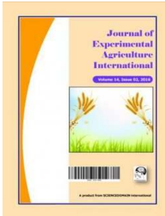

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Area and Dry Mass Estimation of Cashew (*Anacardium occidentale*) Leaves: Effect of Tree Position within a Plantation around Parakou, Benin

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Authors' contributions

This work was carried out in collaboration between all authors. Authors AYJA and ADS designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors AYJA, LAT, SAAS and MHA reviewed the experimental design and all drafts of the manuscript. Author AYJA managed the analyses of the study. Authors AYJA, ADS, SAAS and LAT identified the plants. Author AYJA performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

Accurate and non-destructive methods to determine individual leaf areas and dry mass of plants are very important. Since they stand as key parameters linked to plant production and are used in functional–structural plant models to simulate plant growth. This paper describes an investigation of the variation in cashew leaf dimensions at different sites within a plantation with the aim of

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developing a model for calculating leaf area and dry mass. Five location (South, Central, North, East and West) were considered in an eight years old cashew plantation, with rectangular plot and with an area of 3.5 ha. Two trees were selected randomly by location. Their crown was divided vertically into three zones. Within each zone, 60 leaves were collected randomly on different categories of the tree axis. The length, width, area, and the dry mass of each leaf were measured. The longest leaves were obtained in the North, Center and South of the plantation (15.27 cm). The tree leaves located in the South of plantation were the largest (9.6 cm) and had the largest areas (109.1 cm²). The largest quantities of dry mass were obtained from the leaves of the trees located in the South and in the East of the plantation (1.35 g per leaf). The best models according to adjustment and prediction qualities were in all cases stated as follows: $S^{\wedge} = aln(LW) + b$ for leaf area and $m^{\wedge} = aln(LW) + b$ for dry mass. The results indicated an important variation in leaf size and dry mass according to a tree location in the plantation. Therefore, it is important to take into account this variability in the sample constitution when trying to estimate leaf area and dry mass.

Keywords: Leaf area; dry mass; tree position; sunlight; cashew; models; variation.

1. INTRODUCTION

Leaves are important plant components involved in plant biomass production through photosynthesis [1]. On an individual plant scale, the leaf area and specific leaf area, i.e. the ratio between leaf area and dry biomass, have been shown to be good indicators of plant productivity, for instance on poplar clones [2]. Leaf area therefore, is an important variable for most eco-physiological studies in terrestrial ecosystems concerning light interception, evapotranspiration, photosynthetic efficiency, fertilizers, and irrigation response and plant growth [3]. The leaf area is also required for assessment of fruit growth, evaluation of training and pruning systems, and estimation of pest population densities [4,5]. Functional–structural plant models (FSPM) can facilitate the understanding of the functional links among leaf characteristics, carbon production and allocation [6]. Consequently, the easy, economic and precise estimate of leaf area or dry mass of leaf have been a concern to plant scientists for a long time. The most common approach is to develop ratios and regression estimators by using easily measured leaf parameters such as length and width [7]. Comparing several non-destructive models of leaf area of taro, Lu et al., [8] proposed that the simple and linear relationships between leaf area and leaf dimensions (length, width) could be useful for non-destructive estimation of leaf area. Thus, non-destructive models for leaf area determination have been established for many species such as maize [9], bean [10], taro [8], kiwi [11], ginger [12] and watermelon [13]. Similarly, within the framework of fruit trees, several combinations of measurements and models relating length and width to area have been developed for several fruit trees, such as grape [14,15] and Avocado [16]. However, models to estimate the leaf area of cashew (*Anacardium occidentale*) are almost absent in the literature.

The cashew tree originated to the Caribbean and the North-eastern Brazil. It is now widely cultivated in all tropical zones, such as Africa, Caribbean, Brazilian Northeast, Southeast Asia and India. The economic importance of this plant lies mainly on its fruit (cashew nuts). For example, in Benin, cashew nuts are the second export crop after cotton and its importance is increasingly growing in agricultural production systems [17]. Cashew accounted for 8% of the total exports values in 2008, 7% of agricultural GDP and 3% of GDP [18].

The predictive accuracy of non-destructive models of leaf area or biomass depends on the variation of the leaf shape within the same plant and between accessions [19]. This variation may also be related to environmental factors including the quantity of sunlight captured by the plant. Indeed, plants produce several types of leaves in their development process. The first few early leaves produced are usually smaller, simpler, and anatomically different from leaves produced later in development [20]. Change in shape and size of successive leaves on a plant are related to physiological changes associated with increasing age of the plant [21], interaction between the shoot apical meristem and the developing leaf is fundamental [22], genetically controlled shape maturation and a variety of environmental factors [20]. Therefore a good estimate of the production model requires accurate estimation of the area and mass of leaves taking into account any possible variability.

The aim of this study is therefore to develop a non-destructive estimation model of the area and dry mass of leaves of cashew taking into account the trees location within a plantation for a better understanding of the variability of dry matter production by photosynthesis.

