地面覆盖对皮叶两用杜仲(*Eucommia ulmoides* Oliv.)林冠层辐射能分布的影响

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摘要:通过在杜仲林地种植白三叶草、覆膜和覆秸秆,研究了地面覆盖对 8a 生皮叶两用杜仲林冠层光能分布的影响。结果表明:地面种植白三叶草、覆膜、覆秸秆和不覆盖条件下,林冠中部的总辐射分别比林冠表面降低了 18.8%、20.0%、17.1%、17.1%;在林冠层,不同地面覆盖的林冠下表面接受的地面反射辐射差异较大,种植白三叶草、覆膜和覆秸秆的林冠下表面接收的反射辐射分别较地面无覆盖的高 42.8%、56.4% 和 8.1%,且林冠中部接受的地面反射辐射明显低于林冠下表面;种植白三叶草、覆膜和覆秸秆的林冠中部的净辐射能分别较地面无覆盖的高 14.4%、18.5% 和 5.6%。不同覆盖处理的冠层净辐射垂直分布趋势基本一致,在冠层范围内,净辐射能随高度升高呈指数规律增大。

关键词:杜仲林;地面覆盖;冠层;辐射能

文章编号:1000-0933(2008)07-3221-07 **中图分类号**:S718.512.2 **文献标识码**:A

Effects of ground coverings on radiant energy distribution in the canopy of *Eucommia ulmoides* Oliv. coppice forest

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***Acta Ecologica Sinica*, 2008, 28(7): 3221 ~ 3227.**

Abstract: Ground white clover (*Trifolium repens* Linn.) planting (CM), plastic film mulching (FM), and straw mulching (SM) were applied to an 8-year-old eucommia (*Eucommia ulmoides* Oliv.) forest to study the effects of these ground coverings on light energy distribution within the forest canopy. The forest none ground mulching (NM) was used as a control. Total radiation in the middle part of the forest canopy decreased by 18.8%, 20.0%, 17.1%, and 17.1% for the treatments of CF, FM, SM, and NM respectively compared with those in the upper part of the forest canopy with the same mulching treatments. There were relatively large differences among the amounts of ground-reflected radiation received by the lower part of the forest canopy with different coverings; the ground-reflected radiation received by the lower part of the forest canopy with CM, FM, and SM increased by 42.8%, 56.4%, and 8.1% respectively, compared with the control. The amounts of ground-reflected radiation received by the middle canopy were markedly lower than those received by the lower

基金项目:陕西省"十五"科技攻关资助项目(2001KG01-G15-03)

收稿日期:2007-08-28; **修订日期**:2008-05-09

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Foundation item: The project was financially supported by Shaanxi Tenth Five Year Project (No. 2001KG01-G15-03)

Received date: 2007-08-28; **Accepted date**: 2008-05-09

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part of the forest canopy with these coverings. The net radiant energy in the middle forest canopy with CM, FM, and SM increased by 14.4%, 18.5%, and 5.6% respectively, compared with that in the lower part of the forest canopy without any covering. The net radiation distribution in the forest canopy with different coverings appeared to vary identically, and the net radiant energy values appeared to increase exponentially from the lower part to the upper part of the forest canopy. Our results showed that CM as an agricultural practice in orchards was the best ground cover than other two and had high potentials developed for non-timber forests in the Qinling Mountains.

Key Words: eucommia forest; ground covering; canopy; radiant energy

Solar radiation is the essential source of all terrestrial ecosystems. When solar radiation reaches the forest canopy, it is partially absorbed, reflected and scattered throughout the forest canopy. Consequently, the radiant energy level varies among the different canopy layers in height. Current studies of radiant energy distribution in the canopy have mainly involved timber forests and fruit trees addressing the effects of planting densities and stand types on light energy distribution in the forest canopy[1–3]. Researches have shown that the total radiation in the forest canopy is related to the leaf area index[4–7], that the reflectivity of the forest canopy is related to the solar elevation angle[4,8], and that there are significant differences in light energy distribution in different parts of the canopy[9–12].

