Optimized design of the 4TSQ-2 sugar beet top cutting machine

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Abstract: To solve the problems faced by 4TSQ-2 sugar beet top cutting machine, i.e. large structure, high power consumption and high manufacturing cost, the multi-roller mechanism for leaves removal and fixed-thickness cutting method was studied. Using five-factor and two-level tests, the structure configuration of the leaf removal device was optimized, and the scheme of two roller shafts defoliation, the roller shaft rotation speed of 800 r/min and the forward speed of 0.8 m/s were determined. Through the working process and mechanical analysis of the top cutting device, the cutting device with the slant profiling plate structure characterized by a profiling angle of 25°-45° for the profiling plate and a cutting angle of 20°-40° was studied. With the two-factor and three-level experiments, the profiling angle of profiling plate of the top cutting device was 35°, and the cutting angle was 30°. Compared with the 4TSQ-2 sugar beet top cutting machine before optimization, the structure size of the machine was reduced by 30%, the weight was reduced by 15%, the cost was reduced by 25%, the qualified rate of top cutting wad was increased by 2.6%, and the push over rate of sugar beet was reduced by 0.5%. Besides, each index met the index requirements of beet top cutting harvest.

Keywords: beet harvest, leaves cleaning, top cutting, structure, optimization

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1 Introduction

In China, sugar beet is an important raw material for sugar production, which is of important significance to the development of sugar industry and with a planning area ranking 10th in the world[1-4]. However, the Chinese mechanized harvesting of sugar beet is less mechanized, which has an adverse impact on the economic benefit of sugar beet growers[5-10]. In particular, to solve the problem of strong labor intensity and low efficiency of manual beet top cutting, as well as high sugar beet damage rate and low qualified rate of mechanized sugar beet top cutting, it is urgent to improve the mechanized sugar beet top cutting.

In the developed countries, relatively more advanced sugar beet top cutting technologies and equipment as well as higher level of theoretical research and automation are available; and the operations are mainly carried out by smashing the leaves before top cutting. The German self-propelled sugar beet combine adopts harvesters swinging blade rollers for smashing the leaves, and contour toothed plates for top cutting, which is suitable for the standardized planting due to high power consumption[11]; while the American multi-roller sugar beet top cutting machine adopts the swinging blade rollers for smashing leaves, the swinging rollers for removing leaves and the contour planar plates for top cutting, which is able to perform fixed-thickness cutting of green sugar beet top, and with the drawbacks of large size of structure and high power consumption[12]. In addition, the Japanese roller-type beet top cutting machine adopts rollers for crashing beet leaves, and realizing fixed-thickness cutting of sugar beet top, which has the drawbacks of low efficiency and poor adaptability to beet[13]; The self-propelled sugar beet combine harvester produced in Spain has large size and adopts plough type operation mode. It has large working width and high working efficiency, but it is not suitable for sugar beet planting mode in China. In China, different types of sugar beet top cutting machines have been developed, most of which copy the multi-roller trimming and contour planar plate top cutting mechanism. The sliding cutting and top-removing sugar beet cutter developed by Shandong University of Technology has a large size, and the profiling effect is poor in the operation process, which remains to be improved. The 4TSQ-2 top cutting machine developed by Qingdao Agriculture University completes the top cutting operation by the defoliation device of the three roller shafts and the flat profiling top cutting device, but high power consumption and high possibility of damage to the sugar beet[14-19]; the contour planar plate is characterized by the merits of simple structure and even thickness of cutting and also the drawbacks of heavy collision with sugar beet and the high possibility of missed or inadequate cutting of sugar beet. Through the preliminary test, it is found that using different combinations of leaf crushing roller and leaf removing roller can simplify the structure and reduce the power consumption, and changing the position of profiling plate and cutter can improve the qualified rate of top cutting. In this case, based on the diversified planning modes of sugar beet in China, it is of great significance to optimizing the parameters and structure of 4TSQ-2 top cutting machine through field tests theoretical analysis, to achieve high efficiency and low loss cutting of sugar beet. Thus, developing a type of sugar beet top cutting machine with lower manufacturing cost will have higher economic benefit.

