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Effect of thinning on generation of bamboo forest in Taiwan

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Abstract

Based on the fourth forest inventory 2014 in Taiwan, there was 63,200 ha of monopodial rhizomes bamboo forest in Taiwan with the majority in *Phyllostachys makinoi*. This study investigated the effect of thinning on generation of *Phyllostachys makinoi* bamboo forest in Taiwan. Five reservation densities (1,600 culms ha^{-1}, 2,500 culms ha^{-1}, 3,900 ha^{-1}, 5,000 culms ha^{-1}, and control) after thinning were used in the study. Each treatment with three duplicates were randomly assigned and 15 plots with 10 m*10 m each in total were set up. Results in the case of reservation density in 1,600 to 5,000 ha^{-1}, showed no significant difference among one another in growth for the new culms. If the 12,500 culms ha^{-1} was considered as the optimal density, for the long-time abolished bamboo stands in Compartment 167 in Dasi Working Circle, the reasonable reservation density should be 3,900 culms ha-^{1} or 5,000 culms ha-^{1} in the operation. While no thinning practice was carried on the control plots, we still cut the dead and fall culms on the control plots. The new culms were 59-75 culms (10 m*10 m) which is apparently higher than that in 1-yr culms before thinning. This demonstrated that only cut dead and fallen culms is helpful for the new culms' growth as well because of more space and lights in the stand. All results mentioned above come from one year data after thinning. The generation of the new culms were continuously monitored in following 3 years (2020-2022) showed the increased stand density over the original densities and DBH of new culms grew larger after thinning. This study demonstrated the feasibility in makino bamboo forest management applying thinning in cycles of 4 years with 3,900 culms ha^{-1} or 5,000 culms ha^{-1} reserved after thinning for the sustainable bamboo management and utilization.

Keywords Bamboo Thinning; Bamboo Generation; *Phyllostachys makinoi*

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1. Introduction

Due to a climate and environment favorable to bamboo growth, Taiwan is rich in bamboo resources both in species diversity and amount of bamboo forests. Owing to the Tropic of Cancer across Taiwan and high elevations of Central Mountain Range in Taiwan, different types of bamboo can be found in Taiwan. There are 46 species and varieties of bamboo found in Taiwan, of which 20 are indigenous and 26 exotics (Lin 1967). Bamboo shoots and culms grow from the dense root rhizome system. Generally, bamboo rhizomes can be broadly classified into two categories: monopodial and sympodial. Monopodial rhizomes grow horizontally, often at a surprising rate with the nickname of ‘runners. The rhizome buds develop either upward, generating a culm, or horizontally, with a new tract of the rhizome net. *Phyllostachys* and *Teragonocalamus* are two genera of monopodial rhizomes that were found in Taiwan. The major species of monopodial rhizomes in Taiwan include *Phyllostchys makinoi*, *Phyllostachys pubescnes* (Lü 2001). Monopodial bamboos generate an open clump with culms distant from each other, and therefore, can be invasive. The acreage of bamboo forest in Taiwan was 75,275 ha in 1962, 175,638 ha in 1971, 149,516 ha in 2000, and 183,330 ha in 2014, which is 8.34% of total forest area in 2014 in Taiwan. Among them, 63,200 ha are monopodial bamboo forests in 2014 (TFB 2014).

Phyllostchys makinoi, a kind of monopodial rhizomes, is an important endemic species in Taiwan. The size of makinoi forest in culms varies notably depending on the site conditions (Wang and Chen 2015). It is widely distributed in the Northern and Central Taiwan from plains to lower mountain areas with an elevation 100-1200 m (Lin 1962), totally with area of 44,906 ha (Lü 2001). Both culms and shoots have economic value for excellent properties and food sources. Having monopodial rhizomes, makinoi forest becomes pure stands in large scale and expands the habitat annually. Based on inventory, from 1973 to 2007, the area of makinoi forest has increased about 62,645 ha with 1,842 ha annually increase in Northern Taiwan (Chiou et al. 2009).

In Taiwan, the utilization of makinoi culms is starting from the head to the tip. Different usages with specific price were found depending on the location in culms. Usually, the part from head to 4.15 m in height is most valuable with the usage for bamboo sword.