As a commercial tree species, eucommia is not only used for timber production, soil and water conservation, and reforestation, but is also a highly valuable medicinal plant because its bark, leaves, and fruit contain many medically active ingredients[13–16]. In particular, eucommia has a significant curative effect on high blood pressure[17,18] and is accordingly prized around the world as a high-quality natural medicine[19]. In recent years, China has continuously expanded the planting area of eucommia, regarding it as a major commercial tree species. Eucommia is heliophilic[20] so that insufficient light in its canopy has a significant detrimental influence on its growth, causing yield reductions in bark, leaves, and seeds[19]. Different ground-covering treatments are capable of improving soil moisture profile[21–25] and soil structure[26,27], increasing soil fertility[28,29] and exerting an influence on light conditions in the canopy[30]. In this study, three treatments including CM, FM, and SM, were applied to investigate the effect of ground reflection on radiant energy distribution in the forest canopy to provide a theoretical basis for enhancing the efficiency of solar energy utilization by eucommia and provide implications for improving the management of eucommia forests.

1 Materials and methods

1.1 Brief description of the experimental site

The experiment was conducted in the town of Pingmu in Fengxian County (33°34′57″N, 106°24′54″E), Shaanxi Province. The town lies on the south-facing slope of the Qinling Mountains at a mid-range elevation (1400 m) and has a warm temperate subhumid climate, with an average annual temperature of 11.4℃ and an annual rainfall of 613 mm. Frost-free period in the area is 188 days, and its cumulative temperature (10℃ is 3556.3℃). The experimental site was mountain terrace land on a southeast-facing slope with a gradient of 15°, with brown soil 60 cm in depth.

1.2 Materials

The experiment was conducted in an 8-year-old eucommia forest with a planting density of 2 m × 2 m. The bark was not peeled since the trees were still young. The forest stand is managed as a kind of coppice forest. When the trees were four years old, their stems were truncated at a height of 0.8 m. Their average stand height was 1.6 m, the average canopy height was 1.4 m, the average tree diameter (0.8 m above the ground) was 4.1 cm, and the crown density of the stand was 0.7. All the trees were growing well.

The ground coverings were applied as follows: (1) white clover (*Trifolium repens* L.) planting, in which white clover seeds were sown at a density of 0.5 $g \cdot m^{-2}$ in May 2002; (2) white FM (0.08 mm thick) spread in April 2005, and (3) SM spread with a thickness of about 2 cm in April 2005. The covered areas were 50 cm wide and 50 m long, and five duplicate rows were made for each treatments; the land without any covering was used as control. All tests were in the same eucommia forest.

1.3 Measurement methods

Net radiation, ground-reflected radiation, and total radiation along the vertical forest canopy with different ground coverings were measured between 7 am and 7 pm on consecutive clear days of July 15 — 20, 2006.

Net radiation readings were taken by using a DFY5 pyranometer (Changchun Meteorological Instrument Factory, sensitivity of 7.2 — 13.0 $\mu V/W \cdot m^{-2}$) at 0.6, 0.8, 1.0, 1.2, 1.4 and 1.6 m above the ground and 60 cm away from the tree trunks. Total radiation and ground-reflected radiation readings were taken with a DFY2 sky radiometer diffusometer (made in Changchun Meteorological Instrument Factory, sensitivity 7.2 — 14.3 $\mu V/W \cdot m^{-2}$) in the upper canopy (1.6 m above the ground), middle canopy (1.2 m above the ground), and lower canopy (0.8 m above the ground), 60 cm away from the tree trunks in all cases.

Air temperatures in the middle canopy were measured with an aspirated psychrometer, and ground temperatures were measured with an angle geothermometer, measuring time was 8:00 — 20:00 on June, 2006.

2 Results

2.1 Total radiation

Differences were observed among the total radiation values in different parts of the eucommia forest canopy with the different coverings (Table 1). The highest radiation values occurred in the upper part of the forest canopy and the lowest in the lower part of the forest canopy. The total radiation values from the upper to the middle canopy with CM, FM, SM, and NM decreased by 18.8%, 20.0%, 17.1%, and 17.1% respectively. The corresponding values at the lower part of the canopy were 64.7%, 63.5%, 59.0%, and 58.6% lower respectively than those in the upper canopy. These results indicate that CM and FM lead to a greater decrease in the total radiation in the forest canopy than SM does. These decreases were statistically significant in cases of CM and FM, but not for SM.

