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Relationship between species diversity and biomass of eucalyptus plantation in Guangxi, south China

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Abstract To reveal the relationship between species diversity and biomass in a eucalyptus (*Eucalyptus urophylla* × *E. grandis*) plantation located in the Dongmen State Forestry Farm of Guangxi, south China, 18 sample plots were established and the total biomass, arbor layer biomass and undergrowth biomass of communities were subsequently harvested. The results were as follows: 1) Species richness in eucalypt plantation had remarkable positive correlation with biomass of arbor layer, undergrowth and community ($\alpha = 0.001$), its correlation coefficients were 0.6935, 0.7028 and 0.7106 respectively. 2) Leaf area index (LAI) had remarkable positive correlation with species richness and undergrowth biomass ($\alpha = 0.001$). Its correlation coefficients were 0.7310 and 0.6856, respectively. 3) Arbor layer biomass had remarkable correlation with soil organic matter and hydrolysable N, its correlation coefficients was 0.6416 and 0.6203 respectively. Species richness had remarkable correlation with soil organic matter and correlation coefficient was 0.6359. Among them, the correlation was significant at the 0.1 level. Undergrowth biomass had little correlation with nine soil nutrients and correlation coefficients were under 0.4. To sum up, species diversity was advantageous to the promotion of the biomass of the eucalyptus plantation, and the variation of LAI and soil nutrient in small-scales could result in the difference of species diversity and biomass in different sample plots.

Keywords eucalyptus plantations, species diversity, biomass, soil nutrient, leaf area index

1 Introduction

As early as more than 100 years ago, the relationship of plant diversity and biomass were discussed in Darwin's *Origin of Species*. In the 1990s, lots of scientists have carried out extensive studies (Tilman et al., 1996, 2001; Hooper and Vitousek, 1997; Hector et al., 1999), but today the relationship of plant diversity and biomass is still an open question (Kaiser, 2000; Loreau et al., 2001). For a long time, the objective of plantation management is to harvest timber by the greatest degree. The vegetation of undergrowth and the ecological functions of plant diversity were not be considered, leading to sharp reduction of plant diversity, soil fertility decline and fall of production, and the plantation sustainable management has been seriously affected (Yao et al., 1991; Sheng and Yang, 1997; Wen, 2006). The reason why the undergrowth vegetation and ecological functions of plant diversity were ignored is that people have inadequate awareness on the relationship between plant diversity and biomass.

China has the largest area of plantations in the world. At present, eucalyptus plantations are developing most rapidly in southern China. Eucalypti are exotic tree species, and is the most controversial plantation tree species in China for their possible bad ecological effect on biodiversity and environment factors such as floristic composition, species diversity, water, soil and so on (Yang et al., 2003; Wen et al., 2005a). Some scholars of China have carried out a lot of research on the eucalyptus plantation, including biodiversity, biomass, productivity and so on (Chen et al., 1995; Yu et al., 1999; Wen et al., 2000a, 2000b, 2005a, 2005b; Wu et al., 2003). However, there is only little research on the relationship between plant diversity and biomass. This research is very important because it can reveal the variation of energy balance, energy flow and nutrient cycling of the ecosystem, provide key data for carbon sinks and the carbon cycle research (Gower et al., 1997; Kurz

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and Apps, 1999; Houghton et al., 2001; Baldwin et al., 2001), and is conducive to sustainable management of eucalyptus plantations.

2 Materials and methods

2.1 Study site and stand descriptions

The study was conducted at the state-owned Dongmen Forest Farm of Guangxi Zhuang Autonomous Region, latitude 22°17'–22°30'N, longitude 107°14'–108°00'E. In area, this forest farm is one of the largest eucalyptus plantations in southern China and has one of the longest histories. This farm experiences a north tropical monsoon climate, characterized by a wet summer and a dry winter. The annual mean temperature ranges from 21.2 to 22.3°C and precipitation varies from 1100 to 1300 mm per year. The average annual evaporation is 1600 mm and relative humidity averages 75%. The natural vegetation belongs to the evergreen monsoon forest in this region, but has gradually been converted into eucalyptus plantations and *Saccharum sinensis* land (Wen et al., 2005a).

