Effects of Mechanical Harvesting on Sugarcane Stubble Quality and Growth of Ratoon

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Abstract The experiment was conducted with the traditional manual harvesting and mechanical harvesting of sugarcane, to compare the effects of different harvesting method on the sugarcane stubble quality and the growth of ratoon. The experimental results are as follows. (i) The stubble height and breaking stubble rate of mechanical harvesting was significantly higher than manual harvesting, the stubble height of lodging species and difficult defoliation species increased in mechanical harvesting condition. Varieties with higher levels of fiber had lower rate of broken stubble. (ii) The effects of mechanical harvesting on germination of next year ratoon were quite different due to different varieties, indicating that the better perennial species have less impact than the poor perennial species. (iii) Compared with manual harvesting, mechanical harvesting had slightly higher plant height and single-stem weight and less effective stems number, the difference of cane yield was not significant, but sucrose content increased 0.53%. (iv) Mechanical harvesting combining with leaves crushing could reduce the impact on the germination of ratoon, improve the single-stem weight and increase the effective number of stems.

Key words Mechanical harvesting, Stubble quality, Ratoon, Yield, Sucrose content

Sugarcane harvesting includes sugarcane cutting, tip cutting, root cutting, bounding up and shipping. The operation capacity takes up about 55% of the total operation capacity of sugarcane planting management[1]. Since we entered the 21st century, labor load has experienced an annual increase of 14%, and in Guangxi, it has been even up to 24%[2]. Serious shortage of labor forces and strenuous labor intensity result in significantly difficult worker recruitment. The increasing manual harvesting cost and deteriorating difficulty in worker recruitment have posed serious threats to sustainable development of China's sugarcane industry. In this situation, it is urgent to realize mechanization of sugarcane harvesting[3-4], which is an inevitable trend of sustainable development of sugarcane industry. In recent years, the research on mechanization of sugarcane harvesting receives wider and wider attention. Liang Zhaoxin *et al*[5], Chen Chaoping *et al*[6], and Li Tianshao *et al*[7] analyzed technical features of sugarcane harvesting machines; Liang Tian *et al*[8] and Wang Weizan *et al*[9] analyzed key supporting technologies for sugarcane harvesting machines; Liu Wenxiu *et al*[10] discussed the effect of cutting quality of sugarcane harvesting machines on yield of ratoon; and An Yuxing *et al*[11] studied effect of mechanical harvesting on insect pest of ratoon and growth of sugarcane seedlings.

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1 Materials and methods

1.1 Experimental materials We adopt following sugarcane brands: Xintaitang No. 22, Liucheng 03/182, Ganzhe No. 18, Yuetang 00/236, and Zhanxuan 05/18. The harvesting machine adopts HS180 Integral rod type sugarcane combined manufactured by Guangxi Yunma Hansheng Machinery Manufacture Co., Ltd.

1.2 Experimental method The experiment is carried out in Nanning Agricultural Machinery Experimental Base in Shuhe Village of Luowei Township, Wuming County of Guangxi. The experiment place is sloping field, and basic physical and chemical properties of soil are as follows: organic matter 29.3 k/kg, alkaline hydrolysis-N content 75.85 mg/kg, quick-acting P content 27.44 mg/kg, quick-acting K content 127.8 mg/kg and pH 4.24.

Mechanical harvesting refers to the process from cutting sugarcane by combined harvester, manually tying up the sugarcane stems, taking out of the field, loading onto vehicles, to delivery to sugar refinery; manual harvesting refers to the process of cutting, harvesting and handling sugarcane by traditional manual method. Mechanical harvesting and manual harvesting are compared in the experiment. The experimental area has 5 row areas, and each row is 10 m long with 1.1m spacing between each row. The experimental area covers a place of 55 m^2. The experiment is repeated for three times. All brands are new sugarcane planted in 2009, harvested on January 30 of

2010, and area cleared and ridge broken in middle February of 2010. The subsequent fertilizer application, earthing up, weeding, and prevention of plant diseases and insect pests are the same as production in large field. For Xintaitang No. 22, Liucheng 03/182, Ganzhe No. 18, Yuetang 00/236, and Zhanxuan 05/18, except difference in harvesting method, the cultivation management level is the same, and sugarcane leaves are not returned to field. For Yuetang 00/236, mechanical harvesting, mechanical leaf cutting, returning leaves to field and covering the ridges are conducted at the same time; while leaves are not cut in manual harvesting. On December 21, 2010, the ratoon was harvested by manual cutting method.

