Bamboo Resources and Carbon storage in Taiwan

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Abstract

In this paper, we examined bamboo resources and reviewed studies concerning bamboo biomass, carbon storage and sequestration for different bamboo species and at varying site conditions in Taiwan. Owing to a suitable climate and environment for the bamboo growth, it is rich in bamboo resource both in species and area in Taiwan. In 2000, bamboo forests had approximately covered 7.11 % of total forest land in Taiwan. Generally, both monopodial and sympodial bamboos are available in Taiwan. Among them, several bamboo species are regard as economic bamboos because of their high economic value in culms and shoots. During the past, many studies were carried out to assess bamboo biomass and carbon storage for the bamboo productivity. This paper showed, generally, the biomasses aboveground of sympodial bamboos were higher than those in monopodial types because of the bigger size in culms in the former and the major contribution of culms to biomass aboveground for both bamboo types. While the carbon storage aboveground in bamboo was less than that in tree plantations, due to the more rapid growth occurring in bamboo, bamboo forests in Taiwan showed an apparent superiority to tree forests in the carbon sequestration capacity. However, bamboo forests under well-managed to have a good balance in age structure is necessary to maintain the vigor of bamboo forests. Based on the average value of bamboo forests obtained by this paper, the total carbon storage of national bamboo forests in Taiwan at 2000 was approximately estimated to be 9.5 Tg C.

Keywords: bamboo, carbon storage, carbon sequestration

Introduction

Bamboo belongs to the *Gramineae* family and has about 90 genera with over 1200 species around world (Lobovikov et al. 2007), of which 14 genera and 120 species are found in Asia (Azmy et al. 1997). Bamboos naturally distribute in the tropical and subtropical belt between approximately 46° north and 47° south latitude, and is commonly found in Africa, Asia and Central and South America. Some species may also grow successfully in mild temperate zones in Europe and North America. Bamboo is an extremely diverse plant, which easily adapts to different climatic and soil conditions.

Bamboo size ranges from dwarf bamboo species that grow to only a few centimeters (cm), to medium-sized bamboo species that reach a few meters (m) and to giant bamboo species growing to about 30 m, with a diameter of up to 30 cm (Lobovikov et al. 2007). Bamboo stems are generally hard and vigorous, and the plant can survive and recover after severe calamities, catastrophes and damage.

Based on data reported to FAO/INBAR by countries around the world, by 2005, Asia owns the richest bamboo resources with 65% of total world bamboo resources, followed by American (28%) and Africa (7%). In Asia, the major bamboo producing countries are India (almost 11.4 million hectares) and China (over 5.4 million hectares), followed by Indonesia (2 million hectares) and the Lao People's Democratic Republic (1.6 million hectares). India accounts for roughly half the total area of bamboo reported for Asia and, together with China, approximately 70 percent. Over the last 15 years, the bamboo area in Asia has increased by 10 percent, primarily due to large-scale planting of bamboo in China and, to a lesser extent, in India (Lobovikov et al. 2007). Compared to the total forest area in the reporting countries, the ratio of bamboo to forest area is about 3.2%.

Bamboo has many advantages over timbers such as fast growth, high production, rapid maturation from shoot to culms and versatility (Scurlock et al. 2000). Generally, bamboo forests are developed through rhizome and both culms and rhizome produced annually, thus, bamboo forests are unevenly aged forests where differently aged culms are intermixed in the stands with the appeal for stand structure and production capacity in bamboo forests (Scurlock et al. 2000, Lü 2001).

Bamboo species in Taiwan

Due to a climate and environment favorable to bamboo growth, Taiwan is rich in bamboo resources both in species diversity and amount of bamboo forests. Owing to the Tropic of Cancer across Taiwan and high elevations of Central Mountain Range in Taiwan, different types of bamboo can be found in Taiwan. There are 46 species and varieties of bamboo found in Taiwan, of which 20 are indigenous and 26 exotic (Lin 1967). Bamboo shoots and culms grow from the dense root rhizome system. Generally, bamboo rhizomes can be broadly classified into two categories : monopodial and sympodial. Monopodial rhizomes grow horizontally, often at a surprising rate with the nickname of 'runners'. The rhizome buds develop either upward, generating a culms, or horizontally, with a new tract of the rhizome net. *Phyllostachys* and *Teragonocalamus* are two genera of monopodial rhizomes that were found in Taiwan. The major species of monopodial rhizomes in Taiwan include *Phyllostchys makino*, *Phyllostachys pubescnes* (Lü 2001). Monopodial bamboos generate an open clump with culms distant from each other, and therefore, can be invasive.