The plantations were established using clonal seedlings of a eucalyptus hybrid (*Eucalyptus urophylla* × *E. grandis*) at the same time in April, 1998. The soils were all latosolic red soil developed from arenaceous shale parent materials with heavy texture, poor nutrients, pH values of 5.0–5.5 and soil thickness greater than 1 m. The site conditions were nearly identical, as shown in Table 1. The site was prepared using a mechanical plow (depth 35–40 cm) after a prescribed fire. The plantations were established with a spacing of 3.4 m × 1.7 m. In the first two years, the sites were fertilized with 200 kg nitrogen, 150 kg phosphorus and 100 kg potassium per hectare with base manure of 0.5 kg per pot followed by additional fertilization twice a year; weeding was conducted in a 30 cm radius around each tree.

Three plots (30 m × 20 m each) separated by 100 m were laid out randomly in August, 2005. The sample plot conditions are shown in Table 1. The entire area of each plot was divided into multiple neighboring sub-plots (10 m × 10 m). On the average, each plot had a total of 6 sub-plots.

2.2 Species diversity and importance value

Plant species and its composition surveys of woody (tree seedlings and saplings, shrubs, liana) and herbaceous

(grass and herb) species of the understory vegetation were conducted in each of the 18 sub-plots. All plants were identified by their specific names and the number of each was counted and recorded. Height and coverage were also measured. The species importance value was calculated (Song, 2001). Alpha diversity was evaluated using the following indices as outlined by Magurran (1988): species richness (*S*), and Shannon-Wiener index (*H'*).

2.3 Biomass sampling and allometric equations

The biomass of the community was measured and estimated by the methods of harvest and relative growth (Wen et al., 1988; Feng and Wang, 1999). Height (*H*) and diameter at breast height (DBH) of each eucalyptus tree was measured. Nine trees were selected from each sample plot to represent different size classes according to the distribution of diameter grade of 2 cm. The selected trees were harvested, and fresh weight of bole wood, bark wood, branch, foliage biomass were determined for each tree by the Monsic method, and the fresh weight of main root, coarse roots (root diameter > 2.0 cm), fine roots (0.6–2 cm) and absorbing roots (< 0.6 cm) were determined for each tree by the method of mining entire roots (Wen et al., 1988), and representative sub-samples (ranging from 500 to 2000 g) of each component were taken for moisture determination (dried at 80°C) to calculate total dry mass. For each stand and biomass component, allometric equations were established in the form:

$$W_{ij} = a_{ij} \times (\text{DBH}^2 \times H)^{bij} \quad (1)$$

where W_{ij} is the dry mass of compartment *i* at stand *j*, and *a* and *b* are the intercept and slope parameters to be estimated, respectively. The allometric equations are shown in Table 2.

Otherwise, fresh weight of shrub and herbaceous biomass (aboveground and underground parts) were determined for each sub-plots (10 m × 10 m) and fully harvested, and representative sub-samples (ranging from 1000 to 2000 g) of each parts were taken for moisture determination (dried at 80°C) to calculate total dry mass.

2.4 Soil sampling and analysis

During the biomass harvesting, nine soil profiles were constructed in the number of 1, 3, 5, 7, 9, 11, 15 and 17 sub-plots, respectively. The soil samples were removed from

Table 1 Survey of sample plots

plots	planting time	elevation/m	slope aspect	gradient/°	soil density/(g·cm ⁻³)	organic matter/(g·kg ⁻¹)	canopy density	LAI/(m ² ·m ⁻²)
1	1998–04	90	northeast 27°	9	1.17 ± 0.108	19.2 ± 52.7	0.48	1.48 ± 0.31
2	1998–04	91	northeast 36°	8	1.10 ± 0.09	18.3 ± 50.7	0.55	2.58 ± 0.32
3	1998–04	92	northeast 38°	8	1.16 ± 0.11	21.2 ± 60.5	0.51	2.15 ± 0.21

Note: LAI means leaf area index.

