Parameter optimization of banana crown-cutting machine using combined cutters

Zeyu Xu, Zhou Yang* and Zhengbo Zhu

College of Engineering, South China Agricultural University, Guangzhou, Guangdong, 510642, China

Banana crown cutting is an important part of banana harvesting. High quality of cutting incision can result in better economic value for the fruit. Mechanized cutting can reduce labour and production cost, and increase production efficiency. This article is aimed at solving the problem of poor cutting quality and high energy consumption of banana crown cutting machine. Cutting experiments of banana crown were carried out on an electronic universal testing machine by replacing the cutter components with different parameters. The effects of number of cutting sets, cutting speed, cutting edge angle of thick cutter, thickness of thick cutter, width of thick cutter and length of thin cutter on cutting force, cutting power consumption and cutting quality were studied. The optimum values of each parameter were obtained by experiments and analysis. The results are as follows: number of cutter sets is five groups, cutting speed is 60 mm/s, cutting edge angle of thick cutter is 16°, thickness and width of thick cutter are 2 mm and 12 mm respectively, and length of thin cutter is 13.07 mm.

Keywords: Banana harvesting, combined cutters, crown cutting machine, parameter optimization.

BANANA is grown in about 136 countries around the world. It has been rated as the fourth largest food crop after rice, wheat and corn in the world by the United Nations[1,2]. In 2017, global banana production reached 113.92 million tones, with an average annual growth rate of about 1.62% (ref. 3). The postharvest process of banana mainly includes harvesting, transportation, crown cutting, disinfection, cleaning and packaging. Among these, crown cutting is the process of cutting and separating the fruits from the stalk using a cutter[4,5]. At present, mechanization of the entire process has not been realized in banana production around the world, especially in the crown-cutting process. This is basically a manual operation, with meager research on crown-cutting machinery. This makes it impossible to effectively link the different machines used in banana harvesting and processing. As a result, improvement in production efficiency and mechanization is limited[6]. Therefore, it is necessary for more studies on banana crown-cutting machinery.

*For correspondence. (e-mail: yangzhou@scau.edu.cn)

In order to improve the efficiency of banana harvest and the level of mechanization, we examined a banana crown-cutting machine. This machine uses combined cutter sets and is designed on the basis of manual operation[7–9]. It can cut the banana crown along the surface of the curved fruit stalk and thus separate the fruit from the crown. The combined cutter is tested and the results show that the structure can obtain high quality cutting surface. This machine could replace manual labour to complete the crown-cutting process. Its cutting quality meets the harvesting requirements.

In this article, the maximum cutting force, useful power consumption and cutting surface quality grade are taken as evaluation indexes. Through cutting experiment of banana crown, the combined cutter set was studied and its parameter combination was optimized. The purpose of this study was to reduce cutting force and energy consumption, improve cutting surface quality, and also improve mechanization level of banana harvest.

The core part of banana crown-cutting machine is the combined cutting part. Figure 1 shows the main mechanical structure of the combined cutting part. It consists of adjustable number of cutter sets. These are installed in different directions and connected to each other to form a closed circle. Each cutter set has one thick cutter, two thin cutters, one slider, one sliding rail, one spring and one pillow block. Two adjacent thin cutters are hinged to each other. In the process of cutting, all sliders could move on sliding rails when the diameter of banana fruit stalk changes, so that the diameter of the closed circle follows the change in diameter of fruit stalk. Under spring action, although diameter and bending of fruit stalk, keep changing, each thick cutter could still well adhere to the surface of fruit stalk for cutting. The thick cutters are made of T9 carbon tool steel with quenched and heat-treated surface. The hardness scale after the quenching zone is HRC50-60. The rest of the parts are made of stainless steel. The thick cutters mainly play the role of cutting and supporting the thin cutters. If the number of cutter sets is n, then the number of edges of a polygon approximating a circle composed of thin cutters is $2n$. The parameters that could be adjusted on this device are: number of cutter sets n, cutting speed v (mm/s), cutting edge angle of thick cutter θ (°), thickness of thick cutter δ (mm), width of thick cutter d (mm) and length of thin cutter l (mm).