2. MATERIALS AND METHODS

2.1 Data Collection

The cashew plantation selected for the study was 8 years old planted in a rectangular form on an area of 3.5 ha with 400 trees/ha density. It is located near the city of Parakou, Benin (9°20 'North latitude and 2°35' East longitude) where the climate is of Sudanese type with a rainy season (June to November) and a dry season (December to May). The annual rainfall average varies from 1100 to 1200 mm per year and the annual average temperature varies between 26° C and 30°C. The warmest month of the year is February while the coolest is August. The relative humidity varies from 15% in the dry season (January-February) to 99% in the rainy season (August-September) while the annual average insolation varies between 2200 and 2400 hours. In the study area, the soil is of tropical ferruginous type. The relief is characterized by a plateau.

The plantation was divided into five zones (South, Central, North, East and West) according to the direction of solar radiation movement. In each zone two trees were randomly selected. The selected trees have an average diameter at breast height (DBH) of 20.68 cm and an average height of 5.15 m. In order to have different categories of leaves (young and mature, leaves exposed to sun light and some shade), the crown of each tree was divided vertically into three zones. In each zone, 60 leaves were collected by the means of random way and took into account the possible wide range of dimensions for the categories of axes. A total of 180 leaves were collected per tree. On each leaf, the following data were collected:

- The length of the leaf representing the distance between the top of the leaf blade and stipule of the leaf; it was measured using a doubling rule in centimeter and millimeter with a maximum length of 30 cm;
- The width of the leaf corresponds to how large it measured at half of the length; it was also measured through a doubling rule in centimeter and millimeter with a maximum length hitting 30 cm;
- The leaf area representing the entire area occupied by the blade. Each leaf was photographed with a digital resolution of 18 Mega pixel camera. The leaf area corresponding to each image obtained was determined using the Mesurim Pro version 3.4 software;
- The dry mass is the ones of the leaf when it is free from all the amount of water it contains. To determine the mass, each leaf was dried in an oven at 103°C for 24 hours and then stored in a room heated close storage for 24 hours. They were then weighed using a balance.

2.2 Data Analysis

The tree location effect on the dimensions of the cashew leaf was evaluated using analysis of variance method with factors for the position (five modalities: South, Central, North, West and East) and the trees. The Newman-Keuls test [23,24,25] was also used to structure the mean in case of significant difference. Covariance method was used to test the effect of the location on the leaf area estimation and dry mass. The estimation models of leaf area and dry mass were established using the linear regression method. In this context, different types of models were tested (Table 1). The Box and Cox transformation was applied to the response variable in order to rendering valid the application method conditions. The Box-Cox transformation is indeed a transformation of the dependent variable that can be closer to the normal distribution and make constant variances.

The prediction quality of the models was evaluated by the cross-validation method [26] in order to limit the over fitting problems. The model is constructed by the observations means of the training data set, and the predictive power is tested using observations from the testing data set. The prediction error is estimated by calculating the mean square error on the testing data set. Since, the sample size in this study was not large enough, the approach used was leave-on-out cross validation method which divide the original sample in n samples (n is the sample size); then, by selecting one of the n samples as the validation set and uses the ($n-1$) remaining samples as the training set. The mean square error was calculated. The operation was repeated n times by selecting another validation sample from the ($n-1$) samples which have not yet been used for model validation. The average of *n* mean square errors were calculated to estimate the prediction error.

Table 1. The different forms of regression models tested to estimate leaf area and dry mass for cashew trees (*Anacardium occidentale*) near Parakou, Benin

Model	Equation	
	Leaf area	**Dry mass**
1	$S^{\lambda} = aLW + b$	$m^{\lambda} = aLW + b$
2	$S^{\lambda} = a\ln(LW) + b$	$m^{\lambda} = a\ln(LW) + b$
3	$S^{\lambda} = aL + b$	$m^{\lambda} = aL + b$
4	$S^{\lambda} = a\ln(L) + b$	$m^{\lambda} = a\ln(L) + b$
5	$S^{\lambda} = aW + b$	$m^{\lambda} = aW + b$
6	$S^{\lambda} = a\ln(W) + b$	$m^{\lambda} = a\ln(W) + b$
7	$S^{\lambda} = aL^2 + b$	$m^{\lambda} = aL^2 + b$
8	$S^{\lambda} = aW^2 + b$	$m^{\lambda} = aW^2 + b$

S = leaf area, m = quantity of dry mass, L = length of leaf, W = width of leaf, λ = coefficient maximizing Box-Cox transformation, ln = natural logarithm, a, b = constant to be estimated

3. RESULTS

3.1 Description of Data

The average leaf length ranged between 13.70 cm and 15.49 cm, with an average error of 0.12 cm and 0.15 cm (Table 2). The longest length occurred on the leaves of the trees situated at the northern part of the plantation, while the shortest length occurred in the west section. The average leaf width ranged from 8.37 cm to 9.60 cm appeared respectively on trees in the south and west sections. As for the leaf area, the average ranged between 66.77 cm² (obtained in the east) and 109.14 cm² (obtained in the south). The mean dry mass of the leaves ranged from 1.03, (obtained in the west) to 1.29 g (obtained in the south).

