Engenharia Agrícola

ISSN: 1809-4430 (on-line)

www.engenhariaagricola.org.br

Scientific Paper

Doi: http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v42n5e20210219/2022

EXPERIMENTAL AND INFLUENCING FACTORS OF CORN STALK PULLING FORCE

Dapeng Li[1], Haiqing Tian[1*], Yue Sheng[1], Xianguo Ren[1], Jiancheng Zhou[2]

[1*]Corresponding author. Inner Mongolia Agricultural University/ Hohhot, China.
E-mail: hqtian@126.com | ORCID ID: https://orcid.org/0000-0001-5438-5629

KEYWORDS

agricultural machinery, root-soil disturbance, impurity content of feed, response surface method.

ABSTRACT

The harvesting of straw by the flail knife type straw cutting device will cause loose contacts between straw roots and soil, affecting the straw feed's impurity content. In this study, a theoretical analysis of the straw cutting process was conducted to explore the factors influencing the root-soil disturbance. A pulling force test device was designed to test the pulling force of the corn stalk. The response surface method was used to study the effects of various factors on the straw pulling force under different conditions of draft angles (20°, 30°, 40°), soil moisture content (15.23%, 17.62%, 20.47%), and different straw root diameters. The test results showed that the straw pulling force was directly proportional to the straw root diameter and inversely proportional to the soil moisture content. The straw pulling force decreased first and then increased with the increase of the draft angle. According to the established second-order regression model, when the draft angle was 28.5°, the soil moisture content was 20.47%, the root diameter was 22 mm, the minimum pulling force of straw was 189.635N. The test results can provide a reference for the design of straw feed harvester.

INTRODUCTION

Maize is one of the most widely planted and distributed crops globally, and the current top three countries in terms of maize acreage are China, the United States, and Brazil (Dias et al., 2019). According to the China statistical yearbook (2020), the planting area of maize in China is 41.26 million hm^2. The annual yield is 260.67 million tons, which is calculated according to the yield ratio of maize kernel to corn stalk of 1:1.17, and the annual yield of corn stalk is approximately 304.9839 million tons, which is the first crop straw yield (Zhong et al., 2021; Gao et al., 2022). However, the development and utilization rate of corn stalks is not high, and a large number of straw are burned, resulting in environmental pollution and resource waste (Qin et al., 2019). On the other hand, forage resources are not enough to support the needs of animal husbandry, so the development of the feed industry based on corn stalk is a critical way to achieve a virtuous cycle of agricultural and animal husbandry development (Zhang et al., 2017; Ouédraogo et al., 2021).

The straw cutting device is the key to the technology of straw feed harvesters, and the current straw cutting devices mainly include the reciprocating type, the disc knife type, and the flail knife type (Dam et al., 2019; Cui et al., 2015; Igathinathane et al., 2010). The reciprocating knife-type straw cutting device uses the wobble box to convert the rotation of the sprocket into the reciprocating motion of the moving knife to perform the straw cutting operation (Tian et al., 2017; Wang et al., 2020). The disc knife-type straw cutting device uses a set of vertical cutting rollers rotating in opposite directions relying on moving and stationary knives to perform supported cutting operations on straw. The flail knife-type straw cutting device adopts a horizontal cutting roller to carry on the unsupported cutting operation to the straw by the high-speed rotation of the flail knife (Mathanker et al., 2015; Zhao et al., 2017). Among them, the flail knife-type straw cutting device has the advantage of nonaligned operation, can adapt to most areas of operation and is thus more widely used (Azadbakht et al., 2014). North China is the main maize-producing area in China, and its soil type is mainly sandy loam with high sand content (Zhao et al., 2020; Li et al., 2007). The flail

[1] Inner Mongolia Agricultural University/ Hohhot, China.
[2] Inner Mongolia LINGYINONG Technology Development Co., Ltd/Hohhot, China.

Area Editor: Fábio Lúcio Santos
Received in: 11-30-2021
Accepted in: 8-29-2022

knife-type straw cutting device adopts the impacting straw method and is prone to loose straw stubble. Even root stubble is pulled out, leading to the incorporation of more soil into the straw, which seriously affects the palatability of the straw feed.

