Study on Eight Tree Species' Combustibility and Fuelbreak Effectiveness[1]

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Abstract

Fuelbreak play an important role in fuel management and landscape system management. The paper analyses the differences of ten tree species' combustibility and effectiveness of fuelbreak based on the combustion experiments, measuring microstructures of leaf and branch, and wildland fire experiment. Leaves and branch are collected for experients. The species includes Schima superba, Camellia sinensis, Camellia oleifera, Viburnum amabuki, Photinia serrulata, Ligustrum lucidum, Pinus massoniana and Cunninghamia lanceolata. Cone calorimeter is applied to assess thermal characteristics of leaves by comparing their thermogravimetry, heat release rate and carbon dioxide and carbonic oxide release. Paraffin cut sheet of leaf and branch of those tree species were made for organism ratio measuring. And a wild fire experiment has been done in the suburb of Guangzhou, China. We measured the fuel loads and their distribution in the stand of pine and fuelbreak before and after fire. The weather and fire behavior are also measured to compute fire intensity. Conclusions include: i) A fire potential index (FPI, which is the ratio of ignition time to peak value of heat release rate) was compute for comparing the combustibility differences of the tree species. FPI of Camelia sinensis, Schima superba and Michelia macclurei are 0.82, 1.18 and 1.31 respectively. That indicated these tree species are suitable to fuelbreak. ii) The microstructures of leaf affect its combustibility. The higher the ratio of nervation, the more favorable the water transportation. The ratio of spongy tissue to palisade tissue has distinct regression correlation with the fire occurrence index. The ratio of spongy tissue to palisade tissue of Camellia sinensis and Schima superba is high and their fire resistance high. The ratio of vessel is positive correlation with the fire resistance of branch. Schima superba has a high weight of vessel, and they have fire resistance. iii) The fire experiment result indicates that the fuelbreak has effects on mitigating fire intensity and stop fire spread in some degree. The shaded fuelbreak has the ability of fire resistance and its dense crown can block spotting fire resources.

1 introduction

Fuelbreaks are widely used in China for fire prevention and play an important role in fuel management. A lot of work have been done on tree species selection for fuelbreaks (Shu et al. 1999 ; Bambang et al. 1994; Gao et al. 1995) . All those researches selected the tree species for fuelbreaks on base of comparing moisture content, extractive content, and tree's combustibility (Chen et al. 1988; Bao et al. 1997). The analysis for combustibility research is based on some simple burning experiment in lab. Cone calorimeter hasn't been used in those research activities. The cone calorimeter can measure the difference of flammability of species under the conditions of external heat source. Compared with the traditional measures of experiment, this measure means can provide much more parameters and the result

[1] Supported by the National Natural Science Foundation of China (No. 30671695) & National Key Technology R&D Program (No.2006BAD04B05)

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approaches its behavior in practice (Gilman et al. 1997; Hshieh et al. 1997; Baggaley et al. 1997) . Tree's combustibility has relationship with its microstructures. In this paper we will analysis how the microstructures of leaf and breach have influence on its combustibility.

Schima superba has been widely used in Southern China for fuelbreaks, which is a volunteer for forestation in wildland in tropical and sub-tropical zones. It is able to grow well in arid and barren sites and have a strong power of sprouting from stools. Fire experiment in wildland will benefit our understanding of the fuelbreak effectiveness combined with the experiments in lab.

In China the fuelbreak is often created by planting broadleaf trees along the ridge or under the hill. That is different from the concept discussed in some papers (Green 1977; Omi 1996; Agee et al. 2000) . The fuelbreaks in southern China also is a type of shaded fuelbreak, which is made of broadleaf trees and the surface litter has been removed by manual or mechanical means. This forest belts have a higher efficient than a common shaded fuelbreak just created through coniferous forest alteration.

2 Materials and Methods

2.1 Materials

Experimental materials are come from the 15-20 years trees. The tree species includes Schima superba, Camellia sinensis, Camellia oleifera, Viburnum amabuki, Photinia serrulata, Ligustrum lucidum, Pinus massoniana and Cunninghamia lanceolata. Moisture contents of Leaf and breach are measured on site and the samples are taken into the lab for further experiments.

