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Carbon Storage in a *Eucalyptus* Plantation Chronosequence in Southern China

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Abstract: Patterns of carbon (C) allocation across different stages of stand development in *Eucalyptus urophylla* × *E. grandis* plantations are not well understood. In this study, we examined biomass and mineral soil C content in five development stages (1, 2, 3, 4–5, and 6–8 years old) of a *Eucalyptus* stand in southern China. The tree biomass C pool increased with stand age and showed a high annual rate of accumulation. Stems accounted for the highest proportion of biomass C sequestered. The C pool in mineral soil increased initially after afforestation and then declined gradually, with C density decreasing with soil depth. The upper 50 cm of soil contained the majority (57%–68%) of sequestered C. The other biomass components (shrubs, herbaceous plants, litter, and fine roots) accounted for <5% of the total ecosystem C pool. Total C pools in the *Eucalyptus* plantation ecosystem were 112.9, 172.5, 203.8, 161.1, and 162.7 Mg ha^{−1} in the five developmental stages, respectively, with most of the C sequestered below ground. We conclude that *Eucalyptus* plantations have considerable biomass C sequestration potential during stand development.

Keywords: biomass; carbon allocation; *Eucalyptus* plantation; southern China; stand age

1. Introduction

The increased concentration of carbon dioxide (CO₂) in the atmosphere is believed to have contributed greatly to climate change and is caused in part by the use of fossil fuels, changes in land use, and other human disturbances [1]. Global warming has become an important issue that needs to be addressed. The control of CO₂ and other greenhouse gas emissions is the most important approach to mitigating climate change [2]. Forests play important roles in reducing the greenhouse effect by storing atmospheric CO₂. Forest ecosystems have been shown to contain 861 ± 66 Pg C, with 383 ± 30 Pg C in soil, 363 ± 28 Pg C in living biomass (above- and belowground), 73 ± 6 Pg C in dead wood, and 43 ± 6 Pg C in litter [3]. Forest plantations make up 7% of the world's forest area and have expanded by approximately 5 million hectares per year between 2005 and 2010, thus having significant impacts on global C cycling [4–6]. At current rotation lengths, most forest plantations do not reach their maximum biological storage, so they have great potential for further carbon fixation [6].

Biomass is an important carbon pool in forest ecosystems [7], especially tree biomass, including the trunk, branches, foliage, and roots. Most of the total carbon in plantations is stored in aboveground biomass (trunk, branches, foliage) [8,9]. Many researchers have focused only on carbon sequestration by the tree [8,10–12]; less is known about the carbon pool in understory vegetation. The understory is an important functional component of the forest ecosystem, especially in plantations; management practices for the understory affect the aboveground biomass and carbon pool [13,14].

In forests, litter is an important source of matter and energy in the soil, where it plays significant roles in carbon dynamics [15–17]. The quantity and quality of litter determine patterns of soil organic carbon accumulation [17]; litter decomposition affects nutrient circulation, and thus has direct and indirect effects on plant growth rates and the ecosystem carbon pool [15,16].

Roots, especially fine roots (<2.0 mm), play a vital role in ecosystem functions such as carbon storage. Although it represents a small fraction of the C content of forest trees, fine-root growth accounts for approximately one-third of annual net primary production, indicating that a significant amount of assimilated C is allocated to these roots [6,18,19]. Roots are more effective pathways for building up soil organic carbon stocks than foliar litter [13,20]. Stand age and disturbances due to forest management can affect the mass of roots present in soil [21,22] and thus can have a large impact on the soil C balance.

Forest soils play an important role in the global C cycle [23,24]. Because they contain approximately two-thirds of the C stored in forest ecosystems, soil C dynamics can have significant effects on ecosystem C balance [25]. Soil C stocks are determined by the balance between inputs of C through litter-fall and roots, and loss of C, mainly through decomposition of soil organic matter. Carbon fluxes are influenced by numerous factors, including topography, climate, soil properties, tree species, management regime, previous land use, and stand age [7,26,27]. Thus, understanding the dynamics of soil carbon storage in forest ecosystems is an important undertaking.

