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切枝对三峡库区两种榕属乔木生物量积累和枝供给的影响

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摘要:榕(*Ficus microcarpa* L.)和黄桷树(*Ficus virens* Ait. var. *sublanceolata* (Miq.) Corner)是在三峡库区广泛栽植的优良绿化树种。在三峡库区诸多公路、铁路修建和移民搬迁城镇建设等工程建设后的生态恢复和环境改善中,需要大量的榕和黄桷树。榕和黄桷树的繁殖通常采用切枝扦插的营养繁殖方式进行。因种苗培育的需要,对榕和黄桷树进行切枝时常发生,并且为了尽快获得大的种苗,通常切取榕和黄桷树植冠下部的大枝条用于种苗培育。切枝导致植株大量光合叶组织损失,对榕和黄桷树的总体光合生产和生物量积累会发生影响,同时,也会影响新枝的生长和发生数量以及植株再次提供切枝的能力。为了明确切枝对榕和黄桷树生长的影响,对切枝后榕和黄桷树的生物量积累和枝供给进行了研究,目的在于阐明在三峡库区亚热带气候条件下,生长速度比较快的榕和黄桷树是否可以在每年1次的切枝后很好恢复,从而能够可持续地提供切枝用于种苗培育。实验中对榕和黄桷树1a切枝1次,连续进行了3a。实验共设置了4个切枝强度(从植冠下部开始,分别切去植冠长度0%(对照)、20%、50%和70%范围内的所有枝条)和两个切枝处理季节(春季切枝和秋季切枝)。实验结果表明,切枝会减少榕和黄桷树地上部分生物量增量,生物量增量减少的程度与切枝强度呈正相关;并且,每年连续进行的切枝使地上部分生物量增量减少加剧。实验发现,在20%、50%和70%的3个切枝强度中,高切枝强度可以保证在第1次切枝处理中获得高的枝收获量,但并不能保证在第2次和第3次切枝处理中也能获得高的枝收获量。与春季切枝处理相比,秋季切枝处理使榕和黄桷树获得更高的地上部分生物量增量,从而获得更高的枝收获量。就植株地上部分生物量增量和枝收获量而言,切枝强度对二者的影响并不因切枝季节不同而表现出差异。研究表明,对于本实验研究中采用的榕和黄桷树植株,当切枝强度高于20%时,每年1次的切枝不能使榕与黄桷树植株的生长完全恢复。如果切枝每年进行1次,为保证能够可持续地获得切枝并且对植株的生长不造成过大影响,对于本研究中所采用的榕和黄桷树植株而言,最适的切枝强度应低于20%。

关键词:切枝;枝供给;生物量积累;榕;黄桷树;三峡库区

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Effects of branch removal on biomass production and branch availability of two fig tree species in Three Gorges reservoir region of China

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Abstract: In Three Gorges reservoir region of China, many roads, highways, railways, buildings and even new towns and cities have been constructed or are under construction. In this region, fig tree species *Ficus microcarpa* and *Ficus virens* are extensively planted for the ecological restoration and environmental improvement. Using branch cuttings to vegetatively cultivate saplings is a

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chief way of tree propagation for these two species in Three Gorges reservoir region, annual branch removal from trees of the two species for obtaining branch cuttings are common in the region. To evaluate the effects of annual branch removal on plant growth and subsequent harvest of branch cuttings, a branch removal experiment with four removal intensities (0%, 20%, 50%, and 70%), two removal seasons (spring and autumn) was carried out. Branch removal was conducted in three successive years. Aboveground biomass production of branch-removed *Ficus microcarpa* and *Ficus virens* trees decreased following treatment, and this reduction was correlated with branch-removal intensity. Annually repeated branch removal aggravated the decrease of aboveground biomass production. Among removal intensities of 20%, 50%, and 70%, higher removal intensities led to larger branch harvests in all species at the first pruning, but did not necessarily lead to larger branch harvests at the second and the third treatment. Trees subjected to branch removal in autumn produced higher aboveground biomass production, and resulted in a larger branch harvest than trees subjected to branch removal in spring. However, with respect to the aboveground biomass production and branch harvest, no interactions were found between treatment seasons and removal intensities. The results indicate that, in Three Gorges reservoir region, the annual branch removal regime can not provide enough time for these two fig trees to fully recover from removal intensities higher than 20%. The optimal removal intensity which ensures the largest sustainable harvest of branch cuttings from these trees under annual removal regime should be less than 20%.

