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RESEARCH PAPER

Managing Bamboo for Carbon Sequestration, Bamboo Stem and Bamboo Shoots

Weiguang Wu · Qiang Liu · Zhen Zhu · Yueqin Shen

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Abstract Bamboo forests are fast growing and renewable resources, and their carbon sequestration potential has attracted wide attention. Bamboo can be used for multiple purposes. *Land expectation value* (LEV) was estimated for various moso bamboo management models using the Faustmann–Hartman formula. Sensitivity analysis was also conducted to examine the impacts of carbon policy, interest rates, stem and shoots prices, and labour costs on LEV and management model choice. Two moso bamboo management models, one for stem production and another for stem and shoots production, were compared. Under current market conditions the estimated LEV per ha of stem bamboo plantations and for stem and shoots bamboo plantations were 48,454 and 51,292 CNY (Chinese Yuan. USD 1 = CNY 6.46 in year 2011) in the baseline year of 2011 respectively, and annual above-ground carbon sequestration potential of mature stands was 4.30 and 3.38 tons per ha, respectively. If carbon credits were available to growers, the LEV would increases and it seems likely farmers will be induced to expand the moso bamboo forested area, and convert some stem and shoots bamboo plantation into stem bamboo

W. Wu (✉) · Z. Zhu · Y. Shen
School of Economics and Management, Zhejiang Agriculture and Forestry University,
Lin'an 311300, Zhejiang, China
e-mail: wuwgccap@126.com

Z. Zhu
e-mail: zhuzhen8149278@126.com

Y. Shen
e-mail: shenyueqin-zj@163.com

W. Wu · Z. Zhu · Y. Shen
Center for Farmer's Development Research, Hangzhou, Zhejiang Province, China

Q. Liu
School of Management, Zhejiang Universitiy, Hangzhou 310058, Zhejiang Province, China
e-mail: niumeng119@126.com

plantation, leading to greater carbon sequestration intensity. The LEV for stem and shoots bamboo plantations appears more sensitive to labour cost, while LEV for stem bamboo plantations is more sensitive to the price of stems. Low interest loans provided by the government to farmers or a carbon emission reduction credit trading system may help promote improved moso bamboo management.

Keywords Moso bamboo (*Phyllostachy pubescens*) · Management model · Land expectation value (LEV) · Sensitivity analysis · China

Introduction

Bamboo crops are highly important to the livelihoods of rural populations in Asia, Latin America and Africa. Bamboo can serve multiple uses, including food, construction material, and furniture (Marsh and Smith 2007). The global bamboo forest area is about 31.5 M ha, accounting for about 1 % of total forested area. Although the total forested area has continued to decline over the last 30 years, the area of bamboo has increased at an average rate of 3 % annually (FAO 2010). There are about 2.5 billion people worldwide who utilize various bamboo-related products daily (Belcher 1995; Scurlock et al. 2000). Bamboos are native to China, which has 5.38 M ha of bamboo forests and a rapidly emerging bamboo economic sector worth USD 11.8 billion annually (Buckingham et al. 2011).

Bamboos are among the fastest growing renewable forest resources, with high economic and ecological values (Guo et al. 2005). Moso bamboo (*Phyllostachy pubescens*) is one of the most valuable and important bamboo species. An individual stem of moso bamboo can complete its physical growth—or reach maturity in terms of the physical quality—within 1 year. At stand level, newly planted moso bamboo plantation takes 7–10 years to reach full canopy closure where light can barely penetrate to the forest floor. The limited sunlight reduces the amount of vegetation growing under and between the mature stands, leaving the ground mostly free of weeds. Moso bamboo is grown under uneven-aged management without a specific biological rotation age. Once the moso bamboo plantation reaches canopy closure it can be selectively harvested biennially and generate a stable income flow. It is only when the moso bamboo is widely flowering that the stand is dieing. Although moso bamboo has been observed to flower in intervals of at least 67 years (Watanabe et al. 1982; Shibata et al. 2002), flowering is usually restricted to individual clumps and not likely to result in death of a total stand. Therefore moso bamboo plantations can be managed and harvested biennially for many years after stand maturity.

As a highly important components of forest resources, bamboos possess valuable and unique features, including rapid growth, high annual regrowth after harvesting, and high biomass production (Zhou and Jiang 2004; Yen and Lee 2011). These features have received attention for their potential to mitigate climate change (Henley and Lou 2009; Ly et al. 2012). Bamboo can be integrated into an array of forest-based climate change mitigation activities, including afforestation, reforestation, avoided deforestation, and forest management (Lobovikov et al. 2012; Kuehl et al. 2013).