Forty bunches of banana waiting to be harvested at the maturity stage were used for the experiment. Each bunch had 6–8 banana crowns to be cut. The fruits were sourced from Machong Farm, Dongguan City, Guangdong Province, China, located at 23°2′24″N lat. and 113°34′48″E long. It is the largest banana-growing area in China. The fruit variety is Brazilian banana and the maturity stage is green[10]. In the experimental pretreatment, the fruit stems between two adjacent banana crowns were cut into equal length segments. This ensures that the cutting experiment

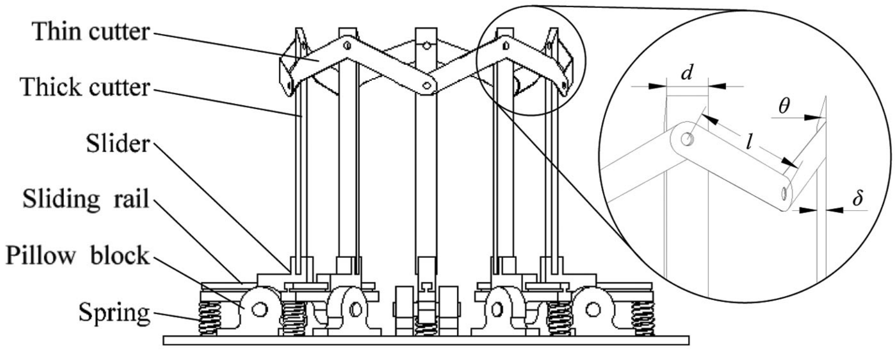

Figure 1. Main mechanical structure of the combined cutting part.

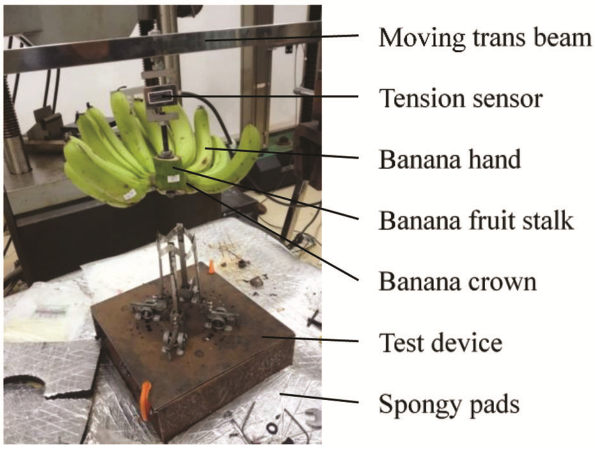

Figure 2. Experimental prototype.

Figure 3. Cut surface at different cutting quality scores. ***a***, Banana finger separated from banana hand by the cutter. ***b***, Cut surface with some rough edges near the banana stalk. ***c***, Cut surface with few rough edges not near the banana stalk. ***d***, Cut surface with no rough edge near the banana stalk.

of each banana crown is not interfered with by other banana crowns. In order to make sure that the water content of fruit stalk remains unchanged, all the experiments were started immediately after the fruit stalk has been cut from the banana tree, and all the experimental environments were the same.

The experiments were conducted in the laboratory of South China Agricultural University, Guangdong, China. Figure 2 shows the prototype of the experiment. The banana fruit stalk was fixed under a tension sensor (Celtron STC-100 kg, Vishay Celtron Technologies Co, Ltd). The tension sensor was fixed under a moving trans beam, which can move up and down by a stepper motor (110BYG350C, Shantou Hongbaoda Electrical Machinery Co, Ltd, Guangdong, China). Table 1 shows the experimental factors and their test values at different levels.

When experimenting with one factor, the level of the other factors was set at 3. Before the beginning of all the experiments, the tension sensor was set to zero and then the banana crown was cut under a selected experimental speed. Fifty cutting force data were recorded every second. Cutting force data and displacement values can be controlled and recorded by a computer. Each group of experiments was repeated three times. The useful power consumption, viz. the power consumed by the combined cutters in the cutting process could be calculated based on the integral of cutting force data on displacement. According to whether the cut surface quality of banana crown meets the agronomic standards and processing requirements, the cutting incision was divided into four grades for scoring: the worst incision quality is 60–69 points (Figure 3 *a*), not too good is 70–79 points (Figure 3 *b*), good is 80–89 points (Figure 3 *c*) and the best is 90–100 points (Figure 3 *d*).