According to the problems mentioned above, it can be seen that the straw pulling force is an essential technical index in the design process of flail knife-type straw feed harvesters. At present, scholars have also conducted research on the straw pulling force. Zhang et al. (2019) built a test platform for a tobacco stalk pullout crusher. Tan et al. (2013) measured and analyzed the relationship between tobacco stalk pulling force and pulling displacement, tobacco stalk diameter, soil moisture content, and soil compaction. Jia et al. (2019) analyzed the effects of pulling speed, soil moisture content, and other factors on the straw pulling force of onion. Lu et al. (2020) and Li et al. (2013) studied the effects of cotton stalk draft angle, soil conditions, straw diameter, and other factors on cotton stalk pulling force. Wang et al. (2014) tested the pullout forces of rice seedlings and barnyard grass by a universal testing machine controlled by a WDW-5-type microcomputer to obtain the pullout forces of rice seedlings and barnyard grass.

However, there are few studies on the pulling force of corn stalk. In this paper, a field corn stalk pulling force test device was designed to test the pulling force of corn stalks under different soils. Conditions and to explore the influence law of straw diameter, soil moisture content, and angle between straw and ground on the pulling force to provide a reference for the design of flail knife-type straw cutting devices, reduce the disturbance to the soil when harvesting straw, and improve the quality of straw feed.

MATERIAL AND METHODS

Experimental material and conditions

In October 2019, the pulling force test of corn stalk was conducted in Shibuxieqi Village, Hohhot City, Inner Mongolia, China (location: 111°76' E, 40°75' N). The soil in the test area was sandy loam. The row spacing of corn stalks in the test field was 45 mm, the plant spacing was 32 mm, and the corn variety was Xinsheng No. 18. The diameter of the roots of the selected straws ranged from 15-35 mm. To reduce the error caused by the straw stems and leaves, the straw stems and leaves above 250 mm from the ground were cut off during the test. To study the influence of moisture content on the pulling force of straw, several tests were carried out at the same test site before and after rainfall. The soil moisture content and firmness during the test are shown in Table 1.

TABLE 1. Soil moisture content and compaction.

Test period	Soil parameters	
	soil moisture content (%)	soil compaction (kPa)
Before rainfall	15.23	612.4
Day after rainfall	20.47	454.6
Four days after rainfall	17.62	545.3

Force analysis of the straw cutting process

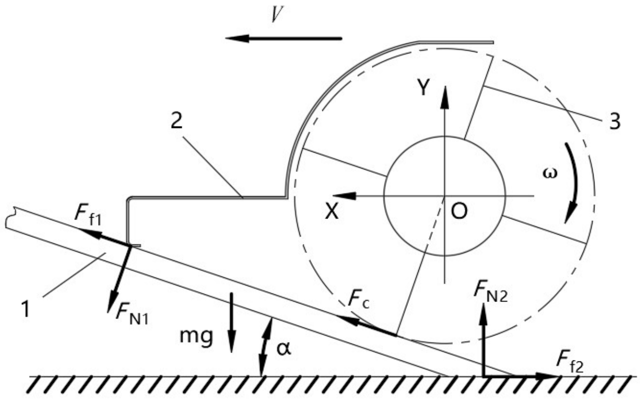


FIGURE 1. Force analysis diagram of the stalk cutting process.

1-corn stalks; 2-machine shell of flail knife-type stem cutting device; 3- flail knife

Figure 1 shows the force situation of the flail knife-type straw feed harvester at the moment of contact between the flail knife and the straw. The forces on the straw upon contract include the pressure (F_{N1}) and friction (F_{f1}) of the machine shell on the straw, the gravity of the straw itself (mg), the cutting force (F_c) of the flail knife, the supporting force (F_{N2}) and the friction force (F_{f2}) of the soil to the straw. The pressure (F_{N1}) is perpendicular to the straw downward, the friction force (F_{f1}) is upward along the inclination direction of the straws, the supporting force (F_{N2}) is vertically upward, and the friction force (F_{f2}) is horizontal to the right. When the flail knife contacts the straw, the line connecting the contact point and the rotation center (O) of the flail knife is perpendicular to the straw. At this time, the cutting force (F_c) direction of the flail knife is left along the surface of the straw, and the angle between the straw and the ground is α.

