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ABSTRACT

The carbon sequestration potential of an unmanaged and previously unstudied *Guadua angustifolia* bamboo forest in the Carrasco National Park of Bolivia has been studied, by estimating the total aboveground biomass contained in the forest. It was found that the aboveground biomass consisting of stems, branches, and foliage, contains a total of 200 tons per hectare, leading to an estimated 100 tons of carbon being stored per hectare aboveground, which is comparable to some species of tree such as the Chinese Fir; this bamboo species therefore has the potential to play a significant role in the mitigation of climate change. The relation between the biomass, M, of each component (stems, branches, and foliage) and the diameter, d, of the plant was also studied, by fitting allometric equations of the form $M = \alpha d^{\beta}$. It was found that all components fit this power law relation very well ($R^2 > 0.7$), particularly the stems ($R^2 > 0.8$) and branches ($R^2 > 0.9$) for which the relation is found to be almost linear.

Keywords: Climate change, mitigation, carbon sequestration, bamboo, Bolivia
JEL codes: Q23, Q54.

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1. INTRODUCTION

Evidence for the contribution of man-made emissions of greenhouse gases (GHGs) to global climate change is increasing. This has been documented by the Intergovernmental Panel on Climate Change (IPCC) that provides scientific and socio-economic information relevant to the understanding of anthropogenic climate change, its potential impacts, and options for its mitigation. Its latest report from 2007 (IPCC, 2007a) revealed that the observed increase in global temperatures over the past half-century is more than 90% likely due to the increase in human GHG emissions, mainly carbon dioxide (CO_2), nitrous oxide (NO_2), and methane (CH_4). Of these, CO_2 is the most relevant gas in terms of its ability to trap heat as well as its concentration in the atmosphere. Its level has been rapidly increasing since the spread of industrialization – in 1880 it was 280-300 parts per million (ppm), in 1980 was 335-340 ppm (Hansen et al., 1981), and the level recently reached 400 ppm, the highest level in recorded history (Monastersky, 2013).

The consequences of climate change are that average world temperatures and sea levels will rise, and that the probability of extreme weather events such as heat waves, droughts, and cyclones will increase. This will lead to problems such as flooding, unpredictable crop growth, and changing distributions of diseases, amongst many others. Due to this, governments and scientists alike agree that urgent action is needed to halt the current rate of climate change. Even if GHG emissions are stabilized now, average temperatures and sea levels will continue to rise for centuries, due to the time-lag between the release of GHGs and its visible consequences.

To mitigate the current rate of climate change, the IPCC suggests several strategies (IPCC, 2007b) to decrease the emissions of GHGs: developing cleaner and more efficient energy supplies, transport, buildings, industry, and waste management; and also altering agricultural techniques to reduce methane from paddy fields and manure, and nitrous oxide from fertilizer. To decrease the accumulation of CO_2 in the atmosphere, the IPCC suggests increasing the natural ability of the planetary ecosystem to absorb this gas, by increasing afforestation and reforestation, reducing deforestation, and improving forest management. To optimize this strategy we need to deepen our knowledge about the role of forests in the global carbon cycle, by studying their carbon sequestration properties.

Carbon sequestration is the term given to the extraction and long-term storage of CO_2 that would otherwise be released into the atmosphere. There is growing interest in carbon sequestration by artificial means, such as the capture and storage of carbon from fossil fuel power plants where the waste CO_2 is transported to an underground storage reservoir where it remains trapped for several millennia (see e.g. Herzog, 2001). However, the process also occurs naturally in plants, which absorb CO_2 to synthesize organic molecules during photosynthesis, sequestering the carbon within the plant's body. Although some CO_2 is released as a waste product of aerobic respiration, the majority of the CO_2 is 'fixed' into the solid compounds that compose the plant material. The net result is the long-term storage of CO_2, which is not released back into the atmosphere until the plant dies, by either natural or unnatural means.

