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Effect of a New Continuous Production Technology of Ramie (*Boehmeria nivea*) on Fiber Yield and Fineness

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ABSTRACT

To resolve the bottleneck problems hindering the development of the ramie (*Boehmeria nivea* L. Gaud) cultivation industry, the feasibility of a new harvesting mode was investigated. This allows a continuous supply of ramie within a growing season and provided theoretical and technical support for industrialized production of ramie. Huazhu 4 was used and harvesting times were within 28 May to 21 October 7 days interval. Five harvesting modes were designed with 3 replications, with traditional harvesting mode as the control. The results showed that the range in fiber fineness among the five harvesting modes was 1659–1958 m/g. The mean in mode 1 was the highest of the five modes (1958 m/g) and was 6.47% higher than in controls. Compared to controls, the average fiber fineness in mode 5 was 1.96% higher, and that of mode 4 was the same as the controls. However, modes 2 and 3 had 9.79 and 5.55% lower mean fiber fineness compared with controls, respectively. The harvested yields of raw fiber in modes 2 and 3 were 21.50 and 5.04%, respectively higher than controls - with no increases in other modes. This suggested that 1–30 June was the most suitable time for continuous harvesting producing higher yields. The latest that ramie should be harvested is mid–late October. Continuous harvesting mode was feasible for ramie production, and provides a novel harvesting method for perennial crop, which is mainly harvested from nutritive organs. © 2012 Friends Science Publishers

Key Words: Ramie; Continuous harvest; Fiber yield; Fiber fineness

INTRODUCTION

In China, fiber crops include seven main species: ramie (*Boehmeria nivea* L. Gaud) (Tewolde & Fernandez, 2003; Sarkar, 2005), hemp (*Cannabis sativa* L.) (Vera *et al*., 2004), jute (*Corchorus capsu-laris* L.) (Alam *et al*., 2002), kenaf (*Hibiscus cannabinus* L.) (Agbaje *et al*., 2009), sisal hemp (Agave sisalana Perrine), fiber flax *(Linum usitatissimum* L.*)* and cotton (Gossypium spp.) (Wiedenfeld *et al*., 2008). Among them, ramie, a perennial bast fiber crop originating from China is known as 'China grass' by Westerners. In addition, ramie as an important industrial crop in the Chinese textile industry has high-quality fiber and has captured much attention from government officials and scientists. A large area of ramie has been planted in China, covering approximately 100 000 ha, and accounting for about 90% of total global ramie yield (Peng, 2009).

With the rapid development of a market economy in China and the massive rural labor force immigrating into urban areas, the labor costs for cultivation of traditional crops has continuously increased. Simplified cultivation has been studied and popularized in many crop species e.g., rice (Fang *et al*., 2009), cotton (Mao, 2007) and rape (Tu *et al*., 2007), and has made huge progress. The amount of labor allocated to harvesting accounts for > 80% of the total labor used in ramie production. Moreover, ramie harvesting has significant seasonal characteristics with heavy labor intensity and demanding skills. Relying upon traditional human harvesting, a household can generally manage only several hectares of ramie plantation. Delayed ramie harvesting will severely affect fiber quality and ramie production in the next season (Peng, 2009). Thus, it is a huge challenge for textile factories to heavily invest in mass production of high-quality ramie due to the massive labor input needed. One of the key solutions for the ramie industry is to implement simplified cultivation by mechanical or semi-mechanical operations and converging ramie production properly and establishing special plants for fiber stuffing. The key problem in mass ramie production lies in a stable source supply, guaranteeing a certain amount of raw ramie stem delivered to plants for further processing. However, traditionally ramie is harvested three times per year, generally in June, August and early–mid October. No raw materials are available in other seasons, undoubtedly increasing operation costs and making it difficult to achieve massive fiber stuffing.

Thus, maintaining a continuous supply of raw materials to plants has become the top priority for industry

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(for May–October, sustaining operations for approximately 150 d), and is also the target of our investigation. Whether continuous harvesting mode affects yield and fineness remains to be elucidated compared with traditional harvesting mode. We designed and performed this study to validate the feasibility of continuous harvesting methods.