Sympodial rhizomes are short and thick, and the culms above ground are close together in a compact clump, which expands evenly around its circumference. Three genera of Sympodial rhizomes were found in Taiwan. They are *Bambusa, Dendrocalamus* and *Schizoztachyum*. The major species of sympodial rhizomes in Taiwan are *Dendrocalamus latiflorus*, *Dendrocalamus giganteus*, *Bambusa oldham*, *Bambusa dolichoclada* and *Bambusa Stenostachya.* Because of the compact clump, they are not invasive.

Recently, the carbon cycle has become an important issue around the world and plants play a major role in carbon storage. Many studies assessed the carbon storage capability in trees, but few of studies investigate one in bamboo. The purpose of this paper is to describe bamboo resources in Taiwan and review previous studies on bamboo growth, biomass and carbon storage for different bamboo species and at different sites.

Material and Methods

Site descriptions

In this paper, we reviewed previous studies which carried out for different bamboo species, and at various sites around Taiwan. The species and environmental information were given in Table 1.

Table 1. Species and environmental information for sites of cited references around Taiwan

species	Site location	Elevation (m)	Temperature (^{0}C)	Precipitation (mm yr^{-1})	reference
Phyllostachys makinoi	Northern Taiwan	405-1299	20	2350	Chen et al 2009 a.
Phyllostachys makinoi	Central Taiwan	450-550	15-23	1800-2400	Yen et al 2010
Phyllostachys makinoi	Tung-Tou (Nan-ton County)	300-350	19.1	2249	Lü and Chen 1992
Phyllostachys pubescens	Hui-sun (Nan-ton County)	667	20.3	3389	Wang et al. 2009
Phyllostachys pubescens	Shi-zhuo (Cha-yi County)	1300	11.5	4616	Wang et al. 2009
Denrdrocalamus	Yue-Tzu village,	610	19.2	2404	Wang

latiflorus	Nan-ton County.				(2004)
Bambusa stenostachya	Zeochen Tainan County	64.8	24.3	1777	Chen et al. 2012

Methods

Estimates of characteristics of bamboo stands

Usually, a sampling unit of plot size 10*10 m or 5 * 5 m was set up in bamboo forests to estimate characteristics of bamboo stands in Taiwan. In the plots, species, age, number of culms, mortality, diameter at breast height (DBH), culms height and height at crown base for all culms were identified, measured, and converted into unit area (ha) base.

Bamboo biomass, carbon storage and carbon sequestration

To estimate the bamboo biomass, several culms based on DBH distribution were cut and measured in detail. Usually, the general procedure for bamboo biomass assessment was illustrated as below:

1. Culms selected are felled at base, measured DBH, total culms height and height to crown base.

2, Divide culms into segments, cut them first from the base to 1.3 m at height, and then, with the interval of 2 m in height.

3. Measure diameter and thickness at small ends in each section, and weigh them individually to get fresh weight.
4. Chop branches and leaves off, and weigh them separately.
5. Take samples of culms, branches and leaves to dry them to get dry weight.
6. Based on dry weight of samples, calculate the dry weight for culms,branches and leaves for each culms felled.
7. Establish DBH allomatric relationships for culms, branches and leaves. Calculate stand biomass in culms, branches and leaves through allomatric equation, and summarize them to get biomass above ground.
8. Multiply biomass by carbon contain percentage (empirically or assumed) to get carbon storage.
9. In the case of periodic growth data available, carbon sequestration was obtained by the following equation:
   carbon sequestration (Mg ha^{-1} yr^{-1}) = periodic carbon storage increments (Mg ha^{-1}) / number of years in the period