Eucalyptus are fast-growing and preferred species in plantations; they are widely grown in the tropics and subtropics, especially in Brazil, India, and China, and thus are of great commercial importance [28]. At present, *Eucalyptus* is grown on more than 20 million ha of plantations around the world [28]. Large-scale afforestation and reforestation during the last three decades have resulted in China having the greatest amount of global *Eucalyptus* plantation area (constituting 29%) [4]. *Eucalyptus* is a major plantation species in southern China, where it has been planted on more than 2.5 million ha and accounts for approximately 6% of all forested plantation area in China [29]. Plant biomass and plant and soil carbon pools have been examined in monocultures or mixed-species *Eucalyptus* plantations [30–34]. However, few studies have examined carbon storage in plants and soils across stand developmental stages in *Eucalyptus* plantations [35]. An investigation of above- and belowground C dynamics according to stand age for the traditional rotation cycle is needed to understand the processes that drive degradation of C storage in plantations and to develop plans for more effective management of C storage. Because of the significance of these plantations, such understanding could assist in regional, national, and global C assessments.

Patterns in carbon pools during forest development have received increasing attention compared to a century ago. In general, plant biomass increases gradually with stand age, but soil C might show different trends. In this study, we compared total ecosystem carbon in a *Eucalyptus* plantation at five developmental stages. Our primary objective was to determine changes in the size and contribution of the major C pools (trees, understory, litter, fine roots, and soil) to total ecosystem C storage with increasing stand age. We hypothesized that biomass and soil C storage of *Eucalyptus urophylla* × *E. grandis* would show different trends with increasing stand age and that the contribution of tree biomass to total C would increase significantly over time. Our findings should provide valuable information for estimating potential C sequestration in *Eucalyptus* and for determining rational forest management practices to mitigate climate change.

2. Materials and Methods

2.1. Site Description

The study area is located in southeastern Guangxi Province (104°28′ to 112°04′ E, 20°54′ to 26°23′ N; 20–500 m a.s.l.), one of the largest forestry provinces in southern China. The eighth National Forest Resource Inventory showed that *Eucalyptus* plantations covered 1.712 million ha in Guangxi Province [29]. The area is in a subtropical monsoon climate zone with transitional characteristics from tropical to subtropical. The annual average temperature is 21.7 °C, with monthly mean temperatures of 13.1 °C in January and 28.1 °C in July and with 1600–1800 h of sunshine per year. Mean annual precipitation is 1300–1800 mm and occurs mainly from April to September; mean annual evaporation is 1600 mm, and relative humidity is 74.8%. The topography is characterized by low mountains and hills. The main soil type is lateritic red soil [36], an acidic loamy clay with high porosity.

In the major *Eucalyptus* plantation production areas, we selected three sites (three times repeated for each site) to establish nine 20 × 50 m sampling plots of five stages (1, 2, 3, 4–5, 6–8 year old, hereafter referred to as P1, P2, P3, P4–5, P6–8), respectively (Figure 1). All plots were characterized by similar

parent material, soil texture, and topography (Table 1). Stands were located on well-drained lower slopes, and the soil profile was more than 100 cm deep.