Table 2 Allometric equations of eucalyptus biomass (W in kg, DBH in cm and H in m)

age/year	compartment	allometric equations	correlation coefficient	F value
7.3	stem	$W = 0.012569 \times (D^2 H)^{1.03385}$	0.9976	1420.75
	bark	$W = 0.003495 \times (D^2 H)^{0.90612}$	0.9902	351.08
	branch	$W = 0.000265 \times (D^2 H)^{1.20755}$	0.9620	86.94
	foliage	$W = 0.000143 \times (D^2 H)^{1.15710}$	0.9852	230.66
	root	$W = 0.006238 \times (D^2 H)^{0.91633}$	0.9933	519.96
	total	$W = 0.020259 \times (D^2 H)^{1.01770}$	0.9980	1702.10

Note: all regressions were significant at $F = 0.01$.

each section of 0–20 cm and 20–40 cm. Soil sample was collected for analysis of its organic matter content, total N, P, K, available N, P, K and exchangeable Ca and Mg (Institute of Soil Science, Chinese Academy of Sciences, 1978).

2.5 Leaf area index

Leaf area index was measured by CI-110 Digital Plant Canopy Imager for each sub-plot in August, 2005.

3 Results and analysis

3.1 Species diversity of undergrowth

We all collected a total of 71 species in the 18 sub-plots, belonging to 66 genera and 33 families. There were 52 species in the shrub layer, among which *Litsea glutinosa* and *Rhus chinensis* were the dominant populations with importance values 95.76 and 38.28, respectively. In the herb layer, there were 19 species, of which *Miscanthus floridulus* has an absolute advantage with an importance value of 146.07, followed by *Eupatorium odoratum* with an importance value 59.17. The average species richness of the community is 21.11 ± 4.20 per 100 m². The average number of individuals is 170.28 ± 47.58 per 100 m², and the average Shannon-Wiener index is 2.31 ± 0.16 per 100 m² (Table 3).

3.2 Characteristics of biomass

The community biomasses of each sub-plot are given in Table 4. In the 18 sub-plots, the mean density of eucalyptus trees is 1472 ± 104 hm². The mean diameter 12.13 ± 0.83 cm and the mean height 18.06 ± 1.27 m. The mean total biomass of the community is 112.89 ± 19.49 t/hm², of which the mean biomass of arbor layer and understory vegetation is 109.81 ± 18.96 t/hm² and 3.08 ± 1.02 t/hm², respectively.

3.3 Relationship of species diversity and biomass

A highly significant correlation was found between the species diversity and the arbor layer biomass and

Table 3 Species diversity in each sub-plot

number of sub-plots	number of individuals	species richness	Shannon-Wiener index
1	172	19	2.3195
2	127	18	2.5022
3	93	14	2.2136
4	111	17	2.2344
5	90	16	2.4059
6	99	16	2.2456
7	208	23	2.3117
8	221	27	2.4587
9	170	26	2.6248
10	191	26	2.1696
11	231	28	2.0196
12	189	24	2.1864
13	178	21	2.2376
14	182	20	2.0627
15	185	20	2.4687
16	235	23	2.4227
17	220	24	2.5051
18	163	18	2.1982

community biomass, respectively (arbor layer biomass: $n = 18$, $r = 0.6935$, $F = 14.82$, $p < 0.001$; community biomass: $n = 18$, $r = 0.7028$, $F = 16104$, $p < 0.001$; correlation formula: $y = \exp(b_0 + b_1/x)$). The community biomass and arbor layer biomass all increased with the increase of the species diversity, and the change can be simply described by a graph that always looks like an “S” type (Fig. 1). When the number of species was less than 15, the total biomass of the community is 83.0 t/hm². When the number of species were 15, the total biomass is about 90.0 t/hm². When the number of species is 20, the total biomass is 112.0 t/hm² and the rate of increase was 22.0 t/hm². However, when the number of species is 25, the total biomass is 128.0 t/hm², the rate of increase was decreased significantly to only 16.0 t/hm². The change of arbor layer biomass shows the same trend.

A highly significant correlation was also found between the species diversity and the undergrowth biomass ($n = 18$, $r = 0.7106$, $F = 16.32$, $p < 0.001$; correlation formula:

