Carbon Storage Allocation Characteristics of Platycladus Orientalis Plantation Ecosystem with Different Densities

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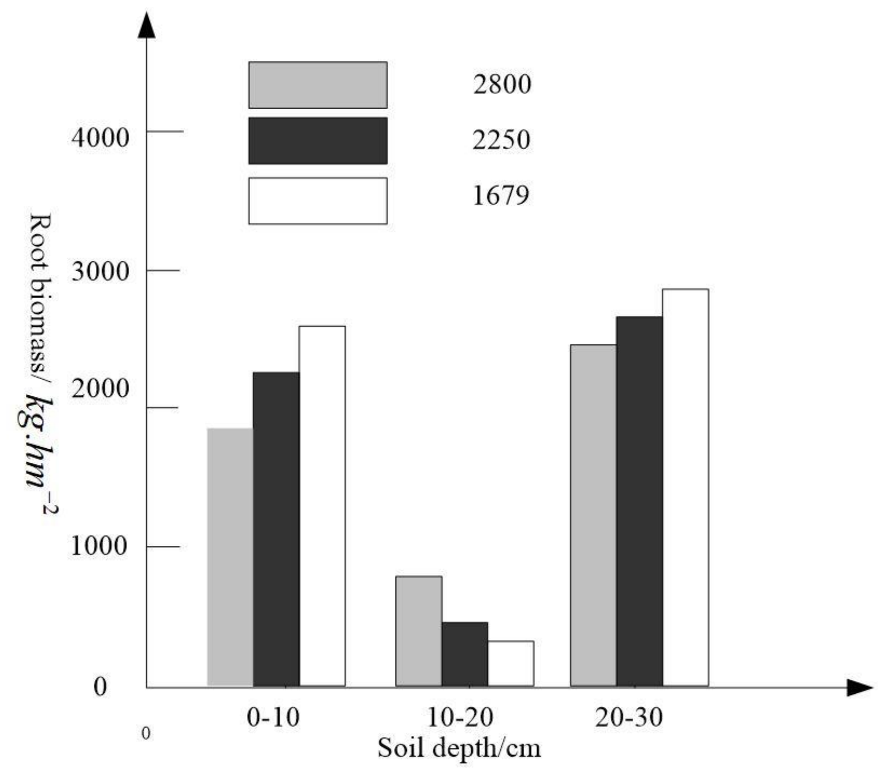
GRAPHICAL ABSTRACT



Abstract

Purpose: To research the influence of different densities of Platycladus orientalis plantation on the allocation characteristics of carbon storage in the ecosystem, the density regulation experiment on the Pinus massoniana plantation with different densities was carried out to discuss the change of the carbon storage of the ecosystem. Method: The density regulation experiment was carried out using random block design along contour line. Through the estimation of tree layer biomass of single Pinus massoniana, the determination of the carbon storage in the tree layer of Pinus massoniana, the estimation of the understory shrub, the grass layer, and the wood layer, the determination of carbon storage in vegetation and litter layer under forest, the determination of organic carbon content and carbon storage in the sample, and the carbon storage of the plantation ecosystem of different stand density sample plots, the effects of stand density on biomass and carbon storage of Pinus massoniana plantation were analyzed. Results: The results of average carbon storage per unit area of Pinus massoniana plantation was different stand densities are $94.11\ \mathrm{t/tm^2}(1679\ \mathrm{plants\ \ t/hm^2})$, $79.06\ \mathrm{t/tm^2}(2250\ \mathrm{plants/hm^2})$, and $73.32\ \mathrm{t/tm^2}(2800\ \mathrm{plants/hm^2})$. With the increase of stand density, the proportion of carbon storage in Pinus massoniana plantation decreased. This is because the larger the stand density, the more trees with small and medium diameter are grown in the Pinus massoniana plantation. The average diameter at breast height of the stand is very small, and the biomass of single tree decreases. The density $1566\ \text{plants}/\text{hm}^{-2}$ is most beneficial to the improvement of the carbon storage of the tree layer. Conclusions: Density regulation promotes the accumulation of carbon storage of the Pinus massoniana plantation and increases the carbon storage of understory vegetation, litter, and soil layer.

Keywords: Different density, Platycladus orientalis, Plantation, Ecosystem, Carbon storage, Allocation characteristics.

1. Introduction

Global warming is one of the most concerned environmental problems. More than 80% of CO_2 comes from urban emissions. In recent years, the increase of CO_2 concentration is about 28%, which is one of the main factors leading to global warming. Forest is the largest carbon pool in the terrestrial ecosystem, and forest carbon storage accounts for 46.27% of the total amount of the global terrestrial carbon pool, and its soil carbon accounts for about 73% of the global organic carbon pool in the global soil. Forest plays an irreplaceable role in the process of global climate change, and has the functions of source, sink, and storage (Cicuzza et al., 2010). The plantation plays an important role in forest ecosystem, ecological protection, environmental safety, and timber supply (Gonzalez-Trinidad et al., 2017), (Kim et al., 2018), (Sanchez Camacho and Martinez Morales, 2017), (Vicente-Molina et al., 2018). The function of carbon sink is a mechanism and effective choice to mitigate global climate change. It is of great significance to strengthen the carbon storage change, prediction, assessment, and productivity maintenance of plantation ecosystem (Ahamed et al., 2018), (Mocan et al., 2018), (Muhammad Tariq et al., 2019).