2.2 Methods

2.2.1 Methods and Test Conditions of Cone Calorimeter

The cone calorimeter (produced by Rhenometic Co., UK, ASTM E1354-90 , ISO 5660-1) can measure some parameters of burning characteristics. The test sample is put in a 100mm×100mm square test trial with iron grid on cover. The sample thickness should be less than 50mm. The experiments are done under the conditions of radiant intensity 45-75kW/m2 in vertical direction and external fire source. All the tests use the same weight sample (accuracy 0.01g). And the samples are laid as uniformly as possible. The experiments measure some parameters including heat release ratio, total heat release ratio, and weight loss ratio, etc. All experiments are repeated no less than three times.

2.2.2 Making Paraffin Cut Sheet

The picked leaves and breach (<1 cm in diameter) are fixed immediately by using formalin-acetic acid-ethanol (FAA) (Li 1987 ; Zheng 1979) . Paraffin cut sheet of those leaves measure are made of measurement. We use optical microscope to take photo for those cut sheet and measure ratios of issues by weighing method.

2.2.3 Fire Experiment in Wildland

The test plots of fuelbreak and pine plantation are set with the size of 12m×20m and 10m×10m respedtively. In plots, we measured some indexes of every tree, such as diameter at breast height, height, and timber height. A sample tree was select according to the average diameter at breast height. Weights of leaves, timber and twigs of the sample tree have been weighed after its cutting down. The shrub and grass investigations adopted 2m×2m and 1m×1m test plots respectively. Their loadings were measured by cutting all of them. The samples also have been taken to lab for measuring moister content.

In order to avoid escape fire, we made a fifteen meters wide fireline on the two sides of pine forest except the side of fuelbreak. The fire experiment has been done under low wind speed condition. A set of portable climate instrument were used to observe the temperature, relative humidity, and wind speed at five meter height. The fire was set along the ignition line at the same time. Some symbols have been made on the two sides of pine forest. There are two observers to record the fire behaviors on the sides of fire spot. Two video cameras were set up outside the fire spot and in fuelbreak respectively.

3 Results and Discussion

3.1 Comparing of the Tree Species' Combustibility

Effective heat of combustion means the ratio of heat release rate and the mass loss rate at sometime. It indicates the degree of combustive volatiles burning. The first stage (about 60S) of the effective heat curves is heating period (Fig. 1). In this stage there are combustible gases release, such as methane, ethane and combustible liquids release such as acetone, methanol and acetic acid. After the gases get a concentration, they are burning and effective heat of combustion grows up quickly. Because the leaves have high moisture content, the water is vaporized firstly then combustible volatiles release. Experimental result shows that the effective heat of combustion of Ligustrum lucidum is the highest one, which means its release much more combustible gases. The effective heat curves of Camelia sinensis, Schima superba, Pinus massniana, Cunninghamia lanceolata are similar, and they get the peak at the time about 125s. Only Fribotrya japonica has a low effective heat peak value (14MJ/kg). The heat release goes with mass loss process (Fig. 2). Carbon burns after the mass loss rate peak, and