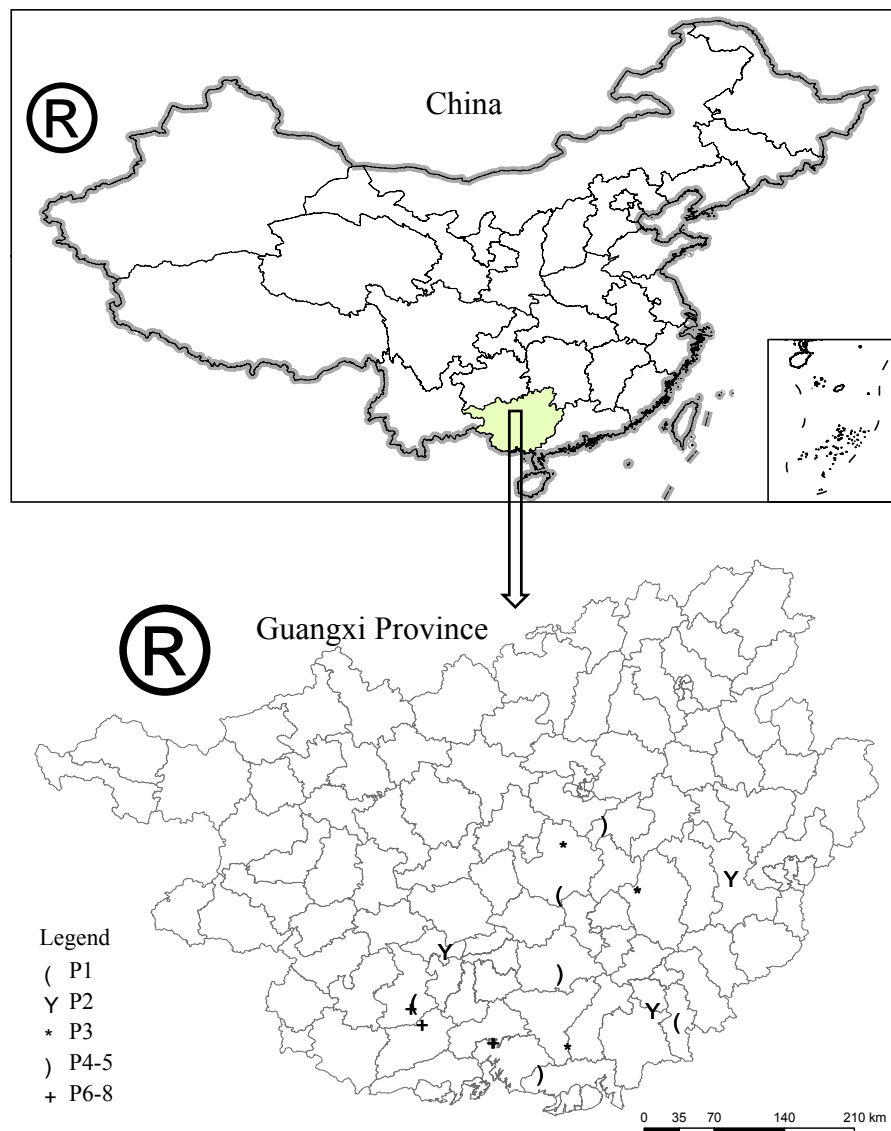


Figure 1. Map of plots in study area.

Table 1. The general status of five age classes of *Eucalyptus* plantation.

Stand Age (Years)	Stand Density (Trees ha ⁻¹)	Mean DBH (cm)	Mean Height (m)	Altitude (m)	Slope Degree (°)	Soil Types
1	1116	4.3	4.4	140–150	0–10	Lateritic red soil
2	1348	9.6	11.8	85–170	27–34	Lateritic red soil
3	1355	10.6	12.4	37–171	12–36	Lateritic red soil
4–5	1197	11.8	14.2	24–161	0–36	Lateritic red soil
6–8	1100	14.8	18.6	33–133	0–27	Lateritic red soil

2.2. Overstory and Understory Biomass

Stand density, tree height, and diameter at breast height (DBH, 1.3 m above ground) were recorded in each plot. We used a *Eucalyptus* growth model (Table 2) developed specifically for southern China to estimate plant biomass [37], including leaves, branches, stems, and roots, in each plot.

Understory biomass (shrub and herbaceous material) was determined by destructive harvesting. Three 2 × 2-m shrub subplots were randomly selected in each plot. All shrub biomass, including leaves, branches, and roots (>2 mm), was harvested. We also selected three 1 × 1-m quadrats in each shrub subplot in which we measured the above- and belowground biomass of herbaceous material. All biomass components were dried at 75 °C to constant weight.

Table 2. Allometric regression models used to estimate biomass for *Eucalyptus*.

Component	Allometric Equation	R^2	P	RSS
leaf	$W = 1.182e^{0.003D^2}$	0.762	<0.01	0.690
branch	$W = 0.042D^{1.835}$	0.894	<0.01	1.530
stem	$W = 0.028D^{2.996}$	0.978	<0.01	0.811
root	$W = 0.06D^{1.771}$	0.851	<0.01	1.831
total	$W = 0.138D^{2.436}$	0.977	<0.01	0.556

D is the stem diameter, W is the dry weight of different components.

2.3. Litter Fall Biomass

Litter biomass includes dead plant material such as fruit, leaves, bark, and small branches (<2.5 cm) on the soil surface. All litter was collected from the three 1 × 1-m herbaceous quadrats in each shrub subplot and was dried at 75 °C to constant weight.

2.4. Fine-Root Biomass

We measured fine-root (<2 mm) biomass in soil cores. Ten soil cores (composited as one sample) were collected from random locations in the 0–20 cm and 20–40 cm layers of each plot using a stainless steel corer (5 cm inner diameter). The cores were washed with tap water to remove adhered soil and organic debris. Root samples were transferred to paper bags, oven-dried at 75 °C, and weighed. Fine-root biomass was calculated based on the cross-sectional area of the cores.

2.5. Mineral Soil Sampling

To calculate soil C storage, mineral soil samples were collected with the stainless steel corer. In each plot, five soil cores were taken from each of five soil layer: 0–10, 10–20, 20–30, 30–50, and 50–100 cm. The five cores per layer were mixed to form a composite sample. All soil samples were taken to the laboratory and air-dried to determine soil C. Rocks and plant residues were removed from the samples. Soil bulk density was also assessed using a bulk density corer in each soil layer.