We propose a new concept of ramie harvesting, which divides the harvesting into different sections according to location and time. This study mainly aims to investigate the effect of harvesting mode upon ramie yield and fiber fineness, and evaluate the utility value of the new harvesting mode. This study provides a novel harvesting mode for perennial crops for which nutritive organs are the main harvested parts, ensuring a stable source supply and enabling mass industrial production.

MATERIALS AND METHODS

Experimental sites and designs: The test location was in Huazhong Agriculture University, and utilized Huazhu 4. A total of five harvesting modes were designed, with 27 plants cultivated per unit of 12 m^2 with 3 replications (Fig. 1). Traditional harvesting mode was the control. Stalk vegetative propagation was performed in April 2008, and the young seedlings of the same size were transplanted into the field in September 2008. Traditional field management was applied for 2008–2009. In 2010, three-years-old ramie plants were chosen for subsequent tests. Nine stumps of ramie of similar size were selected for yield and quality analysis. Base fertilizer consisted of N, P and K of 225, 150 and 300 kg ha^{-1}, respectively. After harvesting as scheduled, 75 kg ha^{-1} N was supplemented for each unit.

Measurements: The weight of fresh stem equaled that of fresh stem after leaf removal. The peeled bast fiber was used to calculate fresh skin weight. The bast fiber was artificially separated from outer skin, dried and weighed as raw fiber yield. The fiber fineness was measured referring to China standards (GB5884-86).

Statistical analysis: Due to the varying harvesting times, multiple comparisons of raw fiber yield among the different modes were not valid. Therefore, average values were calculated for the three harvest times. The total yield of each harvesting mode was counted finally. SAS statistical software (SAS, 1989) was employed to perform analysis of variance and multiple comparisons (Table I).

RESULTS

Raw fiber fineness: The fineness of raw fiber is an important index reflecting the quality of fiber products, and is a commonly used index in textile factories. The range in mean fiber fineness was 1659–1958 m/g for different harvesting modes (Table I). Mode 1 produced the highest mean fiber fineness of 1958 m/g, 6.47% higher than in controls (1839 m/g). The fiber fineness in mode 5 was 1.96% higher than in controls. Mode 4 had similar fiber fineness to controls. Modes 2 and 3 had 9.79 and 5.55% lower fiber fineness, respectively compared with controls. There were no significant differences in fiber fineness between modes 1 and 2. In mode 3, there was no statistical significance in fiber fineness between 18 June, 23 July and 27 August, but these were significantly different ($P < 0.05$) from the index on 30 September. The fiber fineness in modes 4 and 5 degraded as time proceeded, except in mode 4, which increased for the harvest of 11 October. However, there were highly significant differences in fiber fineness for the various harvesting times, suggesting poor consistency in fiber quality.

Raw fiber yield: The fresh stem yield in mode 4 (40928.79 kg/ha) and mode 5 (45356.00 kg/ha) were 5.49 and 26.49% lower than for controls (43304.98 kg/ha), respectively. The other harvesting modes had increased yields of 15.38–103.52%, compared to controls; specifically, for mode 2 the yield was 88132.93 kg/ha, or 103.52% higher than in controls. The trends were similar between fresh skin yield and fresh stem yield. Modes 4 and 5 showed production of 28.57 and 0.58% lower than controls, respectively whereas there were 18.95–95.80% higher yields for the other harvesting modes.

There were higher raw fiber yields for modes 2 and 3, elevated by 21.50 and 5.04% above controls, respectively. The fresh stem yield and fresh skin yield in mode 1 were > 30% higher than controls; however, the raw fiber yield was unexpectedly 18.42% lower than controls.