In the past, the major of makinoi culms production majorly came from aboriginal reserved lands, however, due to the so-called compensation law for forbidden harvest policy in Taiwan starting from 2016, almost no harvest of makinoi forest was carried out which cause the shortage of culms production in short term and the decay of makinoi forest in long-term. On the contrary, due to the recession of bamboo industry in Taiwan, the makinoi forest in national forest land was abolished in management for a long time. Because of the majority in old, dead and fallen culms in the composition, it has the adversity effects on environmental concerns. Therefore, for the benefits of regeneration of new culms, bamboo stands health, and environmental protection, the condensed makinoi bamboo stands, just like Moso bamboo (*Phyllostachys pubescens*) forests under an unmanaged condition, has to be thinned periodically (Lü and Chen 1992; Chung et al. 2010; Chen et al. 2016; Wang and Chen 2019). Not only the culms sizes in the unmanaged bamboo forests become worse, but the decrease of light intensity incurred in stands caused the degradation of biodiversity. Consequently, the thinning activities and removal of dead and fallen culms will be beneficial to keep biodiversity in bamboo forests (Toko and Takayuki 2001). The purpose of this study is to investigate the effects of different thinning intensity on the regeneration of makinoi bamboo forest.

2. Materials and methods

2.1. Site description

Research sites were located in Dasi Working Circle Compartment 167 in Taoyuang City (E121 35' 19", N24 78' 72") with the elevation about 680m above sea level. The annually average temperature is 20^0, with the highest in July (25.6℃) and lowest in February (13.2℃). The average annual precipitation was 2954 mm, focused on June to September. 15 plots with 10*10m each were established for the monitoring.

2.2. Experimental design

Five reserved stand density (1,600 culms ha^{-1}, 2500 culms ha^{-1}, 3,900 ha^{-1}, 5000 culms ha^{-1}, and control) were carried out in the thinning operation. Each treatment with three duplicates was randomly assigned in the plots (Figure 1). Plots 1-10 were on the uphill with plots 11-15 on the downhill. Except plot 10, the gradients of all plots were less than 5°. Thinning practice was carried on the March 2019. The survey of new culms growth was carried in April, June and August in 2019, respectively. The survey of new culms growth was carried on the bamboo growing season for 2020, 2021, and 2022.