The importance of forests as carbon sinks has been emphasized for many years. Dixon (1993) and Brown et al. (1996) found that carbon sequestration by growing forests is a cost-effective solution to mitigating climate change. Brown et al. (1996) calculated that it was theoretically possible to sequester 60-87 gigatons (Gt) of carbon between 1995-2050, by global afforestation and reforestation, accounting for 12-15% of predicted fossil fuel emissions over this period. Similarly, the IPCC estimated that combining strategies to conserve existing forests, and for reforestation, could result in the reduction of 20 to 50 % of net carbon dioxide emissions in the next 100 years (IPCC, 1995). Due to this, in order to meet target emission levels, the 1997 Kyoto Protocol allowed Annex I countries (industrialized countries and those with economies in transition) with large areas of growing forests to claim forest carbon sinks as an alternative to cutting fossil fuel emissions (UNFCCC, 1997).

Currently, the estimated global forest cover is 3,952 million hectares (ha) (IPCC, 2007b), which is around 30% of the world's total land area (FAO, 2006a). The amount of carbon stored by each forest depends on several factors: plant density and species, and the climatic and geographical conditions. In terms of the global distribution of carbon sequestered by plants, Ordónez (1999) found that approximately 37% is found in low latitudes (0 to 25^{o} degrees latitude), 14% in the middle latitudes (25 to 50^{o}), and 49% in the high latitudes (50 to 75^{o}). Dixon et al. (1994) also found that the geographical latitude affects the proportion of carbon captured by vegetation and soil: arctic forest ecosystems (high latitude) contain a total of around 700 Gt of carbon, approximately 40% of which is sequestered in the soil and the remaining 60% in biomass, detritus, and peat (Apps et al., 1993). Meanwhile, tropical forests at low latitudes sequester a total of 375 Gt, of which approximately 60% is found in the soil and the remainder in vegetation (Lugo & Brown, 1993).

Between 2000 and 2005, gross deforestation occurred at a rate of 12.9 million hectares – around a third of a percent of total forest cover – per year, due to conversion of forests into agricultural land, settlement expansion, building of infrastructure, and unsustainable logging (FAO, 2010). The losses were largest in South America, Africa, and Southeast Asia (IPCC, 2007). Although deforestation cannot be halted completely since many people are reliant on forest resources, through good forest management and optimizing the use of resources, efforts can be invested into minimizing the environment damage caused by the process.

In this work we study the carbon sequestration properties of an unmanaged and previously unstudied bamboo forest in the Carrasco National Park in Bolivia, which is primarily composed of the species *Guadua angustifolia*. We only take into account the carbon stored in the aboveground biomass (stems, branches, and foliage), although as mentioned earlier, it should be born in mind that a large fraction of the total carbon is stored in the soil. Additionally, because bamboo has a large underground rhizome system, a significant amount of carbon is stored in belowground biomass.

The paper is organized as follows. Firstly, we will describe the bamboo species that we studied (*Guadua angustifolia*) and the site of the research (Carrasco National Park). We then describe our experimental method and present the results of the aboveground biomass measurements, estimation of the carbon content, and the construction of allometric equations relating biomass to a plant's diameter. Finally, we summarize and draw our conclusions.

2. BACKGROUND INFORMATION

Guadua angustifolia

Guadua angustifolia is classified in the following manner (Rojas de Sánchez, 2004):

Kingdom: *Plantae*
Phylum: *Spematophyta*
Subphylum: Angiosperma
Class: *Monocotiledoneae*
Order: Glumiflorales
Family: *Poaceae*
Subfamily: *Baubusoideae*
Genus: *Bambuseae*
Subgenus: *Guaduinae*
Species: *Guadua*

The *guadua* is a species of monocotyledon with a strong root and pachymorph rhizome system. The culms (stems) are woody and grow upright, with nodes every 10 to 40 centimeters, depending on the variety. The internodal regions are hollow. The outermost layer of the culm is shiny and smooth; when young it has a dark green color with bands of white fibers in the nodal regions. There are between 4 and 12 branches per stem which sprout from between nodes 3 and 18, and approximately 36 apical hook-shaped branches with secondary branches (Rojas de Sánchez, 2004). The standard leaves vary in their exact size and shape but are generally single, narrow and spear-shaped. They are green in color, and have a smooth texture. The triangular cauline leaves are modified foliate organs that act as a protective layer. The sheath and leaf are continuous, of a strong consistency, and are covered with irritant hairs. The flowers are pseudoespiguilla, slim, and up to nine centimeters in length. Sporadic flowerings have been observed in the months of April and November but it is difficult to obtain fertile seeds due to the high rate of degradation (Rojas de Sánchez, 2004).