The obtained experimental data were statistically analysed using SPSS software.

Figure 4 shows the experimental results. The maximum cutting force F and useful power consumption W are seen to increase with increasing number of cutter sets n. The main reason is that thick cutter consumes more energy than thin cutter. The grade of cut surface quality increases first and then decreases with the increasing number of cutter sets n. The main reason is that, when the number of cutter sets n is small, the number of $2n$ edges of the polygon formed by the cutter sets is also small; then

Table 1. Experimental factors and their test values at different levels

Level	Number of cutter sets (n)	Cutting speed (mm/s)	Cutting edge angle (°)	Thickness of thick cutter (mm)	Width of thick cutter (mm)	Length of thin cutter (mm)
1	3	20	10	2.0	8	8
2	4	30	15	2.5	10	10
3	5	40	20	3.0	12	12
4	6	50	25	3.5	14	14
5	7	60	30	4.0	16	16

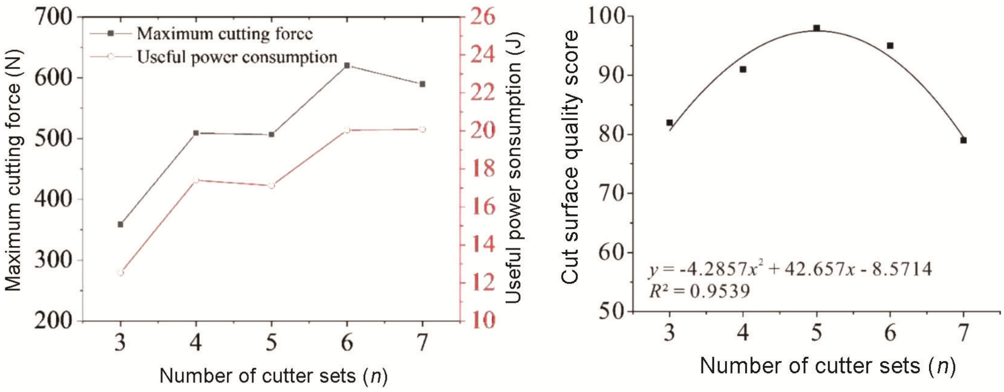

Figure 4. Effect of number of cutter sets.

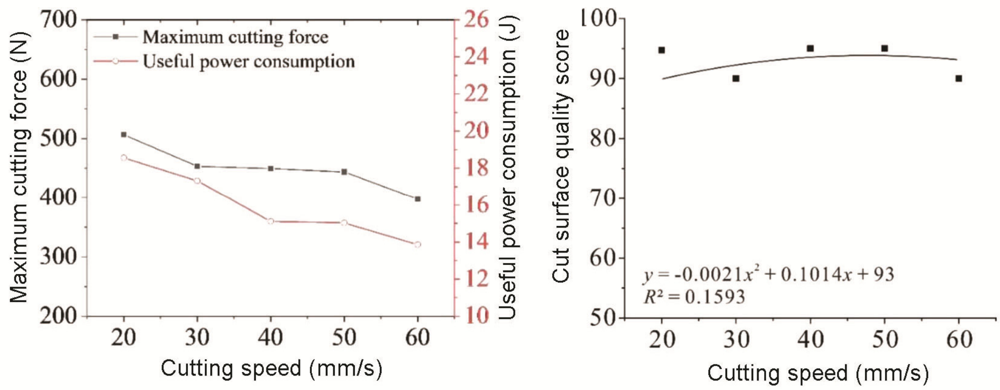

Figure 5. Effect of cutting speed.

the polygon is no longer approximate to a circle, and so the cutting quality becomes poor. With the increase in the number of cutter sets n, the quality of incision becomes better. However, if the number of cutter sets continues to increase, it indicates that the number of thick and thin cutters increases and the altering appearance of thick and thin cutters becomes more frequent. This, in turn causes a decrease in the quality of incision. The incision appears as a mixed staggered phenomenon, and the cutting force F also increases.