The carbon sequestration capacity of bamboos has been intensively investigated in recent years. Chen et al. (2009) estimated bamboo forest carbon storage rates at national and regional levels in China. Various authors have compared carbon sequestration capacity of bamboo stands and other forest stands, including Chinese fir, Masson pine, eucalypts (e.g. Xiao et al. 2007; Jiang et al. 2011; Yen and Lee 2011; Ly et al. 2012; Kuehl et al. 2013). The impacts of the forest management system on carbon sequestration capacity of bamboo plantation have also been evaluated (e.g. by Zhou et al. 2006; Tang et al. 2012; Kuehl et al. 2013).

Carbon sequestration capacity has usually been examined from a biophysical perspective, without consideration of changing markets and policies, including rising labour costs and changes in interest rates, carbon prices, and prices of bamboo stem and shoots. Because bamboo yields multiple products, understanding how to diversify production to maximize the financial return is important to bamboo growers. Management decisions related to varying production objectives will depend on market and economic conditions. Questions land managers may ask include: 'What are the financial and ecological differences among various bamboo management systems?'; 'How do changes in markets and governmental policies affect the *land expectation value* (LEV) of bamboo plantations?'; and 'How will landowners and forest managers respond to changes in markets and government policies?' All of these questions should be examined to improve manage bamboo management.

Based on management objectives, moso bamboo plantations can be classified into: (1) stem bamboo plantations (with stem as the main output); (2) stem and shoots bamboo plantations (with both stem and shoots as the main output); and (3) shoots bamboo plantations (with shoots as main product). This paper focuses only on management of stem bamboo plantations and stem and shoots bamboo plantations because it is rare to manage and produce shoots only.

The main objectives of this paper are to estimate the *land expectation value* (LEV) of various moso bamboo management models, and to examine the impacts on LEV and management model choice with respect to carbon policy, the discount rate, stem and shoots prices, and labour costs, as well as to draw policy implications about how to improve moso bamboo management.

The Study Area

Zhejiang province was selected as the study area because this is a major area of bamboo production and has a rapidly emerging bamboo economy sector. The existing area of bamboo stands in the province is 0.83 M ha, of which moso bamboo accounts for more than 70 %. The total economic output value of the bamboo sector was about 30 billion CNY in 2011, accounting for one-third of the Chinese national bamboo sector output value.

Various management models for moso bamboo plantations are adopted in Zhejiang province, typically based on the production of stems, shoots, or both. Since the 1980s, the province has been implementing a strategy of using bamboo to substitute for wood to cope with the declining domestic wood supply and to narrow the income disparity between rural and urban residents. Through government subsidies and technical support by government, the bamboo forested area expanded dramatically during the 1980s and 1990s, and various models of moso bamboo plantation management have emerged.

An'ji and Longyou are two key bamboo production counties in Zhejiang, and both have abundant bamboo forests and strong bamboo industry sectors. In 2012 An'ji had bamboo forests measuring 72,000 ha and an industry sector worth about 1.2 billion CNY, and Longyou had 28,400 ha of bamboo with an industry sector worth about 0.26 billion CNY.

Research Method

No fundamental difference of input and output in managing moso bamboo is found prior to stand maturity (canopy closure); the major departure is when moso bamboo plantations reach stand maturity, and greater inputs are usually required for stem and shoots than for stems only. When moso bamboo reaches a fully closed canopy, decisions are needed regarding output objectives, and the inputs and outputs remain stable thereafter. If bamboo shoots production is chosen, the bamboo will need more intensive management, such as weed and other shrub control, tilling the soil and applying fertilizer. Therefore the LEV of a moso bamboo plantation can be divided into two parts: the cumulative discounted net cash flow (CNCF) before the moso bamboo plantation reaches stand maturity, and the CNCF after the moso bamboo reaches stand maturity. For this purpose, the model is formulated as follows:

$$NPV_{\infty} = CNCF_b + CNCF_m \tag{1}$$

$$CNCF_b = \sum_{t=1}^{T_b} \frac{(R_t^{bs} + R_t^{bc} - C_t^b)}{(1+r)^t} - C_0 \tag{2}$$

$$CNCF_m = \sum_{t=T_b+1}^{\infty} \frac{(R_t^{ms} + R_t^{mc} - C_t^m)}{(1+r)^{t-1}} = \frac{(R_t^{ms} + R_t^{mc} - C_t^m)}{r(1+r)^{T_b}} \tag{3}$$

