Effect of Slope on Soil Carbon Storage in Prescribed Burning -- A case study of Pinus Kesiya in Jinggu County Yunnan Province

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Abstract. Compared control forest and prescribed burning forest of six slope of humus layer thickness, loads and organic carbon storage, and these soil levels organic carbon content and carbon storage in Pinus Kesiya, and confirmed to be suitable for carrying out prescribed burning. The experimental data showed that prescribed burning before and after, humus layer thickness of FS and GS are highly statistically significant (P<0.01), others were statistically significant (P<0.05). Loads and organic carbon storage of FS are highly statistically significant (P<0.01), GS, SS, AS and DS are statistically significant (P<0.05). Soil organic carbon content of FS, GS and DS on 0-60cm level are highly statistically significant (P<0.01), others slopes are statistically significant (P<0.05), FS and GS on 20-40cm are highly statistically significant (P<0.01), BS, AS and DS are statistically significant (P<0.05), lat slope and GS on 40-60cm are highly statistically significant (P<0.01), BS is statistically significant (P<0.05). Soil organic carbon storage of SS on 0-20cm is statistically significant (P<0.05), others are highly statistically significant (P<0.01), FS, GS and DS on 20-40cm are highly statistically significant (P<0.01), BS and AS are statistically significant (P<0.05), FS on 40-60cm is highly statistically significant (P<0.01), GS, BS and DS are statistically significant (P<0.05). Prescribed burning can decrease loads in forest, and carbon sequestration in different slope is different, preferred to FS to prescribed burning, next considering GS and BS, those can gain better efficiency, prescribed burning could not be carried out in SS, AS and DS.

Key words: Slope; Prescribed Burning; Loads; Organic Carbon Content; Organic Carbon Storage.

1. The introduction
Soil organic carbon pool is the largest and the most important part of the terrestrial ecosystem organic carbon pool, which has an extremely important influence on the regulation of global climate and human living environment [1, 2]. Even slight changes in the soil organic carbon pool may cause rapid response of the atmospheric environment and terrestrial ecosystem [3]. Forest fires are various kinds of...
interference on forest ecosystem organic carbon library [4], the maximum interference have a huge
effect on forest resources and global climate change [5], the global average each year, about 1% of the
forest to suffer interference of fire [6], especially major forest fires will destroy the forest carbon sink
of ecosystem primary productivity, and the years of formation of the vegetation carbon sequestration
and soil carbon library part of carbon leakage in a short time, make the forest vegetation of organic
carbon library and forest soil organic carbon stock decreased dramatically, general forest fires can also
produce small leakage, increase forest of CO2 emissions [7]. In recent years due to the increase of
greenhouse gases and global warming phenomenon has become increasingly apparent, the resulting
forest fire frequency greatly strengthen [8, 9], in order to avoid forest fire release of greenhouse gases
cause serious consequences, ensure the safety of the forest resources to reduce greenhouse gas
emissions and the number of forest fires, reduce the fire loss of forest prescribed burning technology is
applied to the practice of forest management, through the surface tiny fuel inside the burning forest,
human intervention to reduce forest fuel loads, the changing structure of the forest combustible solid,
cut off the continuous distribution of forest fuel. To prevent and reduce large-scale and high-intensity
forest fires [10], so as to reduce the possibility of forest fires and increase the storage of vegetation and
soil organic carbon, which is a forest management model that exchanges a small leakage for a larger
forest organic carbon sink and the efficiency of sequestration of organic carbon [11, 12]. The use of
prescribed burning can prevent forest fires, increase forest organic carbon reserves, reduce greenhouse
gas emissions and mitigate the greenhouse effect, making a significant contribution to the global
environment and climate. Prescribed burning affect the carbon budget of the region through two
pathways: reducing the age structure of the region's ecosystem, providing a large amount of nutrients
and energy, increasing the productivity of the ecosystem, and thereby increasing the carbon absorption
capacity of the system; Reduce the likelihood of larger, more intense fires, thereby reducing the amount
of carbon directly emitted. Fire prevention and prescribed burning are two effective management means,
and rational use will strongly promote the absorption of carbon by the ecosystem and reduce carbon
emissions [13].

It is of great significance to correctly evaluate the role of fire interference in the carbon cycle. At
present, the research on the impact of fire interference on the carbon cycle of the ecosystem focuses on
the estimation of carbon-containing gas, the change of carbon sink of carbon source [13], respiration
and the impact of fire interference intensity [14]. Burning projects affected by wind speed, wind
direction, temperature, relative humidity, such as terrain, and these factors is closely related to the slope,
and the slope is the environmental factors that affect prescribed burning fire behavior [15-17], different
slope of transpiration amount of evaporation, water infiltration, affect plant productivity and litter
decomposition and distribution characteristics of organic carbon [18].