Carbon storage in the forest ecosystem is related to management practices such as tree species, fertilization, rotation, and thinning. The carbon storage of the tree layer increases with stand density increasing (Liu, 2017), (Wang et al., 2018). The density and soil carbon storage of Pinus elliottii plantation are inversely proportional to stand density. There are still differences in relation between soil carbon storage and stand density of the plantation (Ma et al., 2015), (Keshavarzi and Kumar, 2020). As the main body of the terrestrial ecosystem, forest has a wide distribution area, with the highest biological productivity and the largest accumulation of biomass, and its biomass accounts for about 85% of the land biomass, and the carbon storage accounts for about 80% of the terrestrial biosphere carbon storage and 40% of the underground carbon storage. Forest vegetation has strong sustainability and stability in structure and function, and plays an important role in biogeochemical cycling. Forest growth absorbs CO_2 and has a long-term preservation capacity. It plays the role of huge biological pump in regulating carbon exchange between terrestrial ecosystem and atmospheric carbon pool (Al-zaqri et al., 2017), (Bell et al., 2018), (Khaleel et al., 2018), (Nisavic et al., 2018), (Bharati et al., 2020). The relationship between biomass, litter, decomposition and accumulation, soil organic matter, and forest productivity in the forest ecosystem determines the carbon storage and carbon exchange. Therefore, biomass and productivity research has always been the main content of ecosystem carbon balance (Fischer et al., 2016). As an important part of terrestrial forest ecosystem, the plantation plays an important role in the restoration and reconstruction of ecological environment and economic development. Pinus massoniana is one of the main tree species for afforestation in barren hills in South China. The whole tree has high comprehensive utilization rate, fast growing, high yield, and strong adaptability, which has important position in papermaking raw materials and turpentine (Boudreault et al., 2015), (Gohar et al., 2019. The effects of thinning on the growth, productivity, plant diversity, wood properties, and carbon storage of plantation were researched at home and abroad. However, the research on sustainable forest management and forest carbon sink is rather deficient. In this paper, the density regulation experiment on the Pinus massoniana plantation with different densities was carried out to discuss the change of carbon storage in the ecosystem, which provides reference for the sustainable management, carbon sink and development of Pinus massoniana plantation.

2. Materials and Methods

2.1. Basic situation of research area

2.1.1. Basic situation

Xuzhou is located in the northwestern part of Jiangsu Province, the junction of the four provinces of Jiangsu, Shandong, Henan, and Anhui provinces. The geographical position is between 160°22′-118°40′ in the east longitude 33°43′-34°58′ in the north latitude. The city is mainly plain. The plain accounts for 92% of the total area, and hilly land accounts for about 8%. Most of them are flat hound land, and mountainous area accounts for only 30 thousand hectares. Most of them are limestone residual dunes, which are 400 meters above sea level (Maksimova and Abakumov, 2015). There are a few hillock and hillock in the middle and east of the city. In this paper, the sampling plots of Pinus massoniana plantation are mainly distributed in hilly areas near the urban area of Xuzhou.

The tectonics of Xuzhou belongs to the southern part of the North China fault block area, and belongs to the southern margin of the North China seismic zone in seismic zoning. Geological condition and geological structure are not very complicated, and the frequency and intensity of seismic activities are relatively low. From the viewpoint of crustal structure, the crustal thickness of Xuzhou is relatively small.

2.1.2. Climate

The climate of the research area belongs to the warm temperate semi-humid monsoon climate. The solar thermal resource is abundant. The rain and heat are in the same period. The temperature difference between the day and night is large and the monsoon is obvious. It has four distinctive seasons, the average annual temperature of 13 to 16 degrees Celsius. The annual sunshine hours are 2284-2495 h, the annual frost free period is 200-220 d, the annual average precipitation is 800-900mm, and the rainy season precipitation accounts for 56% of the whole year. The climate resource is superior, which is good for crop growth (Anderegg et al., 2015), (Isfarita et al., 2019). The main meteorological disasters are drought, flood, wind, frost, freezing, hail, etc. Zonal vegetation is deciduous broad-leaved mixed forest.

2.1.3. Soil

In the research area, the soil layer is barren and the bare rock rate is high. The soil type is coarse bone brown soil and leaching brown soil formed by limestone. Most soils have no lime reaction, low humus, and poor ability to maintain water and fertilizer (Zhang et al., 2016). The measurement results show that the content of organic matter is 0.6-0.8%, the content of nitrogen is 0.098%-0.111%, the available phosphorus 7.6%-17.4%, the available potassium 60.0-72.5 ppm, the pH value of the soil 7.63-8.07, and the salt 0.49-1.96 g/kg. The soil is extremely poor.

2.2. Experiment design

In the spring quarter of 2016, the plot was used for soil preparation with holes. The size of the planting hole was 40 cm × 30 cm × 30 cm. One year old bare root seedlings are used for afforestation and the row spacing is 2 m×2.3 m. The ways of tending are knife caress and hoe caress (Lun et al., 2018). It is tended 3a (Two times a year). In the autumn of 2017, density regulation experiments were carried out using random block design along contour lines. The four density treatments of the high density (H: $2800\ \mathrm{plants\cdot hm^{-2}}$), the medium density(M: $2250\ \mathrm{plants\cdot hm^{-2}}$), and the low density (L: $1679\ \mathrm{plants\cdot hm^{-2}}$), and non-thinning (CK: $2016\ \mathrm{plants\cdot hm^{-2}}$) are set

(Igu and Marchant, 2016). The distribution of Pinus massoniana corresponding to the first three densities is shown in Fig. 1. Repeat 3 times, and the area of the plot is 30 m × 20 m. Investigations on forest carbon storage of the 4 treatments with 3 repetitions are selected, as shown in Table 1.

(a) 1679 plants$\cdot$hm^{-2}

(b) 2250 plants$\cdot$hm^{-2}

(c) 2800 plants·hm^{-2}

Figure 1. A survey of the forest stand of Pinus massoniana with different stand density

Table 1. Sample plot

Handle	Altitude (m)	Slope (°)	Vegetation coverage	Canopy density	Average DBH (m)	Average tree height (m)	Post cutting density (plant·hm^{-2})
H	760	33	0.87	0.92	11.68	8.89	2800
M	790	30	0.89	0.9	12.86	9.11	2250
CK	769	27	0.9	0.88	12.93	9.42	2016
L	815	23	0.88	0.91	12.86	9.31	1679

Through the estimation of tree layer biomass of single Pinus massoniana (Shrestha et al., 2015), (Ibrahim et al., 2020), the determination of the carbon storage in the tree layer of Pinus massoniana, the estimation of the understory shrub, the grass layer, and the wood layer, the determination of carbon storage in vegetation and litter layer under forest, the determination of organic carbon content and carbon storage in the sample, and the carbon storage of the plantation ecosystem of different stand density sample plots, the effects of stand density on biomass and carbon storage of Pinus massoniana plantation are discussed (Schmerbeck and Fiener, 2015). The reason is analyzed, and theoretical support is provided for tending and management of Pinus massoniana plantation.

