Bamboo biomass

An INBAR Working Paper by I.R. Hunter and Wu Junqi

Abstract

A key issue in the profitability of bamboo plantations is the productivity that can be expected. This working paper summarises the accessible published information. The evidence is scant and contradictory. Consequently it is difficult to reach conclusive findings. However the working paper finds that the biomass of bamboo differs from that of tree crops by degree only. Productivity of bamboo is generally within the range of woody biomass in the same environment with the exception that bamboo culm biomass never seems to reach the very high values attainable by tree stem biomass in favourable situations.

Introduction

A key issue in the profitability of plantations is the productivity of those plantations. There is relatively little published about the productivity of bamboo plantations. This working paper attempts to draw together what is known.

Methodology for Quantifying Bamboo Biomass

Quantifying the biomass of bamboo should pose relatively few new problems to workers experienced in quantifying tree biomass. Bamboo stands can be divided and sampled into the familiar components of :-

1. Leaves
2. Branches
3. Stems or culms. Note however that there may be a complicating factor in the quantification of culms in that the stems are usually hollow. However orthodox ratio-based tree biomass quantification techniques are able to handle this. A further more serious potential complicating factor is that the wet weight: dry weight ratio may vary with the age of the culm – younger culms being wetter. This has implications for those ratio methods generally used to calculate biomass – it being most unusual to weigh and dry the entire biomass. The currently available literature does not seem to address this point.
4. Coarse roots or rhizomes
5. Fine roots.

Bamboo may not grow in pure stands so a complicating factor may be the necessity to include other types of vegetation in the quantification of total biomass or to arrive at a satisfactory method of estimating the proportion of the area covered by bamboo. This seems likely to be more problematic with sympodial bamboo which grows in clumps than with monopodial bamboo (which grows in stands).

Methodology Used

The methodology for quantifying bamboo biomass that has been used by the various authors reviewed in this paper is indeed more or less the same as used for tree biomass. See for example Verwijst *et al.* (1999) for tree biomass methodology and Veblen *et al.* (1980) for its adaptation to bamboo biomass.

1. Most authors worked from a bounded plot, laid out of a sufficiently large size to encompass variation. They measured all the culms inside the bounded plot for diameter and a proportion measured for length. Few of the authors separated culms into different ages although it might be advisable for future workers to test whether classification of the culms into at least three classes (immature, mature and dry) improves accuracy. A subsample of culms was taken, diameter, wet weight and length recorded. From that subsample, leaves, branches and culm were stripped and wet weight recorded. Coarse roots were sometimes dug up and weighed after cleaning. A separate procedure was required to estimate fine roots – either repeat sampling of root cores or root ingrowth cores.
2. A subsample of the leaves, branches and culms (and/or roots) was taken and the wet weight of each component accurately recorded. The subsamples were dried in a cool oven and the dry weight of each component accurately recorded.
3. The biomass was then calculated by working back through the ratios.

Results of studies

1. Total biomass (above ground) and study site environment

Species	Country	Latitude degrees	Altitude masl	Temperature °C	Rainfall mm	Total biomass t/ha	Note	Reference
Chusquea culeou	Chile	40	700	8?	4000	156-162		Veblen *et al.* (1980)
Chusquea tenuiflora	Chile	40	1000	6.5	5633	13	Under-storey	Veblen *et al.* (1980)
Dendrocalamus strictus	India	25	----	26	830	4 – 22		Tripathi and Singh (1994)
Gigantochloa ater; G. verticilata	Indonesia	7	1100	28?	2000	45		Christanty *et al.* (1996)
Bambusa bambos	India	12	540	31	600	122 (at 4) 225 (at 6) 287 (at 8)		Shamnughavel and Francis (1996)
Dendrocalamus strictus	India	24	280-519		1069	30 (at 3) 36 (at 4)		Singh and Singh (1999)

						49 (at 5)		
Phyllostachys pubescens	Japan	34	65	15.3	1581	138		Isagi *et al.* (1997)
Dendroca lamus latiflorus Munro.	China	26^{O}		20.8	1700	28.49		Lin Yiming (2000)
Dendrocalamop sis oldhami	China	24^{O}38'- 25^{O}11'		20.6	1448-2023	134.49		Lin Yiming (1998)
Bashania fangiana	China	32^{O}				0.353	Panda bamboo	Zhou Shiqiang (1997)

One should make several comments about the figures given in Table 1. The *Chusquea tenuiflora* biomass was estimated from bamboo growing under a *Nothofagus* stand with only 35% full light. The results would have been markedly depressed by competition from the trees. The *Bashania* described by Zhou (1997) is a low growing "panda bamboo" that grows at very high altitude and typically has a very low biomass.

