UNDERSTORY BURNING IN STANDS OF MASSON'S PINE

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Abstract:
The diverse types of Masson's pine stands can be simplified into two subtypes by using inflammability as the main criteria: Masson's pine-shrub forests and Masson's pine-fern forests The initial burning of Masson's pine is dictated by the bole height of the targeted stands. Forests lower than 4 meters can not provide enough gap to prevent surface fires spreading into the crown and thus are not suitable for understory burning. The death height and scorching height have the following correlation:

$$Y \approx 3X^{0.873}$$

where Y stands for death height(m) and X stands for scorching height with the coefficient being 0.6. In no cases should the flames of the prescribed burning exceed 4 meters, otherwise, the damages of the intensive fires to the basal meristems will cause unacceptable tree mortality. To minimize soil erosion and tree mortality, 5-15% of patchiness, 60-80% of surface fuel removal rate and 5-10% of tree mortality should be the indicators of proper burning .

Key words: Masson's pine forests surface fuel properties fire environment fire behavior burning effects understory burning prescriptions

1. Introduction

Pinus massoniana L. is the most widely distributed pine species in China, with a natural distribution area of over 2 million square kilometers in 17 provinces from the north to the south of the whole subtropical zone of mainland China (Wu,1956). Geographically, it is found in an area ranging between 21°41′ -33°56′ N and 102°10′ -122°30′ E.

Masson's pine forests in China have a total area of 14,344,300ha. and a gross stock of 4,302,067m^3, accounting respectively for 21% and 14.5% of the timber forests of the country and making it the dominant timber species for South China.

However, the distribution area of the Masson's pines is among the regions in China that suffer the most frequent and severest loss of forest fires. South China accounts for over 90% of the total occurrences of forest fires in China (Wen, 1995) and most of them are in the forests of Masson's pine and Chinese fir.

Prescribed burning has proved to be one of the most effective ways to prevent forest fires and reduce fire losses. In many countries like the U.S.A and Canada, prescribed burning has been intensively studied and used as a regular forest management tool to realize multiple land management objectives (USDI and USDA, 1995, Wagner,1993). In China, however research on and the applications of prescribed burning is still at the early stage. As of today, studies on prescribed burning has only been made in forests of red pine and larches in Northwest China (Liu , 1994) and in forests of Yunnan pine in Southwest China (Wu, 1995; Wang , 1995). Even for this research, the objectives are only oriented to the use of prescribed burns to reduce fire hazards instead of exploring the multiple functions of fires in land management. In view of the importance of Masson's pine in the forestry of South China and the fact that no study has ever been made as to the use of fires in the forests of the Masson's pine forests, the National Office of Forest Fire Management has decided to fund this research.

2. Research Approaches

2.1 Site Selection

As the ecological systems of the Masson's pine forests in the southern zone are more complicated, diverse and productive than those in the north, Shunchang County of Fujiang Province located at the central zone, and Tianlin, Shangsi and Longan counties of Guanxi Provinces in the southern distribution zone of the species are selected as the sites for this research.

2.2 Stand Survey

Stands are surveyed by using randomly selected plots of 20 m×20m. Measurements include the gradients and aspects of the slopes, the DBH(diameter at breast height), height and bole height of the trees and the canopy closure and density of the stands.

Within each plot, 5 plots of 2m×2m are selected to measure the weight of the living shrubs. Still within each plot, 1m×1m plots are used to measure the weight of the herbaceous plants and the litters.

Samples of dead fuels, living shrubs and herbaceous plants are collected to measure the moisture contents (MC) in the labs so as to calculate the fuel loading of the stands.

2.3 Experimental Burnings

To obtain the fire behavior data under different fire weather conditions, the 6 experimental fires are started respectively at times when the fire danger is low, moderate and high. Four of these experimental fires are ignited in two days, one in the morning when the fire danger is low and one in the afternoon when the fire danger is high. The burning process is as follow:

Plots of 30m×30m are selected as the burning sites. Stand parameters, surface fuel features and fire environment factors are all measured. Fire breaks of sufficient width are constructed along the four sides of the plots to prevent fire escape.

To measure the rate of spread (ROS) of the back fires and flank fires, the researchers placed 2 firecrackers every meter along both the perpendicular and horizontal direction. For head fires, the interval of the firecrackers is 5 meters. Back fires, head fires and flank fires are consecutively ignited. By recording the time internal of the consecutive explosions of the firecrackers, the researchers are able to find out the fire spread rate.

