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Litter Productivity and Nutrient Return Characteristics of Three Typical Forest Stands in Golden Mountain

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Abstract

Objective: The paper aims to analyze the dynamic characteristics of litter production and nutrient return of the forest ecosystems in subtropical areas, and provide a theoretical basis for the nutrient cycling study in southwest Hubei Province and carbon sink function of the whole forest ecosystem. **Methods:** Three typical forest stands (Chinese fir plantation, *Cryptomeria fortunei* plantation and evergreen and deciduous broad-leaved mixed forest) in Golden Mountain Forest Farm in southwest Hubei Province were investigated and monitored continuously for the litter types and productivity and nutrient return. **Results:** The annual litter productivity of the three forest stands ranged from 161.77 to 396.26 kg·hm^{-2}; Litters of branches, leaves and reproductive organs accounted for 14.14% - 20.85%, 33.26% - 78.33%, 7.52% - 42.18% of the total, respectively; The litter productivity and total litter productivity of each composition in the three forest stands show unimodal or bimodal changes over months, and the total litter productivity reached the highest value in January, April and October respectively. For different nutrient contents of the three forest stands, the common feature is C > N. The order of nutrient return amount from greatest to least is evergreen and deciduous broad-leaved mixed forest, *Cryptomeria fortunei* plantation and Chinese fir plantation. For different nutrient return amounts, the common feature is C > N, and the nutrient return amounts are 76.51-180.69 kg·hm^{-2} and 2.3 - 5.71 kg·hm^{-2} respectively. **Conclusion:** The annual litter productivity and nutrient return amount of the evergreen and deciduous broad-leaved mixed forest are the highest among the three forest stands. Therefore, protecting the evergreen and deciduous broad-leaved mixed forest and studying the litter changes of Chinese fir plantation and *Cryptomeria fortunei* plantation are of far-reaching significance for the development of sustainable forest management in this region and the further improvement of the carbon sequestration function of the whole forest ecosystem.

Keywords

Golden Mountain, Litter Productivity, Nutrient Return Amount, Nutrient Content

1. Introduction

In the forest ecosystem, litter, as the main medium of nutrient transmission, is an important link in the material cycle between the forest vegetation and soil, and it plays a key role in maintaining soil fertility and material and nutrient cycling. More than 90% of N and P and more than 60% of mineral elements in the forest growth come from litter return [1], and 70% of the annual global CO_2 circulation is generated by litter decomposition [2]. Therefore, it is still necessary to explore the dynamic changes of litter productivity and nutrient return for a better understanding of the litter nutrient return efficiency in the forest ecosystem and the sustainable management of forest ecosystem.

Since 1960s, many scholars at home and abroad have done a lot of research on litters of different forest types, including Chinese fir plantation [3], subtropical evergreen broad-leaved forest [4], subtropical mixed forest [4], tropical mountain rain forest [5], south subtropical coniferous forest [6], subalpine evergreen broad-leaved forest in central Yunnan Province [7], mixed broadleaf-conifer forest [8], secondary evergreen broad-leaved forest in central Yunnan Province [9], Yunnan pine forest [10] and among others. Previous studies mainly focused on the seasonal variation of litters, decomposition rate, nutrient elements and nutrient return. However, the litter productivity of forests varies from region to region due to forest and climate types. This difference is influenced by several factors, such as forest stand type, climatic conditions and geographical factors in the study area. To further explore more generalized patterns and mechanisms, we still need to conduct an in-depth investigation and analysis of litters in forest ecosystems of different regions.

As a typical area of karst landform, southwest Hubei Province exhibits significant variations in habitat heterogeneity at different scales. Compared with forest communities in areas with similar latitudes, the forest communities in southwestern Hubei Province have higher richness and heterogeneity. It is one of the core areas of the "Eastern Sichuan-Western Hubei Endemism Center", one of China's three centers of seed plants, and has been designated as a priority conservation area in China and a key area of global significance for biodiversity. In recent years, studies on litters of different forest ecosystems in southwest Hubei Province focuses on carbon distribution pattern and dynamics [11], dynamic changes of species [12], population structure and dynamic characteristics [13] [14], community structure and species diversity [15], etc. But there are rather few studies on litter composition and nutrient return dynamics of different forest stands. The research objects in the paper are Chinese fir plantation, *Cryptomeria fortunei* plantation and evergreen and deciduous broad-leaved mixed forest in Golden Mountain Forest Farm in southwest Hubei Province. By studying the litter productivity, nutrient content of C and N, nutrient return amount and dynamic characteristics of different forest stands, we can understand the change mechanism and law of litter productivity and nutrient return amount of different forest stands, which can provide scientific data support for an in-depth understanding of carbon cycling and nutrient cycling of forest ecosystems in southwest Hubei Province.

2. Study Area and Methods

2.1. Study Area

The study area is located in the state-owned Golden Mountain Forest Farm in Lichuan City, Hubei Province. The geographical coordinate of the center of the forest farm is 30˚17’17"N, 109˚2’58"E. The region has a subtropical continental monsoon climate with an average annual temperature of 12.7˚C. The soil types are mountain yellow-brown soil and brown soil. The soil layer thickness is 0.3 - 1.2 m, and the soil pH value is 5 - 6, slightly acidic. The annual rainfall of this region is abundant with an average annual precipitation of about 1500 mm, and the rainfall is mostly concentrated from April to September, accounting for around 78% of the annual rainfall.

2.2. Research Methods

2.2.1. Sample Plot Setting

In the typical areas of Chinese fir plantation, *Cryptomeria fortunei* plantation and evergreen and deciduous broad-leaved mixed forest in the forest farm, three fixed monitoring sample plots with specifications of 20 m × 20 m were set up in each forest stand according to the CTFS construction specifications (**Table 1**). As shown in “**Figure 1**”, As shown in **Figure 1**, five self-made litter collection frames with specifications of 1 m * 1 m were set up at the four corners and center of the sample plots to collect litters in the forest month by month. The nylon mesh screen aperture of the collection frames, which were placed horizontally 30 cm above the ground, is 1 mm.

2.2.2. Litter Collection and Treatment

From January 2020 to December 2020, we collected the litters in the litter frames on the 30th of each month, a total of 12 times. The collected litter samples were classified based on plant organs (branches, leaves and reproductive organs).The classified litters were dried in a constant temperature oven at 80˚C to a constant weight, and weighed for a dry weight after drying. Then, the dried litters with different compositions were crushed and sieved (specification of 0.25 mm) for the nutrient content determination.