Table 4 Biomass of communities in sub-plots

number of sub-plots	number of trees	mean DBH/cm	mean height/m	biomass/(t·hm ⁻²)		
				arbor layer	under-growth	total
1	14	12.54	20.45	121.938	2.576	124.514
2	14	10.53	17.39	76.477	2.524	79.001
3	14	10.29	16.17	82.294	2.592	84.887
4	13	13.98	17.31	127.661	2.39	130.051
5	14	11.9	16.147	90.003	1.481	91.484
6	13	11.94	15.39	81.007	1.758	82.765
7	15	12.09	18.77	117.188	3.938	121.126
8	15	12.34	18.35	117.653	2.455	120.108
9	16	13.29	19.07	141.927	3.869	145.796
10	16	11.96	19.73	118.727	5.634	124.361
11	17	12.29	19.39	129.543	5.087	134.63
12	16	12.43	18.09	128.113	3.217	131.33
13	14	11.8	18.19	96.813	2.55	99.362
14	14	11.63	17.18	91.948	2.897	94.846
15	15	12.99	18.01	125.931	2.566	128.497
16	15	12.55	18.8	121.414	3.228	124.642
17	15	11.97	18.41	106.597	3.145	109.742
18	15	11.84	17.95	101.403	3.501	104.904
mean	14.72	12.13	18.06	109.813	3.078	112.891
SD	1.04	0.83	1.27	18.96	1.019	19.492
CV/%	7.09	6.88	7.05	17.27	33.1	17.27

$y = b_0 \exp(b_1 x)$) (Fig. 1). The change of undergrowth biomass also shows the same trend as that of arbor layer biomass and community biomass. This result supported the hypothesis that species diversity has a positive effect on ecosystem biomass.

3.4 Factors affecting species diversity and biomass

The species richness and biomass of undergrowth increased with the increase of the LAI (Fig. 2), and a highly significant correlation was found between LAI and species richness ($r = 0.7310$; $\alpha = 0.001$) and biomass ($r = 0.6856$; $\alpha = 0.001$) of undergrowth, respectively.

The analysis of the soil samples from the nine sub-plots show that, the mean content of organic matters was 19.5 ± 29.2 g/kg, of total N was 0.75 ± 0.05 g/kg, of available N was 101.57 ± 7.63 mg/kg, of total P was 0.51 ± 0.03 g/kg, of available P was 0.43 ± 0.27 mg/kg, of total K was 2.66 ± 0.23 g/kg, of available K was 27.93 ± 5.96 mg/kg, of exchangeable Ca was 64.32 ± 22.61 mg/kg, and of exchangeable Mg was 24.30 ± 4.66 mg/kg (Table 5). The variation coefficient of species richness was 19.89%. That of total biomass and arbor layer biomass were 17.27%, and that of undergrowth biomass was 33.10%. We also found that the high species richness and biomass appeared when

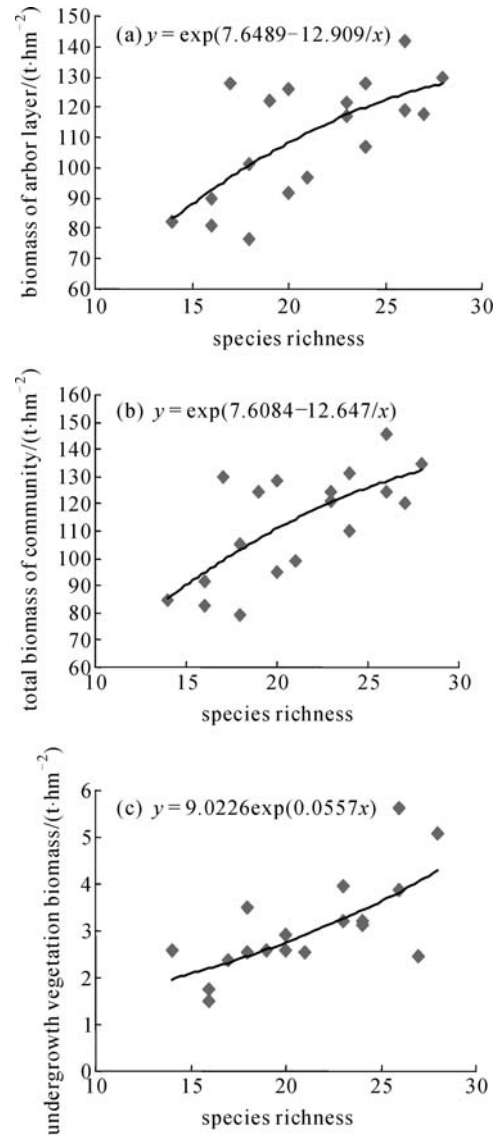


Fig. 1 Relation between species richness and arbor layer biomass (a) and total biomass (b) and undergrowth vegetation biomass (c)

the soil fertility was high (Table 5). The correlation analysis show the species richness, arbor layer biomass and available N had a certain correlation with soil nutrients, except that a positive correlation with soil organic matter at 0.1 level (Table 6). The relationship of undergrowth biomass with nine soil nutrient factors expressed a weak correlation less than 0.4.