The height of the flames is estimated . At hearing the explosions of the firecrackers, three persons estimated the flame height simultaneously, and the average is used as the final value.

The burning process was also recorded by using video cameras so that the researchers can play back to check the accuracy of the estimates made on the spot.

After each burning, assessment was made to determine the burning effect by factors such as the percentage of “patchiness” and the amount of the residual fuel. By comparing the residual fuel loading with the total surface fuel loading before the burning, the researchers were able to find out the rate of fuel removal.

A few months later, the burning sites were surveyed again to examine the scorching height, defoliation height and the mortality rate of the stands.

2.4 Fire Site Investigation

To supplement data collected through experiments, the researchers also visited many forest fire sites. On each site, the stand height, DBH, scorching height and the death height were measured. The researchers used these data to deduce the behavior of those fires. The unburned stands immediately next to the burned sites were also investigated with the stand features and surface fuel characteristics measured and recorded which are used as a substitute for the data of the burned sites before the fires. Fire site investigation can help better understand the relationships between stand features, fire environment and fire behavior and can supplement the experimental fires with more data.

2.5 Fire Danger Rating with Moisture and Temperature

Due to the lack of a universal rating system of fire danger in China, a regional system was used. In this system, Fire danger ratings are calculated through the equation below which is based on the linear relations between two selected factors and fire occurrences (Wen, 1995):

$$Y=29.4-29.3X_1+1.8X_2$$

Where Y----fire danger rating;

X_1-----The relative humidity predicted for the 14:00 hour of the next day
X_2-----daily temperature difference (℃) predicted for the next day

Fire danger ratings are divided into the following classes (Table 1). Studies of the fires recorded from 1981 to 1990 indicate that there exists good correlation between the fire danger ratings calculated from the above equation and the factual fire occurrences. It is found that the probabilities of fire occurrences under different fire danger ratings are respectively: 87% for V, 56% for IV, 20% for III, 7% for II and no fire for I (Wen,1995).

Table 1 Fire Danger Rating Classes

Fire danger ratings		Value interval	Weather conditions
I	Naught	≤15	Cloudy or rainy
II	Low	16--25	Fine or cloudy
III	Moderate	26--35	Fine or cloudy
Ⅳ	High	36--45	Fine
V	Ultra-High	>45	Fine

3. Results and Discussions

3.1 The potential effect of stand and surface fuel features of the Masson's pine forests on fire behavior

3.1.1 Age, height and bole height and fire behavior

As natural stands of Masson's pine forests are not common, the investigations were mainly made in plantations. Altogether, 17 plots in the 4 counties in 2 provinces were investigated. Although, it must be acknowledged that only six(plot 1, 11, 12, 14, 15, and 16) of these were actually burned and thus the actual burn-exposed data are quite sparse. The results of these investigation are shown in table 2. Though forest age, tree height and bole height(the average height of the base of the live crown in the stand) are different concepts, for forest fire experts, their implications on fire behavior are the same: they signify the probabilities of surface fires being developed into crowns fires. Most of the crown fires are caused by surface fires and the probabilities of crown burning are determined by three closely related factors: （1）the energy released by surface fires, which is a function of the types, loading and moisture content of the surface fuels;（2） the thermal energy absorbed by the tree crown, which is related to the distance between the top of the fire flame and the crown ; and（3）vertical continuity of the fuels ; in some cases, even though the height of the surface flames is not great, but due to good fuel continuity, surface fires can easily spread into the crown, causing catastrophic crown fires(Chandler, 1988). In view of this, the bole height of the forests has always been an overwhelmingly important factor in designing prescribed fires.
As can be seen from table 2, the height of the young stands is around 10m, the middle-age stands average 10-16m and the close mature stands are usually about 20m.

Thus, the probability of crown fires in young stands and new plantations is quite high because the brushes or herbaceous plants can usually reach the crown layer, which can easily pass surface fires to the upper story and cause disastrous crown fires.