On the other hand the figures given by Shamnughavel and Francis (1996) are somewhat surprisingly high given the other data recorded about their sample stand (see comments below Table 3).

The various authors quote other studies (not seen by this author) for comparative purposes. Thus Isagi *et al.* (1997) quote biomass of 114.8 t/ha for *Sasa kurilensis*; 143 t/ha for *Bambusa blumeana*; 146.8 t/ha for *Gigantochloa levis* and 136.8 t/ha for *Phyllostachys bambusoides.* Singh and Singh (1999) add 100 t/ha for *Arundinaria alpina* in Kenya. Christianty *et al.* discuss a 43.2 t/ha biomass in *Phyllostachys pubescens* in Taiwan.

Kleinhenz and Midmore (2001) give a table containing biomass data for 26 bamboo species culled from many authors (including some of those in table 1). Their highest total biomass was that reported by Shamnughavel and Francis (1996). Their next highest biomass was a cluster of observations at approximately 180 t/ha. Their lowest biomass was 7 tonnes/ha (above ground), also from "panda" bamboos. Their overall average was 145 tonnes/ha over a range from 23 to 298 t/ha. However if the surprisingly high value of Shamnughavel and Francis (1996) is excluded the average becomes 130 t/ha.

2. Annual productivity

Species	Annual productivity (t/ha/year)	Reference
Chusquea culeou	10 – 11.4	Veblen *et al.* (1980)
Dendrocalamus strictus	1.8 – 7.0 *	Tripathi and Singh (1993) * culms only
Dendrocalamus strictus	1.8 – 7.7 #	Tripathi and Singh (1994) # excludes other vegetation
Phyllostachys pubescens	18.1	Isagi *et al.* 1997

3. Culm weight

Species	Culm weight (t/ha)	Reference
Chusquea culeou	127-130	Veblen *et al.* (1980)
Chusquea tenuiflora	9.4	Veblen *et al.* (1980)
Dendrocalamus strictus	7.8 - 30	Tripathi and Singh 1993
Gigantochloa ater; G. verticilata	34.4	Christanty *et al.* (1996)
Bambusa bambos	93 (at age 4) 187 (at age 6) 243 (at age 8)	Shamnughavel and Francis (1996)
Dendrocalamus strictus	24 (at age 3) 38 (at age 5)	Singh and Singh (1999)
Phyllostachys pubescens	116.5	Isagi *et al.* (1997)
Dendroca lamus latiforus Munro.	16.67	Lin Yiming (2000)
Dendrocalamopsis oldhami	95.51	Lin Yiming (1998)
Bashania fangiana (young)	0.155	Zhou Shiqiang (1997)

The high dry weights given by Shamnughavel and Francis (1996) are surprising, since the average diameter stated at age 8 (8.3 cm) and the average height (28.5 m) would with the stated number of stems (4250) give a volume for perfect (solid) cylinders of only 218 m^3/hectare.

Kleinhenz and Midmore (2001) tabulate culm weights of between 8 and 243 t/ha: the highest value being that of Shamnughavel and Francis (1996). Their next highest values are 112 and 117 t/ha.

4. Leaf weight

Species	Leaf weight (t/ha)	Reference
Chusquea culeou	25.0 *	Veblen *et al.* *Note: weight of "leaves and sheaths"
Chusquea tenuiflora	3.5 *	Veblen *et al.* (1980)
Gigantochloa ater; G. verticilata	4.7	Christanty *et al.* (1996)
Bambusa bambos	1.9 (at age 4) 3.5 (at age 6) 4.0 (at age 8)	Shamnughavel and Francis (1996)
Dendrocalamus strictus	6.1 (at age 3) 7.9 (at age 4 10.7 (at age 5)	Singh and Singh (1999)
Phyllostachys pubescens	5.9	Isagi *et al.* (1997)
Dendrocalamus latiflorus Munro.	3.37	Lin Yiming (2000)
Dendrocalamopsis oldhami	14.81	Lin Yiming (1998)
Bashania fangiana (young)	0.122	Zhou Shiqiang (1997)

The two Chusquea stands in Chile have very high leaf weights because the component was estimated from "leaves and sheaths". These results are therefore not strictly comparable with others. The figure of 4.27 tonnes/ha/year given for litterfall in the more productive stand (see table 8) is probably a better estimate of leaf mass.

Kleinhenz and Midmore (2001) tabulate leaf weights of between 1 and 37 t/ha. The highest value aside, the next highest leaf weight was 11 tonnes/ha.