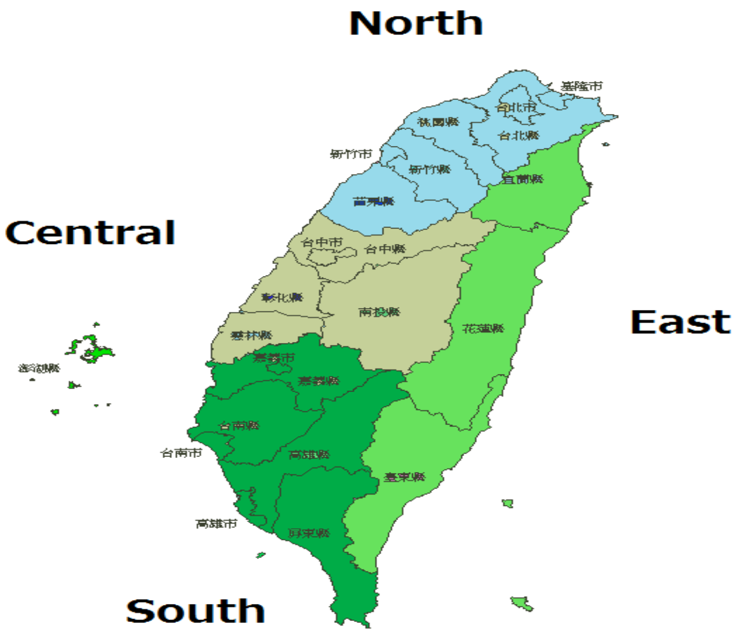
Results and Discussions

Bamboo resources in Taiwan

Based on Taiwan Forestry Statistics, bamboo forests in Taiwan National Forest cover about 149,561 ha in 2000 (TFB 2000), approximately 7.11% of forestland. The bamboo area and bamboo species distributed in four regions in Taiwan were given in Table 2 and Figure 1.

Table 2. Bamboo area and bamboo species distributed in Taiwan.

Region	Bamboo area proportion (%)	Dominant bamboo species
North	29.7	*Bambusa oldhami*
		Phyllostachys makinoi
Central	19.7	*Phyllostachys makino*
		Phyllostachys pubescens
		Dendrocalamus latiflorus
South	40.9	*Bamausa stenostachya*
		Dendrocalamus latiflorus
		Bambusa dolichoclada
East	9.3	*Phyllostachys makinoi*



Owing to the heterogeneous geography (4000 meters range in elevation) in Taiwan, bamboos distributed across four climatic zones, with most abundance in sub-tropic and tropic zone, next to temperate zone, and a few was found in alpine zone. Compared to Japan and Southern-eastern countries in Asia, Taiwan is unique to have bamboo distribution over four climatic zones.

Table 3 showed the major bamboo species distributed vertically in Taiwan. Usually, monopodial bamboos are found in temperate regions, and sympodial bamboos are found in sub-tropic and tropic regions. The vegetations of bamboo can be pure stands or mixed with other tree species in forests.

Table 3. Distribution of bamboo species by elevation in Taiwan

Elevation above sea level (meters)	Bamboo species
Above 3000	*Yuahania niitakayamensis*
2000-3000	*Yuahania niitakayamensis*)
1000-2000	*Phyllostachys makinoi*
	Phyllostachys pubesens
	Sinobambusa kunishii
500-1000	*Bambusa dolichoclada*

0-500	*Sinobambusa kunishii* *Bambusa dolichoclada* *Bambusa oldhami* *Bamausa stenostachya*

Bamboo biomass and carbon storage and sequestration in Taiwan

In this paper, four major bamboo species in Taiwan were cited from previous studies for the discussion. They are:

1. *Phyllostachys makinoi*

Pseudosasa makinoi is an important endemic species in Taiwan. It is widely distributed in the Northern and Central Taiwan from plains to lower mountain areas with an elevation 100-1200 m (Lin 1962), totally with area of 44,906 ha (Lü 2001). Both culms and shoots have economic value for excellent properties and food sources. Having monopodial rhizomes (i.e., runners), *Pseudosasa makinoi* becomes pure stands in large scale and expands the habitat annually. The culms are about 1-5 m in height with a DBH of 0.2-1.5 cm. In the Shihmen Reservoir Watershed Area, a huge of *Pseudosasa makinoi* in pure stands are observed and become an important vegetation resource there (Figure 2). Several sites of *makinoi* bamboo forests on this watershed were investigated for *makinoi* bamboo growth and biomass (Chen et al. 2009 a). The environment of *makinoi* and characteristics of *makinoi* of Chen et al. (2009 a) study were illustrated in Table 4.