2.2.3. Nutrient Content Determination of Litters

An elemental analyzer (Elemental Analyzer vario MICRO cube, Germany) was

Table 1. Standing conditions of three typical forest communities in Jinzishan

Spect	Stand types	Altitude/m	Slope/°	Aspect	Age	Canopy density	Stand density Sytrain·ha^{-1}
P1	*Cunninghamia lanceolata* plantation	1382	27	North	Near-mature forest	0.71	1000
P2	*Cunninghamia lanceolata* plantation	1394	16	North	Near-mature forest	0.75	1250
P3	*Cunninghamia lanceolata* plantation	1393	30	Northeast	Near-mature forest	0.68	1725
P4	Evergreen deciduous broad-leaved mixed forest	1468	33	Northeast	Mature forest	0.5	6225
P5	Evergreen deciduous broad-leaved mixed fores	1482	28	Northeast	Mature forest	0.66	9200
P6	Evergreen deciduous broad-leaved mixed forest	1485	29	East	Mature forest	0.65	7975
P7	*Cryptomeria fortunei* plantation	1447	21	North	Mature forest	0.85	2100
P8	*Cryptomeria fortunei* plantation	1382	27	North	Mature forest	0.95	3500
P9	*Cryptomeria fortunei* plantation	1556	3	Northeast	Mature forest	0.87	900

Figure 1. Layout of apoptosis collection frames.

applied to determine C and N contents in litter samples.

2.2.4. Data Analysis and Calculation

Excel 2016 was applied for data organization, SPSS 26.0 for one-way ANOVA and multiple comparisons ($\alpha = 0.05$) of each month's data, and Origin 2018 for the chart drawing.

3. Results and Analysis

3.1. Dynamic Characteristics of Litter Productivity in the Three Forest Stands

3.1.1. Annual Total Litter Production and Litter Compositions in the Three Forest Stands

Branches, leaves and reproductive organs are the main litter compositions of forest stands. According to "Table 2", the annual litter production of branches, leaves and reproductive organs in different forest stands ranges from 406.21

Table 2. Annual litter of each component of three stands.

Stand types	Litter branches/ kg·hm^{-2}	Litter leaves/ kg·hm^{-2}	Litter reproductive organ/kg·hm^{-2}	Total/kg·hm^{-2}
Cunninghamia lanceolata plantation	406.21 ± 9.59^{aB}	912.32 ± 18.02^{aB}	652.73 ± 14.17^{aB}	1971.26 ± 40.36^{aA}
Cryptomeria fortunei plantation	436.95 ± 11.52^{aB}	765.91 ± 12.61^{aB}	867.83 ± 25.22^{aB}	2070.69 ± 41.85^{aA}
Evergreen deciduous broad-leaved mixed forest	660.44 ± 11.80^{aA}	3724.94 ± 142.87^{aA}	357.55 ± 16.45^{aA}	4742.93 ± 149.44^{aA}

Note: The significant differences between different stands of the same stand are represented by different lowercase letters, and the significant differences between different components of the same stand are represented by different university letters, $p < 0.05$. The same below.

kg·hm^{-2} to 660.44 kg·hm^{-2}, 765.91 kg·hm^{-2} to 3, 724.94 kg·hm^{-2}, and 357.55 kg·hm^{-2} to 867.83 kg·hm^{-2}, respectively, accounting for 13.92% - 24.10%, 36.99% - 78.54%, and 7.54% - 41.91% of the total, respectively. The leaf litter production is 1.75 - 5.64 times and 0.88 - 10.42 times that of branches and reproductive organs, respectively. Among the three forest stands, the evergreen and deciduous broad-leaved mixed forest has the highest litter production of branches and leaves and total litter production, while the *Cryptomeria fortunei* plantation has the highest litter production of reproductive organs. The order of annual total litter production from greatest to least is evergreen and deciduous broad-leaved mixed forest, *Cryptomeria fortunei* plantation and Chinese fir plantation. There were no significant differences in annual total litter production among the three forest stands, nor were there significant differences in litter productivity of each composition in the same forest stand.

3.1.2. Monthly Dynamic Changes in Litter Productivity of Compositions in the Three Forest Stands

As shown in "Figure 2", there are significant differences in the monthly distribution of litter productivity of compositions in the three forest stands. According to "Figure 2(a)", for the Chinese fir plantation, the litter production of branches reaches the peak of 89.12 kg·hm^{-2} in March. The litter productivity of leaves reaches the peak of 188.83 kg·hm^{-2} in January, and that of reproductive organs reaches the peak of 133.75 kg·hm^{-2} in April.

According to "Figure 2(b)", for the *Cryptomeria fortunei* plantation, the litter production of leaves and branches both reaches their peaks of 129.05 kg·hm^{-2} and 188.83 kg·hm^{-2}, respectively in May, and that of reproductive organs reaches the peak of 320.25 kg·hm^{-2} in April.

According to "Figure 2(c)", for the evergreen and deciduous broad-leaved mixed forest, the litter production of branches reaches the peak of 156.25 kg·hm^{-2} in April, that of leaves reaches the peak of 1, 769.13 kg·hm^{-2} in October, and that of reproductive organs reaches the peak of 200.35 kg·hm^{-2} in June.