1.3 Measuring items and methods After harvesting new sugarcane, measure the stubble height (from the ground to top of sugarcane pile) and breaking stubble rate (the percentage of broken sugarcane pile to total sugarcane pile). In May, when the seedlings reach the peak, count number of germination and calculate the germination rate. During May to October, measure plant height once monthly, and calculate the extension speed of sugarcane stem. In July to August, when the ratoon extension is vigorous, measure the vitality of root system and activity of +1 Nitrate reductase. During harvesting, measure the plant height, stem diameter, and field brix of 20 pieces each area (totally 60 pieces for each brand), and count number of effective stems in the area. In addition, cut and harvest sugarcane according to purchasing standard of raw material sugarcane and measure the yield of the area. Then, divide the yield with number of effective stems, we will obtain the single stem weight. Finally, we select 6 effective stemss and deliver them to sugar refinery to analyze sucrose content, reducing sugar content, fiber content, sugarcane juice brix, and gravity purity, *etc.*

2 Results and analyses

2.1 Effect of mechanical harvesting on stubble quality

2.1.1 Effect on stubble height. From Table 1, it can be seen that in spite of different stubble height, the stubble height done by all mechanical harvesting is higher than that by manual cutting. The average stubble height of five brands is 6.1 cm, which is 2.6 cm higher than the manual processed height. Zhanxuan 05/18 is the only brand which has half lodging problem, and the stubble height of mechanical processing is 9.1 cm higher than that of manual processing. Other four brands have no problem of lodging. Funong No. 15, Liucheng 03 –182 and Yuetang 00 –236 are easy to cut leaves, and the stubble height of mechanical processing for these three brands is on average 0.7 cm higher than that of manual processing, and Ganzhe No. 18 is difficult to cut leaves and the stubble height of mechanical processing is 1.6 cm higher than that of manual processing.

Table 1 Survey results of stubble height by different processing methods

Brand	Stubble height//cm			Breaking stubble rateV%		
	Mechanical harvesting	Manual harvesting	Difference ±	Mechanical harvesting	Manual harvesting	Difference ±
Funong No. 15	3.7	3.1	0.7	93.20	14.45	78.75
Liucheng 03/182	5.3	4.6	0.7	44.02	28.65	15.37
Ganzhe No. 18	4.9	3.2	1.6	46.56	15.00	31.56
Yuetang 00/236	4.6	3.9	0.7	–	–	–
Zhanxuan 05/18	12.0	3.0	9.1	88.33	66.67	21.66
Average	6.1	3.6	2.6	68.03	31.19	36.84

Note: Zhanxuan 05/18 is half-lodging sugarcane; for Yuetang 00/236, the breaking stubble rate is not applicable, because broken leaves cover the stubble.

2.1.2 Effect on breaking stubble rate. Table 1 indicates that the breaking stubble rate of four brands that are harvested by machines is significantly higher than manual processing. The average value is 36.84 percentage points higher than that of manual processing, showing that the mechanical harvesting has a greater effect on breaking stubble rate of ratoon. Besides, different brands have great difference in breaking stubble rate, which may be related to difference of fiber content (Table 7). Fiber content in Liucheng 03/182 is the highest, while the breaking stubble rate is the lowest; the next is Ganzhe No. 18, and the breaking stubble rate is also very low; Funong No. 15 has the lowest fiber content, and the breaking stubble rate is the highest.

2.2 Effect of mechanical harvesting on agronomic traits of ratoon

2.2.1 Effect on number of germination of ratoon. The survey on number of germination of ratoon (Table 2) indicates that the germination number is equal or similar between mechanical harvesting and manual harvesting of Liucheng 03/182 and Yuetang 00/236, while the germination number of Funong No. 15 and Ganzhe No. 18 reduces about 12.12% and 30.20% respectively for mechanical harvesting and manual harvesting. The germination number of mechanical processing for these four brands per hectare is 3 090 plants less than manual processing on average (10.75%), indicating that mechanical processing has significant effect on germination capability of ratoon, but the effect is varied with brands. Liucheng 03/182 has better ratoon, and its germination capability is basically not affected; Ganzhe No. 18 has worse ratoon, and its germination capability is greatly affected; the germination capability of Yuetang 00/236 is basically not influenced, possibly because of broken leaves returned to field.