A slightly unusual feature of bamboo species generally by comparison with woody biomass, highlighted by Kleinhenz and Midmore (2001) is the high uptake of potassium in their leaves. Bamboo species seem generally to have a 1:1 ratio of nitrogen to potassium. This may have implications for site preference.

5. Branch weight

Species	Branch weight (t/ha)	Reference
Gigantochloa ater; G. verticilata	6.0	Christanty *et al.* (1996)
Phyllostachys pubescens	15.5	Isagi *et al.* 1997
Dendroca lamus latiforus Munro.	8.45	Lin Yiming (2000)
Dendrocalamopsis oldhami	28.17	Lin Yiming (1998)
Bashania fangiana (young)	0.076	Zhou Shiqiang (1997)

Kleinhenz and Midmore (2001) tabulate branch weights of 6 to 40 t/ha.

6. Coarse roots and rhizomes

Species	Coarse root weight (t/ha)	Reference
Gigantochloa ater; G. verticilata	10.5 + 2.1	Christanty *et al.* (1996)
Dendrocalamus strictus	11.9 (at age 3) 14.0 (at age 4) 18.8 (at age 5)	Singh and Singh (1999)
Phyllostachys pubescens	16.7	Isagi *et al.* (1997)
Dendroca lamus latiforus Munro.	3.31	Lin Yiming (2000)
Dendrocalamopsis oldhami	12.00	Lin Yiming (1998)
Bashania fangiana (young)	0.064	Zhou Shiqiang (1997)

7. Fine roots

Species	Fine root weight (t/ha)	Reference
Dendrocalamus strictus	7.0 – 8.7	Tripathi and Singh (1993)
Gigantochloa ater; G. verticilata	18.9	Christanty *et al.* (1996)
Dendrocalamus strictus	3.6 (at age 3) 5.3 (at age 5)	Singh and Singh (1999)
Phyllostachys pubescens	27.9	Isagi *et al.* (1997)

Dendrocalamus latiforus Munro.	1.10	Lin Yiming (2000)
Dendrocalamopsis oldhami	9.60	Lin Yiming (1998)
Bashania fangiana (young)	0.079	Zhou Shiqiang (1997)

8. Litterfall

Species	Litterfall per year (t/ha/yr)	Reference
Chusquea culeou	4.27	Veblen *et al.* (1980)
Chusquea tenuiflora	0.09	Veblen *et al.* (1980)
Dendrocalamus strictus	4.1 – 1.2	Tripathi and Singh (1994)
Bambusa bambos	9.2 –11.8	Shamnughavel and Francis (1996)
Phyllostachys pubescens	4.4 (6.8 including twigs and sheaths)	Isagi *et al.* (1997)

The litterfall in an established stand of bamboo (in what is an overlapping deciduous plant, where new leaf creation is matched by old leaf senescence) should be roughly equal to the new leaf production. That relationship is broken in the paper of Shamnughavel and Francis (1996). Their leaf weight data is in line with that of other authors but their annual litterfall is not sustainable since it greatly exceeds the total leaf weight.

Singh and Singh (1999) give estimates for litter decomposition of 28 months for 95% mass loss and 8 months for 50% mass loss. Christanty *et al.* (1996) on the other hand thought that bamboo litter decomposed relatively slowly due to its high silica content. They noted that their forest floor at 36 months consisted mainly of bamboo leaves, indicating their relatively slow decomposition.

Discussion

Given the very high degree of variability in the data, it is very difficult to generalise.

For example one would expect a broad relationship between productivity, temperature and rainfall. Kleinhenz and Midmore (2001) quote from several other authors stating that "precipitation affects distribution and limits growth of bamboo more than any other component of climate, except temperature." However such a relationship is difficult to discern in these data.

It does appear that one can generalise, however, that the amount and distribution of bamboo biomass differs from that for tree biomass by degree only. For example Winjum *et al.* (1997) estimate that mean carbon storage in above- and below-ground biomass of forest plantations is 47 t C/ha in high latitudes, 76 t C/ha in middle latitudes, 62 t C/ha in low-dry latitudes and 80 t C/ha in low- moist latitudes. Since carbon is approximately 40% of biomass these figures are equivalent to between 100 and 160 t/ha of biomass.

Santa-Regina and Tarazona (2001) report total biomass ranged from 132.7 t/ha in a beech stand to 152.1 t/ha in the pine stand in Northern Spain. Thus the biomass figures given in table 1 of this paper and in Kleinhenz and Midmore (2001) are fairly much within the expected range for woody biomass.