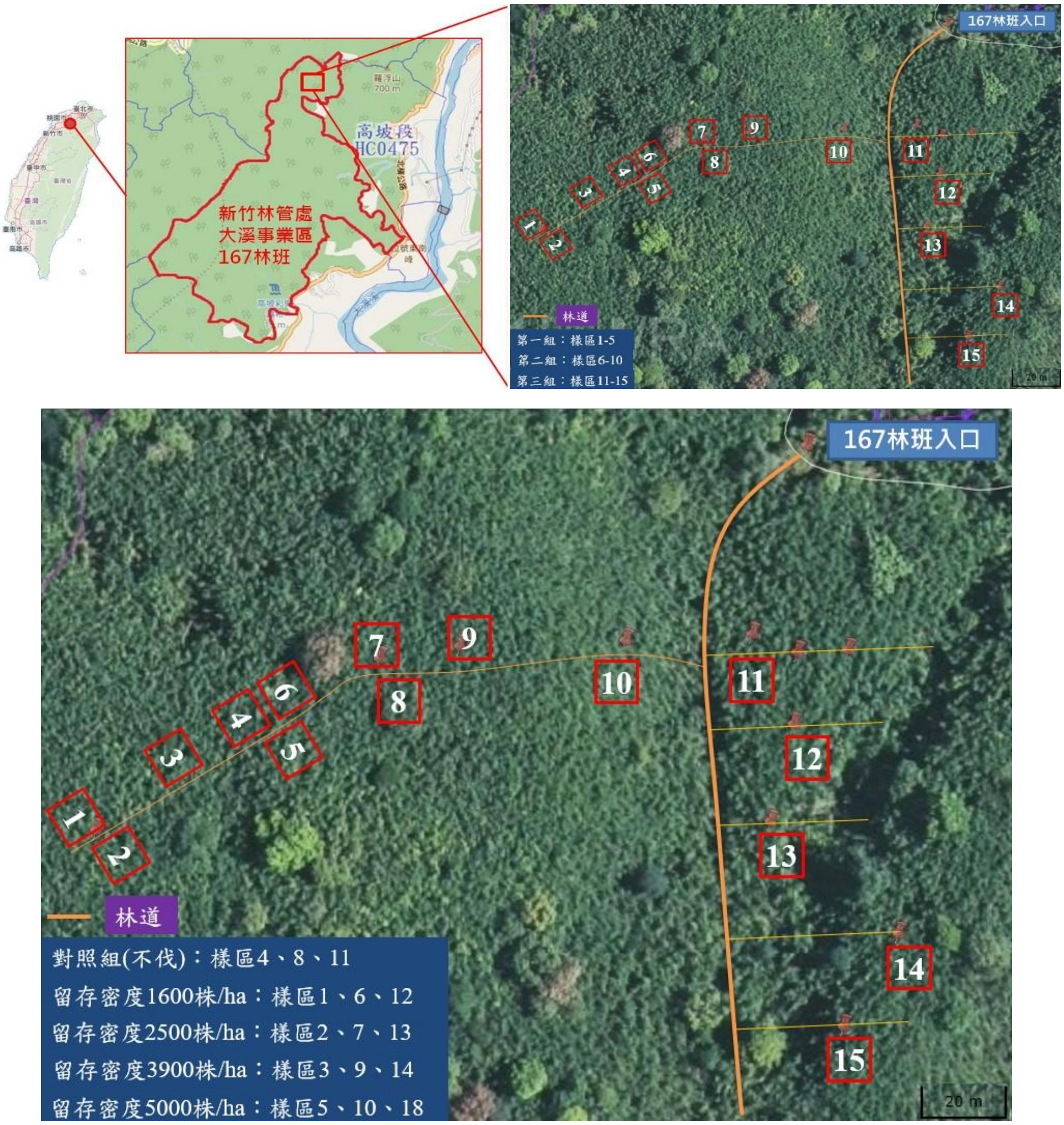

Figure 1. Plots layout for five reserved bamboos stand density

3. Results and discussion

Survey showed that before the thinning, the average density was culms 17,400±3,200 culms ha^{-1}, and average DBH was 4.7±0.7 cm with average12.5±2.7 m in height. In the age composition, culm was dominated by age over 4 years (52.7%), only 3.4% culms in age 1 year were found, indicating the serious unbalanced in age distribution, because of no management over 20 years (Table 1). Moreover, because of many dead and fallen culms in the stands, and some of them was attacked by Witche's broom, and even in flowering, thus, the bamboo stand was regarded as in unhealthy (Figure 1).

Table 1. Bamboo attributes for plots in the Compartment 167 before thinning (March 2019).

plot	DBH (cm)	Height (m)	1-year culms	2-year culms	3-year culms	> 4-year culms	total
1	4.9±1.0^{fg}[1)]	15.4±3.2^{lm}	3	15	37	75	130
2	5.0±1.1^{gh}	15.2±3.6^{l}	2	10	49	83	144
3	5.3±0.9^{hi}	16.3±2.7^{n}	0	6	40	108	154
4	6.0±0.8^{k}	15.8±1.9^{m}	0	7	29	135	171
5	5.0±1.0^{gh}	13.6±2.4^{ij}	0	24	42	122	188
6	5.5±1.0^{j}	14.0±2.1^{j}	0	17	41	104	162
7	5.4±0.9^{ij}	13.5±1.8^{i}	0	16	42	102	160
8	4.7±0.9^{ef}	12.4±2.0^{f}	0	11	72	83	166
9	4.4±0.9^{d}	12.4±2.2^{ef}	0	39	69	123	231
10	4.6±1.2^{def}	10.6±1.9^{c}	7	38	65	114	224
11	4.1±1.1^{c}	8.3±2.1^{ab}	4	41	42	64	151
12	3.9±1.3^{b}	8.7±2.2^{b}	16	66	32	38	152
13	3.3±0.9^{a}	8.0±2.0^{a}	13	68	46	24	151
14	4.5±1.1^{d}	11.9±2.4^{e}	21	53	47	99	220
15	4.5±1.1^{de}	11.3±2.0^{d}	22	36	45	101	204
average	4.7±0.7	12.5±2.7	6±8	30±21	47±13	92±31	174±32
(%)			3.4	17.1	26.8	52.7	100.0

[1)] mean ± standard deviation. The same character means no significant difference under α=0.05 in ANOVA test.

Figure 2. Bamboo stands before thinning.

The comparison of culms growth among age showed that the growth of 1-year culms was the worst in the average DBH (2.5±0.7 cm) and height (7.2±2.1 m) among age classes. However, for culms in age 4-year and over, their growth is best in the average DBH (5.4±0.8 cm) and height (14.0±2.8 m) (Table 2). This difference in culms growth among age indicated that stand was in upper story by culms age 4-year and over. Culms in age 1-year were suppressed, therefore, only a slight growth was attained in the stands.