Key words: branch cutting; branch supply; *Ficus microcarpa*; *Ficus virens*; Three Gorges reservoir region; tree growth

Owing to the largest dam construction of the world at Three Gorges in China, the Three Gorges reservoir region is on its way of fast development. Many roads, highways, railways, buildings and even new towns and cities have been constructed or are under construction. To restore the damaged vegetation and to improve the environmental quality in this region, a lot of trees are needed. *Ficus microcarpa* L. and *Ficus virens* Ait. var. *sublanceolata* (Miq.) Cornor (Moraceae) are two fig species which are naturally distributed in this region. Trees of these two species have shapely crowns and are able to grow on poor soils. Due to these advantages, they are widely planted in Three Gorges reservoir region, especially in cities, towns and along roads. For the two species, vegetative multiplication is the chief means of tree propagation, in which branch cuttings are used to cultivate saplings. Generally, the common mode local people apply to get branch cuttings is to remove branches from the lower crown annually, leaving the upper parts of trees intact.

Branch removal leads to a reduction in leaf area, and this supposedly results in an overall decrease in the assimilate production of the trees. The higher the removal intensity, the smaller the assimilate production. While removal takes away branches and leaves, the stem and root systems are retained. Thus, a large proportion of the assimilates produced by the residual leaf tissue after removal (especially under intensive removal) has to be used for the maintenance of a relatively large mass of remaining unproductive, live support tissue. As a result, assimilate investments in future photosynthetic production become smaller, and the regrowth of trees may be reduced consequently.

However, whether or not tree growth is affected by leaf loss is dependent on the degree of leaf loss and the time the treated trees possess to grow following leaf loss. At a certain degree of leaf loss, if there is a sufficiently long time period after damage, the immediate reduction in regrowth following leaf loss will gradually decrease to zero[1-3] and treated trees may resume their normal growing states[4]. Under the circumstances, branch removal results in obtainment of branch cuttings without impairing tree growth. On the contrary, if branch removal is repeated before the full recovery of damaged trees, a steady reduction in the growth of the damaged trees should be the result and therefore the potential supply of branch cuttings over the years may turn out to be smaller. Some studies showed that in areas with mild climate, tree growth may not be affected by moderate leaf loss. Studies on *Eucalyptus nitens* in south Australia revealed that the rates of CO_2 assimilation of three-year-old *Eucalyptus nitens* increased by up to 175% over a 16-month period following 50% crown pruning[5]. Moreover, the stem dry mass increment of *Eucalyptus nitens* trees was not reduced after 50% crown pruning[6]. In a defoliation study carried out in Three Gorges reservoir region, Cornelissen found that 50% defoliated

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saplings of *Castanopsis fargesii*, an evergreen broad-leaved tree species, achieved the same plant biomass as control saplings within ca. eight months after the treatment[7]. In Three Gorges reservoir region, the favourable period for plant growth is relatively long, about nine months[8,9]. It is likely that in this region there exists an intensity of branch removal up to which annually repeated branch removal does not impair tree growth and branch cuttings can be obtained for tree propagation.

In Three Gorges reservoir region, tree growth is seasonal. Trees grow fast in spring and summer, and grow slow or even do not grow in winter[8,9]. Furthermore, even in fast-growing seasons, the season of maximal growth differs between evergreen and deciduous tree species[9]. It is possible that branch removal conducted in different seasons may affect the growth of trees differently.

This paper is to investigate the effects of annual branch removal on aboveground biomass production and branch supply of two fig trees in Three Gorges reservoir region. Four branch removal intensities and two treatment seasons were adopted in the experiment. The following questions are specifically addressed:

(1) Can branch-removed trees gain the same aboveground biomass production as intact trees after annually repeated branch removal? Is aboveground biomass production affected by removal intensity?