where NPV_{∞} is the net present value for bare land assuming perpetual moso bamboo management, $CNCF_b$ is the cumulative discounted net cash flow before moso bamboo reaches stand maturity, and $CNCF_m$ is the cumulative discounted net cash flow after moso bamboo reaches stand maturity. T_b is number of years from planting to stand maturity. R_t^{bs} and R_t^{bc} are the annual revenue from stem (including shoots) and carbon sequestration in year t. Carbon storage was calculated based on the biomass of the moso bamboo plantations; more details about calculating the amount of carbon sequestrated can be found in Meng et al. (2014). C_t^b is the annual input cost before stand maturity. C_0 is the afforestation cost including land preparation, purchase of seedlings, planting, tending and fertilizer. R_t^{ms} is the annual revenue from moso bamboo stem and shoots, R_t^{mc} is the average revenue annually from carbon sequestration, and C_t^m is the average input cost annually after stand maturity. Sensitivity analysis was conducted to examine the impacts of carbon policy, interest rate, stem and shoots prices and labour cost on LEV and management choice.

A household survey was conducted in An'ji and Longyou counties. Purposive selection was adopted in which two towns with abundant moso bamboo plantations were chosen in each county, two villages with abundant moso bamboo plantations were chosen in each town, and 6–8 households that planted moso bamboo plantations were randomly sampled in each village. It should be noted that some households have more than one moso bamboo plantation. A written questionnaire was developed to obtain data about land characteristics of moso bamboo plantations, management models, input factors required (including seedlings, labour and fertilizer), outputs (bamboo stem, bamboo shoots) and product sales. In addition, five experts on moso bamboo cultivation were interviewed to obtain general information about moso bamboo management. Land quality is a critical factor dramatically affecting the status of moso bamboo management. Therefore, to ensure the analysis results are comparable, only moso bamboo plantation samples from similar sites were selected for the final analysis. A total 61 moso bamboo plantations, including 32 stem and 29 stem and shoots plantations, from 48 households were selected.

Results and Discussion

Table 1 summarizes the input and output data of the two moso bamboo plantation management models based on survey data. The input levels are the same for the two management models for moso bamboo plantations before stand maturity, but differ greatly after stand maturity. Moreover, like any other land-use change, some investment is needed to transition from stem bamboo plantation to stem and shoots bamboo plantation.

Based on the survey data, the annual net revenue after stand maturity was estimated to be 5,475 and 5,781 CNY for stem bamboo plantations and stem and shoots bamboo plantations, respectively (Table 2). The input costs and output prices used were: labour cost at 125 CNY per man-day, bamboo seedlings at 15 CNY per seedling, fertilizer at 2.71 CNY/kg, bamboo stem priced at 0.79 CNY/kg, spring shoots at 1.29 CNY/kg, and winter shoots at 15.9 CNY/kg. A discount rate of 5 % was adopted for the baseline analysis based on current mortgage rates and other major bank loan rates in China. Carbon sequestration estimates have been made for above-ground material only (stems, branches, and leaves).

Without considering carbon sequestration value, LEV is 48,454 and 51,292 CNY for stem bamboo plantations and stem and shoots bamboo plantations, respectively. There appears to be no fundamental difference between stem bamboo management and stem and shoots bamboo management under current market conditions. If carbon emission reduction credits (CERs) were available, the LEV would increase.

Table 1 Inputs and outputs of two management models for moso bamboo plantation (CNY/ha)

Item	Unit	Stem bamboo	Stem and shoots bamboo
Afforestation (year 0)			
Land preparation	man-days	39.4	39.4
Planting	man-days	30.9	30.9
Tending	man-days	14.1	14.1
Seedling	seedlings	395	395
Fertilizer, pesticide	kg	124	124
Before stand maturity (year 1–8)			
Tending	man-days/year	12.3	12.3
Fertilizer, pesticide	kg/year	200	200
Additional investment (year 8)	man-days	0	30
After stand maturity (year 9 forward)			
Tending	man-days	5.4	9.1
Stem harvesting	man-days	14.0	10.0
Shoots harvesting	man-days	1.9	12.0
Fertilizer, pesticide	kg	118	304
Output (year 9 forward)			
Stem yield	kg	10,090	7,933
Shoots yield	kg	273	1,973

Table 2 LEVs of two management models for moso bamboo plantations (CNY/ha)

Item	Unit	Stem bamboo	Stem and shoots bamboo
Afforestation cost	CNY	16,747	16,747
Accumulative net present value of costs (years 1–8)	CNY	11,345	12,211
Annual net revenue after stand maturity (year 9 forward)	CNY	5,475	5,781
Land expectation value (LEV)	CNY	48,454	51,292
Cumulative carbon sequestration before stand maturity (years 0–8)	tons	20.6	20.6
Annual carbon sequestration after stand maturity (year 9 forward)	tons/year	4.30	3.38

Stem and shoots bamboo includes additional investment in year 8

The annual value of above-ground carbon sequestration was estimated at 4.30 and 3.38 tons per ha for stem and stem and shoots bamboo plantations after stand maturity, respectively.