Table 2 Masson pine stands and the major characteristics of surface fuels

No.	Age (yr)	Density (stem/ha)	*C.C. (%)	Slope (degree)	Mean DBH (cm)	Mean Height (m)	Mean Bole height (m)	Height(m) and loading of surface fuel (kg/m^2)			
								Height	Living fuel	Litter	Total
1	8	1500	70	18	11.0	5.4	0.6	0.8	0.13	0.90	1.3
2	8	1750	80	5	9.8	5.7	1.6	0.5	0.13	0.58	0.61
3	12	1125	54	22	17.8	12.8	6.2	0.8	0.91	0.55	1.46
4		1850	85	22	14.5	11.2	6.1				
5		1400	65	17	15.6	8.5	4.0				
6	16	680	50	5	21.0	11.3	4.7	1.2	0.93	0.78	1.71
7		725	55	8	21.7	12.1	4.2				
8	15	1025	75	25	22.5	14.9	7.3	1.5	0.37	2.19	2.56
9		1125	74	20	19.4	14.6	6.8				
10		1125	74	27	18.7	15.2	7.7				
11	17	775	70	11	22.3	13.6	7.4	1.0	0.68	0.28	0.96
12	24	1798	70	17	16.0	14.7	6.5	0.9	1.07	0.79	1.86
13	23	800	50	16	23.0	15.3	7.7	1.0	0.41	2.54	2.95
14	18	1000	40	22	16.3	9.1	2.8	1.0	0.2	1.10	1.30
15	33	1500	70	24	17.5	24.2	11.3	1.4	1.15	2.13	3.28
16	30	1100	65	24	17.2	19.5	11.8	1.8	1.23	1.92	3.25
17	29	475	85	15	31.1	21.9	16.2	1.5	1.11	0.89	2.00

*Canopy closure

One of the tasks of the researchers is to find out the time for initial burning. As Mason's pine is a fast-growing species, the first burning may be planned when the stands are 8 to 12 years old. At this stage, the stands are usually 5.4m to 12m high, averaging 8.6m and the bole height ranges between 0.6m and 6.2m, averaging 3.7m(Plots 1-5 in Table 2,). Besides, the height of the understory of the stands at this stage is about 0.8m and the flame height produced by the surface fires in this fuel is usually 1 to 1.5m high, leaving a gap of about 1.2 to 2.5m between the top of the flame and the bottom of the stand crown, which makes it unlikely for the surface fires to burn into the crown layer. In this case, even if the energy released by the surface can kill part of the trees, the mortality rate will still be acceptable.

Masson's pine reaches its fast-growing stage at the age of 15 to 20. As can be seen from table 2 (plots 6-11 and 14), the middle-age forests are usually 9.1m-15m high, averaging 11.1m; their bole height ranges between 2.8m and 7.7m, averaging 5.1m. The stands become more fires resistant.

The bole height of the mature forests or close-to-mature forests of Masson’s pine ranges between 6.5m and 16.0m, averaging 10.7m (plot 12, 13, 15, 16, and 17 in Table 2). Such a bole height is sufficient to prevent most crown fires. The bole height of forest stands increases with stand age, but it is also intimately related to stand density, canopy closure and site conditions (plots 6 and 7 In table 2). As bole height is affected by multiple factors, it is not always reliable to estimate the bole height by stand age or height. On-the-spot survey may be the best way.

3.1.2 The major characteristics of the surface fuels and their impacts on fire behavior

3.1.2.1 Species

Forests of Masson’s pines usually have a very developed understory composed of diverse species. Saplings, shrubs, grasses, ferns and a variety of herbaceous plants and climbing vines exist. The *Forests of China* records several dozens of understory species in Masson’s pine forests and these species often form the shrub layers or herbaceous layer individually or in combination.

Due to larger diameter and higher moisture content, the shrubs are less flammable. What is more, in stands whose understories are mainly composed of shrubs, the percentage of dead fuel is relatively low and thus fires occurring in these forests are usually of lower intensity. *Miscanthus floridulus*, which is a grass and an important element of understroy of Masson’s pine forests, has similar burning properties to shrubs due to its high moisture content.

Investigation indicates that over 80% of the Masson’s pine forests have *Dicranopteris dichotoma* as the major understory species. This highly flammable fern species is usually 0.45 to 1.2m high, with very fine, tooth-like pinnate leaves which decompose slowly as their surfaces are usually covered by a wax layer and form a layer of fine dead fuel with high void volume (0.50-1.00m in thickness). Most of the forest fires that affect Masson’s pine forests occurred in forests with this type of surface fuel.