3.2. Nutrient Content of Litters in the Three Forest Stands

3.2.1. Annual Nutrient Content of Compositions in the Three Forest Stands

According to "Figure 3", for nutrient contents in each litter composition of the

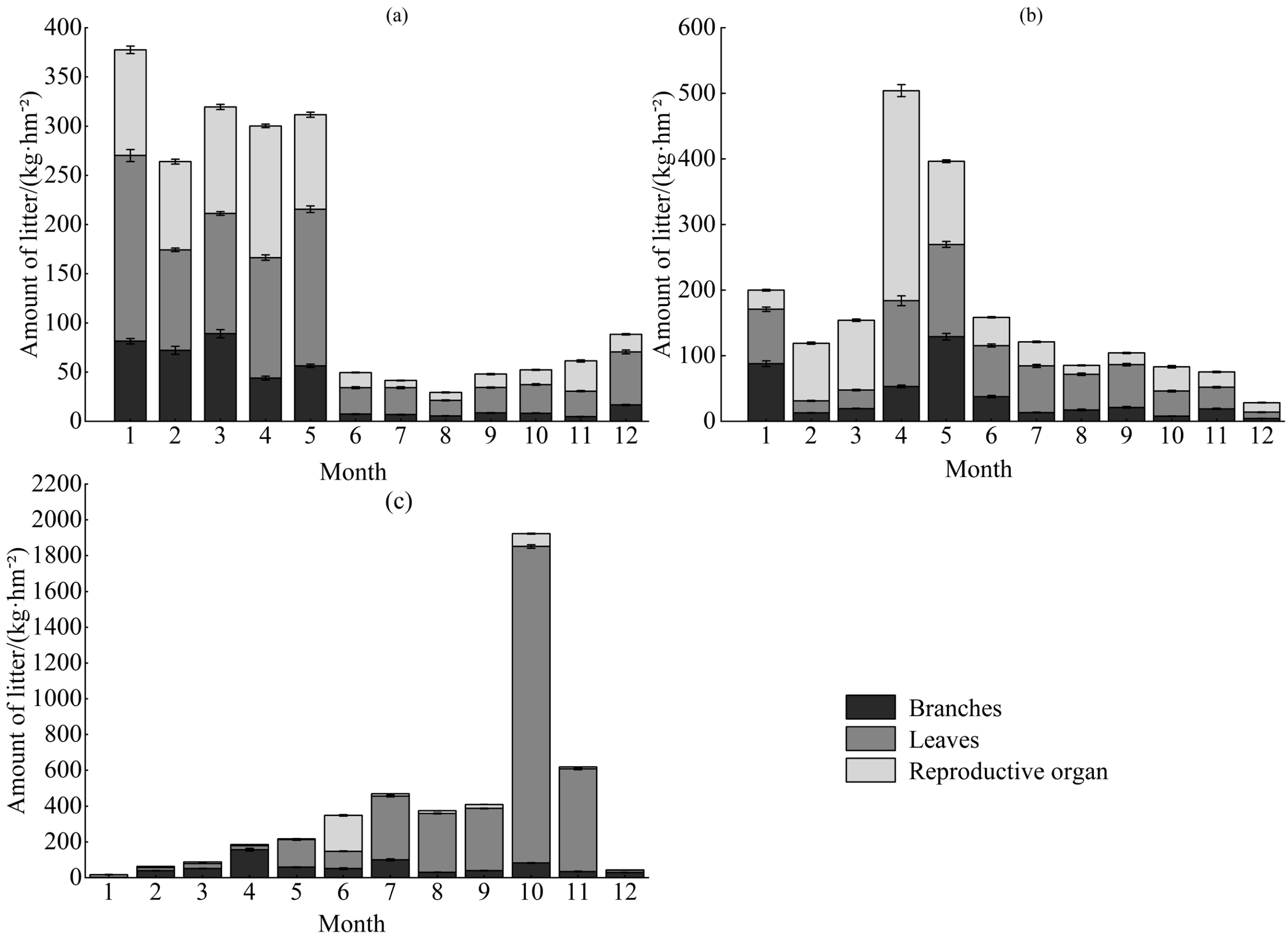

Figure 2. Dynamic variation characteristics of litter in *Cunninghamia lanceolata* plantation (a), *Cryptomeria fortunei* plantation (b), Evergreen deciduous broad-leaved mixed forest (c).

three forest stands, the common feature is C > N. In the three forest stands, the C content shows significant differences among each composition of the other stands, except for the evergreen and deciduous broad-leaved mixed forest ($p < 0.05$).The N content shows significant differences among each composition of the three forest stands ($p < 0.05$). For litters of leaves and reproductive organs, the C content is the highest in the Chinese fir plantation (469.33 $g \cdot kg^{-1}$, 495.63 $g \cdot kg^{-1}$), and the lowest in the evergreen and deciduous broad-leaved mixed forest (447.70 $g \cdot kg^{-1}$, 459.73 $g \cdot kg^{-1}$). However, the N content is the highest in the evergreen and deciduous broad-leaved mixed forest (15.10 $g \cdot kg^{-1}$, 16.83 $g \cdot kg^{-1}$), and the lowest in the Chinese fir plantation (14.36 $g \cdot kg^{-1}$, 9.11 $g \cdot kg^{-1}$). For branches, the C content is highest in the *Cryptomeria fortunei* plantation (451.16 $g \cdot kg^{-1}$), and the lowest in the Chinese fir plantation (448.93 $g \cdot kg^{-1}$). The N content is highest in the evergreen and deciduous broad-leaved mixed forest (11.82 $g \cdot kg^{-1}$), and the lowest in the *Cryptomeria fortunei* plantation (9.26 $g \cdot kg^{-1}$).

3.2.2. Monthly Dynamic Changes in Nutrient Contents of Each Litter Composition in the Three Forest Stands

The monthly dynamic changes in the C content of each litter composition in the

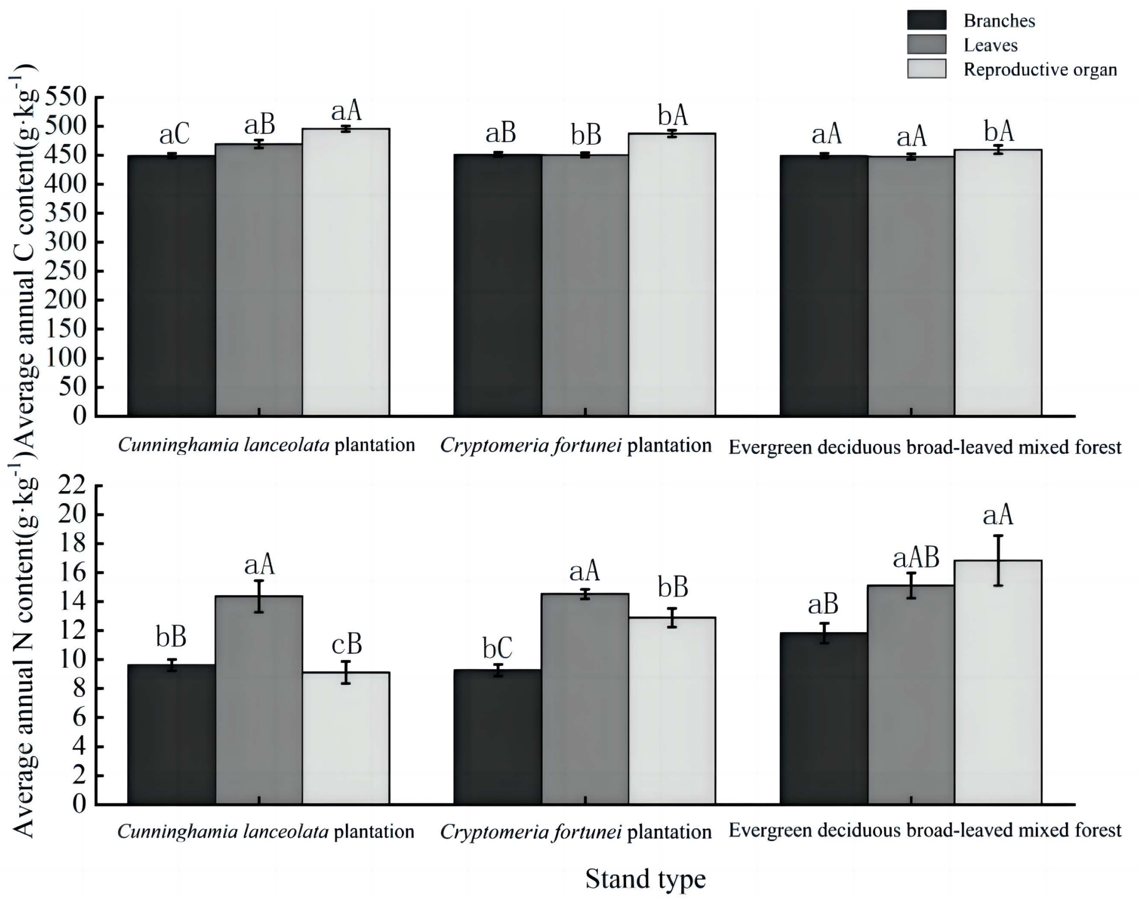

Figure 3. Average annual nutrient content of cech components of different stands.