2.6. Chemical Analysis

The biomass samples were oven-dried, ground, and passed through a 1-mm sieve. Mineral soil samples were passed through a 0.149-mm sieve before chemical analyses. Carbon contents of plant and soil samples were measured by the dichromate oxidation method [38]. The mass of C stored in tree components, shrubs, herbaceous plants, litter, and fine roots was estimated by multiplying the mass of each component by its C concentration. The soil organic carbon (SOC) stock (C_s , Mg ha⁻¹) in each soil layer was calculated based on SOC concentration (C_c , g kg⁻¹), sampled depth (D , cm), and bulk density (BD , g cm⁻³), using the following equation: $C_s = C_c \times D \times BD/10$. The total SOC stock was the sum of each soil layer [24].

2.7. Statistical Methods

Data were analyzed using SPSS ver. 16.0 for Windows (SPSS Inc., Chicago, IL, USA). One-way analysis of variance (ANOVA) was used to assess the differences in carbon concentrations and pools among the five chronosequence stages. Duncan's test was performed to separate means if differences were significant ($P = 0.05$).

3. Results

3.1. Biomass Carbon Pool

Total biomass C (including tree, shrub, herb, litter, and fine-root) increased from P1 to P6–8 (Table 3). Tree biomass C storage increased with forest age, from 3.1 Mg ha⁻¹ in P1 to 24.0, 31.6, 42.6, and 70.1 Mg ha⁻¹ in P2, P3, P4–5, and P6–8, respectively. Biomass C in leaves, branches, stems, and roots showed similar trends to tree biomass, with the exception of leaf biomass C in P4–5. More than 50% of tree biomass C was contained in the stem at all forest stages. The annual rates of biomass carbon accumulation in trees for the five *Eucalyptus* stand age classes were 3.1, 20.9, 7.6, 5.0, and 9.2 Mg ha⁻¹ y⁻¹, respectively. Depending on stand age, leaf, branch, stem, and root biomass accounted for 2.1%–22.3%, 5.0%–12.0%, 51.1%–86.7%, and 6.1%–14.6% of total tree C storage, respectively.

Shrub biomass C values in P1, P2, P3, P4–5, and P6–8 were 0.4, 0.3, 1.0, 0.9, and 0.5 Mg ha⁻¹, respectively. Shrubs accounted for 0.7%–5.9% of total biomass C storage, with the greatest contribution in P1. Carbon storage in the different components was branch > root > leaf, except in P2 in which leaves contained more C than roots. Herbaceous biomass C values in the plantation chronosequence were 1.4 (P1), 0.7 (P2), 1.6 (P3), 2.1 (P4–5) and 2.4 (P6–8) Mg ha⁻¹. Aboveground biomass C was greater than belowground biomass C, accounting for 20.7% of total biomass C storage in P1 and for less (2.3%–4.0%) at later growth stages. Biomass C storage in litter was significantly lower in the one-year-old plantation than in the other stages (Table 3), and it changed little during the later stages. The contribution of litter to biomass C storage decreased gradually from P1 (13.2%) to P6–8 (3.1%).

Fine-root biomass was estimated in the 0–40 cm depth interval, which included the majority of small roots. Living and dead fine-root biomass C ranged from 0.1 to 3.6 Mg ha⁻¹, in the following order: P2 > P4–5 > P3 > P1 > P6–8 (Table 3) and was higher at 0–20 cm than at 20–40 cm in all stages.

Table 3. Biomass carbon (C) storage (Mg ha^{-1}) in different components of the *Eucalyptus* plantation.