3.2 Effect of the Trees Position on the Characteristics of the Leaves

Evaluation of the tree location effect of the tree position in the planting with respect to the solar radiation on the features of the cashew leaf showed that the leaves having larger dimensions and greater dry weight were obtained from trees located in the south area of the plantation (Table 3). Whereas, the leaves of the trees from the west side of the plantation are small and have the lowest value of dry mass. There was a slight gradient to lower values from South to North and East to West.

3.3 Estimation of Leaf Area and Dry Mass

The results of analysis of variance demonstrated that tree location influenced the area and dry mass of the leaves. These effects were confirmed by analysis of covariance whose results have not been presented in the paper for brevity. Indeed, the results of covariance analysis showed that the dummy variable had a significant effect ($p < 0.05$) in each model, thus suggesting that estimating the leaf area and dry mass must be performed by tree location in the plantation.

Table 2. Description of the leaf characteristics of cashew trees (*Anacardium occidentale*) according to the tree location in a plantation near Parakou, Benin

Characteristics	Tree position	Mean	Mean error	Coefficient of variation	Minimum	Maximum
Length (cm)	Center	15.28	0.15	18.80	4.50	25.00
	East	14.06	0.14	18.59	4.80	20.60
	North	15.49	0.14	16.71	7.50	22.30
	West	13.70	0.12	16.32	2.50	20.30
	South	15.02	0.15	18.40	8.80	24.00
Width (cm)	Center	8.45	0.08	17.70	5.30	14.00
	East	8.57	0.08	18.75	3.80	13.80
	North	8.44	0.08	16.87	3.90	12.20
	West	8.37	0.07	15.38	5.70	12.20
	South	9.60	0.09	18.56	5.20	14.70
Area (cm^2)	Center	96.42	1.88	36.98	32.44	234.18
	East	66.77	1.29	36.34	12.73	155.80
	North	91.79	1.70	34.81	29.36	198.78
	West	71.41	1.19	31.30	17.52	139.17
	South	109.14	2.11	36.66	34.61	251.49
Dry mass (g)	Center	1.19	0.02	31.78	0.50	2.47
	East	1.24	0.03	40.01	0.18	3.47
	North	1.19	0.02	32.44	0.38	2.49
	West	1.03	0.02	32.81	0.21	2.06
	South	1.29	0.02	35.02	0.35	2.90

Table 3. The average values of the leaf characteristics of cashew trees (*Anacardium occidentale*) by trees location in a plantation near Parakou, Benin

Position	Length (cm)	Width (cm)	Area (cm²)	Dry mass (g/leaf)
South	15[a]	9.6[a]	109.1[a]	1.3[a]
Center	15.3[a]	8.5[b]	96.4[b]	1.2[b]
North	15.5[a]	8.4[b]	91.9[b]	1.2[b]
East	14.1[b]	8.6[b]	66.7[c]	1.2[ab]
West	13.7[b]	8.4[b]	71.4[c]	1.0[c]

For a given characteristic, mean sharing no letter are significantly different at the 5% level

Table 4. Prediction models for leaf area of cashew trees (*Anacardium occidentale*) by tree location in a plantation near Parakou, Benin