2.2.1. Estimation of biomass of the tree layer

The diameter at breast height and tree height of Pinus massoniana in the standard plot are measured. By using the fitted biomass model and survey data of tree measurement factors of sample plots (Spielvogel et al., 2016), the biomass and carbon storage of the tree layer of plantation stand are estimated, as shown in Table 2. In Table 2, D represents the diameter at the breast, and the H represents the height of the tree.

Table 2. Biomass estimation model

Project	Biomass equation	Correlation coefficient
Dry weight	$y = 0.0573(D^2H)^{0.8657}$	0.97
Branch weight	$y = 0.0043(D^2H)^{1.1085}$	0.89
Leaf weight	$y = 0.0038(D^2H)^{1.0385}$	0.84
Root weight	$y = 0.0485(D^2H)^{0.6886}$	0.80

2.2.2. Determination of carbon storage of the tree layer of Pinus massoniana

By using the data of every tree, the sample near standard stand tree is selected to determine the carbon storage. 1 standard sample (4 plants) is selected in each plot. The fresh weight of the trunk, the barks, the branches, and the leaves was measured by cutting down standard sample. The underground root is measured by using the full digging method, and the fresh weights of the main root and lateral root are determined separately (Fei et al., 2017), (Ilyas et al., 2019). For all organs, 200 g fresh samples are taken back to the laboratory, drying at constant temperature of 80 degrees Celsius for constant mass, and the fresh weight of each organ is converted into dry weight. The dried samples were then ground into 2mm powder to measure the organic carbon content, and then the average carbon density of tree layer was estimated by average standard sample.

2.2.3. Estimation of biomass of shrub, grass layer, and litter layer under the forest

In the selected standard plot, the biomass of the grass layer and litter layer under the forest were determined by quadrat harvest method (Yuan et al., 2017). In each standard plot, three 2 m × 2 m and 1 m × 1 m quadrats were used to measure the biomass of shrubs and grass trees by diagonal method. Five 20 cm × 20 cm quadrats were used to measure the biomass of litter. The collected samples were taken back to the laboratory and dried at 80 degrees Celsius until constant weight. Then the biomass was measured.

2.2.4. Determination of carbon storage of vegetation and litter layer under forest

According to the diagonal line, 3 shrub quadrats (area 2 m × 2 m) and 3 herb quadrats (area 1 m × 1 m) were set up in the plot, and the names of the species in each quadrat were recorded. The fresh weights of the biomass and of aboveground and underground shrub grass were measured by harvest method (Hu et al., 2016), (Ogwah and Eyankware, 2020). Samples from different plants with the same organ were collected 200 g (1/3 in the upper, middle and the lower), and the moisture content and carbon content were measured in the laboratory. The biomass of the litter with 1 square meters is measured. 200 g mixture samples were taken back to the laboratory to dry until constant weight, and the carbon storage of each component was calculated by the ratio of water content and carbon content.

2.2.5. Determination of organic carbon content and carbon storage in the sample

Sample collection: The soil sample is randomly collected in the sampling area according to the S route. After collection, the soil samples are mixed. The quartering method is used to take the samples. 3 samples of fresh soil are taken from each plot and dried. The soil moisture content is measured. Another enough soil samples were taken in the sealed bags, and then returned to natural air drying for one month. Then soil was screened for 2mm soil and the organic carbon is determined. 3 $100\,\mathrm{cm}^3$ ring-knives are taken for the determination of soil capacity. The organic carbon content in soil and plant samples is determined by potassium dichromate hydration heating method. Data is calculated and chart made by using WPS2010 (Mackay and Band, 2015). Single factor analysis of variance (one-way ANOVA) was processed by SPSS 21. The estimation of soil carbon storage is the product of soil thickness, soil density, and carbon content in each soil layer.

2.2.6. Calculation of carbon storage of the plantation ecosystem

The carbon content of organs of Pinus massoniana plantation is: trunk (47.33%) > leaf (43.91%) > branch (43.45%) > root (42.95%) (Yan et al., 2015). The average carbon content of the aboveground part is 44.89%, and the average carbon content of the whole plant is 44.41%.

The carbon content rate of understory shrub layer and litter is obtained by using common 0.45 carbon conversion rate (IPCC.2003).

Carbon storage is calculated by the product of the dry matter weight per unit area (biomass) and its carbon content (Mjöfors et al., 2017).

Plant carbon storage (tghm^2) = plant biomass (tghm^2) * carbon content rate (%)

Soil organic carbon storage (tghm^{-2}) = soil organic carbon content $(\mathrm{g/hm}^2)$ * bulk density $(\mathrm{g/cm}^3)$ * soil thickness (cm) * 10^{-1}.

3. Results and Discussion

3.1. Biomass and allocation of aboveground vegetation and litter layer in Pinus massoniana plantation with different stand densities

3.1.1. Analysis on the biomass of single plant of Pinus massoniana

According to the analysis results, the stand density has a significant effect on the average biomass of single plant of Pinus massoniana. The relationship can be expressed by the exponential function $Y = 189.72e^{-0.0008x}(R^2 = 0.9856)$, as shown in Fig. 2 (Hao et al., 2015). The greater the density of the stand, the smaller the average biomass of the single plant. The average biomass of single plant of Pinus massoniana in the sample plot with the highest density ($2800\ \text{plants}/\text{hm}^2$) is 18.88 kg. The average biomass of single plant of Pinus massoniana in the sample plot with the smallest density ($1679\ \text{plants}/\text{hm}^2$) is 45.36 kg.

From Fig. 3, it can be seen that, the biomass of each plant of Pinus massoniana is trunk > branch > root > leaf. The biomass of all organs in the tree layer has the same trend. The proportion of trunk biomass is more than 50%, and the biomass of each organ decreases with the increase of stand density. The average trunk biomass of single plant in the low density stand ($1679\ \text{plants}/\text{hm}^2$) is 1.26 times higher than that of the high density stand ($2800\ \text{plants}/\text{hm}^2$). For the branch, it is 1.59 times, for the leaf, it is 1.49 times, and for the root, it is 1.06 times. Biomass distribution of different organs of Pinus massoniana stands relatively stable in different stand densities. The range of variation of trunk, branch, leaf, and root is between 53.30%-55.48%, 17.94%-21.79%, 10.40%-11.81% and 13.1%-16.18%, respectively.