(2) Is there a linear relation between branch removal intensity and branch harvest at any annually repeated treatment?

(3) Does branch removal in different seasons affect aboveground biomass production and branch harvest differently?

1 Materials and methods

1.1 Species and study area

Ficus microcarpa and *Ficus virens* are broad-leaved tree species with entire leaves; the former is evergreen and the latter is deciduous. Individuals of both species can reach a height of 20 meters[10]. In the Three Gorges reservoir region, trees of these two species start growth in early March, and new leaves and shoots can occur during the whole growing season. No apparent growth in these species can be observed during winter. The two species can be found everywhere in Three Gorges reservoir region, and Ficus virens is regarded as the "civic tree" of Chongqing city. Due to the high propensity of cut branches to root, it is quite easy to vegetatively propagate these two species and vegetative reproduction is nearly the only applied method for tree multiplication of these two species in Three Gorges reservoir region.

The field where trees of these two species were planted for study is situated at the foot of the Nature Reserve of Jinyun Mountain (29° 50′N and 106° 26′E), ca. 40 km north of the city of Chongqing, China. The substrate is quartziferous stone. Soils are acidic and yellowish. The climax vegetation of this region is evergreen broad-leaved forest. The climate in this region is monsoonal, resulting in hot, humid summers and chilly but mostly frost free winters. Details of the monsoonal climate of this region are given by Cornelissen[11], Fliervoet *et al*.[12], and Li *et al*.[13].

1.2 Experimental design

In early 1996, 300 small trees (saplings with height ranging from 1.1 to 1.4 meters) of each of *Ficus microcarpa* and *Ficus virens* were planted in an experimental garden at the foot of Mt. Jinyun. *Ficus microcarpa* and *Ficus virens* trees had branched when they were planted. Trees of each species were planted in a separate plot, with enough spacing between individuals to avoid mutual shading during the whole experiment. Weeding, watering, and insecticide spraying were applied to all trees when needed.

In early 1997, after one year growth for acclimation, for each species, 20 randomized blocks were established for branch-removal treatment. Environmental conditions were visually homogeneous within and between blocks. Each block contained nine trees. These nine trees were subjected to one of the following treatments: 20%, 50%, 70% branch-removal in spring; 20%, 50%, 70% branch-removal in autumn; one tree was set as control, and the remaining two trees were harvested in the spring or the autumn of 1997. Trees were assigned to treatments randomly.

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Branch removal was conducted in the spring (mid May) of 1997, 1998, and 1999 and in the autumn (early October) of 1997 and 1998. At the first spring branch-removal, the mean heights of *Ficus microcarpa* and Ficus virens trees were 1.5 and 1.8 meters, respectively. At the first autumn branch-removal, the mean tree heights of two species were 2.0 and 2.3 meters, respectively. Branch-removal was done by removing branches and associated leaves from the lower crown, leaving the top of the crown of each tree intact (Fig. 1). This implied that the crown depth (defined as the distance from the apical meristem of a tree to the insertion point of the lowest branch of the tree) of each tree was reduced by 0%, 20%, 50%, and 70%, respectively. The second and the third treatment of branch removal in 1998 and 1999 were performed in the same way, after removing sprouted branches on the pruned lower stem parts of some trees.

1.3 Biomass measurements

At each branch-removal treatment, removed branches and leaves of each tree were weighed separately in the field. Their dry weights (regarded as the branch supply or branch availability) were determined based on the subsamples analysed in the laboratory (oven-dried at 70℃ for 96h). For each tree, the stem length and basal diameter (ca. 10 cm above the soil surface), and the length and basal diameter (ca. 1 cm from the base) of all first-order branches were measured. The number of leaves was counted. Based on these measurements, the dry weights of the stem, residual branches and residual leaves (viz. residual aboveground mass totally) of each tree after branch-removal treatment were estimated non-destructively (see below). The sum of removed mass and residual aboveground mass was regarded as total aboveground mass. In the autumn of 1999, the aboveground parts of all trees of all species were harvested. Dry weights of the stem, branches, and leaves of each tree were determined.