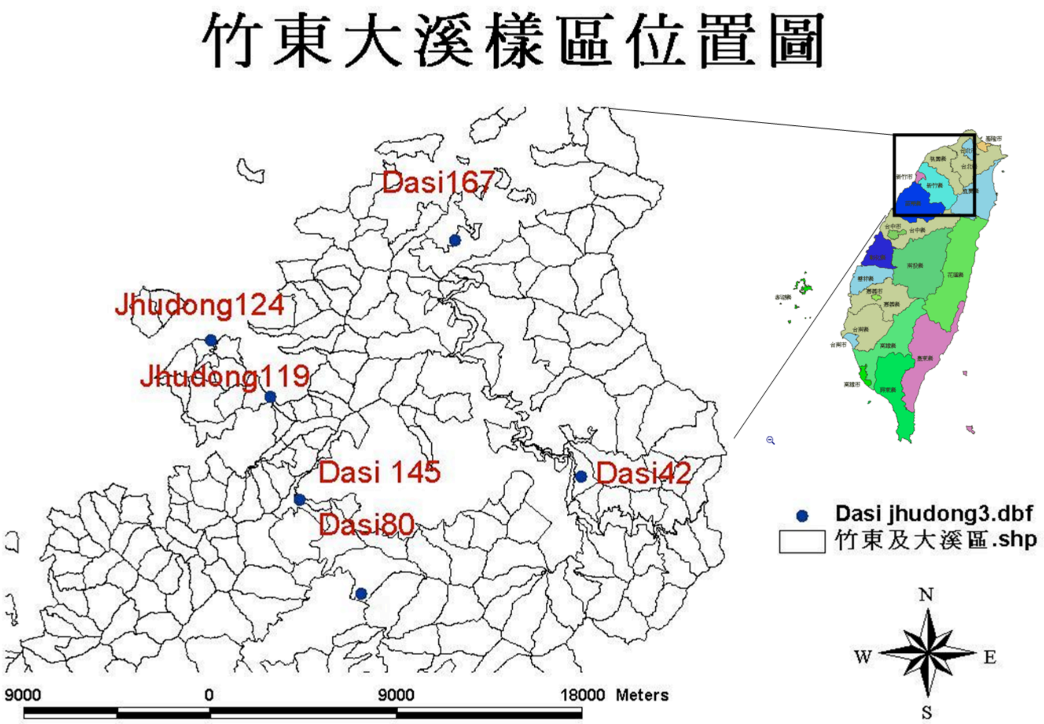


Table 4. The environment and characteristics of *makinoi* bamboo stands in Shihmen Reservoir Watershed Area

Site	Elevation (m)	Aspect	Slope (degree)	Density (culms ha^{-1})	DBH (cm)	Height (m)	Age (yr)
Dasi 80	1299	west	20	15700 ±1389	5.2 ± 0.9	10.2 ± 1.6	5 ± 1
Dasi 145	1256	east	20	16144 ±2848	5.0 ±1.0	10.7 ± 1.3	4 ± 2
Jhudong 119	1220	west	10	17567± 2302	4.7 ± 1.0	10.7 ± 2.3	4 ± 1
Dasi 42	1047	west	10	18767± 1877	5.9 ± 0.8	11.1 ± 0.6	5 ± 1
Dasi 167	470	east	20	15800± 2651	5.4 ±1.2	10.8 ±1.0	4 ±1
Jhudong 124	405	east	25	11667 ±416	5.2 ±1.6	11.3 ± 3.1	3 ± 1

DBH: Diameter at breast height.

It was shown that the density at Jhudong 124 site was significantly less than that at all other sites. Except the low elevation sites, a tendency of decreasing density with increasing elevation was observed. Due to the heterogeneity in environment, a significant difference among sites in DBH and culms height exits. Overall, frequency distribution showed that number of culms at DBH of 6.0-6.9 cm, number of culms with age 6 years, and culms in height of 10.0-11.9 m were highest.

In terms of biomass, due to the highest stand density, higher DBH and culms height, the aboveground biomass at Site Dasi 42 is the greatest of all sites. On the contrary, at site Jhudong 124, because of the lowest density, its aboveground biomass is worst in spite of its high value in DBH and culms height (Table 5).