In this sense, this research proposed to simplify the complicated and diverse Masson pine forests into two subtypes: forests whose understory is mainly composed of fern like *Dicranopteris dichotoma* (Masson’s pine-fern forests) and forests with *Miscanthus floridulus* and shrubs as their major undergrowth species (Masson’s pine-shrub forests).

3.1.2.2 Fuel loading and height

Masson’s pine forests often have very a developed undergrowth of shrubs and herbaceous plants. But due to the fact that most of the distribution areas of this species are humid and hot, the decomposition process is very active, and thus the total fuel accumulation is not very thick. In this research, the surface fuel loading of the Masson’s pine forests ranges between 11t/ha. and 39.5t/ha., averaging 22t/ha. (Table 2), which is significantly lower that that of the coniferous forests in the cold and temperate zones. This means that acceptable fire intensity can be expected when starting prescribed fires in such forests. While the annual production of surface fuel is high, the interval between burnings can be planned for 3 to 5 years when the surface fuel loading is going to reach its maximum.

Investigation shows that in forests with shrubs as the major understory components, the percentage of living fuels is relatively high while the proportion of dead fuels is comparatively low, resulting in a low available fuel loading; while in forests with *D. dichotoma* as the main understory , the percentage of dead duel is quite high and are thus easy to be ignited or once ignited, are easy to be developed into high-intensity fires (Plot 15 and 16 in Table 2).

The general height of the surface fuels in the forests of Masson's pine is around 1.0m, but it varies greatly with species composition and the relative proportion of shrubs and herbaceous plants. Generally, the shrubs are 1 to 2 meters high and the herbs are less than 1.2 meters. The height of the surface fuels has a direct bearings on flame height. In some cases when the surface fuels are high, even low intensity fires may produce high flames equivalent to high intensity fires.

3.2 The effect of surface fuel features and fire environment on fire behavior

The 6 experimental fires of this research were ignited in 3 counties of 2 provinces. The fire environment, surface fuel parameters and fire behavior of these burnings are listed in Table 3.

3.2.1 The effect of surface fuel parameters on fire behavior

Fire behavior is the co-effect of surface fuel characteristics, burning environment and ignition patterns. The results of the 6 experimental fires and the findings from the investigation of the 4 forest fires suggest that for forests of Masson's pines, the types of the understory (whether it consists of shrubs, grasses, ferns or any form of combination) has an overwhelming effect on the behavior of the fires burning through them. Fires occurring in Masson's pine—shrub forests are usually mild, less intensive and move slowly. Shrubs are usually large in size and high in moisture content and thus in the burning process, they can absorb a lot of heat and "cool down" the fires (Plot 1, 12 and 14).

The main species associated in this shrub complex, *M. floridulus*, retain dead leaves on the living stems for a long time and through which fires can spread very quickly, are highly inflammable. But the stems of this plant are of quite high moisture content and very difficult to ignite. Fires burning through this grass are usually of moderate intensity (Plot 11) and result in high residual volume. While fires burning through forests with *D. dichotoma* as the major understory are much more intensive with much wilder fire behavior (Plot 15 and 16). Different from many other plants, the dead plants of *D. dichotoma* can remain standing for many years and decompose very slowly, resulting in a rapid accumulation of dead fuels. The loading of the dead fuels in Plot 15 and 16 reaches 21.3t/ha. and 19.2 t/ ha. respectively, 60% of which being *D. dichotoma*, 30% being pine needles and the rest being bamboo leaves and other herbs.

D. dichotoma belongs to fine fuels which has a high degree of porosity and very good continuity and is easy to be desiccated and ignited. Herbaceous plants try to expand its photosynthetic area so as to make the fullest use of the light, leading to low volume density and even distribution of the modular parts.

Spatially, they are such arranged that favors light absorption when they are alive and facilitates ignition and fire spread when they are dead.

