values are much less than 34.3 $t\ ha^{-1}\ y^{-1}$ reported for a 30-year-old *P. patula* in East Africa (Lundgren 1978) but comparable with 14.4 $t\ ha^{-1}\ y^{-1}$ calculated from age 0 to 22 years for *P. radiata* in New Zealand (Madgwick *et al.* 1977). They exceed the world wide range of 10 - 12 $t\ ha^{-1}\ y^{-1}$ for high productivity sites (Parde 1980).

The results showed that differences existed between the sites in the rate and magnitude of dry matter production. These could be related to a number of factors. Lamb (1973), for example, has stated that the most important factors determining the site quality of *P. caribaea* are rainfall and soil characteristics. Ezenwa (1985) had found a positive correlation between effective soil depth and height growth of *P. caribaea* at Afaka, Nigeria. Climatic elements (annual rainfall and its distribution) and soil characteristics (drainage, depth and nutrient status) were found to be more favourable at both Miango and Nimbia (Kadeba & Aduayi 1985b). These factors seemed to have favoured higher biomass production at the two sites compared to Afaka. Located in the hot subhumid

(900 - 1300 isohyets) tropics, Afaka represents the northern limit beyond which both soil and atmospheric moisture regimes limit the establishment and growth of *P. caribaea* in Nigeria. Tree stocking and the higher altitude (1200 *m*) of Miango contributed to its superior biomass production over Nimbia.

Measurements of stand productivity of tropical and subtropical pines are presented in Table 5 for comparison with the present study. The aboveground dry matter production in the 14-*y*-old stand at Afaka was much lower than the values reported for Caribbean pine stands in the lowland humid tropics (Egunjobi & Bada 1979, Russell *et al.* 1983). Biomass productivity data of Miango and Nimbia are however comparable with data from other plantations (Table 5). In contrast, the production of *P. caribaea* as an exotic can be much higher than in its native habitat where between 87.0 - 105.0 $t\ ha^{-1}$ have been reported in 25 - 30 years old natural regeneration (Stewart & Kellman 1982).

Concluding remarks

The work reported here shows that sites like Miango and Nimbia offer considerable prospects for good growth and yield of *P. caribaea* as an exotic. Compared to biomass production of tropical pines generally, there are locations in the savanna region where for reasons of latitudinal position and site conditions, less than optimum in biomass yield is what can be attained. Afaka is typical of such areas. Even on such marginal sites, the biomass yield of *P. caribaea* is still expected to surpass dry matter yield of the native savanna vegetation in which the harvestable potential of the woody biomass has fast diminished following prolonged effects of grazing, bush burning and overcutting of vegetation.

Table 5. Aboveground dry matter ($t\ ha^{-1}$) of tropical and subtropical pines

Plantation	Age (*y*)	Location	Stems (ha^{-1})	Dry weight ($t\ ha^{-1}$)	Reference
Pinus caribaea	10	Ibadan (Nigeria)	2866	144.4	Egunjobi & Bada (1979)
P. caribaea	5	Sao Miguel (Brazil)	981	66.0	Chijioke (1980)
P. radiata	17	Kaingora (N. Zealand)	855	261.6	Madgwick *et al.* (1977)
P. patula	10	Shume (Tanzania)	1400	249.0	Lundgren (1978)
P. caribaea thinned natural regeneration	30	Mt. Pine Ridge (Belize)	200	87.0	Stewart & Kellman (1982)
P. caribaea unthinned natural regeneration	25	Mt. Pine Ridge (Belize)	-	105.0	Stewart & Kellman (1982)
P. caribaea	14	Afaka (Nigeria)	1199	126.0	Present study
P. caribaea	14	Miango (Nigeria)	1206	231.0	Present study
P. caribaea	14	Nimbia (Nigeria)	1050	155.0	Present study

Except for the work of Egunjobi (1976) and Rance *et al.* (1982) on young Caribbean pine plantations in Nigeria and Australia and that of Stewart and

Kellman (1982) on a natural regeneration stand in Belize, there is an apparent scarcity of published biomass equations for *P. caribaea.* While it is desirable in principle to develop equations for individual sites, there are practical constraints since biomass determination is both laborious and time consuming. In inviolate forest where tree cutting is prohibited, it is necessary to use biomass equations developed elsewhere. Future studies should aim at development of such regression models that are applicable over a wide range of site qualities and tree ages to facilitate comparison of biomass amongst different sites.

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