Components	P1	pct.	P2	pct.	P3	pct.	P4–5	pct.	P6–8	pct.
Tree Layer										
leaf	0.7 ± 0.1	22.3	1.2 ± 0.2	5.0	1.2 ± 0.1	3.8	1.1 ± 0.2	2.7	1.5 ± 0.2	2.1
branch	0.4 ± 0.0	12.0	1.9 ± 0.3	8.0	2.3 ± 0.2	7.2	2.6 ± 0.3	6.2	3.5 ± 0.5	5.0
stem	1.6 ± 0.2	51.1	18.6 ± 2.1	77.4	25.3 ± 3.8	80.1	35.6 ± 4.1	83.7	60.8 ± 8.5	86.7
root	0.5 ± 0.0	14.6	2.3 ± 0.2	9.6	2.8 ± 0.2	8.9	3.2 ± 0.3	7.5	4.3 ± 0.7	6.1
subtotal	3.1 ± 0.3	45.4	24.0 ± 2.7	77.3	31.6 ± 4.2	81.3	42.6 ± 4.7	85.0	70.1 ± 9.8	92.9
Shrub Layer										
leaf	0.1 ± 0.0	25.0	0.1 ± 0.0	28.1	0.2 ± 0.0	17.5	0.2 ± 0.0	20.4	0.1 ± 0.0	19.6
branch	0.2 ± 0.0	40.0	0.2 ± 0.0	46.9	0.5 ± 0.0	52.4	0.5 ± 0.0	52.7	0.3 ± 0.0	51.0
root	0.1 ± 0.0	35.0	0.1 ± 0.0	25.0	0.3 ± 0.0	30.1	0.3 ± 0.0	26.9	0.2 ± 0.0	29.4
subtotal	0.4 ± 0.1	5.9	0.3 ± 0.0	1.0	1.0 ± 0.1	2.7	0.9 ± 0.1	1.9	0.5 ± 0.1	0.7
Herb Layer										
aboveground	0.8 ± 0.1	57.4	0.5 ± 0.0	63.9	1.1 ± 0.1	67.5	1.2 ± 0.1	59.4	1.6 ± 0.2	64.6
belowground	0.6 ± 0.1	42.6	0.3 ± 0.0	36.1	0.5 ± 0.0	32.5	0.8 ± 0.0	40.6	0.9 ± 0.1	35.4
subtotal	1.4 ± 0.2	20.7	0.7 ± 0.1	2.3	1.6 ± 0.1	4.0	2.1 ± 0.1	4.1	2.4 ± 0.2	3.2
Litterfall	0.9 ± 0.0	13.2	2.4 ± 0.3	7.8	2.9 ± 0.3	7.5	2.01 ± 0.3	4.1	2.3 ± 0.2	3.1
Fine Root										
0–20	0.8 ± 0.1	78.0	1.9 ± 0.2	52.8	1.4 ± 0.1	78.5	2.1 ± 0.2	84.4	0.1 ± 0.0	54.5
20–40	0.2 ± 0.0	22.0	1.7 ± 0.2	47.2	0.34 ± 0.0	21.5	0.4 ± 0.0	15.6	0.1 ± 0.0	45.5
subtotal	1.0 ± 0.1	14.7	3.6 ± 0.3	11.5	1.7 ± 0.2	4.4	2.4 ± 0.2	4.9	0.1 ± 0.0	0.1
Total	6.8 ± 0.6		31.0 ± 3.3		38.8 ± 4.7		50.1 ± 5.4		75.5 ± 9.9	

Percentage abbreviated as pct. (the same as below).

3.2. Mineral Soil Carbon Pool

Carbon concentration and storage decreased significantly and exponentially with soil depth, and bulk density increased significantly with depth (Figures 2 and 3, Table 4). The soil C pool at 0–10 cm increased continually up to P3, after which decreased. At the other soil depth intervals, the C pool increased up to P2 and then decreased continually. Soil C (0–100 cm) ranged from 87.2 to 164.9 Mg ha^{-1} . The majority of soil C was contained in the upper 50 cm across the stand development series, ranging from ~57% in P6–8 to ~68% in P4–5.

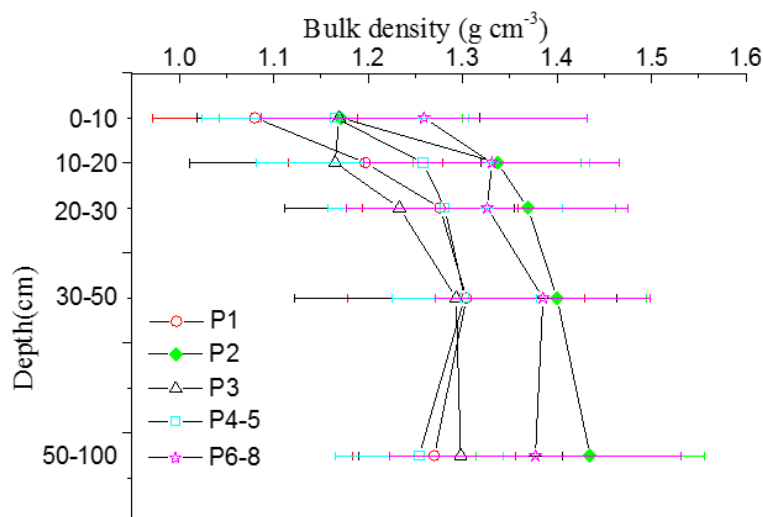


Figure 2. General pattern of bulk density in soil of the *Eucalyptus* plantation.