The impact of the height of the surface fuels on fire behavior is also very significant. The three low intensity experimental fires (Plot 1, 12 and 14) all occurred in the forests in which the surface fuels are short while the two high intensity experimental fires are

Table 3 Surface fuel features, fire environment and fire behavior of the experimental fires

No	*DOB	Surface fuel types	Fire environment						Surface fuel features					Head fire behavior	
			★S	# FDR	☆ FWI	▲T (^{0}c)	◆RH (%)	◎WS (m/s)	※H (m)	Litter		Living fuels		▼FH (m)	⊙ROS (m/min.)
										Loading (kg/m^2)	▽MC (%)	Loading (kg/m^2)	▽MC (%)		
12	11.10	Shrubs	17	Ⅲ	29.4	24	86	0.1	0.9	0.71	25.9	1.07	71.2	0.6	2.7
11	12.17	M. floridulus	11	Ⅲ	33.4	26	70	1.0	1.5	0.28	28.5	0.68	151.5	2.5	8.6
1	3.17	Shrubs	15	Ⅳ	42.1	26	60	3.0	0.7	0.90	14.2	0.13	61.8	1.3	3.0
14	3.17	Shrubs	22	Ⅳ	42.1	28	55	3.5	0.7	1.10	13.8	0.1	61.8	1.4	6.6
15	2.11	Dichotoma /bamboo	24	Ⅳ	38.6	23.2	65	1.0	1.4	2.13	27.7	1.15	57.2	4.1	6.7
16	2.11	Dichotoma /bamboo	24	Ⅳ	38.6	25.0	63	2.3	1.8	1.92	27.7	1.23	57.2	5.4	10.0

*DOB--date of burning #FDR-- fire danger rating ☆FWI -- fire weather index ▲T- temperature
★S-- slope(in degrees) ◆RH-- relative humidity ◎WS wind speed ※H—height ▽MC—moisture content
▼FH —flame height ⊙ROS—rate of spread

both observed in the two plots(Plots 15 and 16) that have the tallest surface fuels. In these two plots, the surface fuels are *D. dichotoma* and bamboos. The tall bamboos have acted as the ladders that pass fire to higher layers. While in Plot 11, the major species of the surface fuels is *M. floridulus*, a grass whose inflammability ranges between that of the shrubs and the fern (*D. dichotoma*. But due to its height (reaching 1.5m), the intensity of this fire is still very high.

3.2.2 The effect of fire environment on fire behavior

Masson's pine is distributed in wet subtropical regions where it is usually hot and humid. Most of the fires occur in the four months from December to March. During this period, rainfall is rare only in December and the relative humidity of the whole period is still high. But fires are still frequent. The researchers found that during rainy days or at night, the relative humidity of the distribution area of Masson's pine is quite high, often reaching 100%, while due to low latitudes and great sun angles, the temperature during the day is usually higher than 20^{0}C (Table 3). High temperature soon dries up the air and the relative humidity drops below 70% in a very short time. On the other hand, high temperature also accelerates the drying-up process of the dead fine fuels. Three to four hours after sunrise, these fine fuels are ready to be ignited (Table 3). This is especially true of dead *D. dichotoma*, which dries much faster and becomes highly inflammable very soon.

The six experimental fires were ignited under three different fire weather conditions, which were reflected in the significant variations of fire behavior. Plot 12 and 1 are quite similar in terms of slope gradients, the height of surface fuels, and litter loading. But the experimental fires on these two sites varied greatly due to differences in fire weather at the time of burning. Fire on Plot 12 was ignited at the beginning of the fire season when the fire danger rating was 29.4 (Class III) and the moisture content of the fuels was 25.9% while the fire on Plot 1 was ignited when the fire danger rating was 42.1 and the moisture content of the down materials was only 14.2%. The flame height and rate of spread of the fire burning through Plot 12 were only 0.6m and 2.7m/min. respectively, while those of the fire on Plot 1 were 1.3m and 3.0m/min.(Table 3).

The effect of fire weather indices on fire behavior is more visible if we compare the behavior of the fires in Plot 1 and 14, two fires that were ignited on the same day but one in the morning and one in the afternoon. From the morning to the afternoon of the day of ignition, the temperature rose from 26℃ to 28℃， while the relative humidity decreased by 5% and the moisture content of the dead fuels dropped from 14.2% to 13.8%, a point that is considered by fire experts as “extremely inflammable”. The differences in fire weather have resulted in quite different behavior of the two experimental fires. For another two fires tested in Plot 15 and 16, the effect of weather factors on fire behavior is even more significant. The effect of the types (especially the height of the surface fuels) on fire behavior is also clearly demonstrated in these two fires. In fact the moisture contents of the down materials through which these two fires burned are significantly “high”, being 27.7%, a point that for most fuels ranges between “ignitable” and “non-ignitable”. But as the surface fuels are mainly composed of *D. dichotoma* and bamboos, the intensities of these two fires are quite high. Their flame heights reached 4.1m and 5.4m respectively and their rate of spread reached 6.7m/min. and 10m/min..