4 Conclusions and discussion

Highly significant correlations were found between species diversity and biomass of arbor layer, undergrowth and

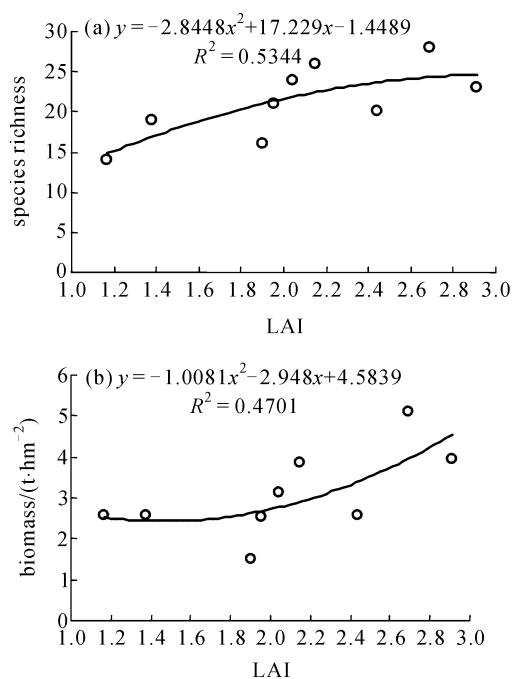


Fig. 2 Relation between LAI and species diversity(a) and undergrowth vegetation biomass (b)

community, and their correlation coefficients were 0.6395, 0.7028 and 0.7106, respectively. It indicated that the proper development of undergrowth plant diversity has a good promotion on biomass of eucalyptus plantations.

The relationship between species diversity and biomass in eucalyptus plantation was affected by lots of environmental factors, especially by leaf area index and soil organic matters. A highly significant correlation was found

between leaf area index and species richness as well as biomass of undergrowth in this study. The leaf area index of eucalyptus plantation was smaller, generally 1.5–3.0 m², mean of that 2 m² (Chen et al., 1995; Zhao et al., 2002; Wen, 2006), so raising LAI of eucalyptus plantations will improve light, heat and high moisture conditions and promote the species diversity and the development of understory plants. The correlation analysis shows the species richness, arbor layer biomass and available N had a positive correlation with soil organic matter at 0.1 level, raising the content of soil organic matters in eucalyptus plantations will promote the species diversity, and more importantly, improve the biomass of the eucalyptus plantations.

Some agreement has existed that undergrowth vegetation promotes ecosystem functions (Yao et al., 1991; Yang et al., 1995a, 1995b; Sheng and Yang, 1997; Jiao et al., 1997; Yang et al., 2003; Sheng and Fan, 2004). However, there is no definite conclusion about the same effect of undergrowth vegetation on tree growth (Shen, 2002). Although the site was prepared using a mechanical plow after a prescribed fire, and no vegetation was reserved, after a serial succession of seven years, there were a rich species diversity including a total of 71 plant species belonging to 66 genera and 33 families in the sample plot of 1800 m². We found weeding in a 30 cm radius around each tree is a better measure than intensive clear-cutting and burning which are used conventionally to maintain undergrowth vegetation.

The relationship between plant diversity and ecosystem biomass is extremely complex. Yet, their relations and the mechanism are not fully understood. It needs more extensive, comprehensive, long-term, quantitative research to draw the final conclusion.

Table 5 Soil nutrient content of sub-plots

number of sub-plots	organic matter/ (g·kg ⁻¹)	total N/(g·kg ⁻¹)	hydrolysable N/(mg·kg ⁻¹)	total P/(g·kg ⁻¹)	available P/(mg·kg ⁻¹)	total K/(g·kg ⁻¹)	available K/(mg·kg ⁻¹)	exchangeable Ca/(mg·kg ⁻¹)	exchangeable Mg/(mg·kg ⁻¹)
1	19.48	0.738	104.50	0.452	5	0.345	2.980	5	32.70
3	14.80	0.700	86.25	0.500	0	0.260	2.720	0	20.70
5	17.94	0.780	103.15	0.500	0	0.190	2.480	0	37.50
7	17.76	0.694	110.55	0.539	5	0.385	2.516	5	25.10
9	20.09	0.746	103.75	0.469	5	0.230	3.012	5	30.65
11	22.33	0.730	107.35	0.490	0	0.550	2.650	0	32.75
13	17.13	0.740	101.95	0.510	0	0.180	2.760	0	24.40
15	23.07	0.754	104.60	0.516	5	0.965	2.526	5	19.75
17	23.24	0.852	92.00	0.569	5	0.730	2.348	5	27.80