Table 2. Average growth in culms among age classed in Compartment 167 before thinning (March 2019).

Age	DBH(cm)	Height(m)
1-year	$2.5\pm0.7^{a1)}$	7.2 ± 2.1^{a}
2-year	3.8 ± 1.0^{b}	9.7 ± 2.9^{b}
3-year	4.3 ± 0.8^{c}	11.8 ± 2.8^{c}
4-year and over	5.4 ± 0.8^{d}	14.0 ± 2.8^{d}

mean ± stand deviation. The same character means no significant difference underα=0.05 in ANOVA test.

The survey of new culms growth showed that the new culms occurred in April is most in number with the notable decrease in amount in May and June. Almost no culms occurred in the August, because of no bamboo shoots emergence at that time (Table 3).

No significant difference in the number of new culms was detected for reserved density from 1,600 ha^{-1} to -5,000 ha^{-1} (Table 3). However, the amount of new culms for all treatments (75-88 culms) are higher than that occurred in the control (65culms). It is consistent with the results of Chung et al (2010) that thinning practice is beneficial to generation of bamboo culms.

Growth survey showed that the average size of new culms in August is not significantly different among treated plots, but is significantly lower than one in the control plots (Table 3). This is perhaps due to the greater number of new culms occurred in the treated plots. While the culms size for new culms in August (DBH 3.3-3.4 cm) were smaller than the average culms size (DBH 4.7±0.7 cm) before thinning in Table 1, however, compared to 1-year culms size before thinning (DBH 2.5±0.7 cm) in Table 2. It is much better in growth.

This study showed that the culms emerged on April, no matter thinned or not, were greatest in size (DBH 3.4-4.6 cm), followed by culms on May and June (DBH 2.3-3.2 cm) and culms on July and August (DBH 1.2-2.3 cm). Since the bamboo shoots started from March, the early sprouted bamboo shoots getting more nutrients from rhizome, consequently, the size of culms is largest, however, with the decrease in rhizome, the culms appeared in later is more slender in size (Table 4).

Table 3. Growth of new culms in Compartment 167 in 2019.

Reserve density	Time for survey	Average DBH (cm)	Average height (m)	New culms emergence	Dead culms	Total new culms (10X10 m)
1,600 culms ha^{-1}	April	$3.6±0.2^{a1)}$	$5.0±0.4^{a}$	70±11	0	$70±11^{abc}$
	June	$3.4±0.2^{a}$	$7.0±0.3^{cd}$	13±4	0	$83±12^{bcd}$
	August	$3.3±0.2^{a}$	$8.3±0.6^{de}$	1±1	1±1	$83±10^{bcd}$
2,500 culms ha^{-1}	April	$3.5±0.5^{a}$	$5.0±0.7^{a}$	66±4	0	$66±4^{a}$
	June	$3.4±0.3^{a}$	$6.7±1.0^{bcd}$	9±3	0	$75±1^{abcd}$
	August	$3.4±0.3^{a}$	$8.0±1.3^{de}$	3±3	2±3	$75±6^{abcd}$
3,900 culms ha^{-1}	April	$3.6±0.3^{a}$	$5.2±0.2^{ab}$	68±10	0	$68±10^{ab}$
	June	$3.4±0.3^{a}$	$7.1±0.5^{cd}$	15±12	0	$83±2^{bcd}$
	August	$3.3±0.4^{a}$	$7.9±0.6^{de}$	5±4	0	$88±3^{d}$
5,000 culms ha^{-1}	April	$3.4±0.5^{a}$	$5.2±0.7^{ab}$	74±8	0	$74±8^{abcd}$
	July	$3.3±0.4^{a}$	$7.2±1.3^{d}$	9±2	0	$83±9^{bcd}$
	August	$3.3±0.4^{a}$	$8.1±1.4^{de}$	3±2	1±1	$85±9^{cd}$
control	April	$4.6±0.6^{b}$	$5.6±0.6^{abc}$	59±9	0	$59±9^{a}$
	June	$4.5±0.6^{b}$	$9.2±1.3^{ef}$	6±1	0	$65±9^{a}$
	August	$4.5±0.6^{b}$	$10.1±0.8^{f}$	0	0	$65±9^{a}$

1) mean ± stand deviation. The same character means no significant difference underα=0.05 in ANOVA test.

Table 4. Comparison of new culms size occurred in different months in 2019.