2 Testing equipment and structure

4TSQ-2 Sugar beet top cutting machine mainly consists of a traction frame, a hydrocylinder, a propelling assembly, a drive

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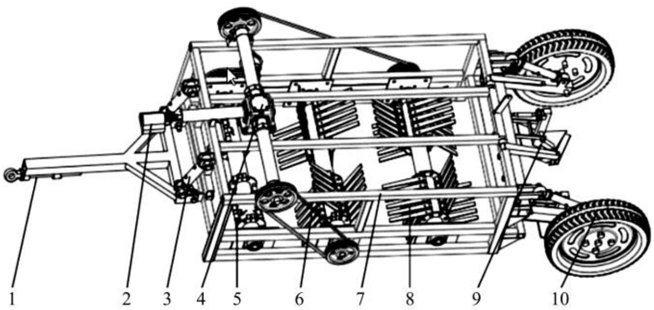
system, leaves smashing rollers, a pressure regulation system, a profiling mechanism, a top cutting mechanism, etc., as shown in Figure 1. The hydrocylinder and propelling assembly are used to control the vertical height of swinging blades for leaves smashing and the swinging rollers for leaves removal. The swinging blades will not cause damage to the sugar beet and the length of partial swinging roller whose contact with the sugar beet is less than 50 mm. The swinging blades or swinging rollers of leaves removal device are evenly arranged along the peripheral direction, so as to ensure the thorough removal of sugar beet leaves. The pressure regulating system controls the downforce of the top cutting device to ensure that the top cutting device falls in time. The profiling plate slides in the direction of sugar beet top to ensure the relative position of sugar beet, profiling plate and blades, thus ensuring the even cutting thickness. The power consumption tester measures the power consumption for leaves removal during the sugar beet top cutting. The main technical parameters of 4TSQ-2 top cutting machine are shown in Table 1.



1. Traction frame 2. Power consumption tester 3. Hydrocylinder 4. Gear box 5. Leaves smashing rollers 6. Leaves removal rollers a 7. Frame assembly 8. Leaves removal rollers 9 Top cutting device 10. Propelling assembly

Figure 1 Testing equipment

Table 1 Main technical parameters of 4TSQ-2 beet cutting machine

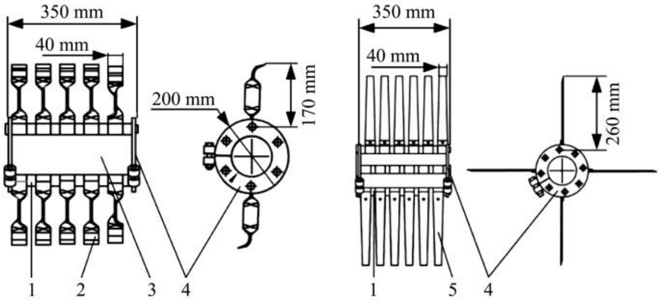
Parameters	Values
Mating power/kW	≥36.7
Shape size (length×width×height)/mm	2300×1200×950
Working rows	2
Ridge spacing/mm	200-300
Row spacing/mm	500-700

3 Optimization of leaves removal device

3.1 Key parameters

The defoliation device of 4TSQ-2 top cutting machine consists of Leaf crushing mechanism and Leaf removal mechanism. The crushing and dispersing of sugar beet leaves and the cleaning of petiole and impurity of green head residue are completed respectively, which provides guarantee for the smooth work of subsequent cutting operation. The structure of the leaves removal device is shown in Figure 2, which consists of shaft, blade, arbor, cartridge and strip. The blade is in the shape of “8” with light weight and high strength, material 65Mn, which is convenient for the crushing and tearing of sugar beet leaves. The strip with Shore hardness 70 has strong flexibility and friction, which can make flexible beating and friction on the leaves and petioles of the residual green head of sugar beet, so as to achieve the purpose of cleaning. The arrangement density of blade and strip are 25 pieces/m and 26 pieces/m, respectively.