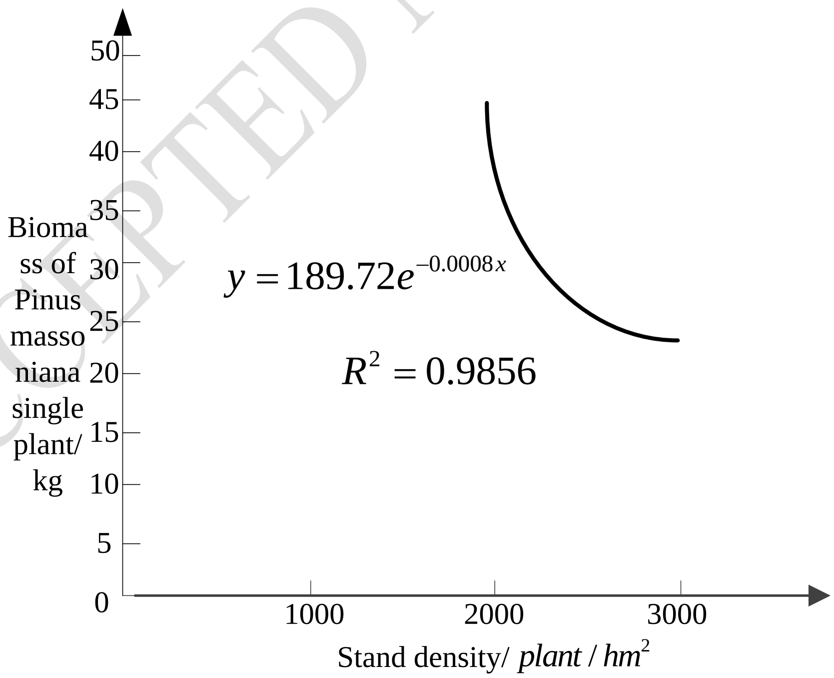


Figure 2. The relationship between average plant biomass and stand density

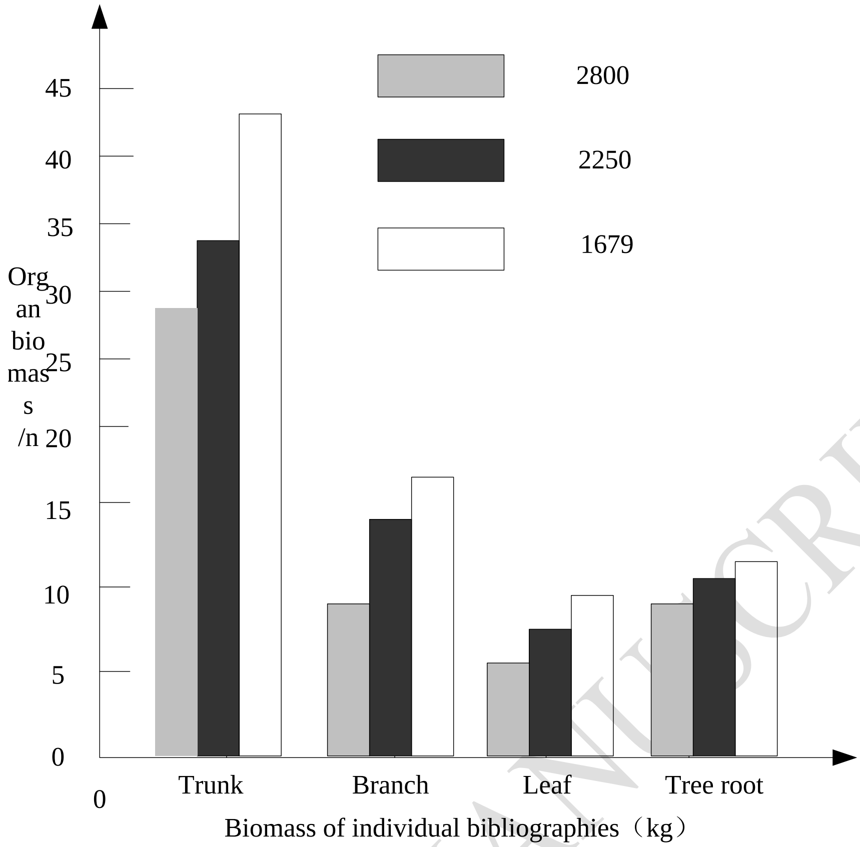


Figure 3. Changes in biomass per plant per plant with stand density

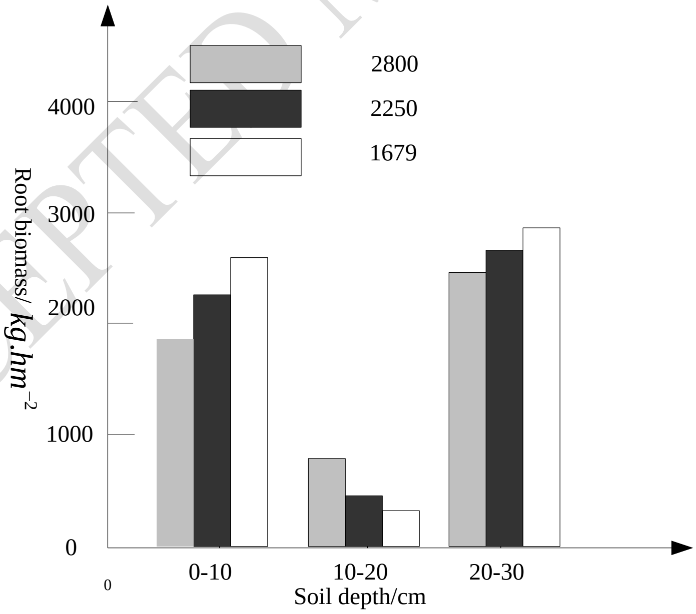


Figure 4. Changes in biomass of different stand density root

From Fig. 4., it can be seen that, the response of fine root biomass to stand density is consistent with that of tree layer, soil layer and ecosystem carbon storage under different stand densities. The highest value appears in low stand density plot, and the lowest value appears in high stand density plot. Therefore, the correlation between fine root biomass and soil carbon storage is larger than that of tree layer carbon storage or system carbon storage. With the decrease of stand density, the length of fine root grows first, which indicates that the function of fine root to absorb water and nutrients is strengthened. The diameter of the higher root in the fine roots is thicker, the carbon distribution is increased, and the transport and the ability to extend deeper into the soil are enhanced. It is to promote the rapid growth of aboveground tree and the increase of the carbon storage of tree layer. With the continue decrease of the stand density, the life of the lower root in the fine roots becomes shorter, the decomposition and turnover speed increase, and the carbon storage in the soil layer increases significantly. It shows that low density does not weaken the carbon sink capacity of the stand. This is because the density of the stand is too large and the nutrient space of the stand is relatively small, which suppresses the increase of the biomass of the stand, and the low density makes the stand have a relatively sufficient nutrient space, accelerates the accumulation of the biomass of the stand, and increases the carbon storage of the stand (Viglietti et al., 2015). Therefore, a reasonable stand density can not only increase the carbon storage of tree layer, but also increase the carbon storage of the whole ecosystem.

3.1.2. Analysis of biomass change of tree layer in Pinus massoniana with different densities

From Table 3, it can be seen that, the biomass of organs in Pinus massoniana plantation is trunk > branch > root > leaf. The average trunk biomass accounts for 54.29% of the biomass of the whole tree layer. The biomass of organs in Pinus massoniana decreases with the increase of stand density. The proportion of the biomass of trunk and root increases in high-density forest. The proportion of the biomass of branch and leaf gradually decreases in high-density forest. It shows that intraspecific competition caused by excessive density affects the elongation of Pinus massoniana branches and leaves. This result is consistent with the research results of other scholars on Pinus elliottii and Pinus massoniana. The number in the bracket is the percentage of the biomass of each organ in the biomass of Pinus massoniana.

Table 3. Biomass of tree layer in Platycladus orientalis plantation with different densities

Index	Component	Stand density (plant□hm^2)			Average
		1679	2250	3074	
Biomass (t□hm^2)	Trunk	40.59 (53.30)	34.92 (54.55)	32.19 (55.48)	35.57
	Branch	16.60 (21.79)	12.61 (19.70)	10.14 (17.94)	25.74
	Leaf	9.00 (11.81)	7.08 (11.07)	6.04 (10.40)	23.22
	Tree root	9.98 (13.10)	9.40 (14.68)	9.39 (16.18)	24.17
	Total	76.16	64.02	58.03	66.07

3.1.3. Biomass and allocation of vegetation and litter in Pinus massoniana plantation with different stand densities