Reserved density	Occurred month	Average DBH (cm)
1,600 culms ha^{-1}	April	3.6±0.2
	May-June	2.1±0.1
	July-August	2.3
2,500 culms ha^{-1}	April	3.5±0.5
	May-June	2.2±0.6
	July-August	1.4±0.4
3,900 culms ha^{-1}	April	3.6±0.3
	May-June	2.3±0.2
	July-August	1.2±0.4
5,000 culms ha^{-1}	April	3.4±0.5
	May-June	2.3±0.6
	July-August	1.5±0.4
control	April	4.6±0.6
	May-June	3.2±0.6
	July-August	1.9

Regarding the recovery of bamboo stand density after thinning practice, for reserved density 1,600 culms ha^{-1} and 2,500 culms ha^{-1}stands, the average culms in five months later recovery back to 9,900 culms ha^{-1}, for the reserved culms 3,900 culms $ha^{-1}$and 5,000 culms ha^{-1}, five months later (August 2019), the culms back to 13,000 culms ha^{-1}. Base on the previous studies (Chung et al. 2010; Yen et al. 2010)., stand culms keeping 12,500 culms ha^{-1} is an appropriate density for the makinoi bamboo management, therefore, in our case, the reserved culms should be kept 3,900 culms ha^{-1} and 5,000 culms ha^{-1}, For the control plots, the average of culms becomes 22,000culms ha^{-1} (Table 5).

Table 5. The restoration of bamboo stand density in 5 months later after thinning practice (August 2019).

Plot	Reserved culms in (10X10 m)	Number of new culms (10X10m)	Mortality of new culms (10X10m)	Mortality of reserved culms (10X10m)	Total culms (reserved and new culms (10X10m)	Average culms (ha^{-1})
1	16	88	1	0	103	
6	16	71	0	0	87	9,900±1,000
12	16	91	1	0	106	
2	25	82	2	0	105	
7	25	77	0	0	102	9,900±800
13	25	76	8	3	90	
3	39	85	0	0	124	
9	39	90	0	0	129	12,700±300
14	39	89	0	0	128	
5	50	81	0	0	131	
10	50	98	2	0	146	13,500±900
15	50	80	1	0	129	
4	171	59	0	1	229	
8	166	63	1	20	208	22,000±1100
11	151	75	0	3	223	

*Culms density before thinning practice is 17,400±3,200 culms ha^{-1}

While no thinning practice was carried on the control plots, we still cut the dead and fall culms on the control plots. The new culms were 59-75 culms (10X10 m), which is apparently higher than that in 1-yr culms before thinning (Table 1.) This demonstrated that only cut dead and fallen culms is helpful for the new culms' growth as well because of more space and lights in the stand.

According to the continuous four years monitoring data after thinning in 2019, stand densities increased no matter what reserved density was proceeded (Table 6), but control plots decreased slightly. Stand densities of 3,900 culms ha^{-1} and 5,000 culms ha^{-1} were exceeded the original densities in 2020-2022. The average DBH of new culms grew lager starting from the 2nd year after thinning (Table 7). These results would be recommended the next cycle of thinning after 3 years later.

Table 6. The new growth, dead clums and stand density (10X10 m) changing in 2019-2022.

Reserved density	Plot	New clums				Dead clums				Stand density			
		2019	2020	2021	2022	2019	2020	2021	2022	2019	2020	2021	2022
1,600 culms ha^{-1}	1	88	53	20	38	3	12	15	29	101	142	147	156
	6	71	45	13	20	0	10	13	15	87	122	122	127
	12	91	37	19	32	3	19	18	22	106	124	125	135
Average		**83.3**	**45.0**	**17.3**	**30.0**	**2.0**	**13.7**	**15.3**	**22.0**	**98.0**	**129.3**	**131.3**	**139.3**
2,500 culms ha^{-1}	2	82	58	15	40	3	10	9	19	104	152	158	179
	7	77	43	2	10	2	4	13	12	100	139	128	126
	13	76	40	16	31	17	20	17	17	84	104	103	117
Average		**78.3**	**47.0**	**11.0**	**27.0**	**7.3**	**11.3**	**13.0**	**16.0**	**96.0**	**131.7**	**129.7**	**140.7**
3,900 culms ha^{-1}	3	85	47	5	46	2	11	8	14	122	158	155	187
	9	90	95	9	57	2	6	9	20	127	216	216	253
	14	90	59	13	25	2	14	11	27	127	172	174	172
Average		**88.3**	**67.0**	**9.0**	**42.7**	**2.0**	**10.3**	**9.3**	**20.3**	**125.3**	**182.0**	**181.7**	**204.0**
5,000 culms ha^{-1}	5	81	60	13	30	0	7	4	27	131	184	193	196
	10	98	72	7	53	5	4	7	17	146	214	214	250
	15	81	49	9	22	5	12	15	18	127	164	158	162
Average		**86.7**	**60.3**	**9.7**	**35.0**	**3.3**	**7.7**	**8.7**	**20.7**	**134.7**	**187.3**	**188.3**	**202.7**
control	4	59	4	12	28	23	30	26	33	207	181	167	162
	8	63	44	9	37	27	23	18	29	202	223	214	222
	11	75	44	7	21	27	40	16	25	199	203	194	190
Average		**65.7**	**30.7**	**9.3**	**28.7**	**25.7**	**31.0**	**20.0**	**29.0**	**202.7**	**202.3**	**191.7**	**191.3**