When working, the tractor power output shaft provides power to the transmission system, and drives the roller shaft to rotate at a high speed. The blade which is uniformly distributed on the arbor first contacts with the beet leaf, and crushes the sugar beet leaf directly. The petioles and uncleaned leaves on the green head of beet were cleaned by strip under flexible impact.



a. Leaf crushing mechanism b. Leaf removal mechanism

1. Shaft 2. Blade 3. Arbor 4. Cartridge 5. Strip

Figure 2 Structure of leaf removal device

During operation, when the machine forward speed is V_m, the shaft is installed on the Z row of whipping parts, the roller shaft speed n to meet

$$n = 60\frac{V_m}{ZS} \tag{1}$$

where, V_m is the advancing speed, m/s; Z is the number of rows of blades; S is the operating advance pitch, m.

It can be seen that, when the advancing speed and the number of rows of swinging blades are determined, the rotation speed n of the rollers is inversely proportional to the operating advance pitch S. By increasing the rotation speed n of rollers, the advance pitch S of swinging blades may be reduced, thus improving the trimming effect. However, this will result in an increase in power consumption, and the vibration of the machine, causing damage to the sugar beet top easily. In the case that the advancing speed of the machine is 1m/s, the test results of leaves smashing rollers and leaves removal rollers are listed in Table 2, and the operating effect is shown in Figure 3. According to Table 2, if the rotation speed is greater than 600 r/min, the qualified leaves removal rate of swinging blades will be higher than 90%, and the leaves removal rate of swinging rollers will be higher than 85%, with moderate power consumption. However, with the increase of roller rotation speed, the rate of damage to sugar beet top is increased. Taking a comprehensive consideration of leaves removal effect and power consumption, the roller rotation speed is determined to be 600-800 r/min. The optimized defoliation device was changed from the working mode of one-roller shaft blade and two-roller shaft blade to two-roller shaft blade. Under the condition of ensuring the qualified rate of defoliation, the power consumption of the prototype operation was reduced, the size of the prototype was more compact, and the performance of the whole machine was significantly improved.

Table 2 Test results of leaves smashing and removal rollers

Name	Rotation speed/r min^{-1}	Qualified leaves removal rate/%	Beet damage rate/%	Power consumption/kW
Leaves crushing mechanism	400	66.6	0	0.50
	600	90.6	0	0.88
	800	100	0	1.34
	1000	100	0	1.99
Leaves removal mechanism	400	35	0	1.004
	600	85.5	0	2.198
	800	97.6	0	3.601
	1000	100	8.5	6.071

a. leaf crushing effect b. leaf removal effect

Note: When the shaft speed is 800 r/min, the operation effect of the defoliation device.

Figure 3 Operation effect

3.2 Experimental optimization

It can be found from the working principle and operating effect that the factors, such as the advancing speed of sugar beet top cutting machine, the number of rollers and roller rotation speed have an impact on the sugar beet leaves removal effect and qualified removal rate. At relatively high advancing speed of the machine, the number of blows on the sugar beet leaves by the swinging blades in a unit of time is reduced, which is accompanied with poorer leaves removal effect and lowered sugar beet damage rate. Similarly, the reduction of number of rollers is also accompanied by poor leaves removal effect and lowered beet damage rate. Based on the five-factor two-level tests, the structure configuration of the top cutting machine is optimized. Suppose that the parameters of leaves smashing rollers, leaves removal rollers a, leaves removal rollers b, roller rotation speed and advancing speed of sugar beet top cutting machine are A, B, C, D, E respectively, and that the qualified beet leaves removal rate, beet damage rate and power consumption are Y_1, Y_2 and Y_3, respectively, the factors and level of test design are listed in Table 3, and the test scheme and result are listed in Table 4. Consider the roller rotation speed of 600-800 r/min and the operating speed of a tractor in the field of 0.8-1.3 m/s, let's assume that the rotation speed of the 3 rollers of the top cutting machine is the same as the low speed of 600 r/min and the high speed of 800 r/min, and that the advancing speed of the machine is 0.8 m/s at low speed and 1.3 m/s at high speed.