Tree position in plantation	Model	λ max	Parameters		Adjustment parameters			Prediction error
			a	***b***	***F***	***p***	***Raj***	
Center	$S^{\lambda} = aLW + b$	0.274	0.006	2.657	734.1	0.00	0.67	0.0385
	$S^{\lambda} = a\ln(LW) + b$	0.032	0.033	0.996	818.2	0.00	0.70	0.0001
	$S^{\lambda} = aL + b$	0.087	0.013	1.281	615.3	0.00	0.63	0.0008
	$S^{\lambda} = a\ln(L) + b$	-0.041	-0.054	0.975	620.3	0.00	0.63	0.0001
	$S^{\lambda} = aW + b$	0.171	0.069	1.581	540.0	0.00	0.60	0.0071
	$S^{\lambda} = a\ln(W) + b$	0.081	0.187	1.043	549.3	0.00	0.61	0.0007
	$S^{\lambda} = aL^2 + b$	0.211	0.002	2.184	577.4	0.00	0.62	0.0151
	$S^{\lambda} = aW^2 + b$	0.248	0.008	2.499	497.0	0.00	0.58	0.0319
East	$S^{\lambda} = aLW + b$	0.428	0.016	3.931	495.70	0.00	0.59	0.3541
	$S^{\lambda} = a\ln(LW) + b$	0.119	0.145	0.948	473.00	0.00	0.57	0.0021
	$S^{\lambda} = aL + b$	0.256	0.076	1.826	412.20	0.00	0.54	0.0334
	$S^{\lambda} = a\ln(L) + b$	0.092	0.182	0.985	394.50	0.00	0.53	0.0011
	$S^{\lambda} = aW + b$	0.295	0.165	2.001	381.80	0.00	0.52	0.0640
	$S^{\lambda} = a\ln(W) + b$	0.174	0.484	1.027	371.00	0.00	0.51	0.0083
	$S^{\lambda} = aL^2 + b$	0.389	0.007	3.593	419.20	0.00	0.54	0.2327
	$S^{\lambda} = aW^2 + b$	0.401	0.020	3.814	378.10	0.00	0.52	0.2891
North	$S^{\lambda} = aLW + b$	0.437	0.025	3.839	1886.00	0.00	0.84	0.1922
	$S^{\lambda} = a\ln(LW) + b$	-0.088	-0.062	0.974	2249.00	0.00	0.86	0.0001
	$S^{\lambda} = aL + b$	0.334	0.187	1.566	1473.00	0.00	0.81	0.0546
	$S^{\lambda} = a\ln(L) + b$	0.110	0.348	0.688	1510.00	0.00	0.81	0.0008
	$S^{\lambda} = aW + b$	0.097	0.033	1.262	1074.00	0.00	0.75	0.0007
	$S^{\lambda} = a\ln(W) + b$	-0.135	-0.137	0.839	1181.00	0.00	0.77	0.0002
	$S^{\lambda} = aL^2 + b$	0.536	0.023	5.322	1372.00	0.00	0.79	0.9056
	$S^{\lambda} = aW^2 + b$	0.293	0.014	2.699	931.70	0.00	0.72	0.0414
West	$S^{\lambda} = aLW + b$	0.555	0.037	6.199	354.30	0.00	0.50	1.7200
	$S^{\lambda} = a\ln(LW) + b$	0.418	1.894	-3.046	372.90	0.00	0.51	0.2978
	$S^{\lambda} = aL + b$	0.419	0.237	2.676	258.50	0.00	0.42	0.3593
	$S^{\lambda} = a\ln(L) + b$	0.362	2.216	-1.142	265.80	0.00	0.43	0.1623
	$S^{\lambda} = aW + b$	0.534	0.908	2.076	370.20	0.00	0.51	1.3046
	$S^{\lambda} = a\ln(W) + b$	0.462	4.880	-3.208	368.80	0.00	0.51	0.5283
	$S^{\lambda} = aL^2 + b$	0.469	0.011	5.142	243.00	0.00	0.41	0.7021
	$S^{\lambda} = aW^2 + b$	0.602	0.078	7.338	359.60	0.00	0.50	2.9732
South	$S^{\lambda} = aLW + b$	0.485	0.026	5.787	401.00	0.00	0.53	1.4494
	$S^{\lambda} = a\ln(LW) + b$	0.314	1.054	-0.899	407.50	0.00	0.53	0.1238
	$S^{\lambda} = aL + b$	0.434	0.309	2.885	337.30	0.00	0.48	0.7835
	$S^{\lambda} = a\ln(L) + b$	0.354	2.520	-1.603	325.30	0.00	0.48	0.2537
	$S^{\lambda} = aW + b$	0.388	0.328	2.932	272.00	0.00	0.43	0.4551
	$S^{\lambda} = a\ln(W) + b$	0.322	1.836	0.339	271.90	0.00	0.43	0.1697
	$S^{\lambda} = aL^2 + b$	0.516	0.018	6.968	332.70	0.00	0.48	2.3817
	$S^{\lambda} = aW^2 + b$	0.448	0.025	5.631	255.00	0.00	0.42	1.0869

S= area, L = length, W = width, λ = coefficient maximizing the Box-Cox transformation, ln = natural logarithm, a, b = constant estimate

Regardless the tree location, results showed that the best models from the point of view of fit quality and prediction quality were in the form of $S^{\wedge} = aln(LW) + b$ for leaf area (Table 4) and in the form of $m^{\wedge} = aln(LW) + b$ for dry mass (Table 5). The adjusted R^2 values for these models are highest, indicating that they were relatively well adapted to the data. In addition, in terms of prediction, the mean square errors obtained by cross-validation were lowest.