Owing to the rhizomes widespread around site, the biomass belowground is greater than that of aboveground for all sites. As the case of biomass aboveground, the below ground biomass at site Jhudong 124 is the lowest of all sites (Table 5).

While carbon storage was not calculated in their study (Chen et al. 2009a), this paper extends biomass to carbon storage based on data from Yen et al. (2010) for makino bamboo study. Carbon storage for each section of bamboo was calculated by multiplying biomass by percent carbon content (PCC). In this paper, we use the average value of PCC from 1 to 5 year-old bamboo for different sections (Yen et al. 2010), and multiply these values by bamboo biomass to get carbon storage for each section, and then, summarize them to get the carbon storage for aboveground (Table 6).

Table 5. Biomass aboveground and belowground makino stands at Shihmen Reservoir Watershed Area (Mg ha^{-1})

Site	leaf	shoot	Culms	Aboveground	Belowground	Total biomass
Dasi 80	4.34 ± 0.17	6.74±0.28	14.9± 1.76	53.08±2.05	164.37±11.66	217.45± 13.46
Dasi 145	4.34± 1.51	6.58± 2.11	44.26±9.40	55.27±12.99	178.35 ± 19.40	233.63 ± 30.78
Jhudong 119	3.37± .62	5.62 ±0.80	40.06 ±5.96	49.14 ±7.30	180.03± 19.32	229.17± 26.46
Dasi 42	8.07±0.52	10.02± 0.80	63.45 ±4.88	81.68± 6.19	190.10 ±15.75	271.78 ±21.85
Dasi 167	5.29± 0.53	6.64± 0.30	46.47± 4.34	58.47± 4.92	165.21± 22.25	223.68± 26.26
Jhudong 124	3.76±0.99	3.53 ±1.05	33.70± 4.58	40.99 ± 6.63	130.53 ± 3.49	171.51 ± 7.74
Average	4.86±1.70	6.52± 2.10	44.97± 10.05	56.44 ±14.36	168.10±23.98	224.54±32.24

Table 6. Carbon storage aboveground and belowground makino stands at Shihmen Reservoir Watershed Area (Mg ha^{-1})

Site	leaf	shoot	Culms	Above ground	Below ground	Total
Dasi 80	1.74±0.07	3.10±0.13	19.96±0.84	24.81±0.97	77.88±5.52	102.69±6.38

Dasi 145	1.74±0.60	3.03±0.97	21.09±4.48	25.86±6.02	84.50±9.19	110.36±14.47
Jhudong 119	1.35±0.25	2.59±0.37	19.09±2.84	23.03±3.42	85.30±9.15	108.33±12.50
Dasi 42	3.24±0.21	4.62±0.37	30.23±2.33	38.09±2.89	90.07±7.46	128.16±10.31
Dasi 167	2.12±0.21	3.06±0.14	22.14±2.07	27.32±2.32	78.28±10.54	105.60±12.44
Jhudong 124	1.51±0.40	1.63±0.48	16.06±2.18	19.19±3.06	61.84±1.66	81.04±3.60
Average	1.95±0.29	3.00±0.41	21.43±2.46	26.38± 3.11	79.65±7.25	106.03±9.95

In addition to the *makinoi* bamboo study in the northern Taiwan (Chen et al. 2009a), Yen et al. (2010) used diameter distribution model to estimate *makinoi* bamboo aboveground biomass and carbon storage in the Central Taiwan with a stand density of 21191±4107 culms ha^{-1}. In their study, both biomass and carbon storage were calculated. According to the estimates, there were 105.33 Mg ha^{-1} and 49 .81 Mg ha^{-1} of biomass and carbon storage from makino 5 years bamboo forest. Converting it into annual base, the annual yields of biomass and carbon sequestration were 21.07 Mg ha^{-1} and 9.89 Mg ha^{-1} yr^{-1}, respectively.

Comparing results from previous studies show that for makino bamboo forest, a variety of bamboo biomass and carbon storage existed among different areas in Taiwan (Table 7).