Figure 5 shows the experiment results. The maximum cutting force F and useful power consumption W are seen to decrease with increase in cutting speed v, and the grade of the cut surface quality does not change much. This is because, with increase in cutting speed v, the cutting point transfer deformation time is less, and so the cutting force F is small[11,12]. According to experimental data, the regression equation between cutting speed and cut surface quality was established. The equation shows that the cutting speed has no significant effect on the quality of incision.

Figure 6 shows the experiment results. The maximum cutting force F and useful power consumption W do not change much with increase in cutting edge angle θ. This is because the water content of banana crown is very high (average 93.43%). Within the experimental scope of cutting edge angle, the angle size has little effect on cutting force[13]. The grade of cut surface quality shows a decreasing

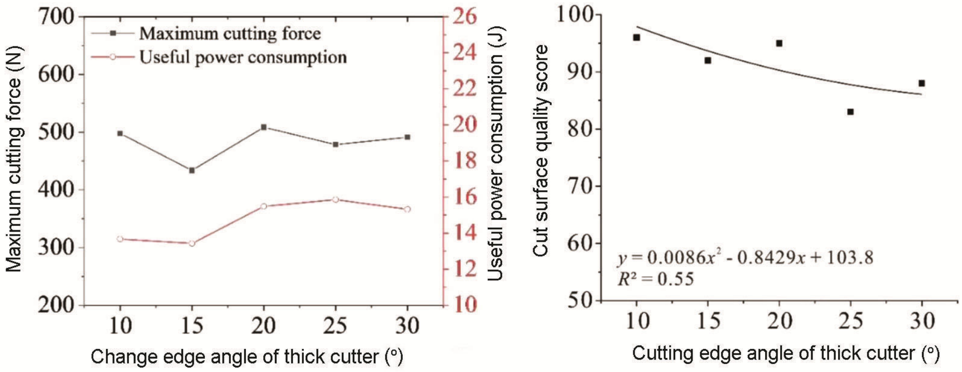

Figure 6. Effect of cutting edge angle of thick cutter.

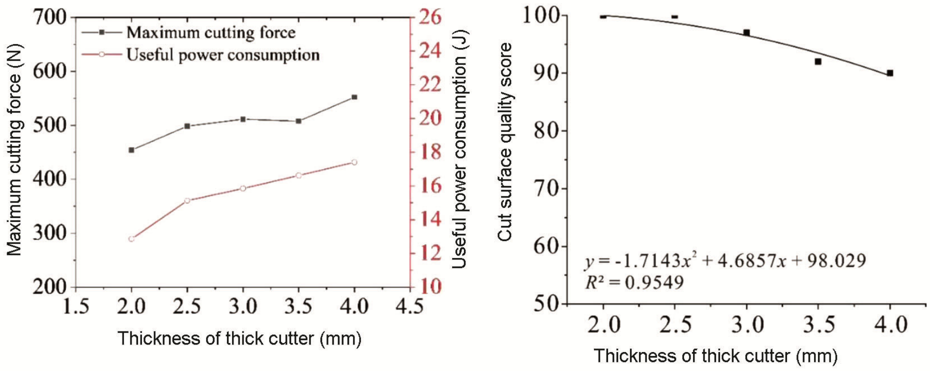

Figure 7. Effect of thickness of thick cutter.

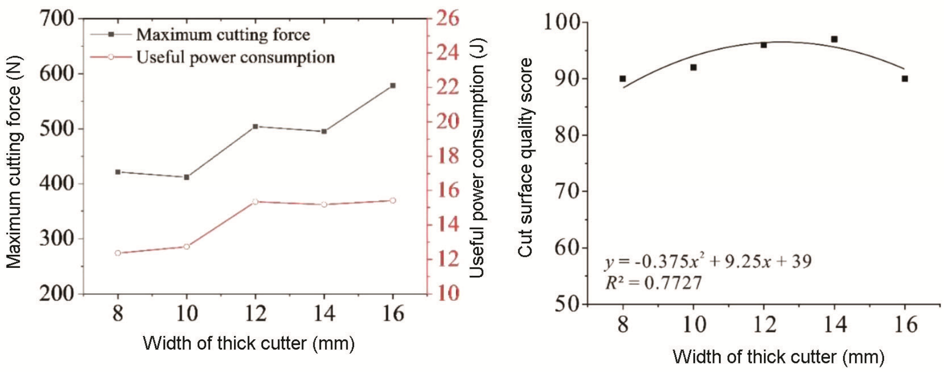

Figure 8. Effect of width of thick cutter.