The density of *guadua* plants varies from 1,000-2,000 to 8,000-10,000 culms ha^{-1}; the most frequent values are 2,500-3,500 culms ha^{-1} (Castaño & Moreno, 2004). The species adapts well to different soils and climates and therefore has a wide geographical distribution; in general it can be found at altitudes ranging from zero to 2600 meters above sea level, temperatures between 14 and 26 degrees celsius, and in areas with a rainfall of 500-950 mm per year (Rojas de Sánchez, 2004).

The *guadua* is fast-growing, reaching dimensions of up to 25 m in height and 22 cm in diameter within three to six years. The rapid growth rate means that it contributes two to four tons of biomass per hectare to the soil each year, which is around 10% of the total vegetative mass generated by the plant. This makes an important contribution to the fertility and richness of the soil (Herrera & Sabogal, 2005). Another valuable characteristics of the *guadua* ecosystem is the plant's ability to store water in its underground rhizomes: Herrera & Sabogal (2005) estimates that one hectare of *guadua* can store up to 30,000 liters of water. The species also plays an important role in biodiversity: so far 45 plant species, 32 species of insect, 25 bird families, and 2 amphibian families, have been found in *guadua* ecosystems (Herrera & Sabogal, 2005).

In addition to its ecological benefits, the *guadua* also has the potential to become an industrial commodity that contributes to the economy: its fibers are naturally strong and flexible, making it an ideal low-cost, sustainable raw material for a wide variety of products including flooring, furniture, and paper, which are sold on the national and international market (Londoño & Riaño, 2002).

The study site: Carrasco National Park

The Carrasco National Park is located roughly 100 km east of the city of Cochabamba in Bolivia. The park covers an area of 6,200 km^2 and includes several river basins, deep valleys, and high mountains. Altitudes range from 30 m below sea level to 4,700 m above. As a result, the climate is very diverse: low-lying areas have a temperate climate all year round with temperatures between 20 and 27^oC, whilst the mountainous regions experience greater variations of temperature that depend on the humidity level.

The park is notable for its extremely rich biodiversity. There are an estimated 3,000 species of plants, of which only 614 are catalogued, including some endemic species of fern. 181 species of mammals (6.4% of all the species in the world) have been identified, as well as more than 700 species of birds, and at least 160 species of fish. However, the park is under threat from several human activities: settlements are gradually encroaching on the park's periphery, and mining, logging, dynamite-fishing, and poaching are damaging the park's ecosystem. The increase in tourism also poses a risk to the stability of the park's environment.

A specific site for the study was chosen in the region of 'El Palmar', which lies under the jurisdiction of Guácharos Camp, at coordinates[1] (X: 227146, Y: 8106615) or geographic points[2] (17°06' - 65°29') and an altitude of 1,000 m. The choice was based on the most significant guadual identified in the area, ease of access and the permission of the directorate of the park, as well as the fact that the region is unmanaged (i.e. entirely natural) and previously unstudied. The study took place in 2009 between September and November. The average temperature for the year was 27^oC and the total rainfall was 5,500 mm. Information about the site was obtained primarily from the following sources: el Diagnostico Biológico del Parque Nacional Carrasco; the meteorological experiment, 'La Jota', belonging to the Servicio Nacional de Meteorología e Hidrología (National Meteorology and Hydrology Service) in Cochabamba; and reports from the Servicio Nacional de Areas Protegidas (National Service for Protected Areas).