2.2.2 Effect on plant height. From Table 3, it can be seen that the effect of mechanical harvesting on growth speed of plant height of different sugarcane brands is different. For Liucheng 03/182, the plant height of mechanical harvesting is lower than manual processing all the time from May to October. Till November, it becomes faster than manual processing. The

final plant height is slightly higher than manual processing. For other three brands, the difference of mechanical harvesting and manual harvesting is not consistent in each month. All these three brands show that the plant height grows slightly slower than manual processing in May, it gradually accelerates from June, and till December (before harvesting), the plant height is slightly higher than manual processing. Except 1.4 cm lower than manual processing in May, the average plant height of mechanical harvesting of four brands, from June, gradually exceeds the plant height of manual cutting. In December, it is 13.5 cm higher than manual processing. This indicates that mechanical harvesting of sugarcane has certain effect on plant height of sugarcane growth at earlier stage. However, since in the middle and late period of the growth, mechanical processing is faster than manual processing, the plant height will not be influenced by slow growth at earlier stage, even it is slightly higher than manual processing.

Table 2 Number of germination by different processing method in May

Brand	Number of germination//plant/hm^2			Difference ±%
	Mechanical harvesting	Manual harvesting	Difference ±	
Funong No.15	21 105	24 015	−2 910	−12.12
Liucheng 03/182	26 925	26 925	0	0.00
Ganzhe No.18	21 465	30 750	−9 285	−30.20
Yuetang 00/236	32 925	33 285	−360	−1.08
Average	25 650	28 740	−3 090	−10.75

Table 3 Plant height of different handling methods

Brand	Handling	Plant height//cm						
		May	June	July	August	September	October	December
Funong No.15	Mechanical	14.7	36.4	101.6	172.9	208.7	234.0	248.7
	Manual	14.1	32.9	94.3	162.2	200.7	225.9	230.8
Liucheng 03/182	Mechanical	34.6	72.5	149.3	205.7	248.0	273.6	271.1
	Manual	37.6	81.0	159.0	223.8	258.3	274.7	261.3
Ganzhe No.18	Mechanical	35.4	67.6	149.3	212.8	255.3	289.3	316.7
	Manual	36.6	65.3	144.2	208.1	248.8	282.4	305.3
Yuetang 00/236	Mechanical	38.3	65.4	132.5	177.0	208.1	232.1	234.4
	Manual	40.1	61.2	120.9	155.9	198.9	218.2	219.5
Average	Mechanical	30.8	60.5	133.2	192.1	230.0	257.3	267.7
	Manual	32.1	60.1	129.6	187.5	226.7	250.3	254.2
	Difference	−1.4	0.4	3.6	4.6	3.3	7.0	13.5

2.3 Effect of mechanical harvesting on physiological and biochemical index of ratoon

2.3.1 Effect on vitality of root system. The vitality of root system of ratoon treated by different methods is listed in Table 4. It indicates that in July, except Funong No.15 whose root system shows slightly weaker vitality than manual processing, other three brands have similar or obviously higher vitality compared with manual processing. In August, except Yuetang 00/236 whose root system shows stronger vitality than manual processing, other three brands have weaker vitality of root system. In August, the vitality of root system treated by mechanical method weakens, possibly related to quick death due to solid surface arable layer and insufficient oxygen, and low absorption ability due to new root system failure to take root deeply. Therefore, the mechanical harvesting has certain effect on vitality of root system of ratoon. Besides, the higher vitality of root system of Yuetang 00/236 may be related to return of broken sugarcane leaves to field.

2.3.2 Effect on nitrate reductase activity (NRA). The Nitrate reductase (NR) is the first enzyme in nitrate nitrogen assimilation system of plants[12], and NRA reflects ability of nitrogen assimilation[13]. From Table 5, it can be known that the effect of mechanical harvesting on NRA is similar to the effect on vitality of root system. NRA of Yuetang 00/236 treated by mechanical method is higher than manual processing in July and September, slightly lower than manual processing in October, other three brands basically show lower NRA compared with manual processing. For Yuetang 00/236, the NRA treated by mechanical method is 0.37 μg NO2/g. hr (FW) higher than manual processing; for Funong No.15, Liucheng 03/182 and Ganzhe No.18, it is 3.03, 0.53 and 2.17 μg NO2/g. hr (FW) lower than manual processing respectively, indicating that mechanical harvesting has certain effect on NRA, but it can be improved if combined with technology of returning sugarcane leaves to field when harvesting.