three forest stands show a bimodal and multimodal pattern (**Figure 3**). According to "**Figure 4(a)**", the C content in the litters of branches of the three forest stands all show a bimodal change. For the Chinese fir plantation, it peaks in May and July, reaching a maximum peak of 464.5 g·kg^{-1}. For the *Cryptomeria fortunei* plantation, it peaks in August and September, reaching a maximum peak of 471.13 g·kg^{-1}. And for the evergreen and deciduous broad-leaved mixed forest, it peaks in July and December, reaching a maximum peak of 472.67 g·kg^{-1}. According to "**Figure 4(b)**", the C content in the litters of leaves of the three forest stands all show a multimodal change. For the Chinese fir plantation, it peaks in February, March and July, reaching a maximum peak of 501.7 g·kg^{-1}. For the *Cryptomeria fortunei* plantation, it peaks in May, June and November, reaching a maximum peak of 471 g·kg^{-1}. And for the evergreen and deciduous broad-leaved mixed forest, it peaks in January, June and December, reaching a maximum peak of 474.03 g·kg^{-1}. According to "**Figure 4(c)**", the C content in the litters of reproductive organs of the Chinese fir plantation and the evergreen and deciduous broad-leaved mixed forest both show a bimodal change, while the *Cryptomeria fortunei* plantation shows a multimodal change. For the Chinese fir plantation, it peaks in July and November, reaching a maximum peak of 533.67 g·kg^{-1}. For the evergreen and deciduous broad-leaved mixed forest, it peaks in

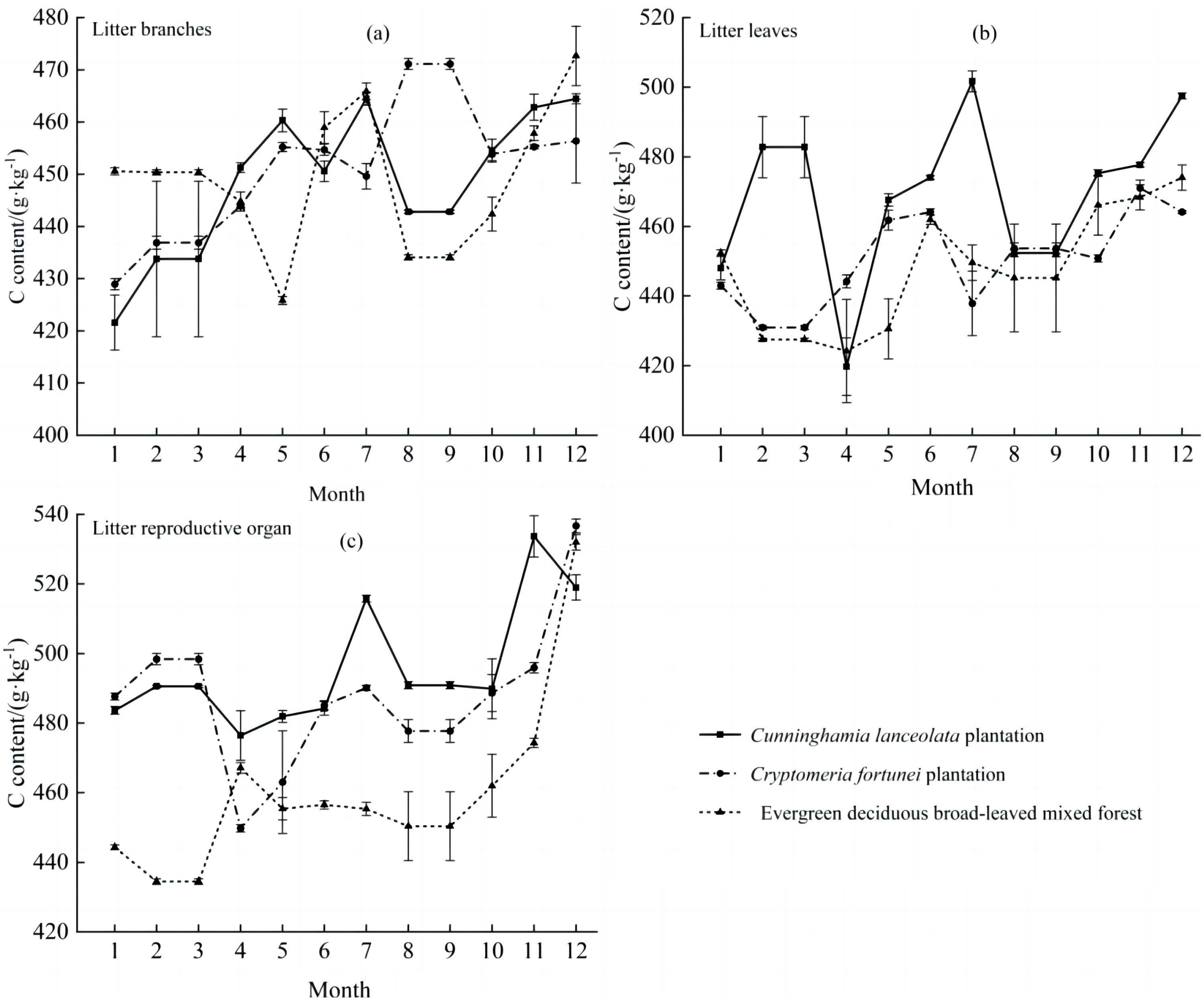

Figure 4. C content of different stands varies with months.

April and December, reaching a maximum peak of 531.97 g·kg^{-1}. And for the *Cryptomeria fortunei* plantation, it peaks in January, June and December, reaching a maximum peak of 536.7 g·kg^{-1}.