Table 3 Test factors and level

S.N. Code	Factors				
	A	B	C	D	E
–1	Working	Working	Working	800	1.3
1	Not working	Not working	Not working	600	0.8

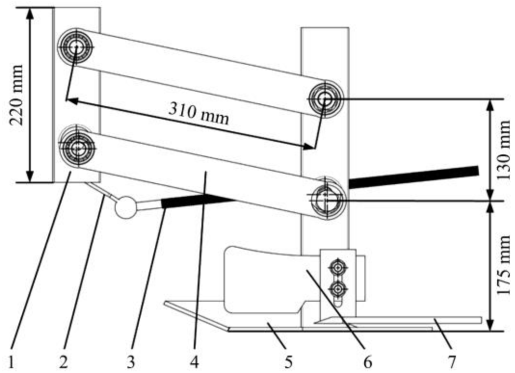
Table 4 Test scheme and result

Test No.	A	B	C	D	E	Y_1/%	Y_2/%	Y_3/kW
1	–1	–1	–1	–1	–1	65.4	0.0	3.517
2	–1	–1	–1	1	1	35.0	0.0	2.135
3	–1	1	1	–1	–1	4.0	4.0	1.256
4	–1	1	1	1	1	54.5	3.0	0.754
5	1	–1	1	–1	1	92.3	26.9	2.177
6	1	–1	1	1	–1	88.9	2.8	1.382
7	1	1	–1	1	1	100.0	40.0	2.135
8	1	1	–1	1	–1	55	5.0	1.256

It can be seen from Table 4 that the influence of the factors on the test index varies. Specifically, when the test factors form a profile of $A_2B_1C_1D_1E_2$, the index of qualified sugar beet leaves removal rate is relatively high, and the significance of the influence of the factors on this index is sequenced as A>E>B>C>D; while in the case that the test factors shows a profile of $A_1B_2C_2D_2E_1$, the power consumption of the machine is lower, and the significance of the influence of the factors on this index is sequenced as D>C>B>A>E. Taking a comprehensive consideration of the requirements of sugar beet top cutting, the sugar beet damage rate and power consumption should be reduced, and a relatively high leaves removal rate should be maintained. Based on the significance of the influence of the factors on the indexes, a profile of $A_2B_1C_1$ is determined. Namely, two contra-rotating rollers with swinging rollers are adopted to enable the leaves removal by sugar beet top cutting machine. The law and significance of roller rotation speed and advancing speed E of the machine on the 3 indexes are not consistent. According to the test results of leaves removal rollers listed in Table 1, the profile is preliminarily determined. Namely, the roller rotation speed is 800 r/min, and the advancing speed is 0.8 m/s. After optimization, the working mode of the leaf removal device is changed from one-roller blade and two-roller strip throwing operation to two-roller strip throwing operation. Under the condition of ensuring the qualified rate of leaf removal, the power consumption of the prototype operation is reduced, the size of the prototype is more compact, and the performance of the whole machine is significantly improved.