Geographical factors such as slopes and aspects are also important in determining fire behavior. But as the Masson’s pines are all distributed in the hilly areas of South China that have more or less the same geomorphology traits. The differences of fire behavior caused by geographical variations are thus not so conspicuous and are “negligible”.

Of course, fire behavior is co-worked by many interrelated factors. For forests of Masson’s pines, the types and height of surface fuels, the loading of down materials and fire weather are paramount factors that need to be given priority consideration.

3. 3 The Effect of Fire Behavior on the Burning Effect and Target Stands

3.3.1 “Patchiness” and surface fuel removal

The effect of the burning is evaluated mainly by “patchiness”, surface fuel removal and damages to the target stands. Undesirably large patchy area means either too-low intensity fires or uneven burning. If the fire intensity is too low as to be unable to clear away most of the fine fuels, the residual fuel will be too much and the objectives of reducing fire danger will be compromised. Whereas, if the fire is too intensive, the mortality of the target trees will be too high to be acceptable and total removal of the surface fuels will also easily cause erosion problems and is not desired either. Generally, 10-20% of patchiness and 60%-80% of surface fuel removal will be desirable (Wu, 1995) As is stated before, when using prescribed burning to reduce the danger of forest fires, the intensity of the fires should be so controlled as to achieve both the best burning effect and minimize the damages to the target stands. Due to the great differences in fire

Table 4 Stand characteristics, fire behavior and burning effect

No..	Stand height (m)	Bole height (m)	Head fire behavior		Burning effect		Effect on target trees		
			Flame height (m)	Rate of spread (m/min)	Patchiness (%)	Surface fuel removal (%)	Scorching height (m)	Defoliation height (m)	Tree mortality (%)
12	14.7	6.5	0.6	2.7	20.0	65	1.5	3.2	0
11	13.6	7.4	2.5	8.6	5	60	3.8	6.8	0
1	4.4	0.6	1.3	3.0	10	75	2.7	5.3	13.3
14	9.1	7.4	1.4	6.6	5	80	3.6	7.6	0
15	24.2	11.3	4.1	6.7	0	89.8	stand height	stand height	100
16	19.5	11.8	5.4	10.0	0	89.8	stand height	stand height	100

behavior, the 6 experimental fires of this research have resulted in quite different "patchiness" and removal rate of surface fuels. Fires in Plot 15 and 16 have the highest intensity with no area left untouched by fire flames and very high rate of surface fuel removal. But the potential of being followed by severe erosion is also quite great. The other four fires have produced more or less acceptable effect. Both the patchiness percentage and the removal rate of the surface fuels are kept within the designed range.

3.3.2 Scorching height, death height and tree mortality

The degree and extent to which the stands may be damaged by fires are determined by the stand features and the fire behavior. When the bole height of the stands is low, even low-intensity fires will cause damages to the stands while if the bole height of the stands is great enough, even high intensity fires will not result in unacceptable tree mortality.

Fire causes tree mortality in the following ways: (1) Crown fires cause tree death by directly burning or killing the apical buds of the trees; (2) the intensity of the surface fire is so high as to have scorched the needles and buds of the crown layer to death and (3) high intensity fires have destroyed the basal meristem of the trees. Research (Wu, 1995) shows that the effect of fires on the stands can be described by scorching height(the average maximum height of bole charring), damaging height(the average maximum height of bole charring) and death height. Scorching height indicates the distance from the ground to the point where the tree barks are blackened by flames, which is a function of fire intensity and the length of time for the barks to be exposed to the flames and thus can be used as a factor signifying the comprehensive effect of the burning. The point of height to which the needles are burned or scorched to death is called the damaging height of the fire. The death height is the distance from the ground to the point of the tree where the apical buds are burned by the fire. After each fire, it is always possible to find the range of these three different “height” on the stands. These three “heights” are related to each other and have the following relationships: Damaging height> death height > scorching height. This is not difficult to be accounted for. Needles are directly exposed above the fire flames without any protection and are thus easily scorched to death even in low intensity fires, while on the other hand, the buds of the pines trees are usually protected by the scales and are more fire resistant. As the amount of heat released by the fire reaching certain point above the fire is negatively correlated to the square of the distance between the fire and the point of concern, for the same fire, the damaging height (defoliation) height is much higher than the death height(Table 4). As fires may cause mortality to target trees or affect the photosynthesis of the stands by destroying the branches or leaves of the trees, it is necessary to regulate the behavior of the fires so as to bring the negative effects of the fires under an acceptable range.