The relationship of Pinus massoniana stands with different stand densities is shown in Table 4. The higher density the Pinus massoniana stand, the lower the total biomass per unit area. The average total aboveground biomass is 71.77 $tghm^{-2}$. The biomass of tree layer is the most important component of total aboveground biomass, which accounts for 92.06% of the total biomass, and the second maximum is litter biomass, which accounts for 2.91%. The biomass of understory vegetation (shrub and grass) decreases with the increase of the stand density. The main reason is that the increase of stand density reduces the light intensity inside the forest, and increases competition within species, and suppresses the elongation of understory vegetation and shrubs. The thinning soil layer of Pinus massoniana plantation is also an important factor affecting the biomass allocation of understory vegetation. The number in the bracket is the percentage of the biomass of each organ in the total biomass of aboveground layer.

Table 4. Biomass and distribution at different levels of Pinus massoniana plantations with different densities

	Component	Stand density			Average
		1679	2250	3074	
Biomass	Tree	76.16 (89.30)	64.02 (94.09)	58.03 (93.67)	66.07 (92.06)
	Shrub	3.04 (3.56)	1.16 (1.70)	1.91 (3.08)	2.04 (2.84)
	Herbaceous	4.16 (4.88)	0.33 (0.49)	0.21 (0.34)	1.57 (2.19)
	Litter	1.93 (2.26)	2.53 (3.72)	1.80 (2.91)	2.09 (2.91)
	Total	85.29	68.04	61.95	71.77

From Fig. 4., it can be seen that, according to the distribution structure of the aboveground biomass, the spatial distribution sequence of the aboveground biomass is tree layer > litter layer > shrub layer > vegetation layer. The tree is the leader of the community. Although the proportion of shrub herb layer is small in the biomass of Pinus massoniana community, its good water absorption and soil conservation function have an important role in the water and soil conservation of Pinus massoniana forest. The average ratios of tree layers of shrub, vegetation, and litter are 92.06%, 2.84%, 2.19%, and 2.91%, respectively. The results of domestic research are slightly different, and the biomass allocation ratio of shrub layer and herb layer is similar to other research results. The allocation of the litter layer is relatively high, which may be due to the single stand structure of the Pinus massoniana plantation, which is caused by less precipitation, thin soil layer, less undergrowth vegetation, weak soil microbial activity, and slow decomposition of litter. It can be concluded that stand density is closely related to stand biomass. With the increase of the density of the stand, the total biomass of the community is decreasing, which is different from that of the previous research. The reason is the difference of the tree species and the region. But it is foreseeable that the density effect is significant in the Pinus massoniana plantation, and the stand with large density should be moderately thinned, and the proper adjustment of stand density can increase the stand biomass and carbon storage.

3.2. Carbon content of different organs and understory vegetation of Pinus massoniana

The carbon content of the organs of Pinus massoniana plantation is between 469.76 and 521.73 $g\cdot kg^{-1}$. The highest carbon content of bark is 521.73 $g\cdot kg^{-1}$. The needle leaf is 521.24 $g\cdot kg^{-1}$. The lateral root is lowest, with 469.76 $g\cdot kg^{-1}$. The carbon content of the aboveground and underground parts of shrub layer is 461.84 $g\cdot kg^{-1}$ and 384.34 $g\cdot kg^{-1}$, respectively. The carbon content of litter layer is 477.43 $g\cdot kg^{-1}$. The carbon content is: tree layer > shrub layer > vegetation layer > litter layer, as shown in Table 5.