trend with increase cutting edge angle θ. Also, large cutting edge angle can cause tearing of the banana crown incision, which results in a drop in cutting quality[14].

Figure 7 shows the experiment results. The maximum cutting force F and useful power consumption W are seen to increase with increase in thickness δ. This is mainly because the thick cutters are too thick, it is difficult to cut into the banana crown but compress the crown, so much of cutting work was done on compression and not on cutting the crowns. The grade of cut surface quality increases with decrease in δ. Because the decrease in thickness of thick cutter indicates that the surface of the cutter will much closer to the banana fruit stalk, and the difference in thickness between thick and thin cutters is reduced. As a result, the cutting quality is improved.

Figure 8 shows the experiment results. The maximum cutting force F and useful power consumption W are seen to increase with increase in width d. The grade of cut

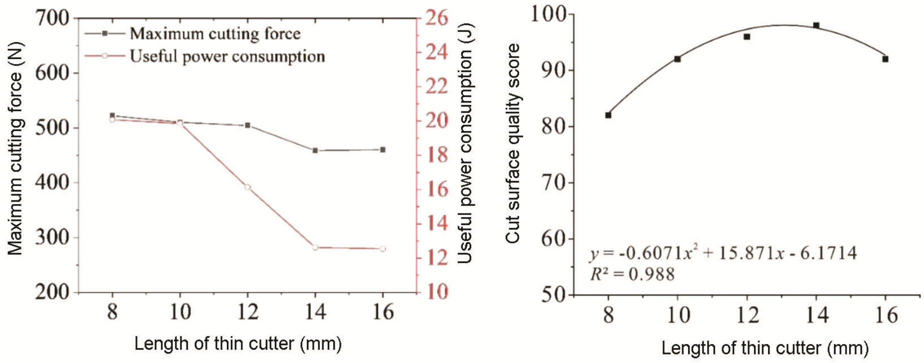

Figure 9. Effect of length of thin cutter.

surface quality increases first and then decreases with increase in *d*. This is mainly because when the width of the thick cutter is small, its strength is too small to drive the opening and closing of the thin cutters connected to it, and the apex of the polygon formed by them becomes smaller and sharper. Therefore, it shows a more labour-saving phenomenon[15]. When the width of the thick cutter increases, the ratio of the total width of all thick cutters to the circumference of the polygon becomes larger, and the quality of incision drops again. Since the thick cutter causes a change in the quality of incision, so if the width of the cutter increases, the cutting quality deteriorates, and the cutting force *F* also increases.

Figure 9 shows the experiment results. The maximum cutting force *F* and useful power consumption *W* are seen to decrease with the increase in length *l*. This is mainly because, when the length of thin cutters increases, the angle between the two connected thin cutters becomes smaller and the phenomenon of sliding cutting occurs, under the condition that distance between two adjacent thick cutters remains unchanged. With sliding cutting, the actual cutting edge angle is smaller than that of the cutting tool, and the tiny serrations on the cutting edge will serve to cut-off the banana crown fibre. Because of this, the larger the length of thin cutter *l*, the more obvious is the sliding cutting effect and smaller is the cutting force *F* required. The grade of cut surface quality increases first and then decreases with the increase in length. Since the length is small, the closed ring tends to be polygonal, if it becomes longer, it tends to be circular. Therefore, with the increase in length, the cut surface quality is improved. However, as the length continues to increase, elastic deformation of the thin cutter takes place, which in turn causes a drop in cutting quality.