Force equation in the x-axis direction:

$$F_{f1}\cos\alpha + F_{N1}\sin\alpha + F_c\cos\alpha - F_{f2} = ma_x \tag{1}$$

Force equation in the y-axis direction:

$$F_{f1}\sin\alpha - F_{N1}\cos\alpha - mg + F_c\sin\alpha + F_{N2} = ma_y \tag{2}$$

and,

$$F_{f1} = \mu_1 F_{N1} \tag{3}$$

Where:

m is the total mass of the straw, kg;

g is the acceleration of gravity, m/s^2;

μ_1 is the straw and machine shell friction coefficient;

a_x is the acceleration of the corn stalk in the x-axis direction, m/s^2,

a_y is the acceleration of the corn stalk in the y-axis direction, m/s^2.

After the straw is impacted by the flail knife, the straw root system will generate friction to prevent the root system from being pulled out, and the friction force on the root system can be calculated by the following equation (Cao et al., 2014):

$$F_{f2} = \frac{1}{2}\mu_2 \pi D_r \rho_d (1+\beta) g L^2 \quad (4)$$

Where:

μ_2 is the root-soil friction coefficient;

D_r is the root diameter, cm;

ρ_d is the soil dry density, g/cm^3;

β is the soil moisture content,

L is the depth of root penetration into the soil, cm.

When the straw feed harvester is working, the straw is bent by the machine shell, then the flail knife breaks the straw upon contact. At this time, the motion state of the straw does not change, and the force on the straw is still in the equilibrium state, so the acceleration of the straw at the moment of interrupted is zero. The acceleration of this equilibrium can be expressed as:

$$a_x = 0, \quad a_y = 0 \quad (5)$$

The force (F_{cmax}) required to cause impact damage to the straw can be calculated by the following formula (Srivastava et al., 2006):

$$F_{cmax} = \frac{60000 P_c}{C_f D_c f_c} \quad (6)$$

Where:

P_c is the cutting energy consumption, kW;

C_f is the ratio of average to peak cutting force;

f_c is the cutting frequency, cuts/min,

D_c is the depth of the flail knife into the straw, mm.

When the straw is cut off, F_{cmax}=F_c, and Formulas (1)~(6) can be obtained:

$$F_{N1} = \frac{\mu_2 \pi D_r \rho_d (1+\beta) g L^2 C_f D_c f_c - 120000 P_c \cos\alpha}{2(\sin\alpha + \mu_1 \cos\alpha) C_f D_c f_c} \quad (7)$$

$$F_{N2} = \frac{(\cos\alpha - \mu_1 \sin\alpha)\mu_2 \pi D_r \rho_d (1+\beta) g L^2 C_f D_c f_c - 120000 P_c}{2(\sin\alpha + \mu_1 \cos\alpha) C_f D_c f_c} + mg \quad (8)$$

To pull out the straw from the soil, it is necessary to overcome the supporting force (F_{N2}) of the soil to the straw. Equation (8) shows that the supporting force (F_{N2}) of the soil to the straw is related to the straw mass (m), the root diameter (D_r), the depth of root penetration into the soil (L), the soil dry density (ρ_d), the soil moisture content (β), the cutting energy consumption (P_c), the frequency of the peak cutting force occurrence (C_f), the cutting frequency (f_c), the depth of the flail knife into the straw (D_c), and the angle (α) between the straw and the ground when the flail knife is cutting the straw. The depth (D_c) of the flail knife into the straw is affected by the diameter of the straw and the angle (α) between the straw and the ground. Since straw mass (m), root diameter (D_r), and depth of root penetration into the soil (L) are related to plant types (Jiang et al., 2014). Moreover, cutting energy consumption (P_c), frequency of peak cutting force occurrence (C_f), and cutting frequency (f_c) are related to cutting devices. Therefore, it is necessary to consider the angle between the straw and the ground, the diameter of the straw, and the soil moisture content to study the influence of straw pulling force on root-soil movement.