Table 5. Carbon content in trees and understory vegetation of Pinus massoniana plantation

Arrangement	Project	Carbon content
Tree layer	Trunk	511.10±1.37
	bark	521.73±1.21
	Branch	508.77±5.53
	Conifers	521.24±4.80

	Taproot	492.23±4.22
	lateral root	469.76±8.26
Shrub layer	The upper part of the ground	471.14±6.24
	Underground part	452.07±4.76
Herbaceous layer	The upper part of the ground	461.84±7.47
	Underground part	384.34±10.46
Litter layer	Litter	521.24±4.80

3.3. Effects of density regulation on carbon storage and allocation of Pinus massoniana plantation

The carbon storage of Pinus massoniana stands with CK, H, M, and L density is 112.75, 115.33, 118.44 $t\cdot hm^{-2}$, and 114.13 $t\cdot hm^{-2}$, respectively, after density regulation 4a. The carbon storage of Pinus massoniana stands with H, M, and L reserve density is 1.22%, 5.05%, and 2.29% higher than CK. The largest carbon storage of the tree layer is M regulation, as shown in Table 6. Except for the carbon storage of bark with H, M, and L regulation is slightly less than CK, and the carbon storage of all organs in Pinus massoniana stands is higher than that of CK under different reserve densities. The carbon storage allocation of tree layer of Pinus massoniana forest is basically the same under 4 kinds of reserve densities. The largest proportion of carbon storage allocation is trunk and the proportion is 71.67%, 68.78%, 66.90%, and 63.86%, respectively. The second is the main root and the proportion is 8.15%, 9.34%, 9.57% and 9.77%, respectively. The third is the bark and the proportion is 9.11%, 8.10%, 7.59%, and 7.20%, respectively. The lowest is the lateral root (all <4%).

Table 6. Effects of density regulation on tree storages carbon storage and distribution characteristics

Project	CK		H		M		L	
	Carbon reserves ($t\cdot hm^{-2}$)	Proportion (%)	Carbon reserves ($t\cdot hm^{-2}$)	Proportion (%)	Carbon reserves ($t\cdot hm^{-2}$)	Proportion/%	Carbon reserves ($t\cdot hm^{-2}$)	Proportion (%)
Trunk	80.80	71.67	79.32	68.78	79.23	66.90	72.8	63.86
bark	10.27	9.11	9.35	8.10	8.99	7.59	8.22	7.20
Branch	6.02	5.34	8.46	7.33	9.72	8.20	9.85	8.63
Conifers	4.37	3.88	4.44	3.85	6.50	5.49	7.83	6.86
Taproot	9.19	8.15	10.77	9.34	11.33	9.57	11.15	9.77
lateral root	2.10	1.87	3.00	2.60	2.65	2.24	4.20	3.68
Total	112.75	100.0	115.33	100.0	118.44	100.0	114.13	100.0

3.4. Effects of density regulation on understory vegetation and carbon storage of litter layer of Pinus massoniana plantation

With the increase of the regulation intensity of Pinus massoniana plantation and the decrease of reserve density, the carbon storage of understory vegetation increases gradually. The aboveground parts of shrubs are CK 31.89%, 38.58%, and 38.98%, respectively, and the densities of M and L are basically the same. The carbon storage of the underground parts of the shrub, the underground and aboveground parts of the grass, and the litter is consistent with that of the underground parts of the shrub, as shown in Table 7.

Table 7. Effects of density regulation on understory vegetation and carbon storage in litter layer

Project	Component	Carbon reserves			
		CK	H	M	L
Shrub layer	The upper part of the ground	1.14±.0.01	1.50±0.12	1.58±0.22	1.58±0.17
	Underground part	0.79±0.10	0.95±0.03	1.11±0.05	2.38±0.45
Grass and tree layer	The upper part of the ground	0.69±0.07	2.04±0.33	2.32±0.02	2.24±0.02
	Underground part	0.92±0.10	0.93±0.12	1.12±0.04	1.31±0.12
Litter layer	Litter	0.30±002	0.44±0.05	0.57±0.03	0.66±0.07

3.5. Effects of density regulation on carbon storage of soil layer of Pinus massoniana plantation

The effects of 4 different reserve densities on soil carbon storage in Pinus massoniana forest are not significant (shown in Table 8, ρ >0.05). The M density is the highest, with $(110.33 \pm 29.10)\ t\cdot hm^{-2}$. The H density is $(108.88 \pm 14.07)\ t\cdot hm^{-2}$. The H density and M density have no significant difference. The CK density is $(105.38 \pm 9.25)\ t\cdot hm^{-2}$, and the carbon storage of L reserve density is lowest, with $(91.95 \pm 14.50)\ t\cdot hm^{-2}$. There is no significant difference in carbon storage of the same soil layer of Pinus massoniana with different reserve densities. It is known that density regulation has no significant effect on soil carbon storage. However, with the decrease of the reserve density, the soil carbon storage increases first and then decreases. The soil carbon storage of the Pinus massoniana forest with M and H reserve density are 3.32% and 4.69% higher than that of CK, and L is 12.75% lower than that of CK.

Table 8. Influence of density regulation on soil carbon storage under forest

Layer	CK	H	M	L
Humic layer	7.74±0.98	9.01±0.50	9.96±1.96	7.72±0.89
0-15 cm	42.24±5.75	42.54±4.50	49.51±12.51	39.88±7.78
15-30 cm	32.55±5.81	30.88±9.09	28.21±8.11	23.56±3.17
30-45 cm	22.85±0.42	26.45±1.88	22.65±8.40	20.79±2.71
Total	105.38±9.25	108.88±14.07	110.33±29.10	91.95±14.50

3.6. Effects of density regulation on total carbon storage of Pinus massoniana plantation ecosystem

After different density regulations 4a, the total carbon storages of Pinus massoniana plantation ecosystem change. The case of CK, H, H, and L is 221.97, 230.07, 235.46 $t\cdot hm^{-2}$, and 214.43 $t\cdot hm^{-2}$, respectively. There is no significant difference between the 3 reserve densities (H, M, and L) and CK. However, H and M increase the total carbon storage of the ecosystem compared with CK, which are 3.65% and 6.08, respectively. The L density is 3.40% lower than that of CK. It is shown that H and M density are beneficial to increase the total carbon storage in the ecosystem. The low reserve density is not conducive to increasing the carbon storage of the ecosystem in the short term. H, M, L regulation and CK Pinus massoniana forest ecosystems have the largest carbon storage in tree layer, accounting for 50.13%, 50.30%, 53.23%, and 50.80% of the total storage, respectively. The second is the soil layer, accounting for 47.32%, 46.86%, 42.88%, and 47.47%, respectively. The undergrowth litter layer has the smallest carbon storage, accounting for 3.58%, 2.60%, 2.36%, and 1.60% of the carbon storage of the ecosystem, and the litter layer accounts for 0.31%, 0.24%, 0.19%, and 0.13%, respectively. The allocation of carbon storage of each component of ecosystem by density regulation is different, as shown in Table 9.