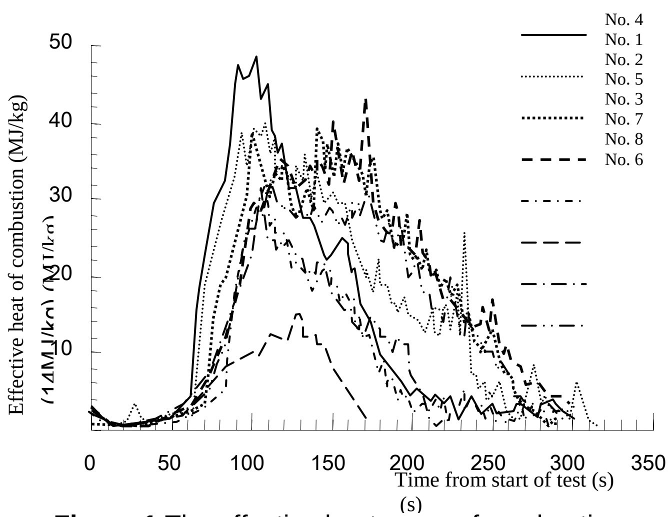

Figure 1 The effective heat curve of combustion

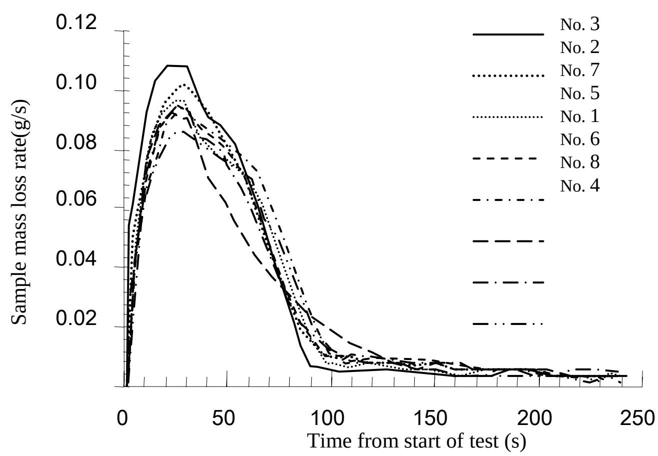

Figure 2 Sample mass loss rate curve

heat release rate decreasing. Heat is transferred to the leaves under the cover by conduct and radiation, and the combustible gases get out through the gaps among the sample leaves.

There is a difference on the leaves' moisture content (Table 1). Ligustrum lucidum has the highest moisture content and Pinus massniana with lowest moisture content. The moisture content has influence on combustion and heat release process. Fire potential index (FPI) is often used with reference to the degree of fire danger (Wickstrom 1992; Gilman 1997). The FPI is the ratio between the time to ignition (TTI) and the peak rate heat release (RHRpeak). The higher FPI value means the stronger fire-resistance. FPI of the test tree species are list in table 1. Camellia oleifera , Schima superba and Michelia macclurei have higher FPI value that means they are not easy to burn. Pinus massniana is easy to ignite with low FPI.

Table 1 *Leaves' moisture content and cone calorimeter experiment result*

Number	Tree species	Moisture content (%)	Test time of ignition (s)	Peak heat release rate (kw/m^2)	Fire possibility index (s.m^2/ kw)
1	*Camelia sinensis*	162.1	64	78	0.82
2	*Michelia macclurei*	142.7	38	29	1.31
3	*Pinus massniana*	150.0	16	26	0.62
4	*Schima superba*	157.0	72	61	1.18
5	*Ligustrum lucidum*	210.6	62	92	0.67
6	*Fribotrya japonica*	139.3	16	18	0.89
7	*Cunninghamia lanceolata*	168.3	20	25	0.80
8	*Camellia oleifera*	120.6	32	26	1.23

3.2 Compared the fire characteristics of schima leaves with pine needles

Fine fuel is a main factor to affect fire occurs, especially the fire characteristics of litter (Chandler et al. 1983; Zheng et al. 1988). We use cone calorimeter to study the burning characters of schima leaves and pine needle. The moister content of the leaves of schima and pine is 36.26% and 33.87% respectively. Effective heat of combustion indicates the degree of combustive volatiles burning. Figure 3 shows that the curve of pine needles burning increase sharply at eighth second and reach the climax at seventieth second with the peck value 49MJ/kg. But schima leaves burn slowly and it's effective heat of combustion increase at 52s and reaches the peak

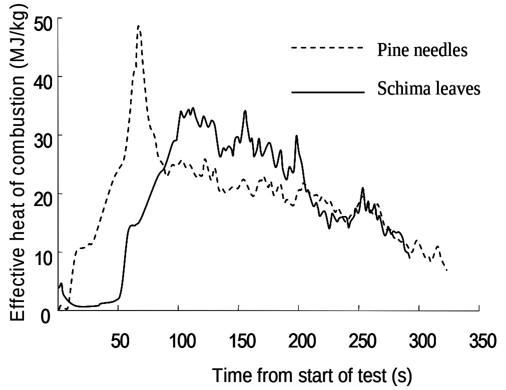

Figure 3 Effective heat of combustion of the two species

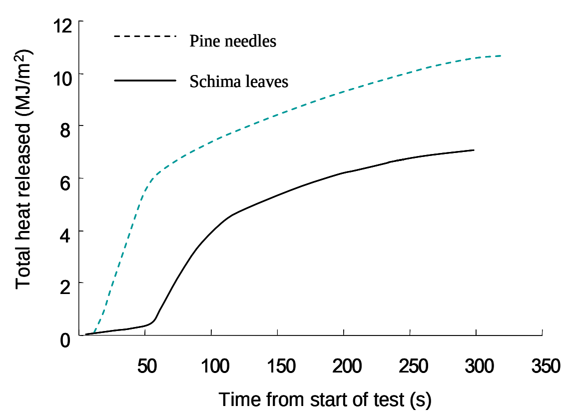

Figure 4 Total heat released of the two species

value 32MJ/kg at 106s. The peak value of effective heat of combustion of pine needles is 53% higher than that of schima leaves. This indicates that the pine needles burning intensively and release more heat energy.