2. Overview of the research area
Jinggu county is located in the southwest of Yunnan province, the national forestry key county, the
forest coverage rate of 74.7%, by the national forest coverage of more than 5 times on average, at
100°02′~101°07′E,22°49′~23°52′N between forest tree species of Pinus kesiya (Pinus kesiya var.
Langbianensis), is one of the main fast-growing timber species in Yunnan province, pure forest is given
priority to, more for forest of the same age, natural regeneration ability is strong, rapid growth,
distributed in the central and southern and southwestern Yunnan, It is a unique species of warm conifer
in the south subtropical region of southwest China. The range is between 99°05′~102°30′E in the south
of 22°24′N. The conifers of Pinus kesiya are rich in oil and have high flammability. Jinggu county has
20 years of experience in carrying out the project and has good representativeness.

3. Research method
3.1. Selection of sample sites
According to the afforestation record files and field survey conducted by Jinggu county forestry bureau,
the representative Pinus kesiya forest with different forest levels and different canopy densities in 5
towns and villages in Jinggu county was selected by using GPS positioning, combined with measuring rope and geological compass to measure the slope. The forest was divided into two management modes: control forest and prescribed burning forest. Under the above two management modes, according to the slope records of forest resource inventory data, 96 standard plots of 20m×20m were set according to the national standards of 6 grades: FS(Flat Slope, 0°~5°), GS(Gentle Slope, 6°~15°), SS(Steep Slope, 16°~25°), BS(Bluff Slope, 26°~35°), AS(Acute Slope, 36°~45°) and DS(Dangerous Slope, ≥46°).

3.2. Humus layer thickness measurement and soil sample collection method

Three soil sample collection points were selected according to the S-type in each standard sample field, and a soil profile with a depth of 0.6m was dug to record the thickness of the humus layer. A 0.5m×0.5m sample was selected from the humus layer, and all samples were collected according to the actual thickness. Soil samples were collected at depth levels of 0~20cm, 20cm~40cm, 40cm~60cm and 150g~200g in layers, and were weighed on site. The collected samples were taken back to the laboratory, and the plant roots, gravel and other debris in bagged soil were carefully removed. After drying naturally, the samples were stored in glass bottle for determination. Soil bulk density was determined by ring knife method.

3.3. Determination of humus layer moisture content

The fresh weight of the humus layer samples was recorded in the field, and then the samples retrieved from each sample were put into the oven, dried continuously at 105℃ for 24h to the constant weight, weighed by an electronic balance, and the moisture content of the humus layer in each sample was calculated. The average value of the three samples was the combustible moisture content of the sample site.

The absolute moisture content of the humus layer in each quadrat is calculated according to the following formula:

\[
\text{Relative moisture content} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Fresh weight}} \times 100\%
\]

3.4. The sample contains organic carbon reserves

Soil organic carbon was determined by potassium dichromate high temperature external heating oxidation - ferrous titration(GB9834-88). Three parallel samples were measured each time, and the results were averaged.

4. Results and analysis

4.1. Sample moisture content

According to the formula of absolute moisture content, the results are shown in table 1.

| Slope | FS     | GS     | SS     | BS     | AS     | DS     | Average |
|-------|--------|--------|--------|--------|--------|--------|---------|
| Control plot | 62.75±0.29 | 59.12±0.31 | 56.86±0.2 | 53.03±0.28 | 50.07±0.26 | 46.21±0.29 | 56.72±0.27 |
| Prescribed Burning | 56.62±0.27 | 54.32±0.29 | 50.64±0.26 | 48.44±0.28 | 46.33±0.28 | 42.25±0.25 | 51.40±0.25 |

Note:In the same row, numbers containing the different capital letters in the superscripts are highly statistically significant (P<0.01), the different letters are statistically significant (P<0.05), the same letters are not statistically Significant (p>0.05). Same as below.

As can be seen from table 1, the FS, GS and SS were significantly reduced before and after burning (P<0.01), while other slope differences were significantly reduced (P<0.05). The water content of the humus layer decreases with the increase of the slope, because the area exposed to solar radiation decreases with the increase of the slope, and the evaporation dispersion increases. The moisture content
of the decay layer in six slopes of the control forest was higher than that prescribed burning forest. The reason was that after prescribed burning, the removal of surface litters and the reduction of canopy cover resulted in the increase of soil temperature, the increase of water evaporation and the decrease of water content in the humus layer.