DISCUSSION

Raw fiber fineness: Many factors affect raw fiber fineness, including cultivation intensity, fertilizer amount, weather conditions and hormone regulation (Cabangbang *et al.*, 1978; Liu *et al.*, 1998, 2000, 2001, 2005; Macarayan, 2005; Wan *et al.*, 2005; Goda *et al.*, 2006; Kumar *et al.,* 2007). In addition, some studies have shown that different harvesting times led to changes in fiber fineness (Wang *et al*., 2008). The results of the present study suggested differences in fiber fineness among harvesting modes, with a range of 1659–1958 m/g. The fiber fineness in mode 1 achieved the highest level of 1958 m/g, 6.47% higher than in controls, suggesting that harvesting in advance enhanced fiber fineness, similarly to findings by Wang *et al.* (2008). However, the mean fiber fineness in modes 2 and 3 declined by 9.79 and 5.55% compared with controls, respectively possibly associated with higher temperature and inadequate rainfall during this growing season. There was a marked decline in mean fiber fineness, especially for mode 3 harvested on 30 September (the statistics released by the Weather Bureau of Hubei Province China showed the average temperature in mid-September was 21.9–29.2°C, increased by 4.5 to 6.5°C in Hubei Province. Maximum temperatures ≥ 35°C or average temperatures ≥ 30°C were observed for three consecutive days during 16–20 September. The cumulative rainfall was 100–150 mm.

Table I: Effects of different harvesting modes upon ramie fineness and yield

Harvest mode	Harvest time	Fiber fineness (m/g)	Fresh stem yield (kg hm^{-2})	Fresh skin yield (kg hm^{-2})	Raw fiber yield (kg hm^{-2})
Mode 1	28 May	1956±181a	37518.75	13840.25	1000.50
	9 July	2144±101a	11464.06	4627.31	483.58
	13 Aug.	1885±71a	4852.43	1742.54	241.79
	17 Sept.	1908±182a	5602.80	1992.66	216.78
	Average	1958 (6.47%)	59438.04 (37.25%)#	22202.76 (34.05%)	1942.64 (-18.42%)
Mode 2	8 June	1619±14a	50358.50	18842.75	1359.01
	16 July	1760±62a	4921.90	1937.08	225.11
	20 Aug.	1610±108a	6253.13	2017.68	208.44
	24 Sept.	1617±268a	26599.40	9632.59	1100.55
	Average	1659 (-9.79%)	88132.93 (103.52%)	32430.10 (95.80%)	2893.11（21.50%)
Mode 3	18 June	1894±78a	20810.40	8595.96	1334.00
	23 July	1891±70a	16491.58	6111.39	700.35
	27 Aug.	1841±130a	10388.53	4110.39	375.19
	30 Sept.	1332±40b	2276.14	883.78	91.71
	Average	1737 (-5.55%)	49966.64 (15.38%)	19701.51 (18.95%)	2501.25 (5.04%)
Mode 4	25 June	2038±89a	18951.14	7720.53	1250.63
	30 July	1850±15ab	10638.65	4777.39	702.02
	3 Sept.	1636±42b	9754.88	3535.10	308.49
	11 Oct.	1894ab	1584.13	433.55	33.35
	Average	1842 (0.16%)	40928.79 (-5.49%)	16466.56 (-0.58%)	2294.48 (-3.64%)
Mode 5	2 July	2222.0±237.63a	14481.89	5135.95	897.13
	6 Aug.	1835.0±91.60b	8879.44	3451.73	441.89
	10 Sept.	1569±53.257b	8470.80	3243.24	351.84
	Average	1875.00 (1.95%)	31832.13 (-26.49%)	11830.91 (-28.57%)	1690.85 (-28.99%)
Normal mode (CK)	15 June	2156±103a	19294.64	7330.33	1283.98
	10 Aug.	1792±44b	12431.21	4832.42	618.64
	15 Oct.	1570±53c	11579.12	4400.53	478.57
	Average	1839	43304.98	16563.28	2381.19

Note: a, b, c: different letters following the values indicate significant differences ($P < 0.05$) between the fiber fineness of ramie; #: the total yield of raw fiber in each harvesting mode

There were no significant differences in fiber fineness between modes 1 and 2 at different harvesting times, demonstrating that fiber fineness was consistent for continuous harvesting. Once again, this suggested that continuous harvesting was feasible.