Table 6 Correlation coefficients among species richness, biomass and soil nutrients content

item	organic matter	total N	hydrolysable N	total P	available P	total K	available K	exchangeable Ca	exchangeable Mg
AB	0.6416*	-0.0525	0.6203*	-0.3016	0.3488	0.3702	0.4788	0.1838	0.5523
UB	0.3680	-0.2487	0.342	0.0135	0.1875	0.1184	0.0253	-0.1203	0.2269
S	0.6359*	0.1509	0.4721	0.1044	0.2717	0.0525	0.1967	0.2382	0.5562

AB: arbor layer biomass; UB: undergrowth biomass; S: species richness; *: significant correlation at the 0.1 level.

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References

- Baldwin V C, Burkhardt H E, Westfall J A, Peterson K D (2001). Linking growth and yield and process models to estimate impact of environmental changes on growth of loblolly pine. *For Sci*, 47(1): 77–82
- Chen B G, Fu G X, Chen X (1995). Biomass and productivity of artificial stands of tow eucalypts. In: Zeng T X, eds. *Studies on the Eucalypts Ecosystem of Short Rotation in Leizhou Guangdong Province*. Beijing: China Forestry Publishing House, 58–65 (in Chinese)
- Feng Z W, Wang X K, Wu G (1999). *Biomass and Productivity of Chinese Forest Ecosystems*. Beijing: Science Press (in Chinese)
- Gower S T, Vogel J G, Norman J M, Kucharik C J, Steele S J, Stow T K (1997). Carbon distribution and aboveground net primary production in aspen, jack pine, and black spruce stands in Saskatchewan and Manitoba, Canada. *J Geophys Res*, 102(D24): 29029–29041
- Hector A, Schmid B, Beierkuhnlein C, Caldeira M C, Diemer M, Dimitrakopoulos P G, Finn J A, Freitas H, Giller P S, Good J, Harris R, Högberg P, Huss-Danell K, Joshi J, Jumpponen A, Körner C, Leadley P W, Loreau M, Minns A, Mulder C P H, O'Donovan G, Otway S J, Pereira J S, Prinz A, Read D J, Scherer-Lorenzen M, Schulze E-D, Siamantziouras A-S D, Spehn E M, Terry A C, Troumbis A Y, Woodward F I, Yachi S, Lawton J H (1999). Plant diversity and productivity experiments in European grasslands. *Science*, 286: 1123–1127
- Hooper D U, Vitousek P M (1997). The effects of plant composition and diversity on ecosystem process. *Science*, 277: 1302–1305
- Houghton J T, Ding Y, Griggs D J, Noguer M, van der Linden P J, Dai X, Maskell K, Johnson C A (2001). *Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (Climate Change 2001)*. Cambridge: Cambridge University Press, 994
- Institute of Soil Science, Chinese Academy of Sciences (1978). *Soil Physical and Chemical Analysis*. Shanghai: Shanghai Science and Technology Press, 1–592 (in Chinese)
- Jiao R Z, Yang C D, Tu X N, Sheng W T (1997). The change of undergrowth, soil microorganism, enzyme activity and nutrient in different developing stage of the Chinese fir plantation. *For Res*, 10(4): 373–379 (in Chinese)
- Kaiser J (2000). Rift over biodiversity divides ecologists. *Science*, 289, 1282–1283
- Kurz W A, Apps M J (1999). A 70 year retrospective analysis of carbon fluxes in the Canadian forest sector. *Ecol Appl*, 9(2): 526–547
- Loreau M, Naeem S, Inchausti P, Bengtsson J, Grime J P, Hector A, Hooper D U, Huston M A, Raffaelli D, Schmid B, Tilman D, Wardle D A (2001). Biodiversity and ecosystem functioning: current knowledge and future challenges. *Science*, 294: 804–808
- Magurran A E (1988). *Ecological diversity and its measurement*. New Jersey: Princeton University Press
- Shen G F (2002). *Forest Cultivation*. Beijing: China Forestry Publishing House, 255–282 (in Chinese)