Carbon policy, prices, labour cost, and interest rates are undergoing change in China, and such changes will affect LEVs and moso bamboo management model selection. Sensitivity analysis plays an important role by systematically testing how LEV and moso bamboo management models would change. In this paper the sensitivity analyses are performed jointly for the two moso bamboo managements based on the common critical parameters. The results of the sensitivity analysis are presented in Figs. 1, 2, 3, 4 and 5.

Figure 1 shows that LEV correlates positively with carbon price. Stem bamboo plantations more sensitive to carbon price change than stem and shoots bamboo plantations because the former have relatively higher carbon storage capacity. If the carbon price were to reach 300 CNY per ton, the LEV of stem bamboo plantations would exceed that of stem and shoots bamboo plantations. Under this condition, converting stem and shoots bamboo plantations into stem bamboo plantations would increase returns and could increase carbon sequestration capacity as well.

Figure 2 shows that LEV decreases with increasing labour costs. Stem and shoots bamboo plantations are more sensitive to labour cost change than stem bamboo

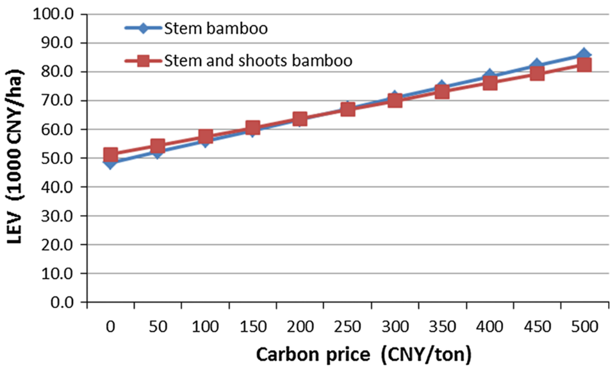

Fig. 1 The impact of carbon price on LEV

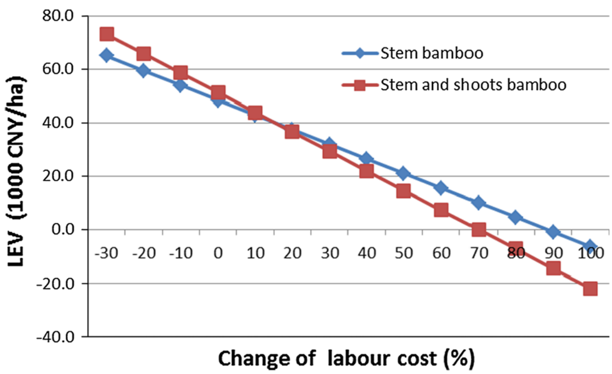

Fig. 2 The impact of labour cost change on LEV

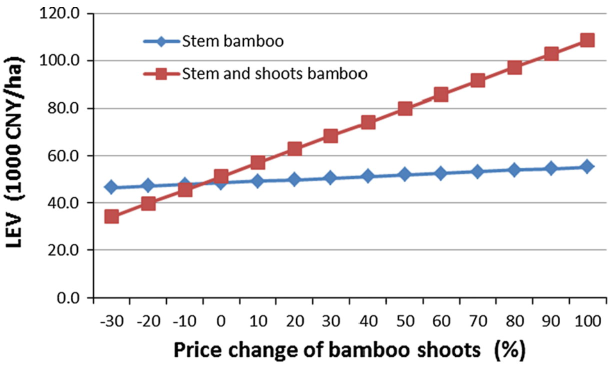

Fig. 3 The impact of stem price on LEV

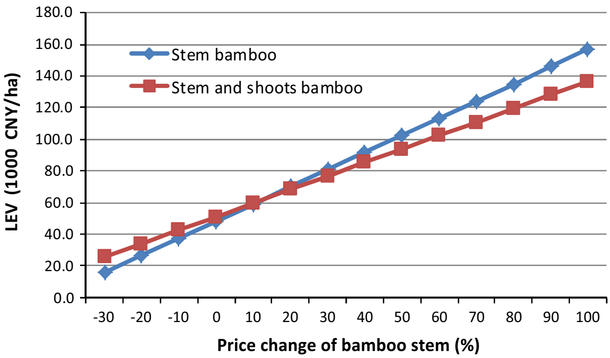

Fig. 4 The impact of shoots price on LEV

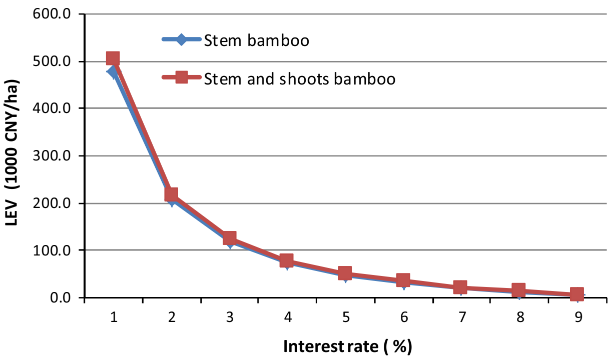

Fig. 5 The impact of interest rate on LEV

plantations because the former requires more labour input. If the labour cost were to increase by 20 % (150 CNY per man-day), the LEV of stem bamboo plantations would exceed that of stem and shoots bamboo plantations. If the labour cost increased by 70 and 90 % for stem and stem and shoots bamboo plantation respectively, the LEV would approach zero. Moso bamboo management cannot generate land value at these higher labour costs.

Figure 3 shows that LEV increases sharply with increasing bamboo stem prices. Stem bamboo plantations are more sensitive to price changes than stem and shoots bamboo plantations because the former have higher stem yields. If the price were to increase by 20 % (0.95 CNY/kg), the LEV of stem bamboo plantation would exceed that of stem and shoots bamboo plantations.

Figure 4 shows that LEV increases moderately with increasing prices of bamboo shoots. Stem and shoots bamboo plantation are more sensitive to price changes of bamboo shoots than stem bamboo plantations because the former have higher bamboo shoots yields. If the price were to drop by 20 % (1.23 and 15.10 CNY/kg for spring and winter shoots, respectively), the LEV of stem bamboo plantations would exceed that of joint stem and shoots bamboo plantations.