3. METHODS AND RESULTS

Estimation of plant density

Several species of *guadua* were found in the study site but only the predominant one was included in this study. The population was determined by taking a sample in an area equivalent to 2,500 m^2, then extrapolating to a hectare (10,000 m^2). The result was a population density of 1,125 culms in 2,500 m^2, equivalent to 4,500 culms ha^{-1}.

Estimation of the carbon content

Using a confidence level of 95% and an error of 20%, the initial sample size was calculated to be 25. With the total population in the study region being 1,125, the significant sample size was 24 plants, which was used to estimate the biomass and carbon content. Measurements of the plants' dimensions yielded a range of heights between 19.0 m and 24.3 m with an average of 21.3 m, and diameters (measured at 1.3 m above ground level) between 15.0 cm and 19.3

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[1] Sistema de coordenadas cartesianas (Cartesian coordinate system)

[2] Sistema de coordenadas geográficas (Geographic coordinate system)

cm with an average of 16.8 cm. These results are summarized in Table 1 and detailed in Appendix A. The measurements are consistent with those obtained by Rojas de Sánchez (2004), who records that the species reaches dimensions of up to 25 m (height) and 22 cm (diameter).

The aboveground biomass consists of stems, branches, and foliage, which constitute the 'green material'; its weight is called the 'green mass'. Measurements of the green mass were performed for each of the 24 plants in the sample, weighing each component separately. The total average green mass for a plant was 99.50 kg, consisting of 87.14 kg (88%) in stems, 8.41 kg (8%) in branches, and 3.95 kg (4%) of foliage. The minimum mass per plant was 87.80 kg and the maximum 114.10 kg. These numbers are summarized in Table 1 and detailed in Appendix B.

Table 1: Ranges and average values for plant heights, diameters (measured 1.3 m above ground level), and masses.

	Height (m)	Diameter (cm)	Total mass (kg)
Minimum	19.0	15.0	87.8
Maximum	24.3	19.3	114.1
Average	21.3	16.8	99.5

After the water content has been removed from the green material, the remainder is called the 'dry material'. If only the green mass of *Guadua angustifolia* is known, the dry mass can be determined using the following mathematical relation developed by Riaño & Londoño (2002):

$$\text{dry mass} = -1.0007 + 0.467 \times \text{green mass}.$$

The 24 samples which had been weighed manually were used to test this relation. To confirm its accuracy, a small sample of these weighed plants was taken to the laboratory at the Universidad de Nuestra Señora de La Paz (UNSLP) to remove the water content by drying the material in an oven at 75°C until a constant weight was obtained, following the method of Castañeda et al. (2004). A further sample was sent to the Instituto Boliviano de Ciencia y Tecnología Nuclear (IBTEN) to determine the dry mass through molecular methods. The summarized results are shown in Table 2 (with more details provided in Appendix C) where it can be seen that all three methods yield similar results, with a maximum deviation of around 3% from the average value.

To obtain the carbon content, the dry mass must be multiplied by a figure between 0.45 and 0.55, with the value depending on the particular plant. In the absence of this specific information, a value of 0.5 is generally used (Brown, 1997), as in this study. Using this estimate and the figure obtained earlier for the plant density, we can estimate the density of carbon stored in aboveground biomass by *Guadua angustifolia* (bottom row of Table 2). The final value of 100.0 t ha^{-1} is close to the value obtained by Castañeda et al. (2004), who measured the above-ground biomass of a *Bambusa oldhamii* plantation in Colombia to be 103.7 t ha^{-1}.

Table 2: Measurements of aboveground dry mass and carbon density, obtained via three different methods (see text for details).