4 Optimization of structure of top cutting structure

The 4TSQ-2 top cutting device consists of a machine base, connecting levers, side links, a profiling plate, a cutter, a blade holder, torsional spring, etc. with the structure of top cutting device shown in Figure 4. A parallel four-lever structure consisting of a side link and a connecting rod enables the cutting device to float up and down according to the height of the beet, thus ensuring the uniform cutting thickness. The profiling angle of profiling plate has an influence on the force direction of sugar beet, and the cutting angle of cutter has an impact on the cutting ability and cutting space of cutter. During the operation, when the profiling plate is in contact with the beets, it will slide along the contour of sugar beet top; the connecting levers and side links rotate in the relative direction; the profiling plate and cutter rise simultaneously to coordinate the top cutting. With the cooperation of the four-bar profiling plate, the stability of the position of the cutter and the green head of sugar beet is ensured in real time. However, the top cutting effect is greatly affected by the participation of green head of sugar beet in the leaves with low qualified rate of top cutting. To deal with the problems of unstable cutting operation and low passing rate of existing cutting device, the structure is optimized to improve the qualified rate of cutting.

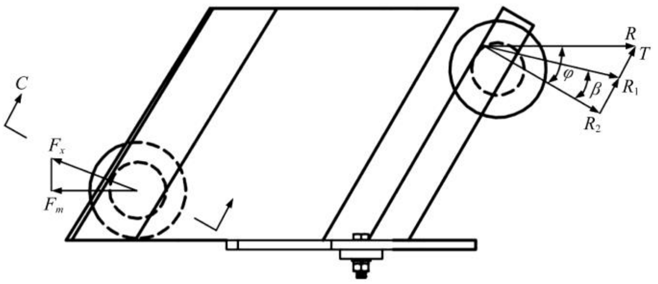


1. Machine base 2. Torsional spring 3. Regulating lever 4. Side link
5. Profiling plate 6. Blade holder 7. Cutter

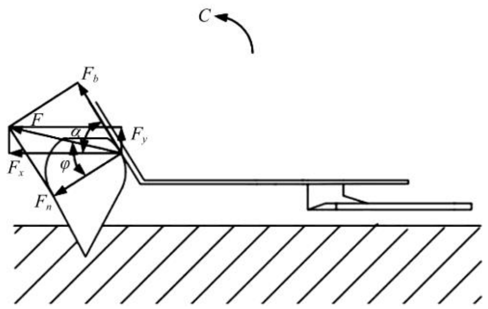
Figure 4 Top cutting device

4.1 Mechanical analysis

The profiling angle of the profiling plate and the cutting angle of the cutter are important factors affecting the working performance of the cutting device. In the process of contact between the profiling board and sugar beet, too large profiling angle of the profiling board will make the top cutting device cross the sugar beet, and too small profiling angle will cause the top cutting device to push down the sugar beet. Cutting tool cutting angle is too large will lead to increased cutting resistance, green cutting is not smooth, too small cutting angle makes the cutting space is too large, prone to leakage, has a direct impact on the cutting quality. Ignoring the deformation of sugar beet during the cutting process, the force of the profiling plate and the cutter during the cutting operation is shown in Figure 5.



b. Top view



a. C direction view

Note: φ is the sliding frictional angle between the sugar beets and the cutter, (°); α is the profiling angle of profiling plate, (°); β is the cutting angle of cutter, (°); F is impact force on sugar beet; F_b is friction between sugar beet and profiling plate; F_n is positive pressure of profiling plate on sugar beet; F_x is the horizontal component of F; F_y is the vertical component of F; F_m is the component force of F in the forward direction of the machine

Figure 5 Analysis of stress borne by the profiling plate and cutter

The profiling plate and sugar beet collide in a slanted way. Assuming that the collision force borne by the sugar beet is F, the friction force with the profiling plate is F_b, the positive pressure is F_n, the horizontal component of F is F_x, the vertical component is F_y, and the component in the advancing direction of machine is F_m, according to the theorem of impulse, the greater the F_m, the greater the impulse of collision and the easier the occurrence of the falling or damage of the sugar beet. The stress borne by the sugar beet satisfies:

$$F_{\mathrm{m}} = \cos(\alpha + \varphi - \frac{\pi}{2})\cos\beta \le [F] \tag{2}$$

where, φ is the sliding frictional angle between the sugar beets and the cutter, (°); α is the profiling angle of profiling plate, (°); β is the cutting angle of cutter, (°); $[F]$ is the maximum horizontal thrust of sugar beets.