Information for non-destructive determination of the biomass of branch-removed trees were obtained from harvested trees.

In the spring of 1997, the aboveground parts of 20 trees (one from each of the 20 blocks) of each species were harvested. For each tree, stem, branches, and leaves were weighed in the field. Length and basal diameter (ca. 10 cm above the soil) of the stem, and length and basal diameter of each first-order branch were measured. The number of leaves was determined. Stem, branch, and leaf dry weights were determined based on the biomass subsamples analysed in the laboratory (oven-dried at 70℃ for 96h). Regression formulas were constructed for two tree species for stem dry weight on the product of stem length times squared stem basal diameter, and for total branch dry weight on the sum of the product of length times squared basal diameter of all first-order branches (Table 1).

Table 1 Regression formulas constructed for stem dry weight and total branch dry weight of *F. microcarpa* and *F. virens* trees

Item	Stem	Branch
F. microcarpa		
spring 1997	$y = 0.157x + 3.83$, $r^2 = 0.90$, $p < 0.001$	$y = 0.282x + 2.51$, $r^2 = 0.88$, $p < 0.001$
autumn 1997	$y = 0.142x - 18.4$, $r^2 = 0.91$, $p < 0.001$	$y = 0.242x + 3.62$, $r^2 = 0.94$, $p < 0.001$
autumn 1998	$y = 0.108x + 245.4$, $r^2 = 0.91$, $p < 0.001$	$y = 0.236x + 23.4$, $r^2 = 0.91$, $p < 0.001$
F. virens		
spring 1997	$y = 0.098x + 20.7$, $r^2 = 0.91$, $p < 0.001$	$y = 0.165x + 0.217$, $r^2 = 0.98$, $p < 0.001$
autumn 1997	$y = 0.077x + 94.1$, $r^2 = 0.94$, $p < 0.001$	$y = 0.115x + 13.5$, $r^2 = 0.97$, $p < 0.001$
autumn 1998	$y = 0.085x + 289.8$, $r^2 = 0.93$, $p < 0.001$	$y = 0.177x + 24.4$, $r^2 = 0.95$, $p < 0.001$

Regression formulas for stem dry weight (y: stem dry weight (g); x: product of stem length times squared stem basal diameter (cm^2)) and total branch dry weight (y: total branch dry weight (g); x: sum of the product of length times squared basal diameters of all first-order branches (cm^2)) of *F. microcarpa* and *F. virens* were constructed. For each species, 20 trees were harvested in the spring and autumn of 1997, respectively, and 35 trees were harvested in the autumn of 1998

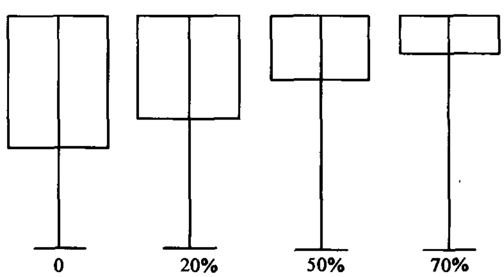

Fig.1 Illustration of branch removal intensities
See text for details of the branch-removal treatment

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Average dry weight per leaf was determined for both *Ficus microcarpa* and *Ficus virens* species. With this information, the dry weights of the stem, residual branches and leaves of each spring-treated tree after the first spring branch-removal were determined. Average dry weight per leaf was also used to estimate the total dry weight of residual leaves of each spring-treated tree in the spring of 1998 and 1999.

Similarly, in the autumn of 1997, another 20 trees (from 20 blocks) of each species were harvested and analysed in the same way. With the information from harvested trees, the dry weights of the stem, residual branches and leaves of each autumn-treated tree after the first autumn branch-removal treatment were estimated. Constructed regression formulas for stem dry weight and branch dry weight based on the harvested trees were also used to estimate stem dry weights and branch dry weights of treated trees in the spring of 1998 (Table 1). Average dry weight per leaf based on harvested trees was used to estimate the dry weight of residual leaves in each autumn-treated tree in the autumn of 1998.