The monthly dynamic changes in the N content of each litter composition in the three forest stands show a bimodal and multimodal pattern (**Figure 5**). According to "**Figure 5(a)**", the N content in the litters of branches of the three forest stands all show a bimodal change. For the Chinese fir plantation, it peaks in January and June, reaching a maximum peak of 12.77 g·kg^{-1}. For the *Cryptomeria fortunei* plantation, it peaks in May and November, reaching a maximum peak of 11.17 g·kg^{-1}. And for the evergreen and deciduous broad-leaved mixed forest, it peaks in January and May, reaching a maximum peak of 15.17 g·kg^{-1}. According to "**Figure 5(b)**", the N content in the litters of reproductive organs of the *Cryptomeria fortunei* plantation and the evergreen and deciduous broad-leaved mixed forest both show a unimodal change, while the Chinese fir plantation shows a bimodal change. For the Chinese fir plantation, it peaks in

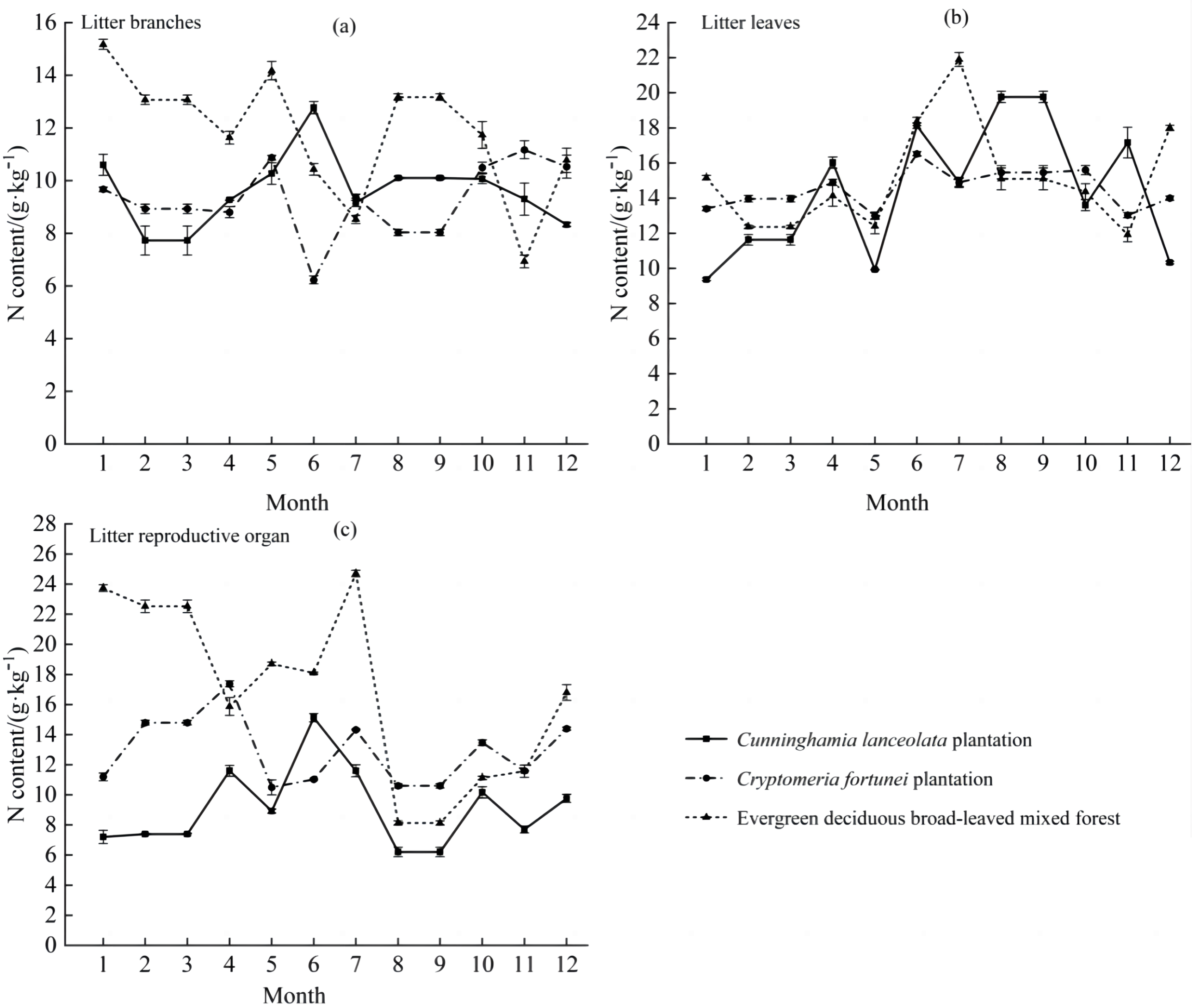

Figure 5. N content of different stands varies with months.

August and September, reaching a maximum peak of 19.77 g·kg^{-1}. For the *Cryptomeria fortunei* plantation, it reaches the peak of 16.53 g·kg^{-1} in June. And for the evergreen and deciduous broad-leaved mixed forest, it reaches the peak of 21.9 g·kg^{-1} in July. According to "**Figure 5(c)**", the N content in the litters of reproductive organs of the Chinese fir plantation and the evergreen and deciduous broad-leaved mixed forest both show a bimodal change, while the *Cryptomeria fortunei* plantation shows a multimodal change. For the Chinese fir plantation, it peaks in June and October, reaching a maximum peak of 15.13 g·kg^{-1}. For the evergreen and deciduous broad-leaved mixed forest, it peaks in January and July, reaching a maximum peak of 24.7 g·kg^{-1}. For the *Cryptomeria fortunei* plantation, it peaks in April, July and December, reaching a maximum peak of 17.37 g·kg^{-1}.

3.3. Dynamic Characteristics of Nutrient Return of Litters in the Three Forest Stands

3.3.1. Annual Nutrient Return Amount of Litters in the Three Forest Stands

For different nutrient return amounts of the three forest stands, the common feature is C > N (Table 3). For litters of branches, both C and N return amounts are the highest in the evergreen and deciduous broad-leaved mixed forest (24.68 $kg \cdot hm^{-2}$ and 0.63 $kg \cdot hm^{-2}$, respectively). The order from greatest to least is evergreen and deciduous broad-leaved mixed forest, *Cryptomeria fortunei* plantation and Chinese fir plantation. For litters of leaves, both C and N return amounts are the highest in the evergreen and deciduous broad-leaved mixed forest (142.40 $kg \cdot hm^{-2}$ and 4.61 $kg \cdot hm^{-2}$, respectively). The order from greatest to least is evergreen and deciduous broad-leaved mixed forest, Chinese fir plantation and *Cryptomeria fortunei* plantation. For litters of reproductive organs, the C and N return amounts were the highest in the Cryptomeria japonica plantation (34.20 $kg \cdot hm^{-2}$ and 1.04 $kg \cdot hm^{-2}$, respectively). The order from greatest to least is *Cryptomeria fortunei* plantation, Chinese fir plantation and evergreen and deciduous broad-leaved mixed forest. There were no significant differences in nutrient return amount among the forest stands, nor were there significant differences in each litter composition in the same forest stand.