Test device and methods

From the force analysis of the corn stalk cutting process, it can be seen that the angle between the stalk and the ground is a significant factor that affects the pulling force of the straw. To reduce the angle error generated during the pulling of the straw, a straw pulling force test device is designed in this paper. The device uses a wire rope traction method to test the pulling force of the corn stalk, which adjusts the pulling angle by adjusting the distance between the support frame and the straw. During the test, one end of the steel wire is connected to the corn stalk, the other end is connected to the hand crank pulley through a movable pulley, and a tension sensor is connected between the wire ropes, as shown in Figure 2. The pull-out force test of the straw is carried out by rotating the hand crank pulley, and the digital display push-pull gauge is set to peak mode to store and record the maximum pulling force. The HF-5KN digital display push-pull gauge external sensor produced by Jingcheng Instrument Company Ltd, as shown in Figure 3, has a rated load of 0～5000 N, an accuracy of 1 N, and an indication error that does not exceed ±0.5%.

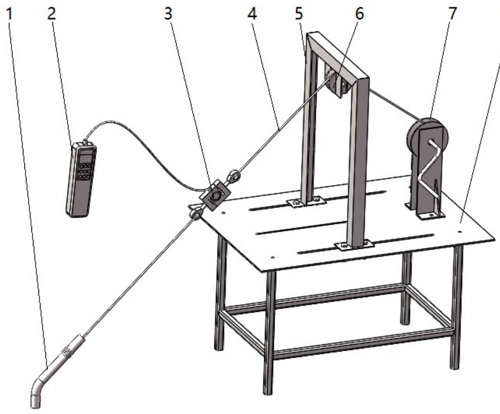


FIGURE 2. Three-dimensional schematic diagram of the straw pulling force test device.
1-corn stalks; 2-digital display push-pull gauge; 3-pulling force sensor; 4-steel wire rope; 5-support frame; 6- fixed pulley; 7-hand crank pulley; 8-frame.

FIGURE 3. HF-5KN digital display push-pull gauge.
1-feeding hopper; 2-hammer; 3-sieve frame and sieve; 4-outlet; 5-frame; 6-motor; 7-grinding chamber

The draft angle θ can be determined by [eq. (9)], as shown in Figure 4.

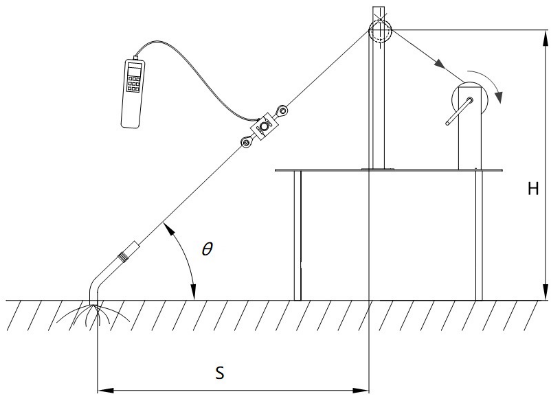


FIGURE 4. Schematic diagram of the draft angle.

According to the geometric relationship of Figure 4:

$$\theta = \arctan\frac{H}{S} \tag{9}$$

Where:

θ is the draft angle, °;

S is the horizontal distance between the corn stalk and the tangent point of the fixed pulley, mm;

H is the height of the wire rope and the tangent point of the fixed pulley from the ground, mm.

The height of the tangent point between the steel wire rope and the fixed pulley of the straw pulling force test device from the ground is a fixed value; the S value is adjusted by altering the distance between the support frame and the straw to change the draft angle. During the test, the straw was winded and clamped by a steel wire rope at a distance of 50 mm from the ground, the draft angle was adjusted, and the hand crank pulley was turned to pull out the straw. The maximum pulling force data were recorded and stored by the digital display push-pull gauge and the test device, as shown in Figure 2.

Test design

According to the force analysis of the corn stalk cutting process, the draft angle, soil moisture content, and root diameter of the corn stalk were selected as the experimental influencing factors to test the straw pulling force. Based on the single factor test results analysis, the appropriate draft angle and root diameter were selected, and the three factors and three levels of response surface optimization experiments were designed by Design-Expert 8.0 software. The response surface test factors and levels are shown in Table 2.

TABLE 2. Response surface test factors and levels.