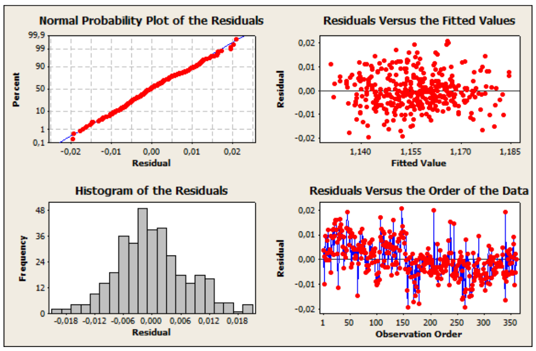
Table 5. Prediction models for leaf dry mass of cashew trees (*Anacardium occidentale*) by tree location in a plantation near Parakou, Benin

Tree position in plantation	Model	λ max	Parameters		Adjustment parameters			Prediction error
			a	*b*	*F*	*p*	*Raj*	
Center	$m^{\wedge} = aLW + b$	0.399	0.001	0.871	593.10	0.00	0.63	0.00186
	$m^{\wedge} = aln(LW) + b$	0.075	-0.043	1.199	688.50	0.00	0.66	0.00011
	$m^{\wedge} = aL + b$	0.097	-0.002	1.023	465.60	0.00	0.57	0.00002
	$m^{\wedge} = aln(L) + b$	-0.061	-0.204	1.535	495.70	0.00	0.58	0.00100
	$m^{\wedge} = aW + b$	0.328	0.027	0.793	510.90	0.00	0.59	0.00115
	$m^{\wedge} = aln(W) + b$	0.188	0.069	0.860	519.00	0.00	0.59	0.00010
	$m^{\wedge} = aL^2 + b$	0.228	0.000	0.953	417.80	0.00	0.54	0.00043
	$m^{\wedge} = aLW + b$	0.451	0.002	0.859	475.60	0.00	0.57	0.00322
East	$m^{\wedge} = aLW + b$	0.515	0.004	0.551	912.90	0.00	0.73	0.0134
	$m^{\wedge} = aln(LW) + b$	0.037	0.247	-0.136	1020.00	0.00	0.75	0.0028
	$m^{\wedge} = aL + b$	0.268	0.049	0.374	682.30	0.00	0.67	0.0081
	$m^{\wedge} = aln(L) + b$	0.026	0.417	-0.057	691.60	0.00	0.67	0.0033
	$m^{\wedge} = aW + b$	0.343	0.090	0.300	764.80	0.00	0.69	0.0093
	$m^{\wedge} = aln(W) + b$	0.149	0.544	-0.112	782.40	0.00	0.69	0.0049
	$m^{\wedge} = aL^2 + b$	0.450	0.002	0.625	637.30	0.00	0.65	0.0146
	$m^{\wedge} = aLW + b$	0.510	0.006	0.609	698.80	0.00	0.67	0.0155
North	$m^{\wedge} = aLW + b$	0.454	0.005	0.405	779.40	0.00	0.69	0.0221
	$m^{\wedge} = aln(LW) + b$	0.122	0.493	-1.302	771.20	0.00	0.69	0.0116
	$m^{\wedge} = aL + b$	0.332	0.070	0.018	569.30	0.00	0.62	0.0195
	$m^{\wedge} = aln(L) + b$	0.194	0.921	-1.424	568.70	0.00	0.62	0.0146
	$m^{\wedge} = aW + b$	0.287	0.128	0.019	627.10	0.00	0.64	0.0181
	$m^{\wedge} = aln(W) + b$	0.131	0.888	-0.797	611.00	0.00	0.64	0.0134
	$m^{\wedge} = aL^2 + b$	0.454	0.003	0.500	550.40	0.00	0.61	0.0255
	$m^{\wedge} = aLW + b$	0.431	0.009	0.488	607.30	0.00	0.63	0.0243
West	$m^{\wedge} = aLW + b$	0.687	0.006	0.309	1320.00	0.00	0.79	0.0115
	$m^{\wedge} = aln(LW) + b$	0.352	0.530	-1.500	1403.00	0.00	0.80	0.0060
	$m^{\wedge} = aL + b$	0.405	0.069	0.050	835.80	0.00	0.71	0.0092
	$m^{\wedge} = aln(L) + b$	0.239	0.799	-1.084	865.80	0.00	0.72	0.0062
	$m^{\wedge} = aW + b$	0.572	0.145	-0.204	1029.00	0.00	0.75	0.0116
	$m^{\wedge} = aln(W) + b$	0.447	1.085	-1.288	1026.00	0.00	0.75	0.0091
	$m^{\wedge} = aL^2 + b$	0.547	0.003	0.473	767.50	0.00	0.69	0.0128
	$m^{\wedge} = aLW + b$	0.695	0.009	0.356	969.00	0.00	0.74	0.0149
South	$m^{\wedge} = aLW + b$	0.431	0.002	0.854	138.10	0.00	0.28	0.0152
	$m^{\wedge} = aln(LW) + b$	0.390	0.200	0.084	155.80	0.00	0.30	0.0116
	$m^{\wedge} = aL + b$	0.391	0.024	0.709	130.10	0.00	0.27	0.0125
	$m^{\wedge} = aln(L) + b$	0.368	0.340	0.153	141.30	0.00	0.28	0.0106
	$m^{\wedge} = aW + b$	0.444	0.041	0.694	108.60	0.00	0.23	0.0177
	$m^{\wedge} = aln(W) + b$	0.431	0.367	0.262	110.40	0.00	0.23	0.0166
	$m^{\wedge} = aL^2 + b$	0.412	0.001	0.890	115.60	0.00	0.24	0.0146
	$m^{\wedge} = aLW + b$	0.456	0.002	0.888	100.60	0.00	0.22	0.0192

