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# Carbon Storage of Exotic Slash Pine Plantations in Subtropical China

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## Abstract

Exotic conifer trees have been extensively planted in southern China because of their high apparent growth and yield. These fast-growing plantations are expected to persist as a considerable potential for temporary and long-term carbon sink to offset greenhouse gas emissions. However, information on the carbon storage across different age ranges in exotic pine plantations is often lacking. We first estimated the ecosystem carbon storage across different age ranges of exotic pine plantations in China by quantifying above- and below-ground ecosystem carbon pools. The carbon storage of each tree component of exotic pine (*Pinus elliottii*) increased significantly with increasing age in Duchang and Yiyang areas. The stem carbon storage except <10 years in Ji'an areas was the largest component among all other components, which accounts for about 50% of the total carbon storage followed by roots (~28%), branches (~18%), and foliage (~9%). The mean total tree carbon storage of slash pine plantations for <10, 10-20 and 20-30 years across three study areas was 3.69, 13.91 and 20.57 Mg $ha^{-1}$, respectively. The carbon stocks in understory and forest floor were age-independent. Total tree and soil were two dominant carbon pools in slash pine plantations at all age sequences. The carbon contribution of aboveground ecosystem increased with increasing age, while that of belowground ecosystem declined. The mean total ecosystem carbon storage of slash pine plantations for <10, 10-20 and 20-30 years across China was 30.26, 98.66 and 98.89 Mg $ha^{-1}$, respectively. Although subtropical climate in China was suitable for slash pine growth, the mean total carbon stocks in slash pine plantations at all age sequences from China were lower than that values reported in American slash pine plantations.

**Key Words:** carbon storage, exotic pine plantation, age range, subtropical forest, *Pinus elliottii*

## Introduction

Forests play a critical role in the global carbon cycle and are expected to persist as a considerable potential for temporary and long-term carbon sink to mitigate elevated atmospheric carbon dioxide concentrations (Banik et al. 2018; Kim et al. 2018; Shambhu and Joshi 2018; Zhu et al. 2018; Pugh et al. 2019). China has implemented long-term national ecological restoration programs through afforestation and reforestation to protect its environment and restore the degraded ecosystems since the late 1970s (Zheng et al. 2016; Lu et al. 2018). Implementation of these national programs not only improves the ecological environment and function (e.g., increasing forest carbon storage and se-

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questration), but also greatly helps local farmers and communities escape poverty in the project regions (Zheng et al. 2016; Fang et al. 2018).

Although native species was originally the target species for restoration in the red soil region of southern China, several exotic conifer trees have been introduced over past several decades because of their high growth rate and economic value (Zheng et al. 2008; Wei et al. 2013; Wang et al. 2015; Mao et al. 2019). For example, slash pine (*Pinus elliottii* Engelm.) introduced from southeastern United States, has been extensively planted in subtropical China because of its ecological adaptation, high growth rate and resin production, covering almost more than 1.38 million ha by 2008 (Pu et al. 2012; Ma et al. 2014; Wang et al. 2015). The largest area of slash pine plantations was in Jiangxi Province, covering nearly 40% of the total area in the country (Pu et al. 2012). With gradually expanding area in subtropical China, it is important to evaluate the changes in ecosystem function (e.g. carbon sequestration) of slash pine plantations.

Previous studies on carbon storage of slash pine plantations in China only focused on the same tree age (Zheng et al. 2008; Wei et al. 2013; Ma et al. 2014). However, there is lack of evidence about the carbon pools across different age ranges in slash pine plantations. In this study, to the best of our knowledge, we first estimated the ecosystem carbon storage across different age ranges in slash pine plantations in China by means of quantifying above- and below-ground ecosystem carbon pools.