4.2. Humus layer thickness, load and organic carbon storage at different slopes
Forest organic carbon is carried by forest biomass, and the storage of organic carbon in the humus layer is the humus layer load multiplied by the organic carbon content. The calculation formula for the storage of organic carbon in the humus layer is: C=B×Cc, where C is the storage of organic carbon (t); B is the humus layer load; Cc is the content of organic carbon in the humus layer. The calculation results are shown in Table 2.

As can be seen from table 2, the thickness, load and organic carbon storage of humus layer in control forest all show a trend of increasing first and then decreasing with the slope, which is because the slope affects the stability of the distribution of substances on the slope, thus causing the redistribution of substances on the slope. The thickness, load and organic carbon storage of the humus layer in prescribed burning forest showed a small trend with the increase of slope. Before and after the prescribed burning, the humus layer thickness, load and organic carbon storage all changed, and the humus layer thickness of the FS and the GS had a very significant difference (P<0.01), while the other slopes had a significant difference (P<0.05). The difference of the FS load and carbon storage was extremely significant (P<0.01), while the difference of the GS, BS, AS and DS was significant (P<0.05), while the other differences were not significant (P>0.05).

After the prescribed burning, the increment of load and organic carbon storage gradually decreased with the increase of slope, and the negative growth of SS, SS and DS appeared, and the negative growth increased with the increase of slope. The humus layer thickness, load and organic carbon storage of the FS, GS and SS all increased 0.51cm, 4.038/t·hm⁻², 2.606/t·hm⁻², 0.32cm, 1.587/t·hm⁻², 2.101/t·hm⁻², and 0.15cm, 1.033/t·hm⁻², 0.659/t·hm⁻². The other slopes all decreased, DS and AS decreased maximum 0.17cm, 2.02 t/hm⁻², 1.29 t/hm⁻², and 0.135cm, 1.797 t/hm⁻², 1.147 t/hm⁻².

4.3. Organic carbon content in different slopes
The measured results of soil organic carbon content are shown in table 3.

Table 2. The thickness, load and organic carbon storage of the rotten layer at different slopes under the two management modes

| Category | Forest type | Slope | FS (cm) | GS (cm) | SS (cm) | BS (cm) | AS (cm) | DS (cm) |
|----------|-------------|-------|---------|---------|---------|---------|---------|---------|
| Thickness (cm) | Control plot | 1.21±0.32 | 1.32±0.36 | 1.37±0.37 | 1.17±0.33 | 1.06±0.35 | 0.93±0.33 |
| | Prescribed | 1.72±0.32 | 1.64±0.28 | 1.52±0.30 | 1.05±0.41 | 0.93±0.37 | 0.76±0.32 |
| Loads (t·hm⁻²) | Control plot | 11.302±2.71 | 12.056±3.17 | 12.284±3.75 | 11.246±2.38 | 10.926±2.07 | 10.366±3.51 |
| | Prescribed | 15.385±2.63 | 13.643±2.64 | 13.317±1.88 | 9.633±2.76 | 9.129±3.09 | 8.346±2.90 |
| Organic carbon reserve(t·hm⁻²) | Control plot | 7.213±1.73 | 7.694±2.02 | 7.840±2.39 | 7.177±1.52 | 6.973±2.17 | 6.616±2.24 |
| | Prescribed | 9.819±1.68 | 8.707±1.56 | 8.499±1.20 | 6.148±1.24 | 5.826±1.31 | 5.326±1.34 |

Table 3. Influence of two management modes on organic carbon content of the same slope

| Soil depth (cm) | Forest type | Slope | FS (t·hm⁻²) | GS (t·hm⁻²) | SS (t·hm⁻²) | BS (t·hm⁻²) | AS (t·hm⁻²) | DS (t·hm⁻²) |
|----------------|-------------|-------|-------------|-------------|-------------|-------------|-------------|-------------|
| 0–20 | Control plot | 2.669±0.55 | 2.589±0.66 | 2.334±0.48 | 2.168±0.45 | 1.942±0.31 | 1.713±0.38 |
| | Prescribed | 3.458±0.53 | 3.076±0.49 | 2.721±0.47 | 1.859±0.44 | 1.524±0.48 | 1.213±0.46 |
| 20–40 | Control plot | 2.172±0.32 | 1.956±0.38 | 1.769±0.27 | 1.655±0.29 | 1.441±0.26 | 1.266±0.25 |
| | Prescribed | 2.738±0.29 | 2.366±0.34 | 2.067±0.31 | 1.515±0.26 | 1.153±0.19 | 0.918±0.26 |
| 40–60 | Control plot | 1.615±0.20 | 1.448±0.23 | 1.209±0.16 | 1.069±0.21 | 0.923±0.18 | 0.811±0.12 |
| | Prescribed | 2.122±0.23 | 1.818±0.21 | 1.528±0.16 | 0.981±0.14 | 0.827±0.18 | 0.703±0.15 |
See table 3, burning before and after, 0 to 20 cm soil layers, FS, GS and DS of organic carbon content difference was significant (P<0.01), other grade significant differences (P<0.05), 20-40cm soil layers, FS and GS difference was significant (P<0.01), SS, BS and DS difference significant (P<0.05), 40-60cm soil layer FS and GS difference was significant (P<0.01), SS difference significant (P<0.05), the other no significant difference (P>0.5).