In the middle part of the canopy, the total radiation exhibited a clear pattern of daily variation (Fig. 1), with a peak at about 1 P. M. in the morning and evening. This pattern is accorded with diurnal change of the solar elevation that reaches the highest around noon, when the greatest amount of solar radiation falls perpendicularly onto the earth's surface. Fig. 1 showed that the total radiation in NM was higher, up to a maximum of 681.9 W m^{-2}, but differed among different coverings in a minor degree. It indicates that the leaves and shoots in the upper canopy grew nearly identical and their solar radiation-weakening effects were minimal, although different ground coverings have been applied (Table 1).

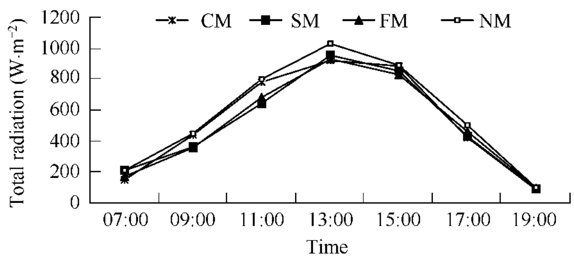

Fig. 1 The diary change of solar total radiation

2.2 Ground-reflected radiation

Ground-reflected radiation differed significantly with the different coverings (Table 1). The ground-reflected radiation received by the lower part of the forest canopy with FM was remarkably higher than others. All the ground coverings increased the ground reflectivity, and as a result the ground-reflected radiation received by the lower part of the canopy with CM, FM, and SM increased by 42.8%, 56.4%, and 8.1% respectively compared with NM. The ground-reflected radiation received by the middle part of the forest canopy declined markedly by 23.8%, 20.5%, and 7.6% with CM, FM, and SM respectively, compared with the values for the lower part of the forest canopy. These results indicate that the ground-reflected radiation values in the low and middle forest canopies were greatly reduced with CM and FM because of higher soil and air temperatures (Table 2) and increasing leaf area indices resulted from higher soil fertility by CM.

Table 1 Radiant energy distribution in the canopy of eucommia forest ($W \cdot m^{-2}$)

Covering modes	Upper part of the forest canopy		Middle part of the forest canopy			Lower part of the forest canopy		
	Total radiation	Net radiation	Total radiation	Net radiation	Reflected radiation	Total radiation	Net radiation	Reflected radiation
CM	700.3a	462.8a	568.9a	318.3ab	66.1a	255.8a	148.4a	86.8a
FM	699.1a	466.5a	559.5a	329.8a	75.6b	247.1a	152.1b	93.1b
SM	698.4a	468.9a	578.6a	293.8b	60.7a	286.1b	128.0c	78.7c
NM	698.8a	459.3a	579.6b	278.3c	49.3c	289.0b	122.8c	60.8c

Values with different letters within a column are significantly different ($P < 0.05$)

Table 2 Temperatures with different ground mulches

Temperature (℃)	Covering mode			
	CM	FM	SM	NM
Air temperature	22.5a	25.6b	23.0a	25.1b
Temperature in 0 ~ 20 cm soil	16.2a	18.2b	15.8ac	17.4d

Values with different letters within a row are significantly different ($P < 0.05$)

As is shown in Fig. 2, the ground-reflected radiation received by the lower part of the canopy varied with time as a single-peak curve, similar with that of total radiation: reaching a maximum around noon and exhibiting lower values in the morning and evening in clear days, indicating that ground-reflected radiation is positively correlated with total radiation reaching the ground. The diurnal variation patterns of the ground-reflected radiation showed that the values with FM differed most from those with the other coverings at about 1 P.M., being 21.7%, 16.3%, and 27.3% higher than with CM, SM, and NM respectively, mainly due to higher reflectivity of plastic film.