## Materials and Methods

### *Study area*

This study was conducted in the central and northeastern parts of Jiangxi Province of China, including Duchang, Yiyang and Ji'an areas (26°27′~29°22′ N and 114°39′~117°22′ E). The climate of this region is humid subtropical monsoon with four distinct seasons. The average annual precipitation is about 1635 mm and the annual average temperature is between 17.1°C-18.6°C. The soil is mostly acidic and red. The dominant plantation vegetation types in study area include coniferous forests (e.g. slash pine, *P. massoniana* and *Cunninghamia lanceolata*), bamboo forests (e.g. *Phyllostachys heterocycla*) and evergreen broadleaf forests (e.g. *Schima superba*, *Castanopsis sclerophylla* and *Cinnamomum camphora*). The dominant shrubs species are *Loropetalum chinense*, *Lespedeza Formosa* and *Gardenia jasminoides*. Herbaceous species are mainly *Dicranopteris dichotoma*, *Arundinella setosa*, *Adiantum flabellulatum* and *Imperata koenigii*. It was almost barren with sparsely distributing arid and semi-arid grasses before slash pine planting and the natural evergreen forests in studied region have been destroyed due to past centuries of logging, litter racking, slash burning and excessive livestock grazing (Wei et al. 2013; Wang et al. 2015). As representative tending practices, cutting shrub and weeding were used by local forest manager in the earlier growth stages of slash pine plantations. According to the 11th provincial forest inventory data, slash pine plantations are mostly distributed in the central and northeastern parts of Jiangxi Province and covered more than $6\times10^5$ ha.

In this study, according to the detailed regulations of provincial forest inventory established by Jiangxi Provincial Department of Forestry in 2009, a 10-year age range was used to group the slash pine into three age ranges: <10, 10-20, and 20-30 years. Except two replications for <10 years in Ji'an areas, each age range had three random replications with a total of 26 plots (Table 1). The plot size was 28.28 m×28.28 m. The distances between the sampled plots range from 500 m to about several kilometers.

### *Biomass estimation*

For each plot, DBH (the diameter at breast height; minimum ≥2 cm) and the height of all trees were measured individually. Live tree biomass was estimated based on allometric equations (foliage, branch, stem with bark, and root) developed for slash pine (Li et al. 2006; Zeng et al. 2015). Samples of each component were bagged separately and taken back to the laboratory for oven dry at 65°C to obtain a consistent weight and carbon concentration.

Understory biomass was determined using destructive sampling techniques. Three 2×2 m subplots for shrub and herb, and three 1×1 m subplots for forest floor litter were set up along a diagonal line inside each plot. The above- and below-ground understory biomass, litter, and humus were weighted in the field. The samples were bagged separately and then taken back to the laboratory and oven dried at 65°C to obtain a consistent weight and carbon concentration.

**Table 1.** The stand characteristics of slash pine plantations measured at three study areas of Jiangxi Province (DBH: diameter at breast height; means±standard errors)

| Location | Age range/age (years) | | Tree density (stems $ha^{-1}$) | Slope (°) | Aspect | DBH (cm) | Height (m) | Soil bulk density (g $cm^{-3}$) |
|---|---|---|---|---|---|---|---|---|
| Duchang | <10 | 8 | 1,400 | 5 | South | 5.7±2.6 | 6.3±2.3 | 1.59±0.24 |
| | | 8 | 938 | 3 | Else | 5.1±2.8 | 5.8±2.1 | 1.50±0.14 |
| | | 8 | 1,413 | 3 | Else | 4.5±2.4 | 5.1±1.8 | 1.55±0.11 |
| | 10-20 | 11 | 2,038 | 4 | West | 11.2±2.8 | 10.4±1.8 | 1.35±0.14 |
| | | 11 | 1,438 | 3 | Else | 13.0±2.5 | 11.0±1.4 | 1.45±0.06 |
| | | 13 | 2,488 | 8 | North | 10.1±3.0 | 9.9±1.9 | 1.55±0.06 |
| | 20-30 | 22 | 1,538 | 5 | East | 11.9±3.9 | 10.8±1.4 | 1.57±0.04 |
| | | 24 | 988 | 3 | Else | 15.7±4.8 | 11.6±0.8 | 1.63±0.14 |
| | | 26 | 1,238 | 2 | Else | 12.8±3.7 | 10.5±2.0 | 1.59±0.15 |
| Yiyang | <10 | 6 | 625 | 3 | Else | 4.7±1.4 | 7.1±3.00 | 1.07±0.09 |
| | | 8 | 1,075 | 5 | West | 6.7±2.5 | 9.5±2.5 | 1.71±0.09 |
| | | 9 | 1,638 | 2 | Else | 10.2±3.9 | 9.6±2.5 | 1.73±0.03 |
| | 10-20 | 15 | 575 | 30 | North | 13.7±4.0 | 10.3±1.9 | 1.68±0.07 |
| | | 17 | 1,263 | 4 | East | 11.0±3.8 | 9.3±2.3 | 1.64±0.04 |
| | | 19 | 700 | 3 | Else | 10.7±4.0 | 10.1±2.6 | 1.76±0.06 |
| | 20-30 | 22 | 1,400 | 2 | Else | 14.4±3.3 | 11.6±1.1 | 1.65±0.10 |
| | | 22 | 1,000 | 3 | Else | 16.4±3.6 | 10.7±2.4 | 1.65±0.10 |
| | | 23 | 1,588 | 13 | North | 12.0±4.6 | 8.5±2.7 | 1.65±0.10 |
| Ji'an | <10 | 5 | 913 | 8 | East | 3.2±0.8 | 4.5±0.6 | 1.62±0.13 |
| | | 5 | 1,013 | 5 | West | 3.6±1.0 | 4.8±0.9 | 1.56±0.04 |
| | 10-20 | 19 | 825 | 3 | Else | 15.6±3.5 | 11.7±0.7 | 1.39±0.08 |
| | | 19 | 875 | 7 | West | 14.2±4.7 | 11.6±2.0 | 1.32±0.08 |
| | | 19 | 575 | 3 | Else | 14.7±3.2 | 11.6±1.0 | 1.22±0.30 |
| | 20-30 | 26 | 800 | 15 | Northwest | 14.5±3.6 | 11.4± 1.3 | 1.34±0.08 |
| | | 28 | 600 | 10 | Southeast | 16.2±4.5 | 11.6±1.2 | 1.37±0.05 |
| | | 26 | 538 | 10 | West | 16.8±3.3 | 12.7±1.1 | 1.34±0.06 |