Total of heat release is total heat of sample burning in the whole course. The index is measured in flow system and it is a net heat (not include the heat release of vapor changing into water). The higher the value, the more heat will be release to surroundings. Figure 4 show the curves of the total heat release of schima leaves and pine needles combustion. Because the pine needles burn quickly and heat release rapidly, its total heat release increase sharply and most heat are released in the periods of 8s-55s.the heat of schima leaves burning release rapidly after 58s. In the whole course of experiment, the total heat release of pine needles burning is always higher than that of schima leaves.

The mass loss rate curves of the two samples show that the pine needles loss mass faster than schima leaves (Fig. 5). The peak mass loss rate of pine needles is 0.14g/s, while schima leaves 0.08g/s. when the fuel is heated, it will release water and some volatile in first and then burn the great volatiles and carbon. So the carbon dioxide release will lag the mass loss rate. The low mass loss rate of schima leaves indicated its burning slowly. In short, the schima leaves burn much more slowly than that of pine needles.

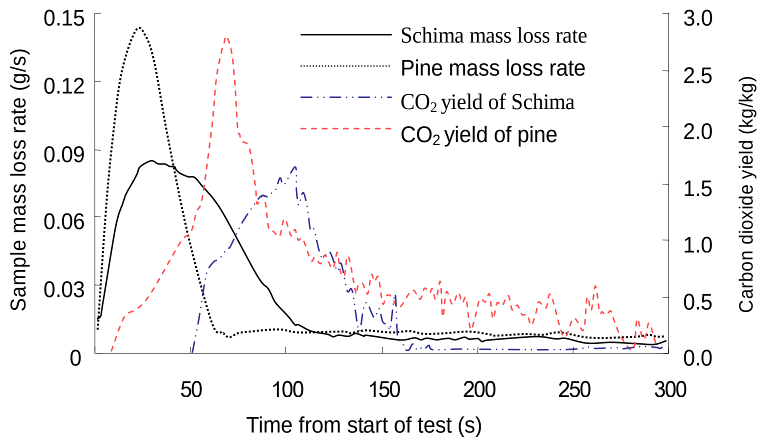

Figure 5 Mass loss rate and carbon dioxide yield of the two samples

3.3 Microstructure of Leaves and Their Combustibility

Evaporation rate of different tree species are affected by their microstructure under the same heating scenario (Tab.2 and Tab. 3). More palisade tissue in leaves indicates the tree species prefer to heliophilous. When the broadleaves get heated, water change into vapor and fill the cell gap. The vapour pressure is getting bigger between outside of the leaves and inside, and then water vaporizes easily. But the coniferous needles have a thick horny layer and small cell gaps. Water in needles is difficult to vaporize under heating conditions. Vaporizing can decrease the leaves' temperature and density of combustible gases, which make against leaves' combustion. Schima superba has a low spongy tissue ratio (34%), big cell gaps and high xylem ratio of nervation, which benefit the water transferring (Tab.2). Camellia sinensis has a high palisade tissue ratio (42%) and low interspace ratio, which make against vaporizing. But it xylem ratio is highest (54%). Its leaves show a good resistance on combustion, which indicates water transferring in xylem play an important role.

Table 2 *The ratios of tissues and nervation of broadleaves*

Tree species	Tissues of leaves	Tissues of nervation

	Cuticle (%)	Spongy tissue(%)	Palisade tissue(%)	Interspace (%)	Cuticle (top and undersurface) (%)	Basic tissues of cortex (%)	Phloem (%)	Xylem (%)
Camellia sinensis	10	42	40	8	6	17	23	54
Eriobotrya japonica	13	40	41	6	9	21	28	42
Camellia oleifera	8	39	45	8	7	42	31	20
Ligustrum lucidum	14	41	33	12	4	45	19	32
Schima superba	11	34	42	13	19	20	22	39

Table 3 *The ratios of tissues of coniferous leaves*

Tree species	Cuticle (%)	Basic tissues of cortex (%)	Vascular bundle (%)
Pinus massoniana	6	57	37
Cunninghamia lanceolata	11	18	47

A regression equation has been gotten through the regression analysis between the ratio of spongy tissue and palisade tissue with FPI：

$Y = 0.8957+0.1240x$, $R=0.2840$

Where: Y- FPI value; X- the ratio of spongy tissue and palisade tissue.

This indicates that the ratio of spongy tissue and palisade tissue has influence on combustibility. The higher spongy tissue ratio shows higher fire resistance ability.