Level	Factor		
	Draft angle (°)	Soil moisture content (%)	Straw diameter (mm)
1	20	15.23	22
2	30	17.62	24
3	40	20.47	26

RESULTS AND DISCUSSION

Variation curve of the single straw pulling force

In the experiment, the tension sensor was connected to the PC terminal to receive data and analyze the change rule of the single corn stalk pulling force with time. Figure 5 shows that with increasing pulling time, straw root system displacement occurs, and the straw pulling force gradually increases until it reaches the maximum peak. The friction cohesion between the root and soil gradually decreases, and then the pulling force decreases rapidly.

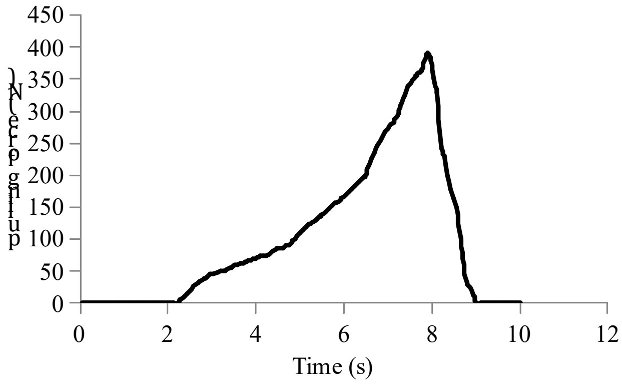


FIGURE 5. Pulling force–time curve.

Effect of straw root diameter change and draft angle change on pulling force

When the soil moisture content was 15.23% and the draft angles were 20°, 30°, 40°, and 50°, twenty straws with a root diameter range of 19-35 mm were selected, and their maximum pulling force was measured. The relationship between the maximum pulling force and the diameter of the straw root under different draft angles is shown in Figure 6.

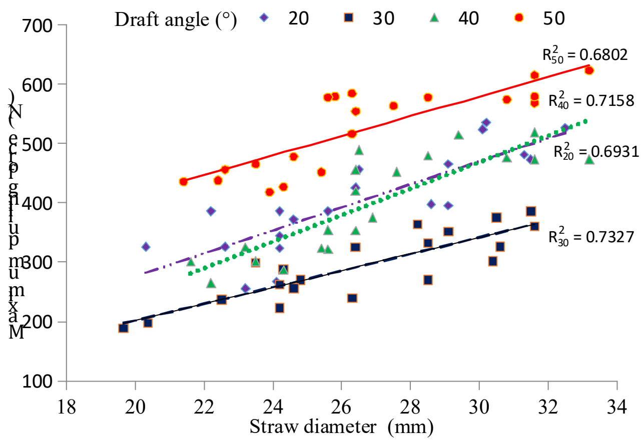


FIGURE 6. The fitting curve of maximum pulling force - straw root diameter at different draft angles.

FIGURE 6 shows that at the same draft angle, the maximum pulling force of straw increases with increasing straw root diameter, and the maximum pulling force has a linear relationship with the root diameter. The trend line in the figure is fitted by linear regression, and the linear regression equations are as follows:

$$y_{20^\circ} = 19.363x - 110.89 \quad (10)$$

$$y_{30^\circ} = 13.98x - 77.511 \quad (11)$$

$$y_{40^\circ} = 22.308x - 200.63 \quad (12)$$

$$y_{50^\circ} = 16.44x + 85.673 \quad (13)$$

Where:

y is the maximum pulling force during the pulling process of the straw, N,

x is the diameter of the straw root, mm.

The correlation coefficients of the equations are $R^2_{,20^\circ}$ =0.6931, $R^2_{,30^\circ}$=0.7327, $R^2_{,40^\circ}$=0.7158, and $R^2_{,50^\circ}$=0.6802. According to the correlation coefficient standard, since $0.3<R^2_{,50^\circ}< R^2_{,20^\circ}<R^2_{,40^\circ}<R^2_{,30^\circ}<0.8$, the root diameter of straw is moderately positively correlated with the pulling force.

Analysis of the maximum pulling force of the straw at different pulling angles is shown in FIGURE 6. The diameter range of the six straw roots was 24-26 mm, and the average value of the maximum pulling force was calculated. When the draft angles were 20°, 30°, 40°, and 50°, the average maximum straw pulling force of the six straws was 346.83 N, 256.67 N, 343.33 N, and 488.67 N, respectively, as shown in FIGURE 7.