In the autumn of 1998, 5 blocks out of 20 were randomly selected and trees in these five blocks were harvested. With these harvested trees, regression formulas for stem dry weight and branch dry weight were constructed (Table 1). The dry weights of stem and branches of each treated tree of two species in the autumn of 1998 and the spring of 1999 were estimated, using these regression formulas.

1.4 Data analysis

Aboveground biomass production per tree was defined as the difference between the aboveground mass one year after treatment and the residual aboveground mass instantaneously after treatment.

For each treatment season, effects of branch-removal intensity and treatment year on the amounts of removed branch and leaf mass (branch supply) and biomass production were evaluated for each species by using two-way ANOVAs. Differences between branch-removal intensities in each treatment year and differences between treatment years were checked by applying Duncan's multiple range test. Data of year 1999 were excluded when the effects of treatment season and branch-removal intensity on biomass production and branch supply were explored by using two-way ANOVAs, since no branch-removal treatment was conducted in the autumn of 1999. Logarithmic transformation was conducted to equalize variances if necessary.

2 Results

2.1 Aboveground biomass production

Branch removal reduced aboveground biomass production of *Ficus microcarpa* and *Ficus virens* in both spring- and autumn-treated trees (Fig. 2). Generally, after each annual treatment of branch removal, aboveground biomass production declined with increasing removal intensities for two species.

Annually produced biomass increased in undamaged trees with the years. But, in most cases, the biomass increase in repeatedly damaged trees was greatly reduced, which resulted in a steadily increasing difference in annual aboveground biomass production between non-branch-removed and branch-removed trees (see the interaction of treatment year and branch-removal intensity in Fig. 2).

In either of year 1997 and 1998, autumn-treated trees had higher aboveground biomass production than spring-treated trees (Table 2, Fig. 2). However, as regards the patterns of aboveground biomass production versus removal intensity, spring-treated trees were not different from autumn-treated trees (Fig. 2). No interactions between treatment season and removal intensity on aboveground biomass production were found for all species (Table 2).

2.2 Branch harvest

At the first branch-removal conducted in 1997, the harvests of branches were larger as the intensity of removal was higher (Fig. 3). However, at the second branch-removal, 70% crown damage did not always yield higher harvests of branches than the lower removal intensities. *Ficus microcarpa* and spring-treated trees of *Ficus virens* showed no difference

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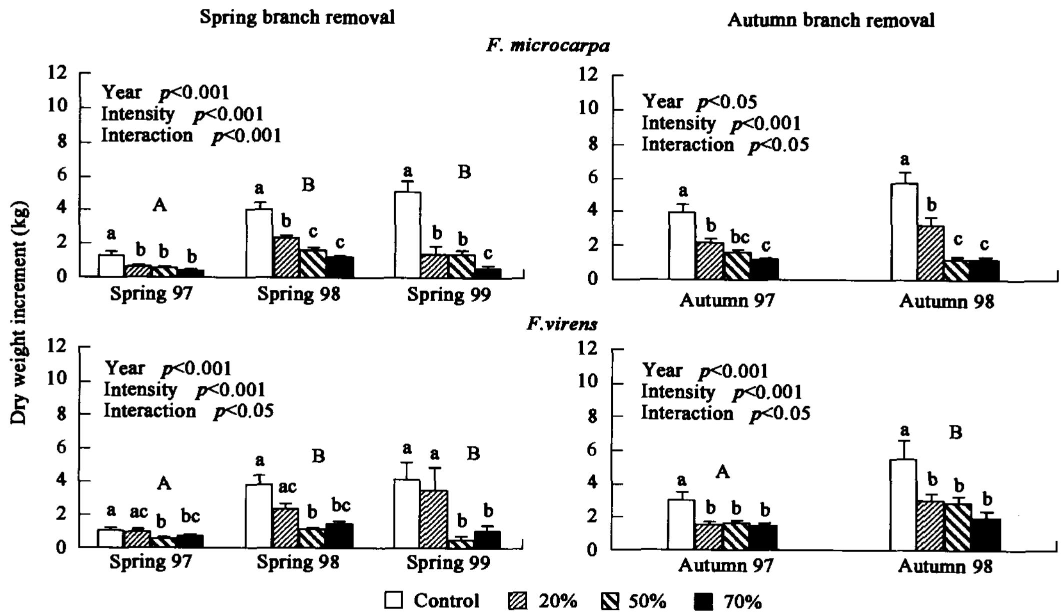