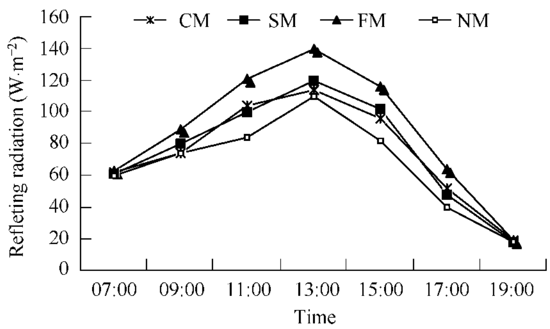

Fig. 2 The diary change of reflecting radiation

2.3 Net radiation

Net radiation differed between absorbed and released energy at an active interface. It is the major driving force for heat, energy, and water exchange at an active interface. Table 1 shows that net radiation values in the upper part of the forest canopy was not significantly different among different coverings, but significantly different in the middle and lower parts of the canopy among different ground coverings. The study revealed that CM, FM, and SM could increase the radiant energy levels in the middle and lower parts of the forest canopy. Net radiation in the middle part of the canopy with the different ground coverings was 14.4%, 18.5%, and 5.6% higher respectively than that in NM, while net radiation in the lower part of the canopy increased by 42.8%, 56.4%, and 8.1% respectively compared with NM. FM was found to greatly improve light conditions in the forest canopies, and light levels in the forest canopy with FM differed significantly from those with CM and SM. However, the net radiant energy in the middle part of the canopy with CM did not show an obvious difference with SM.

For different ground coverings, the vertical distribution of net radiant energy throughout the canopy showed a basically identical pattern. The net radiant energy distributions within the forest canopy layer from 0.8 to 1.6 m above the ground for the different treatments appeared to follow an exponential curve (Table 3) with all correlation coefficients above 0.90 (Table 1). This indicates that the net radiant energy values declined slowly in the upper part of the canopy but quickly in the lower part. The net radiation values declined slowly in the upper part of the forest canopy but rapidly in the lower part. And that the net radiant energy in the forest canopy with FM was consistently higher than that with the other ground coverings and in NM.

Table 3　Regression equations for the vertical distribution of net radiant energy in the eucommia forest canopy

Covering mode	Regression equation	Goodness of fit (R^2)
CM	$y = 443.05\ln x + 253.04$	0.9610
FM	$y = 427.76\ln x + 265.50$	0.9443
SM	$y = 432.82\ln x + 243.93$	0.9285
NM	$y = 435.07\ln x + 240.96$	0.9170

x is the height of the canopy layer (m); y is the net radiation ($W \cdot m^{-2}$)

3　Conclusions and discussion

In general, total solar radiation and net radiation increased with the increasing height above the ground in the canopy, while the opposite trend is observed in ground-reflected radiation.

Total radiation decreased more in the forest canopy with FM than those with CM and SM. Ground-reflected radiation values differed significantly among the different ground coverings. Ground-reflected radiation received by the lower part of the forest canopy showed greatest differences, and the ground-reflected radiation with FM being noticeably higher than that with the other ground coverings and in NM. The ground coverings mainly affected the net radiation in the middle and lower parts of the forest canopy. CM, FM, and SM are all capable of increasing net radiant energy in the middle and lower layers of the forest canopy.

FM and CM can not only markedly improve the light conditions in forest canopy, but also enhance the soil fertility, and thus benefit the plant growth. In apple orchard, the soil temperature rises obviously by depth from 0 to 60 cm with mulching either plastic in growing season. However, the soil temperature is relatively lower in the early season when only under SM, but higher than under NM in the late season[31]. The contents of available soil organic matter, N, P and K increase[32]. The application of bahia grass in China's south fruit area would be of great importance to water and soil conservation, maintenance of ecological environment and soil fertility in orchard, and improvement in fruit yield and quality. According to the study of white clover[29,33,34], due to the well-developed root system, it can improve soil structure and increase soil capillary volume, thus encouraging water and soil conservation and boosting the field yield[35]. In addition, white clover is a manure and forage crop which not only improves soil fertility, but also provides a food source for domestic animals. Therefore, CM is an agricultural practice with developmental prospect for non-timber forests in the Qinling Mountains.

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