Cutting force and power consumption are important indicators for evaluating the performance of the banana cutting machine[16,17]. The quality of incision directly affects the market competitiveness of banana products[18]. In order to ensure that these important indicators are optimized on the machine, six main structural parameters of the banana crown-cutting machine were examined and the influence of each factor was analysed in this study. From the experiment results, it can be concluded that if the number of cutter sets *n* is five groups, the quality of incision is in accordance with the agronomic requirements, thus ensuring better economic value of bananas, and energy consumption is at the middle level.

Cutting speed has a significant effect on power consumption, but has little effect on cutting quality[19]. On the premise of guaranteeing better cutting quality, cutting speed can be properly increased. On the one hand, it can reduce the cost of energy consumption while on the other hand, it can improve production efficiency. Within the scope of this experiment, if the cutting speed *v* is 60 mm/s, it can achieve more energy-saving and increase productivity.

Due to high water content of banana crown, the cutting edge angle shows an insignificant effect on cutting force and energy consumption. In practical production and applications, a very small cutting edge angle can easily cause cracking and damage the cutter. Excessive edge angle needs to consume more energy, and the cut incision is rough[20]. According to the cutting experiments of rhizome crops with high water content[21], the edge angle θ is generally selected in the range of 16°–20°. In the present study, a smaller edge angle could reduce power consumption and improve cutting quality. Therefore, the edge angle θ of the thick cutter is selected as 16°.

The thickness and width of the thick cutter are the main factors to ensure its strength, and they also affect the power consumption and cutting quality. It can be seen from the experiment that the thickness factor has a greater impact on cutting force and power consumption than the width factor, while the width factor has a slightly higher impact on cutting quality than the thickness factor. When choosing their range of values, we should consider their comprehensive performance and ensure the strength of the cutter. Based on the experiment results, we choose the thickness δ and width *d* of the thick cutter as 2 and 12 mm respectively.

The thin cutter connected with the thick cutter also has a significant impact on power consumption. The thick cutter has the characteristics of chopping cutting, while the thin cutter has the characteristics of slipping cutting. Slipping cutting can make the incision smoother, and requires less power consumption. Based on the calculation result obtained from the fitting equation shown in Figure 9, the optimum length of thin cutter l is 13.07 mm.

The banana crown-cutting tool using combined cutters is a core component of the banana harvest machine. It requires less energy consumption and provides high grade of cut surface quality. Experimental results show that the number of cutter sets, width of the thick cutter and length of the thin cutter have significant impact on cutting quality. Cutting speed, thickness of thick cutter and length of thin cutter have an impact on cutting force and power consumption. The optimum parameters of the cutter sets are as follows: number of cutter sets n is five groups, cutting speed v is 60 mm/s, cutting edge angle θ of thick cutter is 16°, thickness δ and width d of the thick cutter are 2 and 12 mm respectively, and length of the thin cutter l is 13.07 mm.