	Riaño & Londoño (2002) formula	**IBTEN**	**UNSLP**	**Average**
Average above-ground dry mass per plant (kg)	44.33	45.65	43.30	44.43
Above-ground dry mass density (tons ha^{-1})	200.5	205.4	194.5	200.0
Above-ground carbon density (tons ha^{-1})	100.3	102.6	97.3	100.0

Castañeda et al. (2004) also took into account the ages of the plants, estimating the average carbon capture rate to be 25.92 t ha^{-1} year^{-1}. However, they found that the annual contribution to carbon capture was not uniform – younger plants absorb more carbon than older plants. In the current work, it was not possible to include the effect of age since the study was conducted in a natural forest with no previous studies undertaken; therefore there is no way to determine the age of the plants. As a result, the data contained here cannot provide any information about the age-dependence of a plant's carbon sequestration ability. However, implementing the relation proposed by Castañeda et al. (2004), the forest of the present study should have a carbon-fixing potential of approximately 27.53 t ha^{-1} yr^{-1}.

We stress that this is a number purely for reference and that further studies would be needed to confirm its accuracy. The amount of carbon expelled by each plant through respiration should also be accounted for; the amount of carbon stored by plants exceeds the amount released during respiration and rotting (Schlesinger, 1997) but approximately one third of the carbon which is absorbed during photosynthesis is released through respiration, with the amount dependent on climatic conditions, soil moisture, and other factors (Schneider & Childers, 1941).

Allometric equations for component and total biomass

Assuming a power-law relation between the dry mass of each component i (stems, branches, foliage), M_i, and the diameter, d, of the plant, which we choose to measure at a reference point of 1.3 m above the ground, we have: $M_i = \alpha_i d^{\beta i}$, where α_i and β_i are parameters to be determined for each component. Linearizing the equation by taking logarithms, we obtain:

$$\ln M_i = \ln \alpha_i + \beta_i \ln d.$$

As suggested by Baskerville (1972), an adjustment should be included to eliminate the bias associated with the logarithmic transformation of the model:

$$M_i = \exp(\alpha_i + \beta_\mathrm{i} \ln d - \sigma_i/2) \text{ (Wiant \& Harner, 1979)}$$

where M_i is the dry mass of the *i*th component (stems, branches, foliage) and σ_i is the mean square error for that component. The regression analysis was performed using SigmaPlot 2001 (Version 7.0) for the dry masses obtained for each of the components by the three different measurement methods. The values obtained for each of the three methods are shown in detail in Table 3. σ_i is the same for all measurement methods.

It can be seen that the two laboratory measurements produce very similar results; the analytic method from Riaño & Londoño (2002) shows a larger discrepancy. The values obtained for the scaling parameter, α, are more spread than the values obtained for the exponent β. The R^2 value for the stems is very large (0.95), showing an almost perfect, near-linear relation ($\beta \approx 0.94$) between the mass of the stems and the plant diameter. The correlation between the mass of the branches and the plant diameter is also very strong ($R^2 = 0.87$) and nearly linear ($\beta \approx 1.01$). For the foliage, the value of α is considerably smaller than for the other components since foliage constitutes only around 4% of the total plant mass (see previous section); this may be a region in which the equation from Riaño & Londoño does not hold. The laboratory measurements find a value of β which is close to 2, but the analytic method shows a large discrepancy. However, the R^2 values for all three methods exceeds 0.7, showing a significant relation between the mass of the foliage and the plant diameter. Further statistics can be found in Appendix D.

Table 3: Fit parameters and R^2 values for the allometric equations relating the dry mass of each of the ith components (stems, branches, foliage) obtained by three different measurement methods, with the plant diameter: $M_i = \alpha_i d^{\beta_i}$.

		α_i	β_i	σ_i	R^2
Stems	R&L2002	2.6896	0.961	0.0478	0.9524
	UNSLP	2.7286	0.9384		0.9525
	IBTEN	2.8624	0.9381		0.9525
Branches	R&L2002	0.0510	1.443	0.1214	0.8762
	UNSLP	0.1506	1.0837		0.8745
	IBTEN	0.1560	1.0832		0.8754
Foliage	R&L2002	9.46×10^{-6}	4.027	0.3665	0.7153
	UNSLP	0.0057	1.9924		0.7207
	IBTEN	0.0074	1.9815		0.7212
Total	R&L2002	2.2311	1.059	0.0508	0.9480
	UNSLP	2.6685	0.9879		0.9486
	IBTEN	2.7599	0.9947		0.9475

Comparison with other studies

This section will briefly discuss how our results for the carbon sequestration compare with others in the literature. As mentioned in earlier sections, the carbon sequestration rate of any plant depends on many factors including the plant species, plant age, plant density, soil fertility, and climatic conditions amongst others, and so this discussion serves merely for reference purposes.