3.4 Microstructure of branch and their combustibility

There is not vessel in Coniferous xylem, and tracheids are used to transfer water. Water transferring ability of conifers is general lower than that of broadleaves. Some pines have resin canal in xylem and phloem. The broadleaves use xylem to transfer water and without resin canal. So, from the point of anatomical structure view, it can conclude that the conifer is easy to burn due to resin and slowly water transferring. There is a significant difference on ratio of branch tissues for the different tree species (Tab. 4). Schima superba has the highest vessel ratio (29%), and it has a good water transferring ability and difficult to ignite.

Table 4 *The ratio of branch tissues of broadleaf*

Tree species	Vessel(%)	Ray (%)	Wood fibre and thin wall cells in axis (%)
Camellia sinensis	17	12	71
Schima superba	29	15	56
Camellia oleifera	22	15	63
Ligustrum lucidum	16	9	75
Eriobotrya japonica	10	14	76

3.5 Fire experiment in wildland

The fuelbreak is thirteen years old with planting density is 2.0m×1.5m (3,333/ha). Width of forest belt is 12m (6 rows), and shade density 0.8. Because the litter in the belt have been clear every year at the beginning of fire season, the rock exposed in some area and there is nearly no weed and shrub understory. Much litter piles along the sides of the forest belt. That make the two border rows grow well. The diameter breast height of the trees has a large verity. But the tree height of the belt is almost sameness. the average tree height of the fuelbreak is 8.5m , average diameter at breast height 9.86cm , live branch height 1.39m, and dead branch height 1.25m. The moister content of schima trunk, twig and leaves are 67.98%, 56.74%, and 56.18% respectively. the timber mass loading is 22.20t/ha , leaves 5.36t/ha , living twigs 5.95 t/ha , and dead twig 1.38 t/ha. There is no fuel ladder in the fuelbreak.

Planting density of the pine forest is 2.0m×2.5m. The canopy density of the 13-year-old pine forest is 0.6, average diameter at breast height 9.86cm , average tree height 5.8m, live branch height 2.66m, and dead branch height 1.4m. Understory there are some shrubs, such as Rhodomyrtus tomentosa, Melastoma candidum, Taxillus chinensis,Ilex asprella, etc. The coverage ratio of shrub is about 0.2 and its average height is 1.8m. The understory grasses include Dicranopteris dichotoma, Miscanthus floridulus, Blechnum orientale, and so on. The grass coverage ratio is about 0.6, and average height 1.3m. The litter is about 8cm thick. Flammable fuel (e.g. Dead twig, litter, duff and grass) loading is 14.43 t/ha.

The weather conditions of the fire experiment are temperature 21 , air relative humidity 47% , weed speed 0.8m/s in northeast direction. The wind direction is similar to that of the fire spread. In the part of pine forest near the shaded fuelbreak, there is mainly surface fire at the speed 1.7m/min because of the high moister content of the fuel. The flame ranges from 0.8m to 3.0m. According to the investigation after the fire, it is found that the consumed fuel is 8.42 t/ha. In this part the consumed fuel includes 64.7% fine fuel, 39.2% grass, 7.5% shrub. The crown of pine is almost not burned.

Because in the test plot the fuel distribution is not uniform and the varied fire behaviors include surface fire and crown fire, using the experimental equation to calculate the fire intensity will be more convenient. The equation is base on the flame height to calculate the fire intensity (Chamlder 1983) :

$$I_l = 273h^{2.17}$$

there, IL — fire intensity (kw/m) ,

h — flame height (m) .

We can calculate the surface fire intensity 168-2,961kw/m. in the part of pine forest far from the fuelbreak the average fire spread speed is 3.3m/min due to the large fuel loading. There form a crown fire after five minutes. The average flame height reached 8-8.5m and consumed 10.77t/ha fuel. Its fire intensity varied from 24,881kw/m to 28,379kw/m. figure 8 shows the fire intensity of the test fire. There are fires with low and high intensity. So the fire experiment tested ability of the shaded fuelbreak to block the surface fire and crown fire. In the section of crown fire, part crown of the first row of the shade fuelbreak burned but not spread to the next tree. The most damaged tree has one third crown burned. In general, the schima forest belt have not damaged seriously. No tree died from the fire.

4 Conclusion

Through the experiments of cone calorimeter, we find that Camelia sinensis, Schima superba and Michelia macclurei are difficult to burn. These tree species are suitable to fuelbreak. Due to the instrument conditions limitation, the cone calorimeter experiments are more likely to study the fuel behavior in low and moderate intensity fire. With the radiant intensity increasing, the difference of the fire characteristics of different tree species will minish. The shaded fuelbreak has an effective block to the low and moderate intensity fire.