1. Li, J., The study on world banana trade pattern and its influence on Chinese banana market. Hainan University, Hainan, China, 2015.
2. Zhu, Z. *et al.*, Parameter optimization and experiment of pneumatic holding part for banana crown cutting. *Trans. Chin. Soc. Agric. Eng.*, 2016, **4**, 33–39.
3. FAO, Production/yield quantities of Bananas in the World, Food and Agriculture Organization of the United Nation, Rome, Italy, 2018; http://www.fao.org/faostat/en/#data/QC/visualize
4. Liu, J., Li, J. and Yang, Z., Review current status of postharvest handling equipment for banana. *J. Agric. Mech. Res.*, 2014, **11**, 249–252 + 257.
5. Xu, Z., Sun, J. and Zhao, L., Classification, integration of preliminary processing technology in banana producing areas of China. *Trans. Chin. Soc. Agric. Eng.*, 2015, **S1**, 332–336.
6. Zhou, K. and Yang, J., An elementary introduction to mechanized management of banana. *Trop. Agric. Sci. Technol.*, 2010, **1**, 24–25.
7. Yang, Z. *et al.*, Rotary type banana combing machine. Chinese Patent No. CN201310067178.3, China, 2013.
8. Duan, J., Yang, Z. and Zhu, Z., Inserting cutting type variable diameter banana shaft removing and combing cutter self-adaptive to diameter of banana spike rod. Chinese Patent No. CN201310548281A, China, 2013.
9. Duan, J., Zhu, Z. and Yang, Z., Reducing impact insertion-cutting type annular banana comb cutting device. Chinese Patent No. CN201410314515A, China, 2014.
10. Von, H., *Bananas*, Interscience Publishers, New York, USA, 1950.
11. Li, Y., Qin, T., Chen, J. and Zhao, Z., Experiments and analysis on mechanical property of corn stalk reciprocating cutting. *Trans. Chin. Soc. Agric. Eng.*, 2011, **1**, 160–164.
12. Shi, Y., Wang, X., Zhang, Y., Morice, O. O. and Ding, W., Test and analysis on the influence factors of reciprocating cutting force of *Artemisia saelengensis* harvester. *J. Chin. Agric. Mech.*, 2018, **12**, 46–53.
13. Zhang, H., Study on the shear properties and cutting parameters of alfalfa stem. China Agricultural University, Beijing, China, 2015.
14. Wang, H., Wang, F., Yang, Z. and Guo, W., Experimental study on the influencing factors of cutting resistance of sunflower stalk. *J. Chin. Agric. Univ.*, 2018, **5**, 102–107.
15. Yang, Z. *et al.*, Longitudinal stability control of orchard cable-driven hanging transport system. *Trans. Chin. Soc. Agric. Eng.*, 2015, **31**, 64–70.
16. Li, J. *et al.*, Dynamics of electric pulley conveying cableway system in banana plantation. *Trans. Chin. Soc. Agric. Mach.*, 2013, **1**, 211–216.
17. Ding, S., Xue, X., Cai, C., Cui, L. and Chen, C., Optimization and experiment of blade parameter for pear branches cutting device. *Trans. Chin. Soc. Agric. Eng.*, 2015, **S2**, 75–82.
18. Li, B., Effects of different drying methods on quality of banana products. *Food Sci.*, 2016, **15**, 100–106.
19. Fang, S. *et al.*, Influence of spindle rotating speed on machining quality for chips of semiconductor. *Chin. Mech. Eng.*, 2007, **18**, 2187–2190.
20. Chen, D., Cheng, L., Li, J. and Wang, X., Analysis simulation on edge angle of fin cutter blade based on finite element method. *Tool Eng.*, 2013, **10**, 44–46.
21. Zhou, S., Yang, W., Yang, J., Liang, Z. and Mo, J., Dynamic simulation experiment of one-blade cutting sugarcane process. *Trans. Chin. Soc. Agric. Mach.*, 2011, **1**, 68–73.

ACKNOWLEDGEMENTS. This research was supported by the National Natural Science Foundation of China (Grant No. 51675189), the China Agriculture Research System (CARS-31) and the Innovative Research Team of Guangdong Province Agriculture Research System (2017LM2153).

Received 10 April 2019; revised accepted 16 May 2019

doi: 10.18520/cs/v117/i3/492-497

Estimation of soil properties and leaf nutrients status of oil palm plantations in an intensively cultivated region of India

Sanjib Kumar Behera[1,*], Arvind Kumar Shukla[1], Kancherla Suresh[2] and Ravi Kumar Mathur[2]

[1]ICAR-Indian Institute of Soil Science, Bhopal 462 038, India
[2]ICAR-Indian Institute of Oil Palm Research, West Godavari 534 450, India

Oil palm (*Elaeis guineensis* Jacq.) is cultivated in several countries of the world. The information pertaining to soil properties and status of leaf nutrients in oil palm plantations (OPP) is essential for proper nutrient management to obtain higher yield of the crop. The study, therefore, was undertaken by conducting a survey of OPP in west Godavari district, India and collecting 306 soil samples and 153 leaf samples. Collected samples (soil and leaf) were analysed for different parameters after their processing. The studied soil parameters (soil pH, electrical conductivity, organic carbon, available phosphorous, available potassium, exchangeable calcium, exchangeable magnesium, available sulphur and available boron) in surface (0 to 20 cm) and sub-surface (20 to 40 cm) soil varied widely. The soil parameters had CV values

*For correspondence. (e-mail: Sanjib.Behera@icar.gov.in)