Table 7. The average DBH (cm) of new clums growing from 2019 to 2022.

Reserved density	Plot	Average DBH of new clums (cm)			
		2019	2020	2021	2022
1,600 culms ha^{-1}	1	3.4 ±0.9	4.0 ±1.1	4.3 ±1.1	5.2 ±1.2
	6	3.5 ±1.1	4.2 ±1.1	5.1 ±0.8	5.5 ±0.6
	12	3.3 ±1.1	4.3 ±1.1	4.4 ±0.7	4.3 ±1.1
Average		**3.4 ±1.0**	**4.1 ±1.1**	**4.6 ±0.9**	**5.0 ±1.0**
2,500 culms ha^{-1}	2	3.2 ±1.1	3.9± 1.1	4.8 ±0.7	5.2 ±0.7
	7	3.7 ±1.1	4.4 ±1.1	5.2 ±0.2	5.2 ±0.9
	13	3.0 ±1.1	4.0 ±1.0	4.5 ±0.9	4.5 ±0.9
Average		**3.3 ±1.1**	**4.1 ±1.1**	**4.8 ± 0.6**	**4.9 ±0.8**
3,900 culms ha^{-1}	3	3.7 ±1.2	4.0 ±1.0	4.5± 0.9	5.1 ±0.8
	9	3.1 ±1.0	3.2 ±0.8	4.4 ±0.7	4.3 ±0.7
	14	3.1 ±1.0	4.2 ±1.0	5.0 ±1.0	4.5 ±1.0
Average		**3.3 ±1.1**	**3.8 ±0.9**	**4.6 ±0.8**	**4.6 ±0.8**
5,000 culms ha^{-1}	5	3.6 ±1.2	3.9 ±1.0	4.9 ±1.0	5.1 ±0.8
	10	2.8 ±0.9	3.5 ±0.9	3.9 ±0.5	4.3 ±0.9
	15	3.4 ±1.0	4.1 ±1.1	4.7 ±1.0	4.4 ±0.8
Average		**3.3 ±1.0**	**3.8 ±1.0**	**4.5 ±0.8**	**4.6 ±0.9**
control	4	5.2 ±0.9	4.0 ±1.4	5.0 ±1.2	5.2 ±1.1
	8	4.2 ±1.1	3.9 ±1.0	4.6 ±0.5	5.3 ±0.9
	11	4.0 ±0.8	4.2 ±0.8	3.8 ±1.0	3.5 ±1.2
Average		**4.5 ±0.9**	**4.0 ±1.1**	**4.5 ±0.9**	**4.7 ±1.1**

Conclusion

This study showed in the case of reservation density in 1,600 to 5,000 ha-1, there was no significant difference among one another in growth for the new culms. If 12,500 culms ha^{-1} the was considered as the optimal density, for the long-time abolished bamboo stands in Compartment 167 in Dasi Working Circle, the reasonable reservation density should be 3,900 culms ha^{-1} or 5,000 culms ha^{-1}in the operation. The four years data in the increased stand density over the original densities and DBH of new culms grew larger after thinning showing in this study indicated that the makino bamboo forest should be thinned in cycles of 4 years with reserved 3,900 culms ha^{-1} or 5,000 culms ha^{-1} in the thinning practice for the sustainable bamboo management and utilization.

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Conflict of interest

The authors declare there is no conflict of interest. All regulations of our institute including intellectual property rights have been followed and there are no impediments to publication.

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