3.3.2. Monthly Dynamic Changes in Nutrient Return Amounts of Composition in the Three Forest Stands

According to "Figure 6", in the evergreen and deciduous broad-leaved mixed forest, the monthly return amount of C for litters of branches shows a bimodal change over months. In contrast, both the Chinese fir plantation and *Cryptomeria fortunei* plantations show bimodal changes. The monthly dynamic changes in C return amount of litters of leaves in the three forest stands are unimodal. For the evergreen and deciduous broad-leaved mixed forest, the monthly dynamic change of C return amount of litters of reproductive organs is bimodal, and for the Chinese fir plantation and *Cryptomeria fortunei* plantation, it is unimodal. For the Chinese fir plantation, the C return amounts of letters of

Table 3. Annual nutrient return of each component of three stands.

Stand types	Litter leaves		Litter leaves		Litter reproductive organ	
	C amount returned/ $kg \cdot hm^{-2}$	N amount returned/ $kg \cdot hm^{-2}$	C amount returned/ $kg \cdot hm^{-2}$	N amount returned/kg·h m^{-2}	C amount returned/ $kg \cdot hm^{-2}$	N amount returned/ $kg \cdot hm^{-2}$
Cunninghamia lanceolata plantatio	14.71 ± 4.12^{aA}	0.31 ± 0.09^{aA}	35.25 ± 8.17^{aA}	2.21 ± 1.36^{aA}	26.55 ± 6.80^{aA}	0.48 ± 0.13^{aA}
Cryptomeria fortunei plantation	16.32 ± 5.16^{aA}	0.34 ± 0.12^{aA}	28.82 ± 5.75^{aA}	0.92 ± 0.18^{aA}	34.20 ± 11.34^{aA}	1.04 ± 0.44^{aA}
Evergreen deciduous broad-leaved mixed forest	24.68 ± 5.29^{aA}	0.63 ± 0.13^{aA}	142.40 ± 66.68^{aA}	4.61 ± 2.06^{aA}	13.61 ± 7.51^{aA}	0.47 ± 0.29^{aA}

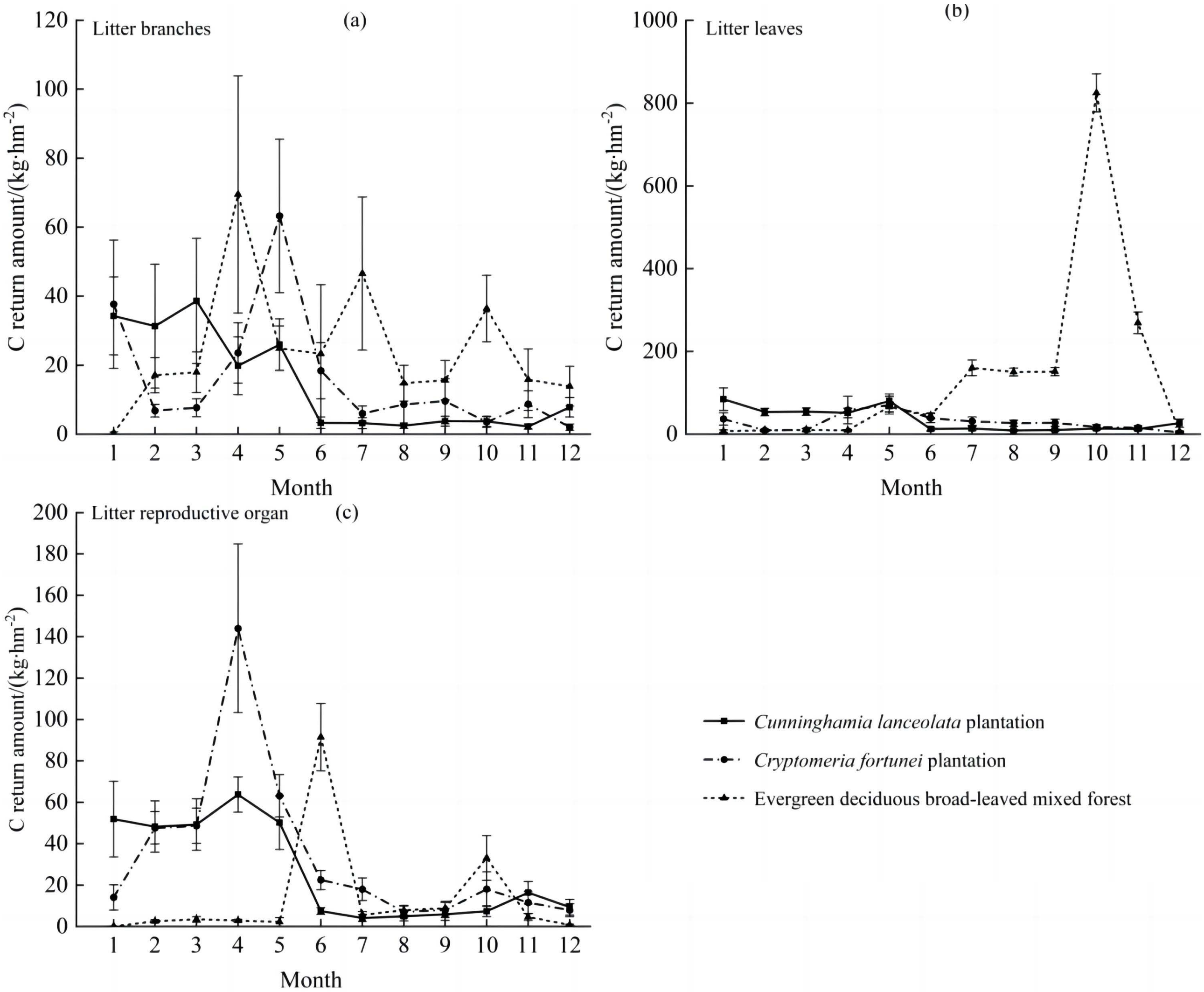

Figure 6. Variation characteristics of C return amount in different stands with months.

branches, leaves and reproductive organs peak in March, May and April, respectively (38.65 kg·hm^{-2}, 80.59 kg·hm^{-2} and 63.73 kg·hm^{-2}, respectively), accounting for 21.89%, 20.00% and 20.00% of the annual C return amount, respectively. For the *Cryptomeria fortunei* plantation, the C return amounts of letters of branches, leaves and reproductive organs peak in May, May and April, respectively (63.26 kg·hm^{-2}, 69.95 kg·hm^{-2} and 144.05 kg·hm^{-2}, respectively), accounting for 32.29%, 20.23% and 35.10% of the annual C return amount, respectively. For the evergreen and deciduous broad-leaved mixed forest, the C return amounts of litters of branches, leaves and reproductive organs peak in April, October and June (69.50 kg·hm^{-2}, 824.64 kg·hm^{-2} and 91.47 kg·hm^{-2}, respectively), accounting for 23.46%, 48.26% and 55.97% of the annual C return amount, respectively.