The key differences are the smaller piece size and higher number of "stems" typical of a bamboo plantation and that bamboo biomass never seems to approach the very high figures possible in some tree stands. For example Alabeck and Juday (1989) report volume estimates for Sitka Spruce in Southern Alaska that would be consistent with dry biomass of over 700 t/ha. Silvester and Orchard (1999) report up to 1700 t/ha of above ground biomass in Kauri (*Agathis*) in New Zealand. Ponette *et al.* (2001) found that total aboveground biomass of Douglas Fir in France increased with increasing stand age, from about 160 t ha-1 in the youngest stands to 360 t ha-1 in the 54-year old plot. Simpson *et al.* (2000) reported that for Queensland total biomass at clearfall of a typical slash pine stand was 316 t/ ha. Laurance *et al.* (1999) studying biomass in the tropical rainforest around Manuas Brazil found that biomass estimates varied more than 2-fold, from 231 to 492 t/ ha, with a mean of 356 t/ ha.

This difference between bamboo and tree crops means that while on average bamboo may sequester as much carbon as tree crops on sites favourable to trees, plantations of trees will sequester much more.

Annual productivity figures (table 2) indicate that bamboo can produce at between 10 and 20 t/ha/year. Kleinhenz and Midmore (2001) tabulate the age class distribution of bamboo stems. They show that for most species culms are distributed between four years of growth. Their average total biomass figure of 130-142 t/ha can therefore be roughly re-worked to show a maximum annual productivity of between 32 and 36 t/ha – lower if the culms last for longer. However growth rates of between 10 and 30 t/ha are not exceptional amongst woody biomass species. Heilman and Xie (1993) report mean annual woody biomass production (aboveground), of between 21 and 25 t/ha/yr in poplar in Canada and in a later paper reported increments of 35 t/ha/yr. Stanley and Montagnini (1999) report that in young plantations of 4 indigenous tree species in Costa Rica total annual tree biomass production rates ranged from about 5.2 t/ha to 10.3 t/ha. Anil-Kumar *et al.* (1998) report 17 t/ha/yr for *Acacia auriculiformis*. Srivastava (1995) estimated 29 t/ha/year for *Casuarina equisitifolia* in Uttar Pradesh, India, showing that the performance of Casuarina is good under dry tropical conditions. Kadeba (1991) reported that mean annual biomass production of *Pinus caribaea* in N. Nigeria was 10.75 t/ha over the 15-year period.

The data for bamboo leaf biomass is variable (table 4). Most stands appear to have leaf weights of ~ 5 tonnes per hectare although there are two observations at 10.7 and 14.8 tonnes/ha. Kleinhenz and Midmore (2001) likewise report leaf weights of between 1 and 11 t/ha with one outlier of 37 t/ha. Five of their 8 observations are 6 t/ha or less. If it were generally true that bamboo has leaf weights of approximately 5 tonnes/hectare yet high productivity that might indicate a possible quantitative difference with tree crops. Tree crops sometimes have higher leaf biomass. For example Chen *et al.* (1998) report that the biomass of a 9-yr-old *Casuarina equisitifolia* stand in Taiwan was 119.3 t/ha (7.4, 27.6, 63.5, and 20.8 t/ha for leaves, branches, stems, and roots, respectively). Madgwick (1985) reported that needle mass can reach 15 t/ha in Radiata pine stands 4-8 year old, but drops to about 10 t/ha in older stands. Thus bamboo may produce more dry matter per unit of leaf mass than some tree crops, but the data are inadequate to determine this.

Bamboo invests a sizeable proportion of its energy below-ground. However the amount may not be significantly greater than for many tree crops. Oleksyn *et al.* (1999) found that total root biomass accounted for between 19 and 28% of total stand biomass in 12-year-old Scots pine (*Pinus sylvestris*) from 19 populations grown in a provenance experiment in central Poland (52°N.). Naidu *et al.* (1998) found that dominant trees of loblolly pine allocated 63.4, 13.2, 11.3, and 12.0% of biomass to bole, branch, needle and root tissue, compared with 75.9, 6.7, 5.6, and 11.7% for suppressed trees. Gaston *et al.* (1998) report that in grass/shrub savannas of Africa the aboveground forest biomass accounted for 75% of the total, below-ground forest biomass for 21%, and grass/shrub savannas for 4%. Heilman *et al.* (1994) working with four-year old poplar found that total weight of stumps and coarse roots at harvest varied from 12.3 to 29.6 t/ha, or 22-33% of the weight of above-ground leafless biomass. Thus the above-ground: below-ground distribution of biomass in bamboo may not be unusual.

Conclusion

The variability of the currently published data makes it difficult to generalise. More, simple biomass determinations are needed. Ultimately the bamboo-growing industry needs a simple productivity relationship linking bamboo biomass growth to environmental variables but to calculate such, much more data are needed.

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