There have been many studies of Moso bamboo in its native China (Huang, 1987; Huang et al., 1993; Li, Lin & Qiu, 1993; Chen et al., 1998; Peng et al., 2002; He et al., 2003; Zhou & Jiang, 2004; He et al., 2007; Zhong et al., 2008; Qi et al., 2009) – see INBAR (2010) for a summary – where it makes up approximately three percent of the country's forests. These studies estimate both the carbon stored aboveground, and belowground; the majority find that approximately two-thirds of the carbon sequestered is found in aboveground biomass, with the remainder below ground. The average aboveground carbon density reported by these studies ranges from roughly 15 to 65 tons ha^{-1}; below ground the range is roughly 10 to 35 t ha^{-1}. The culm density ranges from approximately 2,000 to 4,500 culms ha^{-1}. This information is summarized in a 2010 report from the International Network for Bamboo and Rattan (INBAR, 2010).

These numbers can be compared to the above-ground carbon storage of *Bambusa oldhamii* which is around 100 tons ha^{-1} (Castañeda et al, 2004), similar to the value obtained for the species *Guadua angustifolia* in the present study, although the culm density is roughly the same as for Moso bamboo; therefore the difference must be due to the larger biomass of these species. For further comparison, a species of tree that is native to China, such as the Chinese Fir, stores between 17 and 195 tons of carbon per hectare, depending on the age of the plantation (INBAR, 2010). This means that the species of bamboo discussed here can contribute to carbon sequestration in the same proportions as tree species such as Chinese Fir.

4. SUMMARY AND CONCLUSIONS

In this study we have measured the aboveground biomass contained in an unmanaged and previously unstudied *Guadua angustifolia* bamboo forest in the Carrasco National Park in Bolivia. We have found that the plant density of this forest is 4,500 culms ha^{-1} and contains around 200 t of aboveground biomass ha^{-1}, leading to an estimated aboveground carbon sequestration density of 100 t ha^{-1}. We have also fitted equations relating the mass of each component (stems, branches, foliage) to the plant's diameter, finding that a power-law relation of the form $M_i = \alpha_i d^{\beta i}$, where M_i is the mass of each component and d is the diameter of the plant, fits all the components very well ($R^2 > 0.7$), particularly for the stems ($R^2 > 0.8$) and branches ($R^2 > 0.9$) for which the relation is found to be almost linear.

The relatively large amount of carbon stored by *Guadua angustifolia* means that it has the potential to contribute as significantly to carbon sequestration as some species of tree such as the Chinese Fir. This will be the case if plantations are set up and carefully managed and the mature culms are harvested and turned into durable products that will store carbon for several decades; the flexibility and durability of bamboo make it an ideal building material for several structures, as well as being suitable for a wide range of furniture and decorative products. If this path is followed, care must be taken to ensure that the plantations are appropriately situated, taking into account the growing requirements of the species; that the plantations are properly managed; and to take into account potential undesirable effects on the environment such as species invasiveness. Once these factors have been properly considered, the large biomass density and fast growth rate of *Guadua angustifolia* make it an ideal species for commercially viable carbon sequestration that can help to mitigate climate change.