Previous studies have found that the fiber fineness declined as harvesting time was prolonged during a normal harvesting season (Wang *et al.*, 2008; Peng, 2009). Nevertheless, the fiber fineness for mode 5 (2 July, 2222.0±237.63 m/g) was higher than for controls (2156±103 m/g), probably related to temperature and rainfall, as well as other unknown factors. There was a highly significant discrepancy in fiber fineness by traditional harvesting mode. Peasants are likely to combine raw ramie of different fineness-grades together and sell them, and thus it is difficult to obtain raw materials with consistent fiber fineness, which presents difficulties to subsequent processing. However, the fiber harvested at one respective time point had minor difference in fineness, which suggests a new concept of supplying raw ramie with homogenous and high fiber fineness.

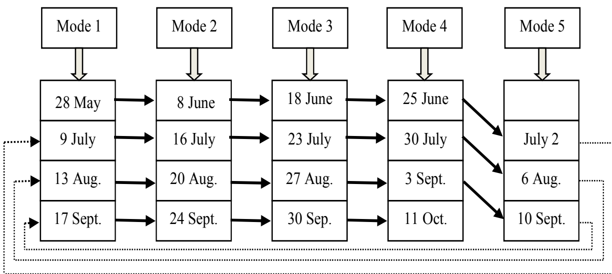
Raw fiber yield: The yield of raw ramie is an important index (Tatar *et al.,* 2010). After carrying out continuous harvesting, textile manufacturers emphasize fiber quality; however, ramie yield may be the major concern of peasants. This study found that modes 1–3 had four harvesting times per year by adopting a continuous harvesting method, and showed a marked increase of 15.38–103.52% in fresh stem yield, suggesting that the biological yield can be enhanced by increasing harvesting times. Although having four harvest times per year, mode 4 showed a yield reduction of 5.49%, mainly attributed to the fact that only two plots were harvested on 11 October, and another plot failed to satisfy the technical standards. The yield reduction of mode 5 may be induced by the excessively late harvesting time for the first batch of ramie, thus affecting the growth of ramie in the following season. The ramie, harvested on 21 October as planned, did not meet the harvesting standard, and so the yield was not counted.

The changing trend in fresh skin yield was basically similar to that for fresh stem yield. However, there were variations in raw fiber yield. In mode 1, both fresh stem and fresh skin yield increased by 30% compared to controls, whereas raw fiber yield decreased by 18.42% – possibly caused by higher water content in ramie fresh stem and skin due to excessively early harvesting.

The present study showed that continuous harvesting mode could increase ramie yield and quality. Production by this harvesting mode seems closely related to weather factors, especially rainfall (Liu *et al.*, 2005). Unlike traditional harvesting mode, the regular pattern of ramie requirements for fertilizer probably change and this remains to be further elucidated. Yield composition showed that the yield of the first batch of ramie (harvested in the

Fig. 1: Continuous harvesting and plantation flow chart in the experimental

Note: Five harvesting modes were established. The first harvesting in the first unit for each mode was conducted on the day of 28 May, 8 June, 25 June and 2 July, respectively. Then the harvesting in the second unit for each mode was on 9, 16, 23 and 30 July and 6 August, respectively. The harvesting methods in other units were analogized successively. Traditional harvesting mode was the control (harvesting time: 15 June, 10 August & 15 October)



first season) accounted for approximately 50% of total yield. Neither determining when to harvest the first batch of ramie, while neither lowering yield nor affecting quality, requires further investigation.

Our results showed continuous harvesting mode is feasible for ramie, which raw fiber yield was increased by 5.04–21.50% compared to controls. Nevertheless, the harvesting yield may be reduced if this technique was misused; June was the most appropriate time for continuous harvesting. Harvesting should be finished in mid–late October and timely and earlier harvesting can enhance the fineness of ramie. Our comprehensive comparisons showed that modes 2 and 3 were better than the other harvesting modes.

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