Fig.2　Aboveground biomass production (mean ± se) of two fig tree species one year after each spring or autumn treatment. Branch removal treatment was done in the spring of 1997, 1998, 1999 and in the autumn of 1997, 1998 for two species. Removal intensities were 0% (control), 20%, 50%, and 70%. For each removal treatment of each species, means which share the same lower-cased letters are not significantly different from one another. For each treatment season of each species, different upper-cased letters are used to indicate differences in overall mean aboveground biomass production (not shown in the figure) between years

in the harvest of branches between branch removal intensities at the second treatment.

At the third spring treatment, the branch harvests in the 20% removal treatments were not lower than those in the 50% and 70% removal treatments (Fig. 3). For the Ficus virens trees, 20% removal led to a higher harvest than 50% removal, and for Ficus microcarpa trees, 50% removal led to a higher harvest than 70% removal. The interactions on harvest of branches between damage intensity and treatment year were significant in both two species (Fig. 3). In either of year 1997 and 1998, autumn treatment led to higher harvests of branches in all species (Table 2, Fig. 3). Treatment season did not change the patterns of branch harvest versus removal intensity. No interactions between treatment season and removal intensity on branch harvests were found for these two species (Table 2).

3　Discussion

Basically, the reduction in tree growth caused by the loss of photosynthetic structures is related to the length of the time period for regrowth. If the time period is long enough, damaged trees are able to recover and eventually no sign of the damage remains[1~3, 14]. The results of this study clearly show that annual branch removal reduced aboveground biomass production of *Ficus microcarpa* and *Ficus virens* (Fig. 2). In this study, the branch-removal intensities were 20%, 50%, and 70%. It is evident that for removal intensities larger than 20% crown depth reduction, one year was not sufficient for the treated trees to gain full recovery and achieve the same biomass increments as intact trees, even though these trees had a relatively long growth

Table 2　The effects of branch-removal season and the interactions between branch-removal season and removal intensity on aboveground biomass production and branch harvest of two fig tree species. Data of year 1999 were excluded when two-way ANOVAs were applied to evaluate the effects of treatment season and the interactions between treatment season and branch-removal intensity

Species	Aboveground biomass production		Branch harvest	
	Season	Interaction	Season	Interaction
F. microcarpa	68.65[a]	0.76	201.62	0.31
	***[b]	ns	***	ns
F. virens	62.51	1.06	96.23	1.91
	***	ns	***	ns

a: F values; b: Significance levels: ns: Not significant; * $p<0.05$; ** $p<0.01$; *** $p<0.001$