The microstructures of leaf affect its combustibility. The higher the ratio of nervation, the more favorable the water transportation. The ratio of spongy tissue to palisade tissue has distinct regression correlation with the fire performance index. The ratio of spongy tissue to palisade tissue of Camellia sinensis and Schima superba is high and their fire resistance high. The ratio of vessel is positive correlation with the fire resistance of branch. Schima superba has a high weight of vessel, and they have fire resistance.

The fire experiment result indicates that the fuelbreak has effects on mitigating fire intensity and stop fire spread in some degree. The shaded fuelbreak has the ability of fire resistance and its dense crown can block spotting fire resources. The shaded fuelbreak can form a dense crown, which can block the spotting fire and the radiation from the flame (Tian et al. 2002) . The fuelbreak also can be used as a control line for prescribed burning and fire attack. That is important in fire management strategy. The effects of the shaded fuelbreak in landscape fire management need to be further studied in the future.

References

Agee J. K. ; Bahro B. ; Finney M. A. 2000. The use of shaded fuelbreaks in landscape fire management. Forest Ecology and Management 127(1):55-66.

Baggaley R. G.; Hornsby P. R.; Yahya R,; Cusack P. A.; Monk A. W. 1997. The influence of novel zinc hydroxystannate-coated fillers on the fire properties of flexible PVC. Fire and Materials 21:179-185

Bambang H S; Watanabe H; Takeda S. 1994. Use of vegetative fuelbreaks in inderstrial forest plantation areas in indonesia. Wildfire (2):14-16.

Bo Ying-sheng; Han Enxian; Han Gang; et al. 1997. A Study on Tree Species Selection for the Fire Protection Forest Belt in Shaanxi Province. Journal of Northwest Forestry College 12(4): 24-30.

Chandler C.; Cheney D.; Fhowas P. 1983. Fire in forestry: forest fire behavior and effects . New Youk：John Wlley and Sons.; 31-33.

Chen C.; Shi X.; Hu H.; Deng Sh.; Huang Y. 1988. Study on the selection of tree species for fuelbreak. Journal of Fujian Forestry College 8(1): 1-12.

Gao G.; Chi G.; Zhou Sh. Study on fire resistance of the main tree species of plantation in Liaoning provinces. In: Zhang X. Study on biological fire prevention. Haerbin: Press of Northeast Forestry University.; 185-192.

Gilman J W; Ritchie S J; Kashiwagi T; Lomakin S M. 1997. Fire-retardant additives for polymeric materials i. char formation from silica gel—potassium carbonate. Fire and Mererals 21:23-32.

Green L R. 1977. Fuelbreaks and other fuel modification for wildland fire control. Washington, DC: U.S. Department of Agriculture; 79 p.

Hshieh Fu-Yu; Beeson H D. 1997. Flammability testing of flame-retarded epoxy composites and phenolic composites. Fire and Materials 21:41-49.

Huggett C. 1980. Estimation of rate of heat release by means of oxygen consumption measurements. Fire and Materials 4(2): 61-66.

Li Zh. 1987. Techniques of plant skiving (2nd edition). Beijing: Science Press.; 18-32.

Omi P N. 1996. The role of fuelbreaks. In: Proceedings of the 17th Forest Vegetation Management Conference. Redding, CA.; 89-96.

Shu Lifu; Tian Xiaorui; Li Huikai. 1999. The development of fire resistance forest belts research. Scientia Silvae Sinicae 35(4): 80-85.

Tian Xiaorui ; Shu Lifu ; Qiao Qiyu ; He Qingtang ; Li Hong. 2001. Research on fire2resistance tree species in south China. Journal of Beijing Forestry University 23 (5) 43-47.

Tian Xiaorui; He Qingtang; Shu Lifu. 2001. Application of cone calorimeter for the a ssessment of the fire resistance of tree species. Journal of Beijing Forestry University 23 (1) :48-51.

Tian Xiao-rui; Shu Li-fu. 2002. Researches and application of fuelbreaks in China. Chinese Forestry Science and Technology 1(4):75-80.

Zheng G. 1979. Micrological technique of Biology. Beijing: Press of public education.; 17～233.

Zheng Huanneng, Ju Ende. 1988. Forest Fire Management. Haerbin: Press of Northeast Forestry University.; 208.