2.4 Effect of mechanical harvesting on yield of ratoon

Summary of plant height, stem diameter, single stem weight, and number of effective stems is listed in Table 6. Compared with manual harvesting, the mechanical harvesting of four brands has increase of plant height, stem diameter, and single stem weight. The number of effective stems of Funong No.15 and Liucheng 03 − 182 harvested in mechanical way is significantly less than that of manual processing, while there is no obvious difference between manual harvesting and mechanical harvesting of Ganzhe No.18 and Yuetang 00/236 in the number of effective stems.

2.5 Effect of mechanical harvesting on ratoon quality

From the measuring results of field brix and quality index (Table 7), there is a great difference in field brix and sucrose content, and the mechanical harvesting is similar to or slightly high-

er than manual harvesting. The average value of 4 brands indicates that the field brix and sucrose content of mechanical harvesting is 0.47 and 0.53 percentage points higher than manual harvesting. The gravity purity of sugarcane juice drops 0.48 percentage points, and there is no obvious difference in reducing sugar content and fiber content.

Table 4 Vitality of root system treated by different methods

Brand	Vitality of root system (TTC reduction rate, mg/g · h)							
	July				August			
	Mechanical	Manual	Difference ±	±%	Mechanical	Manual	Difference ±	±%
Funong No.15	394.26	446.32	−52.06	−11.66	423.19	433.54	−10.35	−2.39
Liucheng 03/182	540.77	464.22	76.55	16.49	284.57	326.20	−41.63	−12.76
Ganzhe No.18	482.07	467.95	14.12	3.02	299.85	380.53	−80.68	−21.20
Yuetang 00/236	510.96	333.37	177.59	53.27	409.13	335.62	73.51	21.90
Average	482.01	427.96	54.05	12.63	354.19	368.97	−14.78	−4.01

Table 5 Results of NRA treated by different methods

Brand	NRA ($\mu gNO_2/g.hr$, FW)								
	July		September		October		Average of months		
	Mechanical	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical	Manual	Difference ±
Funong No.15	17.54	20.09	7.75	12.73	7.14	8.69	10.81	13.84	−3.03
Liucheng 03/182	20.96	20.01	7.58	9.80	11.23	11.56	13.26	13.79	−0.53
Ganzhe No.18	14.24	15.23	6.63	11.81	8.10	8.43	9.66	11.82	−2.17
Yuetang 00/236	17.79	17.45	11.54	10.68	8.13	8.32	12.49	12.15	0.37
Average	17.63	18.19	8.37	11.25	8.65	9.25	11.55	12.90	−1.35

Table 6 Yield traits of sugarcane treated by different methods

Brand	Plant height//cm		Stem diameter//cm		Single stem weight//kg		Number of effective stems//pcs/ ha^2	
	Mechanical	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical	Manual
Funong No.15	228.7	210.8	3.29	3.27	1.16	1.14	44 370	48 360
Liucheng 03/182	251.1	241.3	2.83	2.77	1.25	1.10	42 540	45 885
Ganzhe No.18	296.7	285.3	3.12	3.00	1.84	1.72	32 805	31 500
Yuetang 00/236	214.4	186.5	3.10	3.01	1.13	1.05	46 395	46 335
Average	247.7	231.0	3.09	3.01	1.34	1.25	41535	43 020
Difference ±	16.7		0.08		0.09		−1485	

Table 7 Measuring results of sugarcane quality indexes treated by different methods