Prescribed burning before and after, 0~20cm soil layers of the increase and reduction of maximum value, low, FS potential with the rains washed out to receive water and nutrients from the hill slope and other, increase the carbon content of the biggest, followed by GS and SS, BS, AS and DS because of its large, is not conducive to maintain water conservation and nutrient, increased carbon content reduction gradient are increased. The average organic carbon content of the FS, the GS and the SS increased to 0.621, 0.422 and 0.335, respectively. The other slopes showed negative growth, and the DS, the acute SS and the abrupt SS respectively decreased to 0.319, 0.267 and 0.179.

4.4. Organic carbon reserves of different slopes

According to the bulk density and organic carbon content of each layer of forest land, the organic carbon reserves of different forest types of forest land in the same forest area were calculated $S_d = \sum_{i=1}^{n} C_i \times d_i \times D_i$, where $S_d$ indicates soil organic carbon reserves per unit area within the depth of the soil surface $d$ (t·hm$^{-2}$); $d_i$ represents bulk density of the i soil layer (g·cm$^{-3}$); $C$ represents the content of the i soil layer (g·kg$^{-1}$); $D$ represents the thickness (cm) of the i soil layer, and the results are presented in Table 4.

| Soil depth (cm) | Slope | Forest type | FS | GS | SS | BS | AS | DS |
|----------------|-------|-------------|----|----|----|----|----|----|
| 0–20           | Control plot | FS 66.047±22.48 | 63.637±21.18 | 58.690±22.94 | 53.493±21.68 | 47.264±21.26 | 41.469±19.01 |
|                | Prescribed Burning plot | 84.688±22.02 | 73.691±22.36 | 67.673±21.14 | 46.063±21.45 | 39.763±17.76 | 31.926±16.21 |
| 20–40          | Control plot | 53.336±23.10 | 49.966±16.16 | 45.469±19.01 | 43.102±18.01 | 37.986±14.12 | 32.603±13.54 |
|                | Prescribed Burning plot | 68.673±21.14 | 58.846±26.94 | 51.336±23.10 | 38.943±17.76 | 31.495±15.47 | 25.988±17.18 |
| 40–60          | Control plot | 44.469±19.01 | 39.947±17.57 | 34.926±11.21 | 29.998±13.98 | 26.696±12.55 | 24.307±10.24 |
|                | Prescribed Burning plot | 54.464±21.94 | 44.963±21.45 | 39.524±17.76 | 26.814±9.41 | 23.307±10.24 | 18.877±10.46 |

See table 4, Prescribed burning before and after, 0 to 20 cm soil layers, in addition to the BS, other slope organic carbon content was significant (P<0.01), 20-40cm soil layers, FS, GS and DS difference was significant (P<0.01), slope and SS difference significant (P<0.05), 40-60cm FS difference was significant (P<0.01), GS, SS and DS difference significant (P<0.05), the other no significant difference (P>0.5).

The analysis of the contribution rate of the two management modes to the organic carbon storage in the forestland layer shows that the organic carbon storage in the layer of 0-20cm is significantly higher than that in other layers. In the vertical soil profile distribution, the soil organic carbon storage and its content change rule are similar, that is, it decreases with the increase of soil depth. The soil surface layer (0–20cm) of forest land with six slopes has the largest organic carbon storage under two management modes, and the organic carbon storage decreases with the increase of soil depth.

Prescribed burning before and after, the increase and decrease of soil layer of 0–20cm reached the maximum value, and the carbon storage of FS was the largest, followed by GS and SS, and the carbon storage of AS, BS, DS and SS was negative. The average organic carbon reserves of the FS, GS and SS increased before and after the prescribed burning, and respectively were 42.973t/hm$^{-2}$, 22.95t/hm$^{-2}$ and 19.448t/hm$^{-2}$. The other slopes showed negative growth, and the DS, AS and BS respectively decreased to 21.588t/hm$^{-2}$, 17.081t/hm$^{-2}$ and 13.773t/hm$^{-2}$.