### *Soil sampling*

Volumetric samples of mineral soil were collected using a cutting ring (volume of 100 $cm^3$) at different depths for determining carbon concentrations as well as bulk density. A soil profile pit of a 100 cm depth was dug in each plot. Soil samples were taken at five depths (0-10, 10-20, 20-30, 30-50 and 50-100 cm) on five randomly locations along a diagonal transect within each plot. The soil samples were pooled by the sampling location and layer. Soil samples of each layer were transported to the laboratory and then air-dried and sieved with a 2 mm mesh to remove any vegetation or gravel. The organic carbon concentrations of all samples (vegetation tissue, forest floor and mineral soil) were analyzed by the $K_2Cr_2O_7$-$H_2SO_4$ oxidation method (Ma et al. 2014; Liu et al. 2017).

### *Calculation of carbon storage and statistical analysis*

The biomass of tree and understory component was multiplied by the corresponding carbon concentration to calculate carbon storage. The total vegetation carbon storage is the sum of different biomass components. The soil organic carbon (SOC) storage at different depths were calculated by soil organic carbon concentration, soil bulk density, soil depth, and proportion of gravels. The total SOC storage (Mg $ha^{-1}$) was calculated as follows (Equation (1)):

$$SOCs_{torage}=\sum_{i=1}^{5} C_i \times BD_i \times D_i/10 \times (1-G_i) \qquad (1)$$

where, $C_i$ (g $kg^{-1}$) is the soil organic carbon concentration of the ith layer ($i$=1, 2, 3, 4, 5), $BD_i$ (g $cm^{-3}$) is the soil bulk density of the ith layer, $D_i$ (cm) is the soil depth of the ith layer, and $G_i$ is gravel content (%) in the soil volume of the ith layer.

The 26 sampled plots with different age ranges were established in three different areas (Duchang, Yiyang and Ji'an areas). One-way analyses of variance (ANOVA) were performed to determine the significant differences among the carbon storage of the same type between the different age ranges in the same study area, including the cumulative carbon storage of trees, understory, forest floor, and soil. The Duncan's multiple range test was performed if a significant difference was found ($p < 0.05$). All these statistical analyses were conducted using the SPSS 24.0 software.