Figure 5 shows that LEV changes dramatically with changing interest rates. If the interest rate were 7 %, rather than 5 % the LEV of stem and stem and shoots moso bamboo plantations would be 2,050 and 2,180 CNY rather than 48,454 and 51,292 CNY, respectively. If the interest rate were 10 %, the LEV of both stem and joint stem and shoots bamboo plantations would be approximately zero.

Conclusions

This study provides an example economic evaluation of the forest land use for moso bamboo production, when the value of carbon sequestration is included. Under current market conditions, the LEV differs little between stem and stem and shoots bamboo plantations, but the carbon sequestration capacity of the former is higher than that of the latter. With carbon sequestration benefits included, the LEV of moso bamboo plantation will increase, with stem bamboo plantation management more sensitive to carbon price changes than management of stem and shoots bamboo plantations. If the value of carbon sequestration is factored into the analysis, not only will the land expiation value for bamboo increase, but landowners are likely to shift their focus toward stem bamboo plantations. Therefore, when evaluating production and management model options, either between bamboo and alternative land uses or between stem bamboo plantations or stem and shoots bamboo plantations, land owners and managers should pay close attention to the development of the international carbon market, and governments should establish feasible domestic carbon market policies.

Sensitivity of LEV to prices of inputs and outputs differs between stem bamboo plantation management and management of stem and shoots bamboo plantations. Although LEV will dramatically decrease with increasing labour cost for both management models, returns from management of stem and shoots bamboo plantations are more sensitive to labour price changes. Considering expected labour cost increases, some stem and shoots bamboo plantations will likely convert to stem bamboo plantations, leading to more moso bamboo plantation carbon storage in the future. LEV is closely correlated with prices of stems and shoots of moso bamboo plantations. Clearly, stem bamboo plantations are more sensitive to price change of bamboo stems. In contrast, returns from stem and shoots bamboo plantations are more sensitive to price change of bamboo shoots. In addition, higher interest rates have an obvious negative impact on the LEV of moso bamboo plantations.