Table 9. Effects of density regulation on carbon storage of individual components in Pinus massoniana Plantation Ecosystem

Component	CK		H		M		L	
	Carbon reserves	Proportion (%)	Carbon reserve (s)	Proportion (%)	Carbon reserves	Proportion (%)	Carbon reserves	Proportion (%)
Tree layer	112.5±0.3	50.8	115.33±0.36	50.13	118.44±0.40	50.3	114.13±0.38	53.23
Undergrowth vegetation	3.54±006	1.6	5.42±0.22	2.36	6.13±0.40	2.6	7.68±0.33	3.58
Litter layer	0.30±0.01	0.13	0.44±0.04	0.19	0.57±0.20	0.24	0.66±0.05	0.31
Soil layer	105.38±9.2	47.47	108.88±14.07	47.32	110.33±29.10	46.86	91.95±14.50	42.88
Total	221.97±8.9	100	230.07±14.15	100	235.46±29.02	100	214.43±15.04	100

Density regulation has an effect on carbon storage of each component of ecosystem. Compared with CK, the carbon storages of Pinus massoniana tree layer under H, M, and L reserve densities increased 2.29%, 5.04%, and 1.22%, respectively. Soil carbon storage increased by 3.32% and 4.69% under M and H reserve densities. Soil carbon storage decreased by 12.75% under L density, but is not significantly different from CK. After thinning 4a, under H, M, and L reserve densities, the carbon storage of understory vegetation and litter layer of Pinus massoniana are increased. The understory vegetation layer increased by 116.91%, 73.12%, and 52.99%, respectively, compared with CK. Litter layer increased by 124%, 92%, and 48.88%, respectively, compared with CK. The carbon storage of understory vegetation and litter layer is significantly different from that of CK. Density regulation promotes the accumulation of carbon storage of Pinus massoniana trees, and increases the carbon storage of understory vegetation, litter, and soil layer.

3.7. Effects of stand density on carbon storage of Pinus massoniana plantation

The research results of this paper show that stand density has a significant effect on the ecosystem of Pinus massoniana plantation. Suitable forest density can increase forest carbon sink. The average carbon storages per unit area of Pinus massoniana plantation with three different stand densities are $94.11\ \mathrm{t/tm^2}(1679\ \mathrm{plants\ t/hm^2})$, $79.06\ \mathrm{t/tm^2}(2250\ \mathrm{plants/hm^2})$, and $73.32\ \mathrm{t/tm^2}(2800\ \mathrm{plants/hm^2})$. The carbon storage of tree layer and soil layer of Pinus massoniana plantation changed most significantly. With the increase of stand density, the proportion of tree layer carbon storage decreased gradually in the Platycladus orientalis plantation. This is caused by the large the stand density, the more trees grown in the Pinus massoniana plantation, the smaller average DBH of the stand, and the decreased biomass of single plant of the tree. With the increase of stand density, the proportion of soil layer carbon storage in the Platycladus orientalis plantation ecosystem decreased first and then increased. The reason may be due to the larger interference from the selected Platycladus orientalis stand sample plot with medium density, the more active forest animals, and more disturbances to the litter and the herbaceous shrubs.

Dong Peng and Li Zhao researched the stand structure and stand density of Pinus massoniana plantation, and concluded that the reasonable stand should be $2325\,\text{plants/hm}^2 - 3225\,\text{plants/hm}^2$. Comparing with the research results of this paper, it can be seen that the density of Pinus massoniana plantation can be lower. The carbon storage in the ecological system of Pinus massoniana with the stand density $1679\,\text{plants}/hm^2$ are higher than the stand density of $2250\,\text{plants/hm}^2$, so that the thinning of the dense forest can enhance the carbon storage of the ecological system of Pinus massoniana plantation.

There is a close relationship between stand density and stand biomass and carbon storage. With the same stand age and site condition, as the decrease of the stand density, the individual space in the stand increases and the illumination condition improves, which makes the growth space of the individual increase, the volume of the tree crown increases, and the biomass of the tree leaves increases. Meanwhile, the ground surface temperature of the stand with small stand density is relatively high, which promotes the activity of soil microbes, accelerates the decomposition, improves the soil fertility and is beneficial to the growth of the tree. It reflects the growth of the individual breast height diameter and the tree height for the low density forest. Reasonable stand density improves forest productivity, and is conducive to the accumulation of biomass and carbon storage, so as to better play the function of forest carbon sink.

The total carbon storage of Pinus massoniana plantation in 16 years under H, M and L and CK conditions is 230.07, 235.46, 214.43 $t \cdot hm^{-2}$, and 221.97 $t \cdot hm^{-2}$, respectively. Density regulation increases total carbon storage of Pinus massoniana plantation ecosystem, but the difference is not significant. Different density regulation had certain effects on the composition of carbon storage in Pinus massoniana plantation ecosystem. The increase of carbon storage of the tree layer requires reasonable reserve density. The carbon storage of Pinus massoniana forest with H and M density increased by 3.65% and 6.8% compared with CK, while L density decreased by 3.40%. This is consistent with the results of thinning experiments of 30 year Pinus tabulaeformis plantation with different intensities. High intensity thinning and moderate intensity thinning can improve carbon storage of Pinus tabulaeformis plantation. The increase of the carbon storage of the tree layer is mainly by the density regulation to improve the stand environment, reduce the crown density, improve the nutrition space of the growth of Pinus massoniana, and promote the growth of the stand and the accumulation of biomass. The operation of M density $1566\,\text{plants}/hm^{-2}$ is most conducive to the increase of carbon storage of the tree layer. The carbon storage of L density is mainly due to short regulation time and relatively few trees. Density regulation is beneficial to the improvement of stand productivity, and different species of Pinus massoniana, Cunninghamia lanceolata, megakanium and Castanopsis are verified. By increasing density, the carbon storage of the tree stand increased which provides an effective measure to increase the density of plantation.