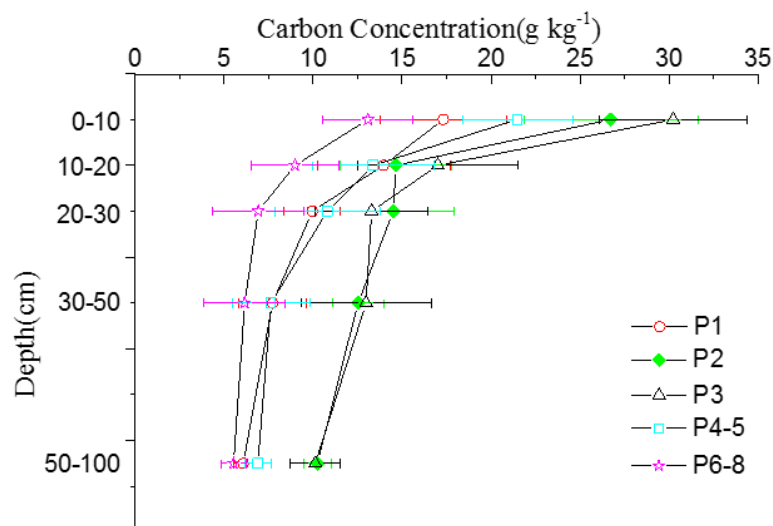


Figure 3. General pattern of C concentration in soil of the *Eucalyptus* plantation.

Table 4. C storage (Mg ha^{-1}) of mineral soil in the *Eucalyptus* plantation.

Stages	0–10		10–20		20–30		30–50		50–100		0–100
	C	pct.	C	pct.	C	pct.	C	pct.	C	pct.	C
P1	18.3b \pm 3.8	17.2	16.5a \pm 3.2	15.6	12.7ab \pm 2.3	12.0	19.9b \pm 3.7	18.8	38.7b \pm 5.6	36.5	106.1bc \pm 10.8
P2	29.9a \pm 3.6	21.1	20.8a \pm 3.7	14.7	17.3a \pm 2.6	12.2	27.1ab \pm 2.9	19.1	46.5ab \pm 3.6	32.8	141.6ab \pm 13.0
P3	32.9a \pm 4.5	20.0	20.0a \pm 3.7	12.1	15.9ab \pm 2.6	9.6	32.9a \pm 3.5	20.0	63.2a \pm 4.6	38.3	164.9a \pm 12.4
P4–5	24.4ab \pm 2.7	22.0	17.3a \pm 2.0	15.6	13.9ab \pm 2.4	12.5	20.1b \pm 2.4	18.1	35.4b \pm 3.6	31.9	111.1bc \pm 10.8
P6–8	15.0b \pm 2.5	17.2	11.0a \pm 1.34	12.6	8.5b \pm 1.4	9.7	16.0b \pm 2.4	18.3	36.7b \pm 3.9	42.1	87.2c \pm 14.2

Significant differences are indicated by different letters (pairwise *t*-test, $P < 0.05$).

3.3. Carbon Allocation

Total carbon storage over the stand development series (Table 5) was highest in soil, followed (in decreasing order) by biomass, belowground C, and aboveground C. The proportion of total C stored in biomass increased with forest age, while that in the soil declined gradually. Trees accounted for approximately 3%, 14%, 15%, 26%, and 43% of total carbon storage in the five developmental stages, respectively. The understory (shrub and herbaceous material), litter, and fine roots each accounted for <2% of total C, and soil contained between 53% and 94% of total carbon (Figure 4).

Table 5. C storage (Mg ha^{-1}) of the aboveground, belowground, and total ecosystem in the *Eucalyptus* plantation.

Stages	Aboveground		Belowground		Ecosystem
	C	pct.	C	pct.	C
P1	4.6	4.1	108.3	95.9	112.9
P2	24.8	14.4	147.7	85.6	172.5
P3	33.5	16.4	170.3	83.6	203.8
P4–5	43.3	26.9	117.8	73.1	161.1
P6–8	70.1	43.1	92.6	56.9	162.7