Different slope leads to different moisture content in forest land and affects the combustion efficiency. Small slopes receive solar radiation with high intensity, long time, high temperature, more moisture in
soil evaporation and vegetation transpiration, and low humus layer moisture content, while large slopes receive solar radiation with short time, low temperature and high water content, resulting in the difference of humus layer moisture content along different slopes. The water content of the humus layer in the SS is low, reflecting that the combustible material in the understory is more flammable, and the combustion is more sufficient. Small slope humus layer water content is higher, reaction undergrowth its fuel non-flammable, not formed a large number of black carbon, complete combustion of fuel, and large gradient of black carbon, washed down with small slope of water thermal environment, is advantageous to the fire after coking plant residues provided to soil organic matter accumulation, soil organic carbon reserves increase rate than other slope.

The degree of erosion by rain is different in different slopes. Large slope has a strong effect on soil denudation, resulting in the loss of combustible materials and a large amount of soil organic matter. As a result, the content of soil organic matter in large slope is deficient, resulting in the loss of carbon. There are relatively more litters and residues on the surface of a small slope, which reduces the intensity of erosion of organic matter by surface runoff, and is conducive to the accumulation of organic matter by plant residues coking after fire. The increase of soil organic carbon storage is larger than that of other slopes. After prescribed burning, the FS has a low potential and receives water and nutrients from the incomplete combustion of black carbon from the upper slope and other slopes as the rain washes away, resulting in the largest increase in organic carbon reserves.

Prescribed burning reduces the accumulation of combustible material in undergrowth and reduces the risk of fire. FS, GS and slope small slope to carry out the plan to burn away the organic carbon reserves of litter can be converted into nutrients and fixed in the soil to improve the forest organic carbon sequestration efficiency. However, after the prescribed burning of SS, SS and DS with a large slope, the burning of forest land surface combustibles will result in the loss of protective layer on the surface and relatively strong soil denudation, resulting in the loss of unfinished combustibles and a large amount of soil organic matter, resulting in the lack of soil organic matter content.

5. Conclusions and discussions

5.1. The conclusion

The humus layer thickness, weight and organic carbon storage, as well as the organic carbon content and storage in the soil layer of 0-60cm were compared between the control forest and the prescribed burning forest. The results showed that:

1) Changes in humus layer thickness, load and organic carbon storage of before and after prescribed burning, the humus layer thickness, load, organic carbon storage and carbon storage of 0-60cm soil layer all changed, and the humus layer thickness of FS and GS showed a very significant difference (P<0.01), and other slopes showed a significant difference (P<0.05). The difference between the FS load and carbon storage was very significant (P<0.01), while the difference between the GS, BS, AS and DS was significant (P<0.05). The humus layer thickness, load and organic carbon storage of the FS, GS and SS all increased (0.51cm, 4.083t/hm⁻², 2.606t/hm⁻², 0.32cm, 1.587 t/hm⁻², 1.013t/hm⁻², 1.033t/hm⁻², 0.659t/hm⁻²). The other slopes all decreased (0.17cm, 2.02 t/hm⁻², 1.29 t/hm⁻², 0.135cm, 1.797 t/hm⁻², 1.147t/hm⁻²).

2) Soil organic carbon content change: 0-60cm 0~20cm soil layers, FS, GS and DS of organic carbon content difference was significant (P<0.01), other grade significant differences (P<0.05), 20-40cm soil layers, FS and GS difference was significant (P<0.01), while the difference between the GS, BS, AS and DS was significant (P<0.05). The average organic carbon content of FS, GS and SS all respectively increased 0.621, 0.422 and 0.335. The other slopes showed negative growth, and the DS and AS showed the largest respectively decrease -0.319 and -0.267.

3) Soil organic carbon change 0 to 60 cm: 0-20cm soil layers, in addition to the BS, other slope organic carbon difference was significant (P<0.01), 20-40cm soil layers, FS, GS and DS difference was significant (P<0.01), slope and SS significant difference (P<0.05), 40-60cm FS difference was
significant (P<0.01), GS, AS and slope significant difference (P<0.05). The average organic carbon storage of FS, GS and DS respectively increased 42.973t/hm$^{-2}$, 22.95t/hm$^{-2}$ and 19.448t/hm$^{-2}$. The other slopes showed negative growth, and the DS and AS decreased the most, respectively to -21.588t/hm$^{-2}$ and -17.081t/hm$^{-2}$.

The carbon sequestration benefits of prescribed burning are different in different slopes. The priority should be given to the burning on the FSs. Secondly, good carbon sequestration efficiency can be obtained on the SS and GS, and it is difficult to carry out prescribed burning on BS, ASs and DS.

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