## Results and Discussion

### *Changes in tree carbon storage*

The carbon storage of each tree component of slash pine increased significantly with increasing age in Duchang and Yiyang areas ($p < 0.05$), while there were not significantly different between 10-20 years and 20-30 years in Ji'an areas (Table 2). The mean values of DBH and height between 10-20 years and 20-30 years for slash pine plantations in Ji'an areas were close. This mainly due to different stand characteristics with large slope, which may affect light, water, and nutrient availability for tree growth and carbon sequestration in 20-30 years slash pine plantations in Ji'an areas (Tables 1 and 2). The stem carbon storage except < 10 years in Ji'an areas was the largest component among all other components, which accounts for about 50% of the total carbon storage followed by roots (~28%), branches (~18%), and foliage (~9%). The mean total tree carbon storage of slash pine plantations for < 10, 10-20 and 20-30 years across three study areas was 3.69, 13.91 and 20.57 Mg ha$^{-1}$, respectively.

Studies on the total tree carbon storage of slash pine plantations in Duchang and Ji'an areas have been reported, and the results seemed different between our finding and others within the the same region (Tu and Liu 2007; Wei et al. 2013; Ma et al. 2014; Cao et al. 2016). For example, Cao et al. (2016) reported that the tree carbon storage in 5-year-old slash pine plantations planted in mild, moderate, and severe desertification lands in Duchang area near Poyang Lake were 19.22, 3.45, and 1.88 Mg ha$^{-1}$, respectively (Cao et al. 2016). The mean total tree carbon storage of slash pine plantations for < 10 years in this study was 2.64 Mg ha$^{-1}$ in the same area. The total tree carbon storage in 19-year-old plantation dominated by slash pine in Ji'an area was 22.36 Mg ha$^{-1}$ in Luoxi forest restoration experimental site, while a value of 86.78 Mg ha$^{-1}$ was reported in slash pine plantation with the same tree age in Qianyanzhou experimental site about 30 km from the Luoxi site (Tu and Liu 2007; Wei et al. 2013). Both were higher than the value of 14.73 Mg ha$^{-1}$ found in slash pine plantations for 10-20 years in the same area of this study. Researchers also found a higher value of 48.64 Mg ha$^{-1}$ in 21-year-old slash pine plantations of Qianyanzhou experimental site compared to our findings (13.4 Mg ha$^{-1}$) found in slash pine plantations for 20-30 years (Ma et al. 2014). Such a large variation was mainly due to the different stand characteristics. For instance, compared to our stand density data for the similar

**Table 2.** The tree (including stem, branch, foliage and root) carbon storage (Mg C ha$^{-1}$ ± standard errors) of slash pine plantations measured at three study areas of Jiangxi Province, and different lowercase letters indicate significant differences among age ranges in the same study area ($p < 0.05$)

| Location | Age range (years) | Stem | Branch | Foliage | Root | Total tree |
|---|---|---|---|---|---|---|
| Duchang | < 10 | 1.16±0.33a | 0.57±0.16a | 0.26±0.07a | 0.65±0.15a | 2.64±0.78a |
| | 10-20 | 8.52±3.29b | 3.32±1.28b | 1.67±0.64b | 4.01±1.71b | 17.51±6.92b |
| | 20-30 | 12.45±5.03c | 4.51±1.63c | 2.00±0.74b | 5.21±2.11c | 24.17±9.51c |
| Yiyang | < 10 | 3.26±0.89a | 1.35±0.44a | 0.65±0.21a | 2.24±1.06a | 7.50±2.60a |
| | 10-20 | 4.29±1.59a | 1.56±0.56a | 0.80±0.29a | 2.84±1.73a | 9.48±4.17a |
| | 20-30 | 12.02±2.05b | 4.21±0.66b | 1.88±0.30b | 6.01±2.25b | 24.13±5.27b |
| Ji'an | < 10 | 0.24±0.06 | 0.18±0.03 | 0.07±0.01 | 0.42±0.03 | 0.92±0.13 |
| | 10-20 | 7.31±3.09 | 2.44±0.87 | 1.27±0.45 | 3.70±1.28 | 14.73±5.68 |
| | 20-30 | 6.68±1.91 | 2.40±0.71 | 1.13±0.33 | 3.20±1.19 | 13.40±4.13 |

age in slash pine plantations in Duchang and Ji'an areas (Table 3), more than twice of stand density with similar tree age were documented in the previous studies (Tu and Liu 2007; Ma et al. 2014; Cao et al. 2016), which may strongly influence tree growth and carbon accumulation in forests (Jagodziński et al. 2018; Khan et al. 2018).