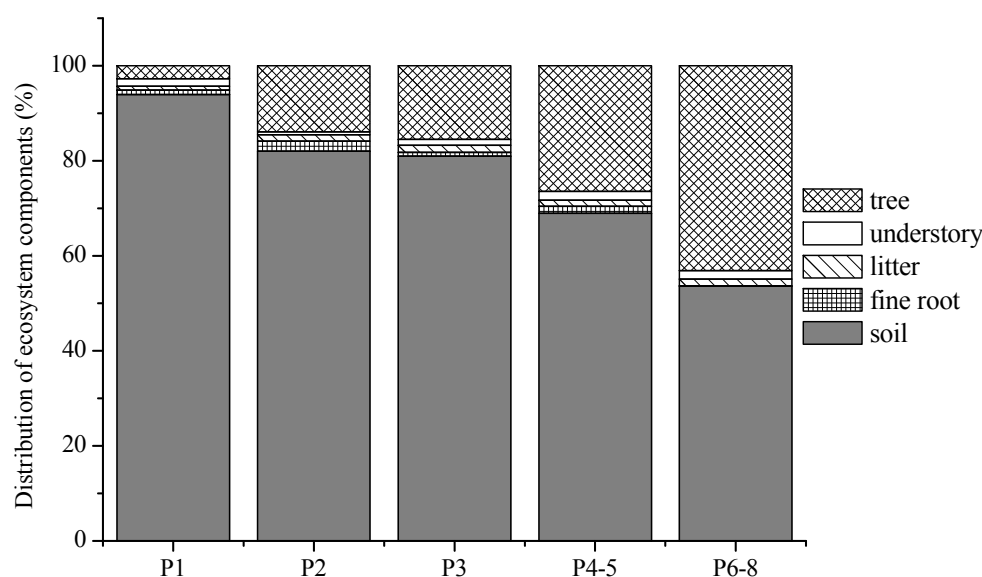


Figure 4. Percentage contribution to the C pool in the individual components of the *Eucalyptus* plantation ecosystem.

4. Discussion

4.1. Biomass Carbon Storage

Estimating C storage in different forest stages is essential for assessing the role of forest ecosystems in regional and global C management. Our results indicate that *Eucalyptus* plantations can accumulate large amounts of biomass C, both above and below ground. In this study, biomass C density in *Eucalyptus* plantations at five stand ages was between 6.8 and 75.5 Mg ha^{-1} . Tree biomass constituted

a major part of the biomass C pool and increased rapidly with plantation age in both the above- and belowground (root) fractions, similar to trends observed in other forests [6,10,11,39]. The highest rate of accumulation was observed in two-year-old stands, and the average carbon sequestration rate of stands between one and eight years old ($8.8 \text{ Mg ha}^{-1} \text{ y}^{-1}$) was slightly higher than that reported for a *Eucalyptus tereticornis* Sm. plantation ($6 \text{ Mg ha}^{-1} \text{ y}^{-1}$) in India, estimated by a dynamic growth model (CO2FIX) [12]. Although C storage of each component tended to increase with age, the proportion of carbon stored in leaves, branches, and roots relative to that in total tree biomass decreased with age. This result was consistent with findings for Korean pine (*Pinus koraiensis*) [39], Chinese pine (*Pinus tabulaeformis*) [11], and Horsetail beefwood (*Casuarina equisetifolia*) [10].

Eucalyptus are fast-growing species; we found that tree biomass C storage in six- to eight-year-old stands was $>70.1 \text{ Mg ha}^{-1}$, which is higher than that reported for 30-year-old *Pinus koraiensis* (50.9 Mg ha^{-1}) in central Korea [39], 25-year-old *Pinus tabulaeformis* (40.3 Mg ha^{-1}) in Huairou District north of Beijing [11], and 16-year-old Chinese fir (*Cunninghamia alanceolata* (Lamb.) Hook) (60 Mg ha^{-1}) in Fujian Province, China [6]. This value was similar to biomass C storage reported for six-year-old *Casuarina equisetifolia* (50.9 Mg ha^{-1}) in Guangdong Province, southern China [10]. Comparing our findings with other studies of *Eucalyptus* in China and other regions, Harper *et al.* found 59.8 Mg ha^{-1} stored in *E. occidentalis* and 53.3 Mg ha^{-1} in *E. cladocalyx* in western Australia in a 26-year-old *Eucalyptus* plantation; carbon storage in four other *Eucalyptus* species (*E. cladocalyx* var *nana*, *E. occidentalis*, *E. sargentii*, and *E. wandoo*) was lower than that of the six- to eight-year-old *Eucalyptus urophylla* \times *E. grandis* plantation observed here [40]. Our value of $31.6 \text{ Mg C ha}^{-1}$ stored in tree biomass in three-year-old stands was higher than that for 44-month-old *Eucalyptus* sp. plantations in Santa Maria (27.7 Mg ha^{-1}) [35].

The rate of change in C storage in understory vegetation observed here was similar to findings for a chronosequence of Korean pine [39]. The lesser understory C content in one- and two-year-old stands was primarily a result of forest management; growth of shrubs and herbaceous plants is usually controlled in the first two years of *Eucalyptus* plantations. The lower quantity of C stored in litter in the first year of stand development was due to decreased leaf, branch, and understory biomass in the young stands.