APPENDICES

Appendix A: Plant heights and diameters

Sample number	Height (m)	Diameter 1.3 m above ground (cm)
1	24.2	19.1
2	23.0	18.0
3	24.0	19.0
4	20.0	15.8
5	23.4	18.5
6	22.0	17.0
7	19.6	15.1
8	19.3	15.0
9	24.0	19.0
10	20.3	15.7
11	22.6	17.4
12	20.1	15.9
13	20.0	15.8
14	21.7	16.7
15	19.0	15.0
16	20.6	16.6
17	22.0	18.5
18	21.2	16.4
19	24.3	19.3
20	23.5	18.4
21	19.1	14.9
22	18.8	14.8
23	20.2	15.9
24	19.2	15.2
Average	**21.3**	**16.8**
Standard deviation	1.9	1.6

Appendix B: Distribution of dry mass between stems, branches, and foliage

Sample number	**Stems (kg)**	**Branches (kg)**	**Foliage (kg)**	**Total (kg)**
1	99.2	9.7	5.2	114.1
2	94.3	9.3	4.9	108.5
3	98.4	10.0	5.5	113.9
4	82.0	8.0	3.0	93.0
5	96.0	9.0	5.0	110.0
6	90.0	8.8	4.3	103.1
7	80.2	7.8	3.8	91.8
8	79.0	7.4	2.4	88.8
9	98.0	9.9	4.9	112.8
10	82.0	7.7	3.2	92.9
11	92.0	9.0	5.0	106.0
12	82.2	8.0	4.0	94.2
13	81.0	7.9	3.4	92.3
14	89.0	8.7	3.7	101.4
15	79.0	7.4	2.9	89.3
16	82.5	7.7	3.6	93.8
17	90.0	9.0	4.1	103.1
18	85.0	7.2	3.1	96.3
19	99.2	9.6	4.6	113.4
20	96.3	9.3	4.8	110.4
21	78.0	7.6	3.6	89.2
22	77.0	7.4	3.4	87.8
23	82.0	7.9	2.9	92.8
24	79.1	7.6	3.5	90.2
Average	**87.1**	**8.4**	**4.0**	**99.5**
Standard deviation	7.8	0.9	0.9	9.4

Appendix C: Measurement of dry mass and humidity content by three different methods – using the equation from Riaño (2002), measurement at the UNSLP laboratory, and measurement at the IBTEN laboratory

Sample number	**Total dry mass (kg)**			**Water content (%)**		
	Riaño& Londoño	**UNSLP**	**IBTEN**	**Riaño& Londoño**	**UNSLP**	**IBTEN**
1	51.29	49.62	52.38	55.05	56.51	54.09
2	48.63	47.18	49.80	55.18	56.51	54.10
3	51.20	49.50	52.28	55.05	56.54	54.10
4	41.25	40.49	42.64	55.65	56.47	54.15
5	49.34	47.86	50.52	55.15	56.49	54.07
6	46.05	44.85	47.31	55.33	56.50	54.11
7	40.68	39.94	42.13	55.69	56.50	54.11
8	39.25	38.69	40.71	55.80	56.43	54.16
9	50.67	49.04	51.75	55.08	56.52	54.12
10	41.20	40.45	42.62	55.65	56.46	54.12
11	47.44	46.09	48.67	55.25	56.52	54.09
12	41.82	40.98	43.23	55.61	56.46	54.11
13	40.91	40.17	42.34	55.67	56.52	54.13
14	45.25	44.13	46.51	55.38	56.50	54.14
15	39.49	38.89	40.96	55.78	56.48	54.13
16	41.63	40.83	43.05	55.62	56.48	54.10
17	46.06	44.85	47.29	55.33	56.45	54.13
18	42.34	41.55	43.76	55.57	56.47	54.08
19	50.96	49.34	52.04	55.06	56.50	54.11
20	49.53	48.03	50.68	55.14	56.40	54.10
21	39.44	38.81	40.93	55.79	56.49	54.12
22	38.77	38.21	40.29	55.84	56.48	54.12
23	41.15	40.41	42.55	55.66	56.46	54.15
24	39.91	39.25	41.39	55.75	56.48	54.12
Average	**44.34**	**43.30**	**45.66**	**55.46**	**56.48**	**54.12**
Standard deviation	4.48	4.08	4.33	0.28	0.03	0.02

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