In this research, a correlation between the death height and the scorching height of fires burning in the forests of Masson’s pine is established through site investigation of historical fires and experimental burnings(Fig.1)：

$$Y \approx 3X^{0.873},$$

Where Y stands for death height（m） and X stands for scorching height， with the coefficient being 0.6.

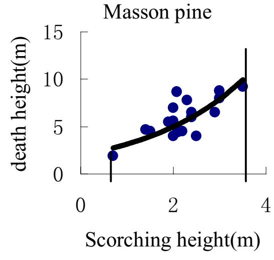

Figure 1 The relationships between the death height and scorching height of fires in the forests of Masson pine

When the scorching height is between 0.7m and 3.5m, the death height increases with the scorching height. In this case, if the stand is higher than the death height, the apical buds will not be hurt, the basal meristem of the trees are not damaged and burnings will not incur unacceptable tree mortality rate(fires in Plot 11, 12, and 14). But as is described previously, the height of the surface fuels in the forests of Masson’s pine is about 1.0m to 1.5m, which means that fires occur in such stands will have a flame height of about 1.5m to 2.0m while the bole height of these forests is usually lower than 2meters. This means that once ignited, fires in such stands will surely develop into destructive crown fires. In another case, when the fire intensity continue to increase, even when the death height as is predicted by the scorching height is much lower than the tree height, the intensive fires will still cause high rate of tree mortality by killing the basal meristems of the trees(Plot 15 and 16).

Based on the above discussions, a technical prescription for understory burning in the forests of Masson's pine is recommended for practical use (Table 5). The central idea of this recommended prescription is to regulate fire behavior through appropriate juxtaposition of the critical factors affecting fire behavior with references to the characteristics of the targeted forest stands.

Table 5 Recommended prescription for understory burning in the forests of Masson's pines

Forest age	Stand characteristics		Surface fuel characteristics		Fire weather	
	Stand height(m)	Bole height (m)	Surface fuel types	Litter loading (kg/m^2)	Fire danger rating	Fire weather index
Young forests	6.0-10.0	2.8-4.0	Ferns/bamboos	≤2.0	III	30-35
				>2.0	III	26-30
			Shrubs/grasses	Any	IV	36-40
Middle age forests	10.1-16.0	4.0-8.0	Ferns/bamboos	≤2.5	IV	40-45
				>2.5	III	26-40
			Shrubs/grasses	Any	IV	40-45
Submature forests	>16.1	>8.1	Ferns/bamboos	≤3.0	IV	36-45
				>3.0	III	26-30
			Shrubs/grasses	Any	IV	36-45

Literature Cited:

U.S. Department of the Interior and U.S. Department of the Agriculture, 1995, Federal wildland Fire Management Policy & Program Review : Final Report

Liu Zhizhong, Xiao Gongwu, Li Zhifang, Li Wenying, 1994. Forest Fuel Management. Press of Northeast Forestry University

Compiling Committee, 1999. Forests of China. Beijing: Forestry Press of China，pp.922-935

Wen Dingyuan, 1995. Fundamentals to Forest Fire Prevention. Beijing: Forestry Press of China，pp. 85-195;

Wang Jinxi, 1995. Reports on Prescribed burning in the forests of Yunnan pine. Chengdu: Science &Technology Press of Sichuan Province

Wu, D., F. Yang, et al: 1995. A Study of Underburning in Stands of P. Yunnanensis and P. kesiya var. langianensis. Proceedings of The Third International symposium on Fire Safety Science. Wlsevier Applied Science, London and New York

Wagner, C.E.Van, Prescribed Fire in the Great Lakes St. Lawrence and Deciduous Forests of Ontario—Problems and Potential ,Technical Report No.93-02

Xu Guozhen，1991. Challenges Faced by Forestry and Forest Management in South China. Bejing: Forestry Press of China

Chandler, C., Cheney, P., Thomas, P., Trabaud, L. And Williams, d., 1983, Fire in Forestry, John, Wiley and Sons, Vol. 1:p42