- Sheng W T, Yang C D (1997). Research on effect of ameliorating soil properties by undergrowth vegetation of China fir. *Acta Ecol Sin*, 17(4): 377–382 (in Chinese)
- Sheng W T, Fan S H (2004). Study on the mechanism of maintaining long-term productivity of plantation: background, present condition and trends. *For Res*, 17(1): 106–115 (in Chinese)
- Song Y C (2001). *Vegetation Ecology*. Shanghai: East China Normal University Press, 45–46 (in Chinese)
- Tilman D, Reich P B, Knops J, Wedin D, Mielke T, Lehman C (2001). Diversity and productivity in a long-term grassland experiment. *Science*, 294: 843–845
- Tilman D, Wedin D, Knops J (1996). Productivity and sustainability influenced by biodiversity in grassland ecosystems. *Nature*, 379: 718–720
- Wen Y G (2006). *Plant diversity and ecosystem functions in a long-term continuous planting Eucalypt plantation experiment*. Dissertation for the Doctoral Degree. Chengdu: Sichuan University. 1–262 (in Chinese)
- Wen Y G, Liang L R, Li J J, Wei B E, Xiong C D (1988). The biological productivity on *Cunninghamia lanceolata* plantation at different ecological geographic regions in Guangxi. *J Guangxi Agr Biol Sci*, 7(2): 55–66 (in Chinese)
- Wen Y G, He T P, Li X X, Liang H W, Zhou J Y, Su Y J (2000a). Study on the biomass and productivity of *Eucalyptus exserta* of coastal protection forest in Hepu of Guangxi. *J Guangxi Agr Biol Sci*, 19(1): 1–5 (in Chinese)
- Wen Y G, Liang H W, Zhao L J, Zhou M Y, He B, Wang L H, Wei S H, Zheng B, Liu D J, Tang Z S (2000b). Biomass production and productivity of *Eucalyptus urophylla*. *J Tropical Subtrop Bot*, 8(2): 123–127 (in Chinese)
- Wen Y G, Liu S R, Chen F (2005b). Effects of continuous cropping on understory species diversity in Eucalypt plantations. *Chin J Appl Ecol*, 16(9): 1667–1671 (in Chinese)
- Wen Y G, Liu S R, Chen F, He T P, Liang H W, Chen T (2005a). Plant diversity and dynamics in industrial plantations of eucalyptus. *J Beijing For Univ*, 27(4): 17–22 (in Chinese)
- Wu D, Liu X T, Yang X H (2003). Study on the undergrowth plant diversity of *Eucalyptus* plantation in Leizhou Peninsula. *For Sci Tech*, 28(3): 10–13 (in Chinese)
- Yang C D, Jiao R Z, Tu X N, Chen Z L, Xiong Y Q (1995a). Developing undergrowth vegetation is an important way to recover soil fertility of Chinese fir plantation. *Sci Silv Sin*, 31(3): 316–322 (in Chinese)
- Yang C D, Jiao R Z, Tu X N, Xiong Y Q, Chen Z L (1995b). Effect of undergrowth in Chinese fir plantation on soil properties in the 5–15 cm layer. *For Res*, 8(5): 514–519 (in Chinese)
- Yang Z H, Yang X B, Yu X B (2003). The progress of study on the artificial forest's understory and problems of *Eucalyptus* forest. *Nat Sci J Hainan Univ*, 21(3): 278–282 (in Chinese)
- Yao M H, Sheng W T, Xiong Y Q (1991). Studies on understory and its biomass in Chinese fir stands. *Sci Silv Sin*, 27(6): 944–948 (in Chinese)
- Yu X B, Xu D P, Long T, Mo X Y (1999). Studies on the biomass and

productivity structure of *Eucalyptus* plantations in continuous planting rotation. In: Yu X B, eds. Management of Long-term Productivity of Eucalypt Plantation Beijing: China Forestry Publishing House, 61–67 (in Chinese)

Zhao P, Zeng X P, Cai X A, Peng S L (2002). Report on measurement of leaf area index of low subtropical forests by using digital plant canopy imager. *Guihaia*, 22(6): 485–489 (in Chinese)