### Carbon storage changes of understory and forest floor

There was no significant difference in the understory

**Table 3.** The mean total ecosystem (including tree, understory, litter and mineral soil) carbon storage (Mg C ha$^{-1}$) of slash pine plantations in China

| Location | Mean age (years) | Mean tree density (stems ha$^{-1}$) | Ecosystem carbon | Reference |
|---|---|---|---|---|
| Duchang, Jiangxi Province | 8 | 1,250 | 61.55 | This study |
| Yiyang, Jiangxi Province | 8 | 1,113 | 71.4 | |
| Ji'an, Jiangxi Province | 5 | 963 | 21.45 | |
| Duchang, Jiangxi Province | 5 | 5,200 | 21.74* | Cao et al. 2016 |
| | 5 | 2,500 | 4.94* | |
| | 5 | 1,200 | 2.59* | |
| Shaoyang, Hunan Province | 7 | 2,000 | 41.28 | Li et al. 2011 |
| | 7 | 1,200 | 27.39 | |
| | 7 | 800 | 20.02 | |
| Duchang, Jiangxi Province | 12 | 1,988 | 95.24 | This study |
| Yiyang, Jiangxi Province | 17 | 846 | 88.94 | |
| Ji'an, Jiangxi Province | 19 | 758 | 77.82 | |
| Hengyang, Hunan Province | 15 | 2,100 | 104.07 | Zheng et al. 2008 |
| Ji'an, Jiangxi Province | 19 | 633 | 103.94 | Wei et al. 2013 |
| Ji'an, Jiangxi Province | 19 | n/a | 121.96 | Tu and Liu 2007 |
| Duchang, Jiangxi Province | 24 | 1,255 | 105.66 | This study |
| Yiyang, Jiangxi Province | 22 | 1,329 | 76.76 | |
| Ji'an, Jiangxi Province | 27 | 646 | 71.72 | |
| Ji'an, Jiangxi Province | 21 | 1,439 | 116.77 | Ma et al. 2014 |
| Longli, Guizhou Province | 20 | 950 | 77.18** | Liu et al. 2017 |
| Pingtan, Fujian Province | 30 | 1,500 | 145.27 | Zhong et al. 2016 |

*Excluding understory carbon storage; **Excluding the carbon storage of mineral soil.

**Table 4.** The understory and litter carbon storage (Mg C ha$^{-1}$±one standard error) of slash pine plantations measured at three study areas of Jiangxi Province

| Location | Age range (years) | Understory | | | Litter |
|---|---|---|---|---|---|
| | | Herb | Shrub | Herb+Shrub | |
| Duchang | <10 | 0.17±0.17 | 1.04±0.90 | 1.57±1.08 | 1.04±0.55 |
| | 10-20 | 0.45±0.56 | 0.68±0.54 | 1.13±1.09 | 1.50±0.59 |
| | 20-30 | 0.23±0.04 | 0.87±0.48 | 1.10±0.52 | 1.49±0.88 |
| Yiyang | <10 | 1.33±0.46 | 1.11±0.92 | 2.43±1.39 | 2.47±1.96 |
| | 10-20 | 0.94±0.68 | 1.34±0.89 | 2.28±1.56 | 2.88±2.37 |
| | 20-30 | 0.88±0.48 | 0.62±0.33 | 1.50±0.81 | 1.33±0.78 |
| Ji'an | <10 | 0.37±0.52 | 1.17±0.03 | 1.54±0.55 | 0.79±0.35 |
| | 10-20 | 0.45±0.56 | 3.65±1.96 | 4.09±2.52 | 2.50±1.76 |
| | 20-30 | 1.51±1.25 | 2.31±0.89 | 3.82±2.14 | 3.20±1.02 |

and forest floor carbon storage between different age sequences of slash pine plantations at the same area (Table 4). There was no age-related trend founded in the carbon storage of understory and forest floor in this study. Carbon storage in understory and forest floor was generally highly variable between our findings and other studies in the same area. For example, results from Wei et al. (2013) showed that the carbon storage of understory and forest floor in 19-year-old slash pine plantations were 0.2 and 9.59 Mg $ha^{-1}$ in Ji'an area, which were not in accordance with our results for the same tree age in the same area (Wei et al. 2013). The mean understory carbon storage of slash pine plantations for 20-30 years in Ji'an area of this study was higher than 2.84 reported in 21-year-old slash pine plantations in the Qianyanzhou site, but the carbon storage of forest floor in our study was lower than 9.24 Mg $ha^{-1}$ in the Qianyanzhou site (Ma et al. 2014). The different findings between different sites were due mainly to the smaller canopy following high stand density and larger carbon input following severe ice storm reported in the Qianyanzhou site compared to our studies (Ma et al. 2014).