Fine roots are the most physiologically active part of the tree root system and play a vital role in acquiring nutrients and water for trees [19,41,42]. The majority of fine-root biomass C occurred in the upper 20 cm soil layer, which was a result of higher concentrations of nutrients in the topsoil [43–45], consistent with findings for other forests and tree species [5,6,19].

4.2. Soil C Storage

The soil carbon pool is affected by soil properties, forest management practices, litter input, and root turnover [46,47]. Soil C storage observed here with the upper 100 cm was lower than the average value for carbon storage in forest soils in China (193.6 Mg ha^{-1}) [48]. The major reason might be that although the highly productive *Eucalyptus* plantation studied here is located in the southern subtropical zone, which has abundant water and heat, the litter decomposition rate is relatively high. In addition, *Eucalyptus* plants take up large quantities of soil nutrients for development, which would lead to lower soil carbon storage. Another explanation is the loss of original soil organic carbon as a result of

plowing and burning before afforestation [48]. Among the five plantation development stages, soil C storage was highest at 0–10 cm and decreased with increasing soil depth. Soil organic matter content is the main source of soil C and is higher in topsoil [49]. Our soil C values in the upper 50-cm were much higher than those for the soil C pool stored in *Pinus koraiensis* plantations across all age classes [39].

Some studies have reported no significant increase in mineral soil C content with stand age [26,50,51], while others showed increasing soil C content in the early decades after afforestation [52–55]. Here, soil C increased in the early stages after afforestation and then decreased gradually with plantation age. This trend was similar to findings by Noh *et al.* [56] for a *Pinus densiflora* plantation. In contrast, Li *et al.* reported an initial decline in soil C after establishment of a *Pinus koraiensis* plantation [39]. Wang *et al.* also reported that soil C decreased in the early stages after reforestation and then increased gradually with *Casuarina equisetifolia* stand age [10]. These differences may result from differences in forest type, tree species, soil properties, litter quantity and quality, forest management, and climate, all of which influence the effects of forest age on soil C storage [6,10,11,26,39,43,47]. We consider that the increase in soil carbon from one- to three-year-old stands was a result of fertilization during the early growth stages and greater decomposition of litter and dead roots left after plowing and before planting. The quantity and quality of litter and roots helps to determine the composition of soil organic carbon [11,57]. As vegetation develops, biomass increases gradually and plants require more soil nutrients, and there is a gradual decrease in the proportion of roots, branches, and leaves, and in the contribution of litter to soil carbon storage.

4.3. Ecosystem Total C Storage

The total ecosystem C stock increased from one- to three-year-old stands and then decreased with stand age from 4–6 to 6–8 years. The relative contribution of individual C pool to total ecosystem C storage in this chronosequence study is shown in Figure 4. Trees and mineral soil were the dominant C pools across all stand ages, consistent with other studies [11,39,47,51,56]. A similar trend was found in the proportion of belowground to total ecosystem C storage, which increased initially, and then declined gradually. However, aboveground C storage increased with plantation age. Peichl and Arain also found that the contribution of belowground C in a white pine (*Pinus strobus* L.) plantation decreased with increasing stand age [51]. This can be explained by the larger accumulation of aboveground C in tree biomass during stand development.

5. Conclusions

Eucalyptus plantations can rapidly accumulate large quantities of biomass carbon. Here, tree biomass gradually became the dominant C pool with increasing stand age. Our findings suggest that *Eucalyptus* is a fast-growing forest tree with high potential biomass carbon sequestration. However, *Eucalyptus* may deplete soil nutrients more than slower growing species. The development of mixed forest communities, with *Eucalyptus* as the dominant species, would improve the ecological function of *Eucalyptus* plantations. This would make these plantations appropriate for large areas of southern China and would allow them to play an important role in the regional carbon budget.

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Author Contributions

Hu Du conducted the literature search for the manuscript, the field investigation, and the statistical analysis for the manuscript as well as writing and editing the majority of the manuscript. Fuping Zeng designed the field survey method. Wanxia Peng conducted the field investigation and edited the manuscript. Kelin Wang organized the research collaboration. Hao Zhang conducted the field investigation, critically read the manuscript, and contributed to the writing. Lu Liu contributed to writing and editing of the manuscript. Tongqing Song supervised the textual and analytical content of the manuscript, critically read the manuscript, and contributed to the writing.

Conflicts of Interest

The authors declare no conflict of interest.

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