During the process of top cutting, the sugar beets endure the resistance R exerted by the cutter. The component R_1 causes the sugar beets to slide along the edge of the cutter; while the component R_2 generates the frictional resistance T, preventing the sugar beets from sliding along the edge of cutter. When $R_1 \ge T$, the sugar beets slide against the cutting edge of cutter; while when $R_1 \le T$, the sugar beets are in stable contact with the cutting edge, which don't slide until R_2 is greater than the rupture strength. The condition for stable cutting of beets is:

$$R_1 = R_2 \tan\beta \le R_2 \tan\varphi \tag{3}$$

where, R_1 is to the sliding force, N; R_2 is the cutting force, N.

The deformation of the sugar beets due to the stress is hereby omitted. In the case that the profiling plate is in contact with the sugar beets, it is considered for a short time when the balance of the sugar beets is broken. When $\alpha = \frac{\pi}{2} - \varphi$, the sugar beets bear the slant downward thrust. F_y is a negative value, which ensures the stable contact between the profiling plate and the sugar beets. To ensure the stable contact between the sugar beets and the slanted profiling plate and the absence of slide of the sugar beets against the cutting edge, it should be ensured that $\beta<\varphi$. Furthermore, the smaller the cutting angle β, the greater the horizontal thrust F_x borne by sugar beets and the easier the occurrence of the falling of the sugar beets. Therefore, when φ=45°, α<45°, β<45°, according to the empirical formula of oblique cutting, $R^3S=C$, C stands for Constant. It can be found that the longer the sliding cutting length, the smaller the cutting force and the more effort saved. After the pretests, it is determined that the profiling angle of beet top cutting machine should be between 25°-45°, and the cutting angle should be within the range from 20°-40°.

4.2 Experimental optimization

In October 2020, the sugar beet cutting operations were conducted in Qiqihar City, Heilongjiang Province, China with the field soil moisture of 13.4%, the hardness of 1018 kPa, and the soil bulk density of 1.10 g/cm^3. The natural height of sugar beet leaves was 480 mm, and the row was 650 mm. Besides, the plant spacing was 250 mm, and the height of sugar beet green head was 30-80 mm. In the process of sugar beet top cutting, when the profiling angle of the profiling plate was too small, the sugar beet was easily pushed down by the profiling plate. According to the *Operation Quality of Beet Harvester*[20], two rows of sugar beets were selected as the width of the experiment, and the length of 30 m was taken for the operation. The total number of root tubers of G, the number of qualified sugar beets for cutting of G_1, and the number of beets pushed down of G_2 were recorded, Average after three statistics, and the qualified rate of top cutting of y_1 as well as the push over rate of sugar beet of y_2 are expressed by the following equation:

$$y_1 = \frac{G_1}{G} \times 100\% \tag{4}$$

$$y_2 = \frac{G_2}{G} \times 100\% \tag{5}$$

Taking the qualified rate of top cutting of y_1 and the push over rate of sugar beet of y_2 as the evaluation indexes, and the profiling angle and cutting angle as the experiment factors, the prototype field experiment was carried out with the factor and level design as listed in Table 5. The test scheme and results are listed in Table 6[21-23].