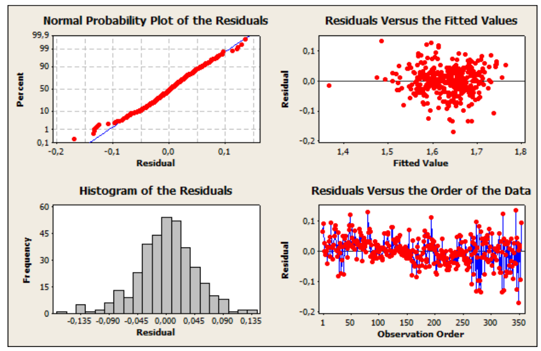
m = mass, L = length, W = width, λ = coefficient maximizing the Box-Cox transformation, ln = natural logarithm, a, b = constant estimate

The diagnostic results of the model's residuals (Figs. 1 and 2) comply with the conditions of applications of the method, thereby indicated no potential outliers in the data. The normal probability plot of the residuals were almost linear, which is consistent with a normal distribution. Diagrams of the residual values based on the adjusted values displayed a random pattern, suggesting that the residuals had constant variance. Graphs of residuals with the predicted and the observed values showed no particular pattern. Therefore, these models were the ones that best predicted the area and the dry mass of a new leaf from a tree located at a given position of the planting.

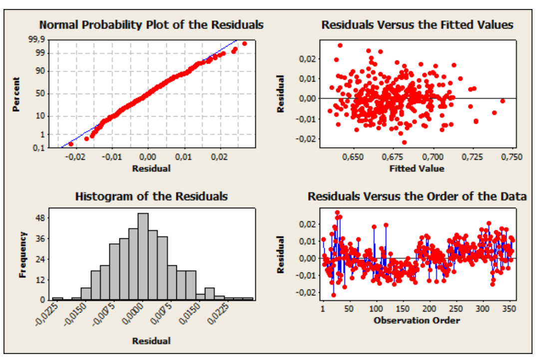
Although the models are in the form of $S^{\lambda} = aLW + b$, $S^{\lambda} = aL^2 + b$ and $S^{\lambda} = aW^2 + b$ for leaf area and form $m^{\lambda} = aLW + b$, $m^{\lambda} = aL^2 + b$ and $m^{\lambda} = aW^2 + b$ for dry mass, had relatively high adjustment qualities close to that of the selected models, they nevertheless presented poorer predictive qualities. The models $S^{\lambda} = aL + b$, $S^{\lambda} = aW + b$, $S^{\lambda} = a\ln(L) + b$ and $S^{\lambda} = a\ln(W) + b$ for leaf area and $m^{\lambda} = aL + b$, $m^{\lambda} = aW + b$, $m^{\lambda} = a\ln(L) + b$ and $m^{\lambda} = a\ln(W) + b$ for dry mass, gave only intermediate results.



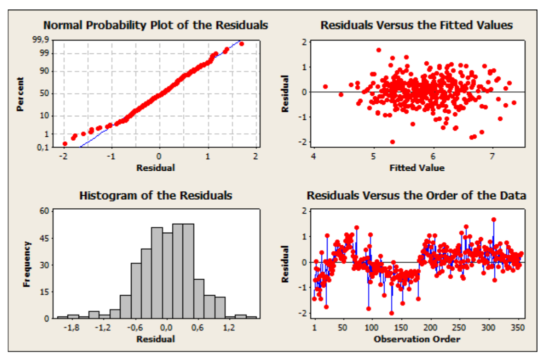
Center



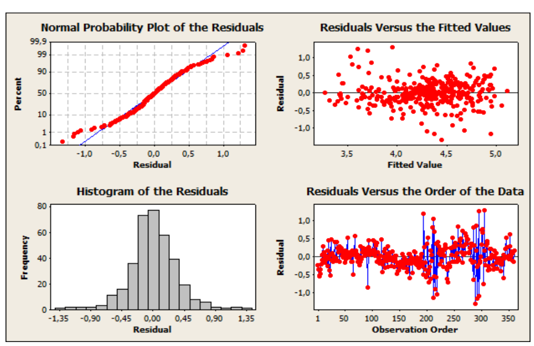
East



North



West



South

Fig. 1. Diagnostics of residuals from the cashew trees regression (*Anacardium occidentale*) leaf area models by tree location in a plantation near Parakou, Benin