According to "Figure 7", for the Chinese fir plantation, the monthly N return amount of litters of branches shows a bimodal change. For the *Cryptomeria fortunei* plantation, it is unimodal, and for the evergreen and deciduous broad-leaved

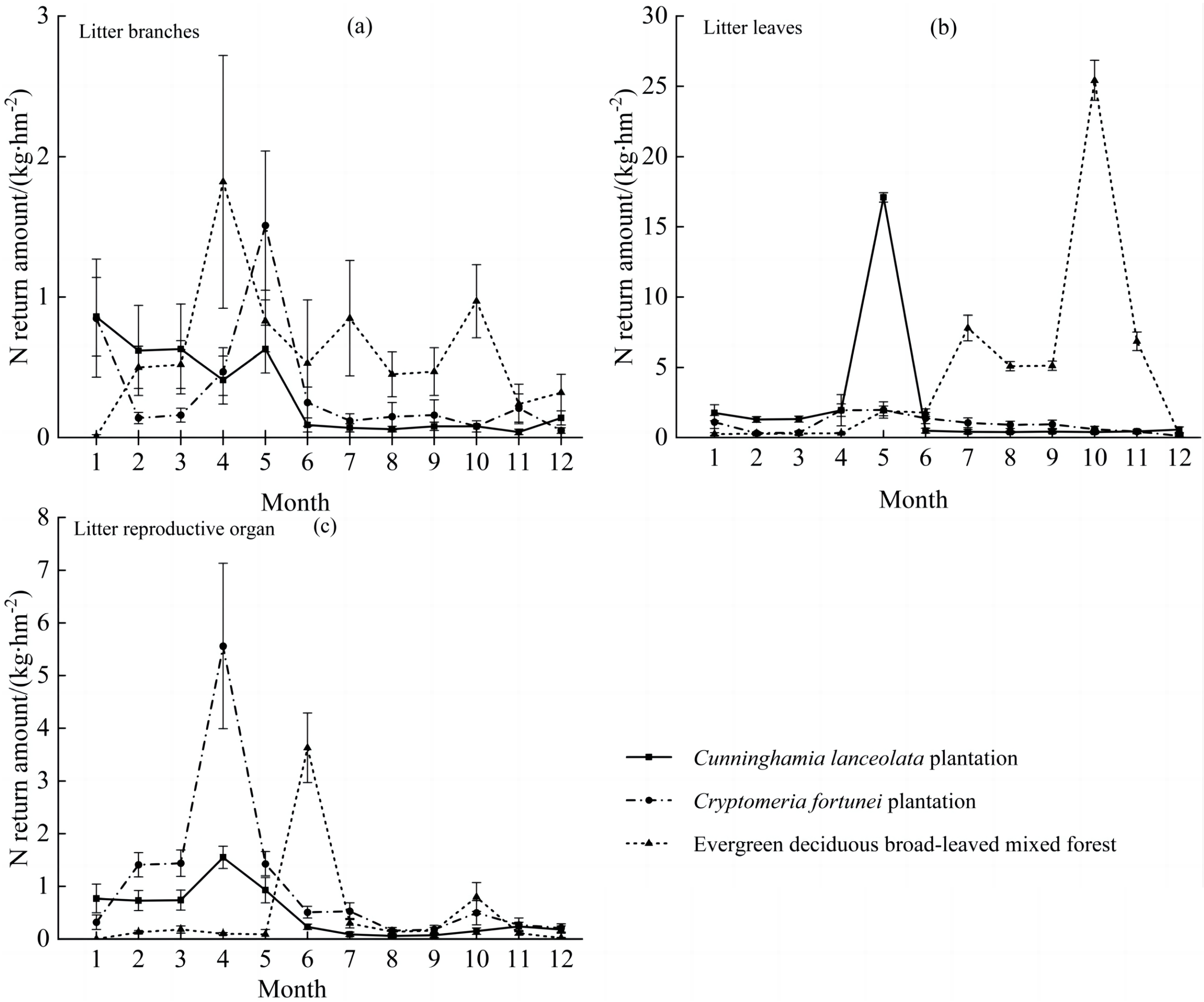

Figure 7. Variation characteristics of N return amount in different stands with months

mixed forest, it is multimodal. The monthly dynamic changes in N return amount of litters of leaves in the three forest stands are unimodal. For the evergreen and deciduous broad-leaved mixed forest, the monthly dynamic change of N return amount of litters of reproductive organs is bimodal, and for the Chinese fir plantation and *Cryptomeria fortunei* plantation, it is unimodal. For the Chinese fir plantation, the N return amounts of branches, leaves and reproductive organs peak in January, May and April, respectively (0.86 kg·hm^{-2}, 17.11 kg·hm^{-2} and 1.55 kg·hm^{-2}, respectively), accounting for 23.12%, 64.42% and 26.96% of the annual N return amount, respectively. For the *Cryptomeria fortunei* plantation, the N return amounts of branches, leaves and reproductive organs peak in May, May and April, respectively (1.51 kg·hm^{-2}, 1.97 kg·hm^{-2} and 5.56 kg·hm^{-2}, respectively), accounting for 36.39%, 17.72% and 44.41% of the annual N return amount, respectively. For the evergreen and deciduous broad-leaved mixed forest, the N return amounts of branches, leaves and reproductive organs peak in April, October and June respectively (1.82 kg·hm^{-2}, 25.42 kg·hm^{-2} and 3.63

kg·hm^{-2}, respectively), accounting for 24.27%, 45.93% and 64.02% of the annual N return amount.

4. Discussion

4.1. Litter Productivity and Dynamic Characteristics

Forest litters are key cyclic materials in forest ecosystems, and play an important role in maintaining soil fertility, and promoting material and biological cycles, and nutrient balance [16]. Under the same climatic conditions, the main factor influencing the litter productivity is the forest type, and it varies with the tree species and spatial density of forest stands [17]. The paper studies the annual litter amounts of three forest stands in the Golden Mountain, *i.e.*, Chinese fir plantation (1971.26 kg·hm^{-2}), *Cryptomeria fortunei* plantation (2070.69 kg·hm^{-2}), and evergreen and deciduous broad-leaved mixed forest (4742.93 kg·hm^{-2}). According to studies by Liu *et al.* [18] and Jia *et al.* [19], the average annual litter productivity in subtropical forests of Asia ranges from 1010 kg·hm^{-2} to 13,000 kg·hm^{-2}; in tropical forests, it is 8730 kg·hm^{-2}; in temperate forests, it is 378 kg·hm^{-2}; and in cold temperate forests, it is 266 kg·hm^{-2}. The results of this study are consistent with these findings. However, the litter productivities of the three forest stands in this study area are less than those of the tropical mountain rain forest in Jianfengling, Hainan (7686 kg·hm^{-2}) [20], and the Eucalyptus plantation in Leizhou Peninsula (8745.84 - 10,877.55 kg·hm^{-2}) [21]. The aforementioned study areas are located in the tropical mountain rain forest in Jianfengling, southwest of Hainan Island and the Leizhou Peninsula in Zhanjiang, Guangdong. Due to the influences of climate types and the size of litter collection frames, there are differences in the annual litter productivity compared to above study areas. The differences in species composition within each forest stand community in the study areas lead to changes in photosynthetic efficiency and ecological niches, which in turn affect the overall productivity level of forest stands [22]. The differences in annual litter productivity among the three forest stands in this study area may be attributed to the above factor.