By using the Design-Expert software, the non-significant items were removed, and the multiple regression model of the qualified rate of top cutting and push over rate of sugar beet was obtained. The p<0.01 of the regression model is not significant with the misfitting term, the variance analysis is listed in Table 6. Besides, the fitting accuracy of the regression models for the qualified rate of top cutting and the rate of beet lodging was high. The influence order of each factor on the qualified rate of cutting top is sequenced as x_2, x_1, x_1x_2, x_2^2, x_1^2, and x_1^2 has no significant effect on the index. The influence order of each factor on the push over rate of sugar beet is sequenced asx_1, x_2, x_1x_2, x_1^2 and x_2^2. The regression equations of top cutting qualified rate and sugar beet push over rate were obtained by excluding non-obvious items.

$$y_1 = -62.3331 - 64.24002x_1 + 0.44762x_2 + 0.071333x_1x_2 - 0.000294574x_2^2 \tag{6}$$

$$y_2 = 5.80323 - 36.33924x_1 + 0.048533x_2 - 0.078333x_1x_2 + 34.43056x_1^2 - 0.00003838x_2^2 \tag{7}$$

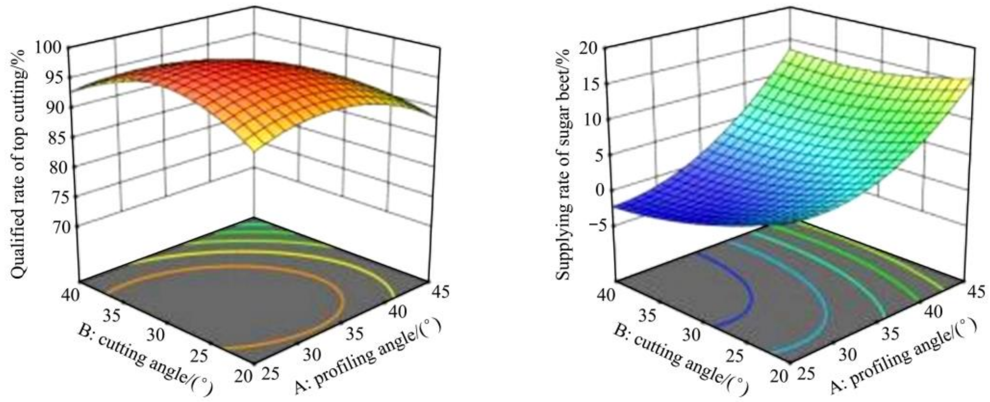
It can be seen from Figure 6a that, within the range of experiment factors, the qualified rate of top cutting top decreases with the increase of cutting angle, and decreases with the increase of cutting angle. The greater the profiling angle, the greater the collusion angle between the profiling board and the sugar beet during the cutting process, resulting in poor profiling effect and the decrease of the qualified rate of top cutting. With the increase of cutting angle, the sliding friction between the sugar beet and the cutting edge increases, and the stability of the sugar beet cutting becomes worse in addition to the decrease of the qualified rate of top cutting.

Table 5 Test factor level coding table

Levels	–1.682	–1	0	1	1.682
Profiling angle/(°)	20.86	25	35	45	49.14
Cutting angle/(°)	15.86	20	30	40	44.14

Table 6 Test scheme and results

No.	Experimental factors		Qualified rate of top cutting y_1/%	Push over rate of sugar beet y_2/%
	Profiling angle	Cutting angle		
1	45	40	70	15
2	35	30	100	0
3	35	30	100	5
4	35	44.14	90	0
5	20.86	30	95	0
6	25	40	90	0
7	35	30	100	0
8	35	30	100	5
9	25	20	95	5
10	35	30	90	5
11	45	20	85	15
12	49.14	30	90	20
13	35	15.86	90	10



a. Qualified rate of top cutting

b. Push over rate of sugar beet

Figure 6 The relationship between factors and indexes

It can be found from Figure 6b that within the range of experimental factors, the qualified rate of top cutting decreased with the increase of the cutting angle and the profiling angle. The larger the cutting angle, the worse the stability of the cutter for top cutting, the smaller the range of sugar beet cut by the cutter, and the higher the qualified rate of the top cutting. On the other hand, the larger the profiling angle of the profiling plate, the worse the passing rate of profiling plate to the beet green head. Besides, the decline of profiling effect leads to the decline of qualified rate of top cutting.