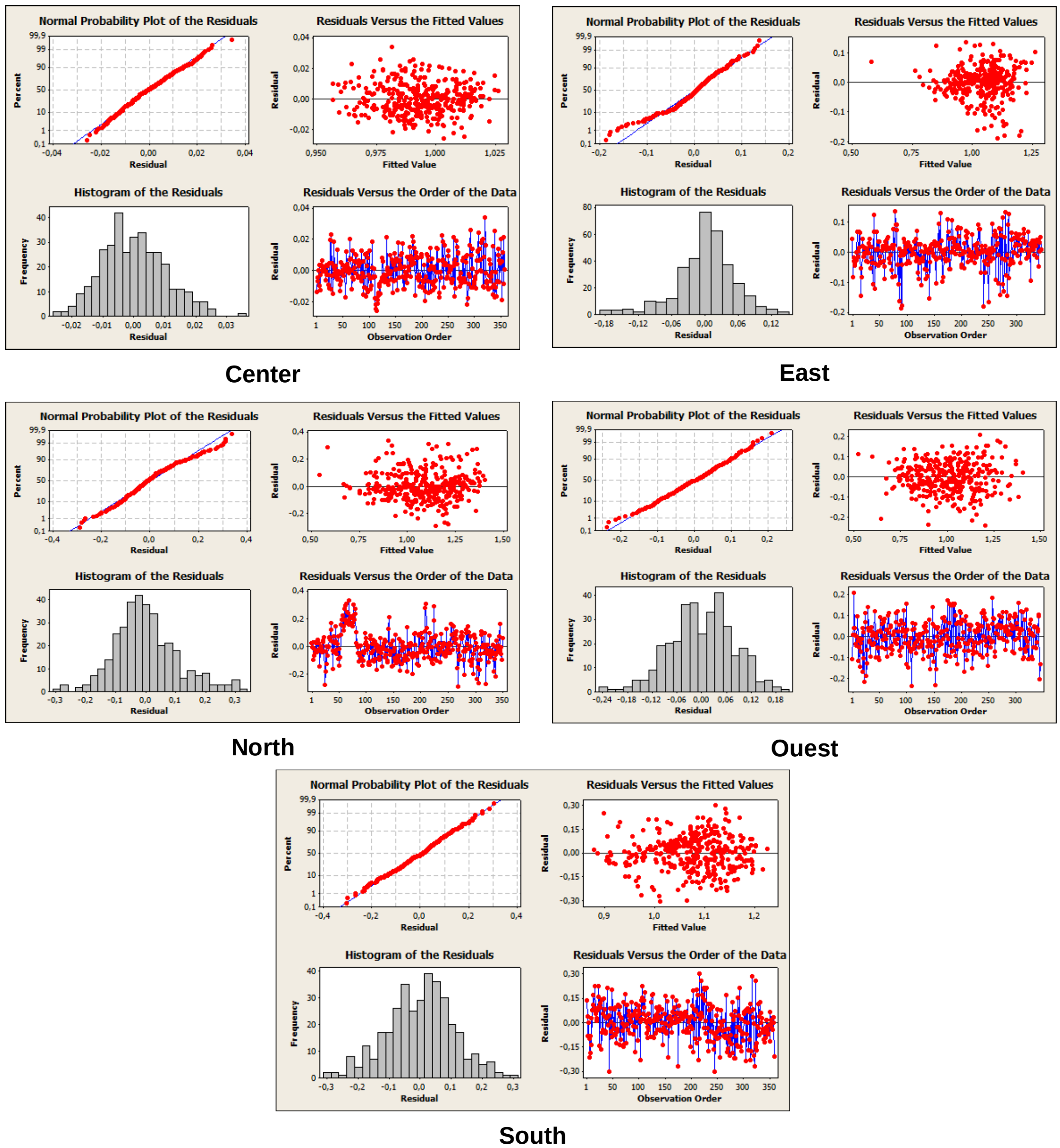


Fig. 2. Diagnostics of residuals from the cashew trees regression (*Anacardium occidentale*) leaf dry mass models by tree location in a plantation near Parakou, Benin

4. DISCUSSION

In this study, the effect of the cashew tree location in the plantation was evaluated on the estimation of leaf area and of the dry mass leaves. In the literature, several models were described to estimate the leaf area of different species which were generally functions of the length and width, but very little information was available for cashew.

The average values obtained in this study for the foliage dimensions for different tree location in the plantation were consistent with those reported in the literature for cashew (the length ranged from 10 to 20 cm and the width ranged from 6 to 10 cm). Similarly the values of the leaf area are consistent with those reported by Archak et al. [27] for cashew (leaf size ranged from 51.4 to 174.3 cm²). Assessing the effect of the trees location on the characteristics of the leaf showed a significant effect on both leaf dimensions and dry mass. The heaviest and largest leaves occurred in the South, whereas the lightest and smallest leaves rose in the East and West sections of the plantation. The type of soil is homogeneous in the plantation and the entire plantation received the same silvicultural treatment. Therefore, the fact that trees located in the South section of the plantation produce more dry mass is a consequence of more sunlight exposure. A leaf subjected to a given illumination (useful quantum light for photosynthesis) will absorb a given quantity of carbon dioxide from the air (CO_2) and produce carbohydrate base compounds for plant growth [28]. A key feature which influences the interception of photosynthetic radiation of a vegetation canopy is the inclination and azimuth of the leaves [28]. The total incident radiation at a given time on a first canopy comes from all directions in varying quantities according to each of these directions [29], and the interception is different for each incidence angle of the radiation [28]. In addition the angular distribution of the incident radiation intensities also vary over time depending on the height of sun in the sky [29]. Furthermore, observations of the surrounding landscape of the studied plantation showed that natural vegetation located south of the plantation was more open with the presence of yam fields in particular. Niinemets et al. [30] reported that variation in leaf size is associated with major changes in the inner-leaf and in large modifications in integrated leaf chemical added to the structural characteristics.