Table 7. Comparison of makino biomass aboveground and carbon storage at different area.

studies	Location	Biomass aboveground (Mg ha$^{-1)}$	Carbon storage (Mg ha$^{-1)}$	Carbon sequestration (Mg ha^{-1} yr$^{-1)}$
Chen et al (2009a)	Shihmen Reservoir Watershed Area	56.44	26.38	5.28
Yen et al (2010)	Chu-Shan Nan-Tou County	105.33	49.81	9.89
Lu and Chen 1992	Tung-Tou Nan-Tou County	27.64	12.98	2.60
Ji （2008）	Chu-Shan Nan-Tou County	75.75	35.54	7.11
Yu (1995)	Hui-sun Experimental Forest Nan-Tou County	44.26	20.97	4.19

2. *Phyllostachys pubescen*

Moso bamboo *(Phyllostachys pubescen)* was introduced from China since 1750. The culms are about 4-20 m in height with a DBH of 5-18 cm (Lü 2001). Moso bamboo was mainly distributed in the Central Taiwan with an elevation 150-1600 m, totally, an area of 3290 ha (Lü 2001). Both culms and bamboo shoots have economic value, especially, moso bamboo winter shoots have a relatively high value in the market.

Wang et al. (2009) investigated the stand structure, aboveground biomass, carbon storage and carbon sequestration of moso bamboos in Hui-sun Experimental Forest Station in Nan-ton County and Shi-Zhou in Chai-yi County. The environmental information and bamboo growth for these two sites was given in Table 8.

Table 8. The stand structure and growth for moso bamboo in two studies area

site	Elevation (m)	Precipitation* (mm yr^{-1})	Average temperature (^{o}C)	Density (culms ha^{-1})	DBH (cm)	Height (m)
Hui-sun (Nan-ton County)	667	3389 ±575	20.3	7933 ±766	6.8 ± 0.1	10.3± 0.1
Shi-zhuo (Cha-yi County)	1300	4618 ±1343	11.5	8344 ±758	10.6±0.1	21.4 ± 0.1

* Precipitation and temperature based on 2002-2007

Table 9. The biomass, carbon storage and carbon sequestration in two studied area

Site	Leaf (Mg $ha^{-1)}$)	Branch (Mg $ha^{-1)}$)	Culms (Mg $ha^{-1)}$)	Aboveground (Mg ha^{-1})	Carbon storage (Mg $ha^{-1)}$)	Carbon sequestration (Mg ha^{-1} yr^{-1})
Hui-sun (Nan-ton county)	3.6±0.3	9.7±0.7	43.1± 3.2	57.9±5.0	26.4 ±1.9	5.3
Shi-zhuo (Cha-yi County)	4.4±0.3	12.0± 0.7	151.7±7.1	171.3±8.1	82.9 ± 3.9	16.58

Their result showed that aboveground biomass in Shi-Zhuo area was larger than that in Hui-Sun area (Table 9). Based on the environmental information of these two sites, Shi-zhuo is more suitable for moso bamboo growth because of higher elevation, more precipitation and lower temperature (Table 8). Generally, moso bamboo prefers the environment at mountains with elevation about 1000~1500 m. In addition to temperature, precipitation is quite important for moso bamboo growth. As the moso bamboo in Shu-Zhuo grow better than that in Hui-Sun area, its aboveground biomass was significantly greater than that in Hui-Sun area (Table 9).

Carbon storage was calculated by multiplying biomass by carbon contain ration (Wang et al. 2009). As carbon contain ratio slightly varies at different component and no significant difference for a given component between two sites, carbon storage majorly depends on biomass, therefore, carbon storage is much higher in Shu-Zhuo area than that in Hui-sun area.

In the well-managed moso bamboo stands, the old culms (age > 5 years) were cut annually to sprout new culms. Therefore, the carbon storage of new culms can be thought of as carbon sequestration. Based on age ranges 1-5 years, carbon sequestration was obtained by dividing carbon storage by 5.

Compared to the moso bamboos in China, the average biomass production in Taiwan is lower than that in China (159.86 Mg ha^{-1}) because most of moso bamboos in China were under intensive management (Chen et al. 2009 b).