Bamboos are not only versatile resources for the livelihoods of many people, but also mitigate impacts of—and adapt to—climate change. This study demonstrates that providing low interest loans and incorporating carbon credits may be viable strategies for promoting bamboo management through economic incentives. Climate change affects populations worldwide, but ultimately will harm the poorest the most. Further policy considerations should be given to ways in which carbon credit systems can substitute for traditional financial support for poverty reduction.

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References

Belcher BM (1995) Bamboo and rattan production to consumption systems: a framework for assessing development options. INBAR Working Paper No. 4, INBAR, New Delhi

Buckingham K, Jepson P, Wu LR, Ramanuja Rao IV, Jiang SN, Liese W, Lou YP, Fu MY (2011) The potential of bamboo is constrained by outmoded policy frames. AMBIO J Human Environ 40(5):544–548

Chen XG, Zhang XQ, Zhang YP, Booth T, He XH (2009) Changes of carbon stocks in bamboo stands in China during 100 years. Forest Ecol Manag 258(7):1489–1496

FAO (2010) Global forest resources assessment 2010: main report. FAO Forestry Paper (FAO), no. 163

Guo QR, Yang GY, Du TZ, Shi JM (2005) Carbon character of Chinese bamboo forest. World Bamboo Rattan 3(3):25–28

Henley G, Lou YP (2009) The climate change challenge and bamboo: mitigation and adaptation. INBAR Technical Paper, INBAR, Beijing

Jiang PK, Meng CF, Zhou GM, Xu QF (2011) Comparative study of carbon storage in different forest stands in subtropical China. Bot Rev 77(3):242–251

Kuehl Y, Li Y, Henley G (2013) Impacts of selective harvest on the carbon sequestration potential in Moso bamboo (*Phyllostachys pubescens*) plantations. For Trees Livelihoods 22(1):1–18

Lobovikov M, Schoene D, Lou YP (2012) Bamboo in climate change and rural livelihoods. Mitigat Adapt Strateg Global Change 17(3):261–276

Ly P, Pillot D, Lamballe P, de Neergaard A (2012) Evaluation of bamboo as an alternative cropping strategy in the northern central upland of Vietnam: above-ground carbon fixing capacity, accumulation of soil organic carbon, and socio-economic aspects. Agric Ecosyst Environ 149:80–90

Marsh J, Smith N (2007) New bamboo industries and pro-poor impacts: lessons from China and potential for Mekong Countries. Enterp Dev Microfinance 18(2/3):216–240

Meng HY, Liu Q, Wu WG (2014) Study on the cost-benefit and carbon sequestration capacity of different management type's moso bamboo plantation. J Zhejiang A&F Univ. doi:10.11833/j.issn.2095-0756.2014

Scurlock JMO, Dayton DC, Hames B (2000) Bamboo: an overlooked biomass resource? Biomass Bioenergy 19(4):229–244

Shibata S, Kumar A, Rao IVR, Sastry C (2002) Flowering of *Phyllostachys pubescens* and germination of caryopses. In: Bamboo for sustainable development, Proceedings of the Vth International Bamboo Congress and the VIth International Bamboo Workshop. San José, Costa Rica, 2–6 November 1998, pp 345–365

Tang XL, Fan SH, Qi LH, Liu GL, Guan FY, Du MY, Shen CX (2012) Effect of different managements on carbon storage and carbon allocation in moso bamboo forest (*Phyllostachys pubescen*). Acta Agric Univ Jiangxiensis 34(4):736–742

Watanabe M, Manabe I, Akai T, Ueda K (1982) Flowering, seeding, germination, and flowering periodicity of *Phyllostachys pubescens*. J Jpn For Soc. http://agris.fao.org/aos/records/JP8205984
Xiao FM, Fan SH, Wang SL, Xiong CY, Zhang C, Liu SP, Zhang J (2007) Carbon storage and spatial distribution in *Phyllostachy pubescens* and *Cunninghamia lanceolata* plantation ecosystem. Acta Ecol Sinica 27(7):2794–2801
Yen TM, Lee JS (2011) Comparing aboveground carbon sequestration between moso bamboo (*Phyllostachys heterocycla*) and China fir (*Cunninghamia lanceolata*) forests based on the allometric model. Forest Ecol Manag 261(6):995–1002
Zhou GM, Jiang PK (2004) Density, storage and spatial distribution of carbon in *Phyllostachy pubescens* forest. Sci Silvae Sin 40(6):20–24
Zhou GM, Wu JS, Jiang PK (2006) Effects of different management models on carbon storage in *Phyllostachys pubescens* forests. J Beijing For Univ 28(6):51–55