The leaf area and dry mass varies based on the tree location within plantation, displaying a coefficient of variation of 30%. This is consistent with other studies [21,31,19]. Other authors like Verwijst and Wen [32] and De Swart et al. [19] also mentioned a difference in shape between the leaves on the main stem and those made by the lateral branches respectively in *Salix viminalis* and *Capsicum annuum*. However, Tondjo et al. [1] did not detect a difference between the leaves shape on the stem and on the branches of teak, but they did find differences between the dry mass of the leaves from the stems and those of the branches. Leroy et al. [33] mentioned also the existence of the variability in leaf mass and leaf area linked to the architectural position and the axis category of the parent shoots.

The influence of tree location on leaf area and dry mass was a significant. In fact, the comparison in pairs of the five estimation models for each characteristic (leaf area and dry mass of the leaf) showed that different models should be used for each location. Regardless the location, the models that best predict the leaf area and dry mass of a new leaf in a plantation of cashew are logarithmic models of $S^{\wedge} = a\ln(LW) + b$ for leaf area and $m^{\wedge} = a\ln(LW) + b$ for dry mass. In terms of suitability, the models obtained are significant ($p < 0{,}001$) and generally satisfactory (R^2 varies from 0.51 to 0.86, for leaf area and 0.30 to 0.80 for the dry mass). Moreover, the prediction errors obtained by cross-validation are rather lower and vary from 0.0001 to 0.2978 for leaf area and from 0.0001 to 0.0116 for dry mass. Prediction accuracy of leaf area of a new leaf are more accurate for models established in tree locations in the North, Center and East. It is less accurate for those in tree location from South and West. Regarding the leaf dry mass, all models obtained predict efficiently the dry mass of a new leaf, although a number of these models have a relatively poorer fitting quality. Accordingly leaf area and dry mass can be estimated with good accuracy from the maximum length and width of the leaf blade. Unlike the logarithmic models obtained in this study, Murthy et al. [34] had determined a linear relationship between leaf area and the product of the length and width for cashew. The differences between our models and those of Murthy et al. [34] can be linked especially to the fact that Murthy et al. [34] did not get used to select their models, and even a criterion based on the assessment of the prediction accuracy. Non-destructive estimation models of leaf area based on the measurement length and width have been established for many species such as maize [9], avocado and kiwi [16], banana [35] and sunflower [36]. Other authors have developed the powerful function models of length and/or width as most suitable for plants such as teak [1], vines [15], black pepper, dwarf coconut and jatropha [37-39]. Others models have been developed from a single characteristic of the leaf (length or width). Thus, Reynolds [40] proposed two models based on each of the two characteristics (length or width) to predict leaf area of a cocoa leaf, Kobayashi [41] used the length to predict leaf area of a guava leaf, and Willaume et al. [42] estimated leaf area of the apple leaf from only the length of the leaf. In this study, powerful function models and models based on the use of a single characteristic (length and width) do not perform well in terms of prediction quality. The differences between the models reside in the variability of the conditions of the study environment and the specificity of the leaf shape to the species studied. The same types of models were obtained for all plantation locations, suggesting that cashew leaves retain their shape regardless of the location. The results of this study are consistent comparable to those of Tondjo et al. [1], who has focused on the basis of the relationship between the leaf area and the product of the length and width that leaves have expand without change in shape. Therefore, we conclude that both length and width measurements are necessary to estimate leaf area and dry mass accurately to cashew leaves, and the tree location in the plantation affects the quantity of sunlight intercepted by the trees.

5. CONCLUSION

This study was conducted to assess the effect of the tree location in the plantation on the characteristics (length, width, area, dry mass) towards the cashew leaves, and to develop models for estimating with good accuracy leaf area and dry mass of the leaves. The tree location in the plantation had an influence on the morphological characteristics of the leaf, even the leaf area and dry mass. The best models for estimating the leaf area and the dry mass of cashew leaves were function to the logarithm of the product and to the length and width, thus, the model coefficients varied according to the tree location in the plantation. As a result, it appears necessary to consider the trees location in the sample design for estimating area and dry mass of the leaves in a plantation, and then, the specific model coefficients for each trees location in relation to the incidence of the solar radiation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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