3. *Denrdrocalamus latiflorus*

Dendrocalamus latiflorus is a giant tropical and subtropical clumping species native to Southern China. *Dendrocalamus latiflorus* was introduced by ancestors from China and planted widely around the island with the majority plantations in the Central-southern Taiwan. The elevations varies from plain to mountains with 1500 m. Usually, the DBH of *Dendrocalamus latiflorus* ranges 8-20 cm with culms height 14-25 m. *Dendrocalamus latiflorus* prefers high rainfall and grows best in moist, sandy loam fertile soils. This bamboo has sweet edible shoots, and is often used in construction and transportation. In addition to Taiwan, *Dendrocalamus latiflorus* is also cultivated in several countries of South-East Asia, such as Burma, Thailand, Vietnam, Japan, Philippines and Indonesia (Lü 2001).

Wang (2004) investigated age structure, culms biomass stock and carbon storage in *Denrdrocalamus latiflorus* at different ages (1 to 5 years) in Yue-Tzu village, Nan-ton county. He found out number of culms aged at 2-3 year is most abundant, and biomass stock and carbon storage of bamboo culms decreased with increasing height in culms height. However, biomass stock and carbon storage increased with increasing age of bamboo. According to allometric equation, culms biomass is 77.9

Mg ha^{-1} and carbon storage is 37.7 Mg ha^{-1}. While only culms biomass was reported in Wang (2004), based on the study of culms ratio to biomass aboveground in Chen et al. (2012), biomass aboveground in Wang (2004) was extended estimated to be 115.4 Mg ha^{-1} and carbon storage to be 55.8 Mg ha^{-1} with carbon sequestration 11.2 Mg ha^{-1} yr^{-1} in this paper.

4. *Bambusa stenostachya*

Bambusa stenostachya is an endemic clumping species widely distributed at low elevation lands in Taiwan. *Bambusa stenostachya* was cultivated as wind-break forests on the farm land (Lü 2001). It is a major species for forestation in the mudstone area in Taiwan. Usually, *Bambusa stenostachya* was culms dense per clump with culms over 16 m in height.

Chen et al. (2012) investigated *Bambusa stenostachya* plantations in the mudstone area in Tainan City. This bamboo forest was planted 60 years ago with planting density 625 culms / ha. Now, the stand has 300 clumps/ha with culms density 24533 culms/ha.

Chen et al. (2012) classified clumps into three categories based on clumps size. They showed that while culms density per clump is biggest in the large clump, culms density per m^2 is fewest, implying the more space for individual culms, therefore, with the biggest DBH, height and biomass in large clump (Table 10). Biomass is calculated by allometric relationship to DBH.

Table 10. The clumps density and aboveground biomass (kg/clumps)

Clumps size (m^2)	Clumps density (culms/m^2)	DBH (cm)	Height (m)	Leaf (kg)	Branches (kg)	Culms (kg)	Total (kg)
Small (7.1)	8.9	8.7± 1.7	15.3± 3.4	33.3	28.9	335.2	397.4
Medium (9.3)	8.0	9.3 ±1.6	17.4± 3.9	72.2	67.2	804.2	943.6
Large (33.4)	4.5	10.2±1.7	20.3± 2.3	105.4	561.0	1341	2007.4

Based on figures in clumps, the biomass aboveground in the bamboo stands was estimated. The biomass underground was calculated based on the average size and biomass on sample stumps, and converted to ha base (Table 11).

Table 11. The above and underground biomass in *Bambusa stenostachya* stands (Mg ha^{-1})

Culms	branches	leaf	Aboveground biomass	Underground biomass	Total biomass
208±12.2	17.5± 1.0	18.3± 0.8	243.8±14.0	318.7 ±33.3	562.5± 47.4

Comparison biomass and carbon storage among bamboo species in Taiwan

Table 12. Biomass, carbon storage and sequestration for 4 species in Taiwan

Bamboo species	Biomass aboveground ($Mg\ ha^{-1}$)	Carbon storage aboveground ($Mg\ ha^{-1}$)	Carbon sequestration aboveground ($Mg\ ha^{-1}\ yr^{-1}$)
(Phyllostachys makinoi)	61.88	29.14	5.81
(Phyllostachys pubescen)	114.6	54.65	10.94
(Denrdrocalamus latiflorus)	115.44	55.8	11.16
(Bambusa stenostachya)	243.8	114.51	22.90
Average	133.93	63.53	12.70

While for a given species, the biomass aboveground varies at different sites (Table 7), generally, the biomasses aboveground of sympodial bamboos are higher than those in monopodial types because of the bigger size in culms in the former and the major contribution of culms to biomass aboveground for both bamboo types (Table 12). The trend of carbon storage is identical to the trend of biomass aboveground among species.