### *Changes in soil carbon storage*

The differences in soil carbon storage between different age sequences of slash pine plantations at the same area were not significant (Fig. 1). The mean total carbon storage in mineral soil (100 cm depth) of slash pine plantations ranged from 56.33 Mg $ha^{-1}$ at $<10$ years to 78.90 Mg $ha^{-1}$ at 20-30 years in Duchang area, 59.01 to 49.84 Mg $ha^{-1}$ in Yiyang area, and 18.21 to 51.31 Mg $ha^{-1}$ in Ji'an area, showing no age-related patterns. Overall, soil carbon storage in our study was close to the results from others (Zheng et al. 2008; Ma et al. 2014). The mean total soil carbon storage of slash pine plantations for 10-20 and 20-30 years in Ji'an area of this study was 56.5 and 51.3 Mg $ha^{-1}$, which were close to 56.05 Mg $ha^{-1}$ (100 cm depth) in 21-year-old slash pine plantations in the Qianyanzhou site (Ma et al. 2014), but lower than 71.46 Mg $ha^{-1}$ (50-100 cm depth) in 19-year-old slash pine plantations in the Luoxi site (Wei et al. 2013). The mean total soil carbon storage of slash pine plantations for 10-20 years across three study areas was 68.63 Mg $ha^{-1}$ in this study were also close to 62.67 Mg $ha^{-1}$ (100 cm depth) in 15-year-old slash pine plantations in Hengyang of Hunan Province (Zheng et al. 2008). Our results suggest that soil carbon pool accounted for most of ecosystem carbon storage in slash pine plantations.

### *Total ecosystem carbon storage*

Total tree and soil were two dominant carbon pools of slash pine plantations in all age sequences in this study (Fig. 2). The relative contribution of total tree to total ecosystem carbon storage increased from 4% at $<10$ years to 23% at 20-30 years in Duchang area, 11% to 31% in Yiyang area, and 4% to 19% in Ji'an area. The contribution of soil to total ecosystem carbon storage declined with increasing age, decreasing from 91% at $<10$ years to 75% at 20-30 years in Duchang area, 83% to 65% in Yiyang area, and 85% to

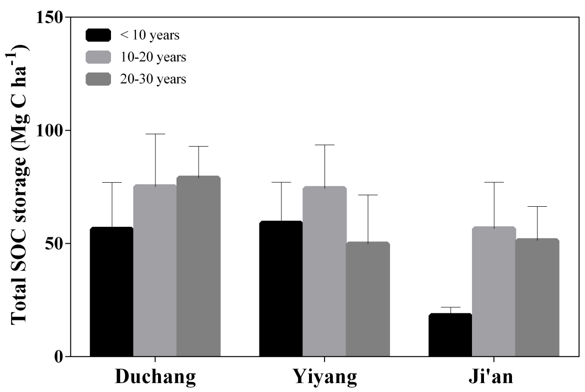


**Fig. 1.** The total soil organic carbon (SOC, 0-100 cm, Mg C $ha^{-1}$) among different age ranges in slash pine plantation measured at three study area of Jiangxi Province.

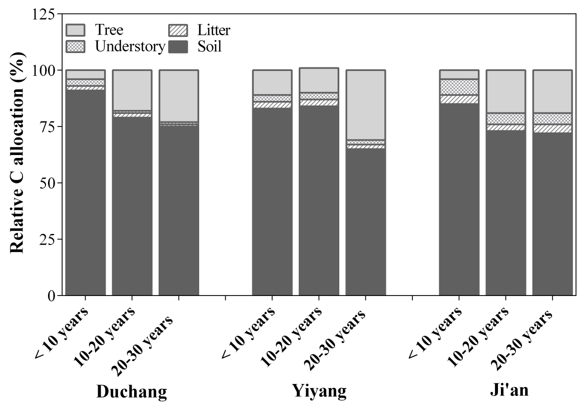


**Fig. 2.** The relative carbon (C) allocation of each ecosystem component (tree, understory, litter and mineral soil) expressed as a percent (%) among different age ranges in slash pine plantation measured at three study area of Jiangxi Province.