Brand	Field brix//%		Sucrose content//%		Reducing sugar content//%		Fiber content//%		Gravity purity of sugarcane juice//%	
	Mechanical	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical	Manual	Mechanical	Manual
Funong No.15	20.28	19.63	16.02	14.69	0.16	0.27	9.5	9.82	89.94	89.24
Liucheng 03/182	21.55	21.36	14.37	14.54	0.2	0.14	12.14	12.09	89.98	89.94
Ganzhe No.18	20.82	20.12	15.24	15.04	0.19	0.2	10.81	10.39	88.23	89.26
Yuetang 00/236	21.33	21.01	16.49	15.74	0.07	0.09	9.46	9.73	91.72	93.48
Average	20.75	20.53	15.53	15.00	0.16	0.18	10.48	10.51	90.00	90.48
Difference ±	0.47		0.53		−0.02		−0.03		−0.48	

2.6 Effect of mechanical harvesting on ratoon cane yield and sugar content On December 21, 2010, we inspected the cane yield, and calculated sugar content of each hectare. The results are listed in Table 8. From the Table 8, it can be seen that except Funong No.15, of which the mechanical harvesting has a production drop of 6.16% compared with manual cutting, other three brands treated by mechanical method have slight rise compared with manual processing (having an increase of 4.69% to 11.02%).

Table 8 Cane yield and sugar content obtained from different methods

Brand	Cane yield//kg/hm^2			Sugar content//kg/hm^2		
	Mechanical	Manual	Difference ±%	Mechanical	Manual	Difference ±%
Funong No.15	51667.5	55062.0	−6.16	8277.0	8088.0	2.34
Liucheng 03/182	53049.0	50671.5	4.69	7623.0	7368.0	3.46
Ganzhe No.18	60259.5	54276.0	11.02	9183.0	8163.0	12.50
Yuetang 00/236	52489.5	48828.0	7.50	8655.0	7686.0	12.61
Average	54366.4	52209.4	4.13	8434.5	7826.3	7.77

3 Conclusions and discussion

(i) The stubble height and breaking stubble rate are important indexes of cutting and harvesting quality of sugarcane. Cutting into ground (2 to 5 cm) or flush ground cutting is favorable to promoting ratoon germination next year and increasing the number of effective stems and single stem weight; during harvesting sugarcane, it is able to avoid or reduce breaking stubble rate, so as to prevent infection of disease and keep vitality of stubble[14]. Liu Wenxiu *et al*, believe that if not cutting into ground, not cutting fast or the cutter is not sharp in manual cutting, the stubble height of mechanical harvesting is lower than manual harvesting, while the breaking stubble rate is higher than manual harvesting; as long as intertillage and earthing up are adequeate, ridge height in both sides is uniform, it can greatly reduce stubble breaking rate if adjusting the cutter disk to ridge surface or into the ground about 2 cm[10]. The results of this experiment indicate that the stubble height of all brands treated by mechanical method is higher than that of manual harvesting, having an average increase of 2.6 cm. At the same time, the stubble height has bigger difference due to lodging during harvesting and the defoliation of varieties. No lodging and easy defoliation are favorable to reducing the stubble height, while lodging and difficult defoliation ones have obvious higher stubble height. Mechanical harvesting damages seriously the stubble breaking rate, 36.84 percentage points higher than that in manual harvesting, while the sugarcane variety with higher fiber content shows little stubble breaking rate.

(ii) The effects of mechanical harvesting on germination of next year ratoon were quite different due to different varieties, indicating that the better perennial species have less impact than the poor perennial species. This result is not consistent with the research conclusion of An Yuxing *et al* that mechanical harvesting has favorable effect on raising the germination rate of ratoon, and reason is to be further studied.

(iii) The effect of mechanical harvesting on growth of plant height takes on slower at early stage, gradual quickening in middle and late period, and slightly higher than the plant height by manual harvesting till the harvesting. The slower growth at early stage is possibly related to poor soil permeability; slightly quickening in middle and late period may be related to less germination number than manual harvesting, less dead seedling and centralized supply of nutrient for effective plant after it enters elongating phase.

(iv) In this experiment, the plant height, stem diameter and single stem weight of sugarcane harvested by machine are better than that by manual cutting, making up effect of reduction of the number of effective stem. Thus, the difference between cane yield and manual harvesting is not significant.

(v) Mechanical harvesting combining with leaves crushing could reduce the impact on the germination of ratoon, improve the single-stem weight and increase the effective number of stems. Thus, the germination number is large and vitality of root system and NRA are higher, manifested as plant height, stem diameter, single stem weight and sucrose content better than manual harvesting, the number of effective stems is approximately equal to manual processing, so it can increase cane yield and sucrose content.

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