In this study, the litter productivity of branches in the three forest stands does not show a uniform change pattern over months. This is due to the randomness associated with woody litters in forests and the fact that the branch fall is not directly related to phenological changes. The branches collected in a given month are often dead ones on trees previously. Litters of branches are greatly influenced by climatic conditions, especially wind, which blows down dead branches from previous months, causing changes in the litter productivity of branches in different months [23]. Affected by the combined influence of local climatic conditions and the ecological characteristics of tree species [17], the monthly dynamic changes in litter productivity of leaves are unimodal. For the evergreen and deciduous broad-leaved mixed forest, the litter productivity of leaves peaks in October due to the clear seasonal pattern of litter, with autumn having significantly higher litter productivity than other seasons. The monthly dynamic changes in litters of reproductive organs are unimodal, with peaks in April for Chinese fir plantation and *Cryptomeria fortunei* plantation, coinciding with the flowering period of these species and the rainy season in the study area. Rainfall leads to the falling of flowers, thus affecting litters of reproductive organs.

In this study, the proportion of each composition of litters in the total litter productivity varies among the three forest stands. For the *Cryptomeria fortunei* plantation, reproductive organs are predominant, and in the other two stands, leaves are the main composition. However, for the *Cryptomeria fortunei* plantation, the litter productivity of leaves is not significantly different from that of reproductive organs, indicating that litters of leaves play a key role in the total litter productivity, which is consistent with the findings of Wu Qiqian *et al.* [24] and Guo Yili *et al.* [25]. The reasons for the different proportion of each litter composition in the total litter productivity are closely related to the withering and falling time and litter productivity of plant organs in different forest stands, which are affected by ecological and biological characteristics such as vegetation type, forest stand density, age structure, ecological factors, stand development, etc. [26] [27], and are also related to climatic conditions of study areas, locations of sample plots and size of adopted litter collectors [7].

4.2. Nutrient Content and Dynamic Characteristics of Litters

The decomposition of forest litters, an important part in forest ecosystems, is the main source of the nutrients needed by plants and soil microorganisms and plays a great role in maintaining the balance of the whole forest ecosystem [28]. The nutrient use efficiency of plants can be reflected by the nutrient contents of litters, and the nutrient reuse is generally achieved by the translocation mechanism. The difference in forest types is the main factor contributing to the difference in the nutrient contents of litters under the same climatic conditions. The important factors affecting the nutrient contents of litters include forest age, community structure, soil nutrients and community biomass [29]. The energy required in the life of plants must be gained through the metabolic process of carbohydrates, because element C is the main composition of the carbohydrate in plants. Therefore, plants need more element C to maintain their growth, and in this study, for different nutrient contents of litters in the three forest stands, the common feature is C > N. However, according to Austin A.T.*et al.* [30], the nutrient contents of litters change with the rainfall in the study area. The contents of lignin and N increase with the increase of rainfall, which is related to the big nutrient content difference between months in this study.

4.3. Nutrient Return amount and Dynamic Characteristics of Litters

The regularity of nutrient return amount and nutrient content of litters in the three forest stands is the same in this study, which is C > N. This is consistent with the findings of Lin Wenquan [31] and Liu Yi [32]. The monthly dynamic change of the nutrient return amounts of litters is similar to the change trend of the litter productivity of forest stands, which is mainly affected by the litter productivity and the nutrient content. The highest peaks of the three forest stands are recorded respectively in April, May and October. This phenomenon is consistent with the hydrothermal conditions and the seasonal characteristics of plants in the study area. The dynamic change trend of litters of leaves, the main composition of nutrient return amount, can also reflect the change trend of the total nutrient return amount of litters to a certain extent, and they are consistent. The order of annual nutrient return amount for the three forest stands from greatest to least is evergreen and deciduous broad-leaved mixed forest, *Cryptomeria fortunei* plantation and Chinese fir plantation. It is found that the evergreen deciduous broad-leaved mixed forest has obvious advantages in nutrient cycling.

The C return amount of each litter composition of the three forest stands is more than that of N. According to the results of this study, the nutrient return amount of litters of leaves accounts for the majority of the total return amount, which is similar to the conclusion of Qi Zemin *et al.* [33]. The nutrient return of litters of leaves is the main form of nutrient return for the three forest stands in this study. 370Compared with litters of branches and reproductive organs, litters of leaves have the largest nutrient return amount as leaves are the part of plants that has the largest contact area with the external environment and are the main organs for photosynthesis and material production (the main organs for aboveground parts of plants to obtain resources), and play an important role in maintaining plant growth and metabolism [34].370

In conclusion, the annual litter productivity and nutrient return amount of the evergreen and deciduous broad-leaved mixed forest are higher than those of the other two forest stands. This indicates the abundant species diversity and the stable community structure in the evergreen and deciduous broad-leaved mixed forest. The litter decomposition is quicker and nutrients are returned to the soil, thus maintaining good soil fertility. Therefore, it is of great significance to explore the mechanism of litter change in the other two plantations while protecting the evergreen and deciduous broad-leaved mixed forest from destruction. This can help to promote the sustainable management of forests in the area and improve the carbon sink function of the whole forest ecosystem. In addition, the relationship between the nutrient return of litters and the soil nutrient is not illustrated in this study. It is necessary to further study the effects of soil nutrients on the nutrient return of litters in different forest communities.

5. Conclusion

For the three forest stands in Golden Mountain Forest Farm, the order of the annual litter productivity and the total nutrient return amount from greatest to least is evergreen and deciduous broad-leaved mixed forest, *Cryptomeria fortunei* plantation and Chinese fir plantation. There is no uniform change over months for the nutrient content and the return amount of each litter composition, and there are unimodal, bimodal and multimodal changes. The common feature is C > N. Among the three forest stands, the evergreen and deciduous broad-leaved mixed forest has the highest annual litter productivity and nutrient return amount, and exhibits rich species diversity and a stable community structure. The litter decomposition is quicker and nutrients are returned to the soil, thus maintaining good soil fertility. Therefore, protecting the evergreen and deciduous broad-leaved mixed forest and studying the litter changes of Chinese fir plantation and *Cryptomeria fortunei* plantation are of far-reaching significance for the development of sustainable forest management in this region and the further improvement of the carbon sequestration function of the whole forest ecosystem. Therefore, adopting multi-species mixed forests based on the characteristics of tree species is more conducive to vegetation and soil fertility restoration in this area.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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