Density regulation does not significantly affect carbon storage and allocation of organs of Pinus massoniana. For H, M and L density treatments and CK, the carbon storage of the tree layer of tree trunk is largest, which accounts for 68.78%, 66.90%, 63.86%, and 71.67% respectively. Bark > roots > branches and leaves. The smallest proportion is lateral root, which is basically consistent with previous researches, and may be determined by the characteristics of the species. By contrast, the lower proportion of carbon storage of tree layer in the low density stand is trunk. The reason is that low density increases the light transmittance of the stand, is beneficial to the growth of lateral branches, increases the carbon accumulation of branches and leaves, and reduces the allocation of biomass of the tree layer. Density regulation has no significant change in soil carbon storage. The soil carbon storage of CK is higher than L density treatment, H and M density treatment is higher than CK. The reasonable management of density is conducive to increasing soil carbon storage, and if the density is too small, the carbon storage of the soil layer will be reduced. Although biomass of trees and understory vegetation increases under L density, the carbon storage of ecosystem is not significantly different due to the number of reserved plants (Liew et al., 2018; Ouyang et al., 2017). In the process of density regulation, a large number of woods are removed, some small branches and leaves have not been cleaned up, and the amount of litter on the woodland is increased to introduce the carbon source of the soil, which may be the reason for the increase of soil carbon storage. For L density, soil carbon storage is decreased, which may be the destruction of soil structure during the removal of thinning wood, thereby reducing the soil carbon pool.

After density regulation 4a, the carbon storage of vegetation under various treatments is 3.54-7.68 $t\cdot hm^{-2}$, which accounts for 1.60%-3.58% of the ecosystem. The carbon storage of litter is 0.30-0.66 $t\cdot hm^{-2}$, which accounts for 0.13%-0.31%. The carbon storage of the undergrowth and litter layer are less in the ecosystem, but play an important role in the accumulation of soil carbon storage and carbon cycle in the ecosystem. Density is inversely proportional to the carbon storage of the understory vegetation and litter. There is a significant difference in carbon storage between litter and CK. Carbon storage of Pinus massoniana plantation ecosystem is the largest under medium density regulation. Therefore, the reserve density $1566 plants/hm^{-2}$ is suitable for the middle age forest of Pinus massoniana.

3.8. Effects of thinning on carbon storage of Pinus massoniana plantation

The carbon storage of Pinus massoniana plantations is significantly different after different thinning. It is also possible to predict the appropriate thinning intensity to increase the carbon storage of the system. Research results show: The carbon storage of Pinus massoniana with thinning two times 76.36 t/hm^2 > The carbon storage of Pinus massoniana with thinning one time 37.35 t/hm^2 > The carbon storage of Pinus massoniana with non-thinning 68.54 t/hm^2. The carbon storage of the tree layer is: Thinning one time 37.35 t/hm^2 > Thinning two times 30.42 t/hm^2 > Non-thinning 28.13 t/hm^2 (Jiang et al., 2017), (Li et al., 2017). The carbon storage of soil layer with thinning two times 39.38 t/hm^2 is higher than non-thinning 36.09 t/hm^2 and thinning one time 32.47 t/hm^2. The carbon storage of the tree layer decreases, which accounts for only 39.84% of the system. Because the number of standing trees decreases after thinning and Platycladus orientalis belongs to slow growing trees, the longer thinning intensity needs longer time to recover. Therefore, the carbon storage with thinning two times is less increased. The biomass and total biomass of the organs of Platycladus orientalis after thinning one time and thinning two times are higher than that of the non-thinned woodland. The biomass of tree trunk increases most obviously. After thinning two times, the biomass of individual tree trunk is 1.05 times that of non-thinning. It is mainly because the thinning provides more space for the individual, the intraspecific competition is slowed down, the light in the forest is full, the photosynthesis is more effective, and the accumulation of organic matter increases faster. The contribution of soil thinning to carbon storage of the soil layer is more than that without thinning.

Thinning affects biomass and carbon storage of the forest by influencing the biomass and carbon storage of tree layer, shrub layer, herb layer, and litter layer. After thinning, the biomass of trees increased, but the total biomass decreased. Some scholars have also researched the relationship between the intensity of thinning and the biomass of the stand. After the thinning, the growth indexes of the Pinus tabulaeformis forest are both high intensity thinning > moderate intensity thinning > weak intensity thinning > control. Moderate and high intensity thinning are significantly greater than control and weak thinning. In the growth process of the forest, two kinds of effects are produced by thinning. One is the growth effect of the stand due to the expansion of the growth space of forest trees, and the other is the loss effect of thinning out some trees. Therefore, the effect of thinning on stand productivity and factors depends on the relative size of the above two effects.

When researching the effects of thinning on stand productivity and factors, it is necessary to decide on the specific conditions. There are different views on the effects of thinning on total biomass and carbon storage of plantation. This is because the total forest biomass and carbon storage are composed of tree layer, shrub layer, herbaceous layer, litter layer, and soil layer, and each layer also has interaction and relationship, so the law of change is more complex.

4. Conclusions

In this paper, density control experiments of Pinus massoniana with different densities were conducted to research the effects of stand density on the allocation of ecosystem carbon storage. The results show that different density regulation has certain effects on the composition of carbon storage of Pinus massoniana plantation ecosystem and density regulation is beneficial to the improvement of stand productivity. Many species of Pinus massoniana, Cunninghamia lanceolata, megakanium, and Castanopsis were verified. Increase of carbon storage of tree stand is achieved by increasing density regulation. Appropriate thinning intensity has a significant effect on increasing carbon storage of the system. Thinning provides more space for individuals to grow, and the competition within species decreases slowly. The forest light is sufficient, photosynthesis is more effective, and organic matter accumulation increases faster. Then the accumulation of individual biomass and carbon storage increased significantly than that of un-thinned plots.

Authors' Contributions

Yanli Du: Modelling and optimization, writing of manuscript.

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