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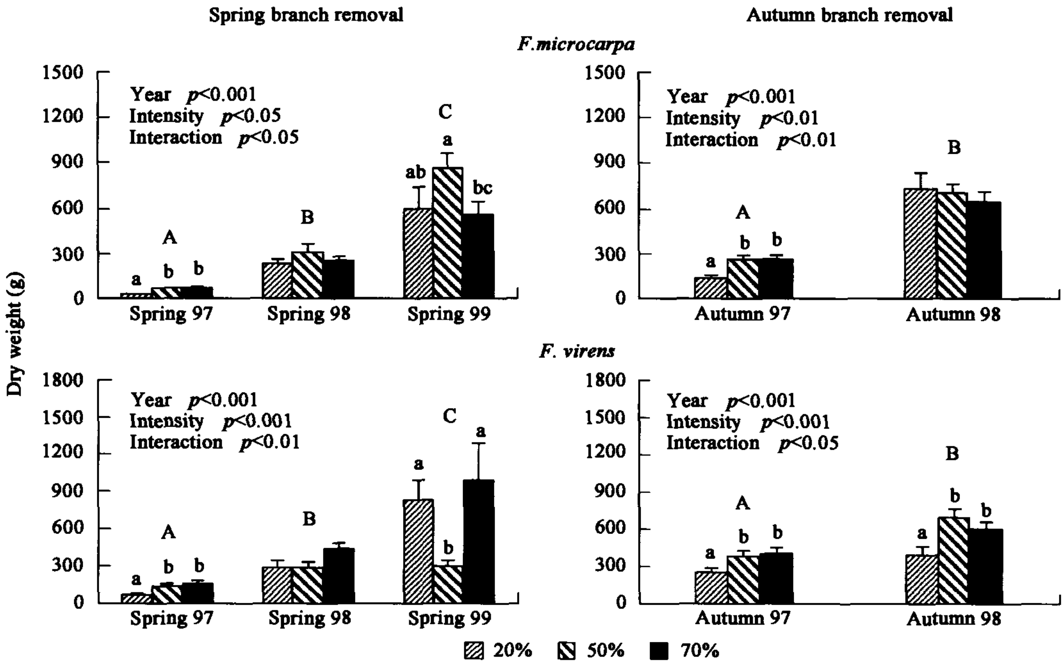

Fig.3 Amount of branch harvest (mean ± se) of two fig tree species at each spring and autumn removal treatment

Removal intensities were 20%, 50%, and 70%, and removal was done in the spring of 1997, 1998, 1999 and in the autumn of 1997, 1998 for all species. For each removal treatment of each species, means which share the same lower-cased letters are not significantly different from one another. For each treatment season of each species, different upper-cased letters are used to indicate differences in overall mean branch harvests (not shown in the figure) between years

period per year in Three Gorges reservoir region[8,9]. Compared to untouched trees, branch harvest of annually branch-removed trees decreased increasingly due to their insufficient recovery. This resulted in the fact that branch harvests in this study were correlated with removal intensities at the first treatment, but not correlated with removal intensities at the second and the third treatment (Fig. 3). In this study, an annual removal intensity of 70% was too high for the studied species to continually provide high harvest of branches. Comparatively, removal intensities of 20% and 50% appeared to be better than 70% in terms of obtainment of branches cuttings. However, since the aboveground biomass production of the investigated trees was decreased at removal intensities larger than 20%, the optimal removal intensity which ensures the largest sustainable branch harvest from these trees under annual removal regime should be less than 20%.

In this study, generally, autumn-treated trees realized higher aboveground biomass production than spring-treated trees (Table 2, Fig. 2), and autumn removal resulted in a larger harvest of branches than spring removal (Table 2, Fig. 3). However, no interactions were detected between treatment season and removal intensity for these two variables (Table 2). It seems that the patterns of aboveground biomass production and branch harvest associated with removal intensity could not be influenced by treatment season. In the experiment, the investigated *F. microcarpa* and *F. virens* have different leaf habits, the former is evergreen, and the latter is deciduous. Based on the experimental results, it was found that *F. microcarpa* and *F. virens* had the similar patterns of aboveground biomass production and branch harvest following removal treatment (Figs. 2,3, Table 2), which implies that in regard to the general tendency of biomass production and branch harvest as affected by branch removal treatment, leaf habit did not make significant difference.

To conclude, in Three Gorges reservoir region, one year was not enough for Ficus microcarpa and Ficus virens trees to fully recover from branch removal higher than intensity of 20%. Under annual removal regime, removal intensities which may not decrease aboveground biomass production of these trees should be less than 20%. Due to the continuous reduction in biomass production caused by annual branch removal, for removal intensities larger than 20%, higher removal

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intensities could only lead to larger harvests of branches at the first pruning, but were not able to result in larger harvests later on. In order to get sustainable supply of branch cuttings without impairing tree growth, it would be better to increase the time interval between branch removal events to a period of longer than one year. As far as the effects on biomass production and branch harvest were concerned, it is found that removal treatment in spring did not differ from treatment in autumn.

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