72% in Ji'an area. Our findings were similar with the results from other chronosequence studies. For example, the contribution of belowground ecosystem carbon storage declined with increasing age, while that of aboveground ecosystem carbon storage increased with increasing age in White pine (*P. strobus* L.) plantation of Canada and Korean pine (*P. koraiensis* Sieb. et Zucc.) plantations in central Korea (Peichl and Arain 2006; Li et al. 2011).

We synthesized the total ecosystem carbon storage in slash pine plantations from the available literature in China (Table 3). The mean total ecosystem carbon storage of slash pine plantations for <10, 10-20 and 20-30 years across China was 30.26, 98.66 and 98.89 Mg $ha^{-1}$, respectively. Owing to its ecological adaptation, slash pine was gradually planted in different provinces of southern China, covering different soil types including karst landform, rocky and sandy desertification areas (Li et al. 2011; Cao et al. 2016; Zhong et al. 2016; Liu et al. 2017). Therefore, the carbon pool sizes of slash pine plantations in different areas showed large variable range for the same tree age sequences (Table 3). The average total ecosystem carbon storage of different age ranges of slash pine plantations in our study was 74.5 Mg $ha^{-1}$, which was much lower than the provincial average (134.8 Mg $ha^{-1}$) in *P. massoniana* forests and (169.5 Mg $ha^{-1}$) in *C. lanceolate* forests in Jiangxi province (Wang and Wei 2007), suggesting that native species would be a viable option for consideration in terms of carbon stock. Furthermore, we compared the synthesized results in China with the ecosystem carbon storage of native slash pine plantations in USA. Although subtropical climate in China was suitable for slash pine growth, the mean total carbon stocks at all age sequences in slash pine plantations from China were lower than that values reported in American slash pine plantations (Shan et al. 2002; Clark et al. 2004; Ma et al. 2014). For example, the biomass (including tree, understory and forest floor) and soil carbon storage (100 cm depth) in 17-year-old slash pine plantations in northern Florida were 135.1 and 140.8 Mg $ha^{-1}$ (Shan et al. 2002). If a factor of 0.5 was used to convert carbon concentration from biomass for vegetation and forest floor, the total carbon storage in 17-year-old slash pine plantations is approximately 208.35 Mg $ha^{-1}$, which is much higher than 98.66 Mg $ha^{-1}$ in slash pine plantations for 10-20 years across China. In another plantations investigated in northern Florida, total carbon stocks (including tree, understory, coarse wood and forest floor) were 56.51 and 108.67 Mg $ha^{-1}$ (Clark et al. 2004). If the sizes of total soil carbon pool are close to 140.8 Mg $ha^{-1}$ in 10- and 24-year-old slash pine plantations, total carbon stocks are approximately 197.31 and 249.47 Mg $ha^{-1}$, which are also much higher than 30.26 and 98.89 Mg $ha^{-1}$ in slash pine plantations for <10 and 20-30 years across China. The discrepancy between two countries may be due to differences in climate. The annual precipitation and mean July temperature are very similar, while lower mean January temperature was found at the sites in China compared to approximately 14°C in Florida (Clark et al. 2004; Ma et al. 2014).

## Conclusion

The carbon storage of each tree component of slash pine increased significantly with increasing age in Duchang and Yiyang areas. The stem carbon storage except <10 years in Ji'an areas was the largest component among all other components, which accounts for about 50% of the total carbon storage followed by roots (~28%), branches (~18%), and foliage (~9%). The mean total tree carbon storage of slash pine plantations for <10, 10-20 and 20-30 years across three study areas was 3.69, 13.91 and 20.57 Mg $ha^{-1}$, respectively. There was no age-related trend founded in the carbon storage of understory and forest floor. Total tree and soil were two dominant carbon pools in slash pine plantations at all age sequences. The carbon contribution of belowground ecosystem declined with increasing age, while that of aboveground ecosystem increased. The mean total ecosystem carbon storage of slash pine plantations for <10, 10-20 and 20-30 years across China was 30.26, 98.66 and 98.89 Mg $ha^{-1}$, respectively. Although subtropical climate in China was suitable for slash pine growth, the mean total carbon stocks at all age sequences in slash pine plantations from China were lower than that values reported in American slash pine plantations.

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