Biomass underground for those species which have been studied before showed that, compared to biomass aboveground, the proportion of biomass underground in the total biomass varies among species and sites (Table 5, 11). Generally, the biomass amount belowground is approximately about 1/4 of biomass above ground in broadleaf tree forests (FFPRI 2007) or 29% of total biomass in camphor tree biomass (Lee and Feng 2010), however, in the bamboo forest, underground biomass shares bigger amount in the total biomass (Table 5) because of lots of rhizomes below the ground. For example, in the makino stands at Shihmen Reservoir Watershed Area, the average of biomass belowground is about 3 times the biomass above ground (Chen et al. 2009 a). Therefore, it is quite important to bring the underground biomass into when we calculate the bamboo biomass and carbon storage.

Comparison bamboo biomass between bamboo, natural forests and plantations

In natural forests without human intervention, the biomass is great because of high volume stocks in the species composed. However, the stand development in natural forests is slow and the net increment of volume of whole stand is low, thus the carbon sequestration is low even a high carbon storage exists in the natural forest. For example, in the 10 years period, the carbon sequestration is only 0.67 Mg ha^{-1} yr^{-1} which is much less than carbon sequestration (2.66 ~5.23 Mg ha^{-1} yr^{-1}) in the Taiwan red cypress and Japanese cedar plantations (Yen and Wang 2013).

While the biomass above ground in makino bamboo is less than that in tree forests, for instance, 204 Mg ha^{-1} in *Taiwania cryptomerioides* (Lin et al. 2004), 170.99 Mg ha^{-1} in subtropical mixed deciduous broadleaf forests and 103.74 Mg ha^{-1} in subtropical broadleaf evergreen plantations (Chen et al. 2009 a), 99.5 Mg ha^{-1} in China fir (Yen and Lee 2011), 68.5~96.81 Mg ha^{-1} in Taiwan red cypress, and 101.14~164.80 Mg ha^{-1} in Japanese cedar (Yen and Wang 2013). Owing to the more rapid growth occurring in bamboo, the annual biomass growth in makino bamboo forest is greater than that of *Taiwania cryptomerioides* (14.76 Mg $ha^{-1}yr^{-1}$ vs. 9.8 Mg $ha^{-1}yr^{-1}$) (Chen et al. 2009 a). Therefore, comparing with trees, carbon sequestration contributions attributed to bamboo forest is obvious greater than one to tree forests. In other words, to achieve the same amount of fixed carbon, bamboo only takes 1/3 to 1/2 of time required by trees (Yen et al. 2010).

The average carbon sequestration in northern hemisphere temperate forest is 0.5±0.3 Mg ha^{-1} yr^{-1} (Myneni et al. 2001), 0.63±0.31 Mg ha^{-1} yr^{-1} in Africa tropic forests , and 0.49±0.2 Mg ha^{-1} yr^{-1} in American and Asia tropic forests (Lewis et al. 2009). Comparing to the tree forests, bamboo forests in Taiwan showed apparent superiority to tree forests in the carbon sequestration capacity. Therefore, in order to reduce carbon Oxide emission, planting bamboo forest and taking a good management is a good way.

Calculate bamboo biomass and carbon storage in Taiwan

While we do not have exact data about bamboo forest area for key species in Taiwan, based on the average value for species discussed in this paper and the bamboo area of 149561 ha in 2000, the total bamboo biomass aboveground and carbon storage in Taiwan National Forests in 2000 can be roughly estimated to be 20.03 Tg and 9.50 Tg C, respectively.

Conclusions

Bamboo is a great resource in Taiwan. Bamboo is very useful both in culms and shoots. Moreover, in terms of carbon sequestration, bamboos show the great superiority to those in timber forests. Just like the need for thinning practice in the plantations, the cut of old age culms is necessary to maintain the vigor of bamboo forests.

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Figure captions

Figure 1. Four regions in Taiwan

Figure 2. Map of site locations in Shihmen Reservoir Watershed Area,

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