Figure 7 Sugar beet top cutting machine and cutting effect

To obtain the highest qualified rate of top cutting and the lowest push over rate of sugar beet, the objective function was established by the above mentioned two indicators, dumping as indexes.

$$\begin{cases} \begin{cases} y_1 \to \max y_1 \\ y_2 \to \min y_2 \end{cases} \\ \text{s.t.} \begin{cases} 25° \le x_1 \le 45° \\ 20° \le x_2 \le 40° \end{cases} \end{cases} \tag{8}$$

By using the objective optimization, the profiling angle of the profiling plate of the roof cutter was set to 35°, and the cutting angle was taken as 30°. The qualified rate of top cutting y_1 was 95.5%, and the push over rate of sugar beet y_2 was 2.53%,which met the mechanized harvesting standard of sugar beet.

4.3 Experimental verification

In order to verify the correctness of the model, a repeated test was carried out in Qiqihar City, Heilongjiang Province in October 2020.The test parameters cutting angle of the cutting device of 30° and the profiling angle of the profiling plate of 35°. The test results are listed in Table 7.

Field experiments show that the experimental results of the response values y_1 and y_2 are basically consistent with the theoretical optimization values, and the errors are less than 1%. Therefore, the parameter optimization model can be determined to be reliable.

Table 7 Experimental results of evaluation indices at optimal condition

No.	Qualified rate of top cutting/%	Push over rate of sugar beet/%
1	95.7	2.48
2	94.9	2.61
3	94.2	2.83
4	96.2	2.51
5	96.8	2.57
Average values	95.56	2.6
Optimal values	95.5	2.53

Therefore, in the sugar beet top cutting operation, this parameter configuration combination is adopted, namely, the cutting angle of top cutting device is 30°, and the profiling angle of the profiling plate is 35°. At this time, the qualified rate of top cutting is 95.56%, and the push over rate of sugar beet is 2.6%, which meets the quality standard of the mechanized harvesting of beet, and can effectively guide the operation. The comparison of the parameters between 4TSQ-2 top cutting machine before and after optimization is listed in Table 8.

Table 8 Performances comparison of different top cutters

List	Before	After
Engine rated power/kW	≥36.7	≥36.7
Overall dimensions/mm	2300×1200×950	1680×1180×890
Weight/kg	640	490
Row space/mm	500-700	500-700
Productivity/$hm^2 \cdot h^{-1}$	0.6-0.82	0.80-1.10
Pass rate/%	93.6	96.2
Multi-cut rate/%	2.1	1.6
Selling price/Yuan	16 000	12 000

5 Conclusions

To solve the problems of large structure size, high power consumption and high cost of 4TSQ-2 sugar beet top cutting machine, through the analysis of the working process and mechanical theory, the structure of leaves removal device and the key parameters of top cutting device were optimized. The optimized top cutting machine adopted 2 roller shaft leaf removal scheme and inclined profiling plate structure to achieve compact overall structure and low power consumption. The roller speed of the machine was 800 r/min, the forward speed was 0.8 m/s, the profiling angle of the profiling plate was 35°, and the cutting angle was 30°, thereby improving the adaptability of the cutting machine to the spacing and growth state of sugar beet. The upgraded top cutting machine enjoyed a reduction of 30% in terms of structural size, 15% in terms of weight, and 25% in terms of cost. Besides, an increase of 2.6% for the qualified rate of top cutting and a decrease of 0.5% for push over rate of sugar beet were achieved. Moreover, each index met the requirement of sugar beet top cutting harvest. As an improvement against the manual cutting operation, the production efficiency of the optimized sugar beet top cutting machine was 1.04 hm^2/h, and the operating cost per hectare was 375 Yuan. Compared with single manual operation, the production efficiency was increased by 50 times, and the cost was reduced to 1/6.

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