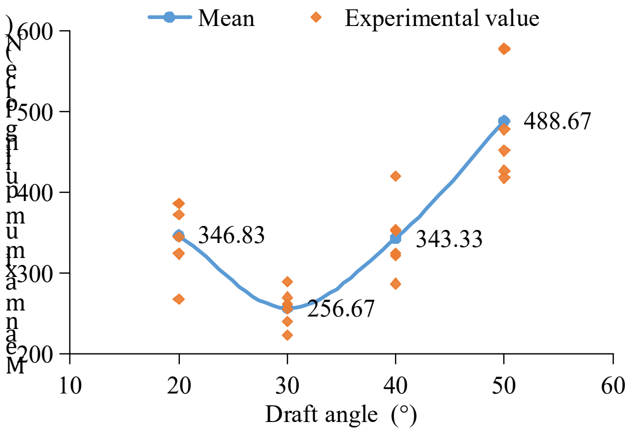


FIGURE 7. The mean maximum pulling force at different draft angles.

It can be seen from FIGURE 6 and FIGURE 7 that the process of the maximum straw pulling force changing with the draft angle is mainly divided into two stages. The first stage is the draft angle between 20° and 30°, and the maximum straw pulling force decreases with increasing draft angle. The second stage is the draft angle between 30° and 50°, and the maximum pulling force increases with the rise of the draft angle.

Compared with the vertical pull-out, the root-soil interaction force is smaller due to unilateral root pulling force when inclined pull-out, and the pulling force decreases when the inclination angle decreases. When the draft angle is too small, the horizontal resistance increases, and the required pulling force increases (Li et al., 2013). Therefore, the appropriate cutting angle should be selected when designing a flail knife-type straw cutting device to avoid the excessively high impurity rate of straw feed caused by root-soil separation, thereby affecting the quality of straw feed.

Response surface test results and analysis

During the test, corn stalks whose root diameter error did not exceed 1 mm were selected as the test object in the field. Moreover, each group was repeated six times, and the average value was taken as the test data. Design-Expert 8.0 software was used for the multifactor Box–Behnken test; the results of this test are shown in Table 3.

TABLE 3. Box–Behnken test design and results.

Number	*A* (°)	*B* (%)	*C* (mm)	*F* (N)
1	30	17.62	24	258.36
2	30	15.23	26	367.00
3	30	17.62	24	280.67
4	20	17.62	26	429.33
5	30	17.62	24	270.63
6	20	20.47	24	317.50
7	30	15.23	22	309.50
8	20	17.62	22	388.83
9	40	20.47	24	406.50
10	30	20.47	26	258.17
11	40	15.23	24	598.33
12	30	17.62	24	289.23
13	40	17.62	22	439.83
14	30	20.47	22	217.67
15	40	17.62	26	522.83
16	30	17.62	24	234.57
17	20	15.23	24	523.67

A: Draft angle; *B*: Soil moisture content; *C*: Straw diameter; *F*: Pulling force.

According to the results of the Box–Behnken test, a quadratic regression model of the draft angle (*A*), soil moisture content (*B*), straw diameter (*C*), and straw pulling force (*F*) is established, and its quadratic polynomial equation is obtained as follows:

$$F = 270.38 + 38.18A - 77.93B + 28.09C + 3.61AB + 10.63AC - 4.31BC + 175.96A^2 + 23.32B^2 + 2.55C^2 \quad (14)$$

As shown in Table 4, the variance analysis results of the model show that the soil moisture content (*B*) and the quadratic term of the draft angle (A^2) have a very significant effect on the pulling force (*F*), the draft angle (*A*) and the straw diameter (*C*) have a significant effect on the pulling force (*F*), and the relationship between the pulling force (*F*) and the regression equation is extremely significant. The *P value* of the lack of fit is 0.1218>0.05, which indicates that the equation fits well. The decision coefficient R^2 and correction decision coefficient $R^2_{,adj}$ in the table are both close to 1, indicating that the fitting equation is highly reliable; the test precision is 15.9360, indicating that the model has good accuracy (Tao et al., 2020; Unal, 2016).

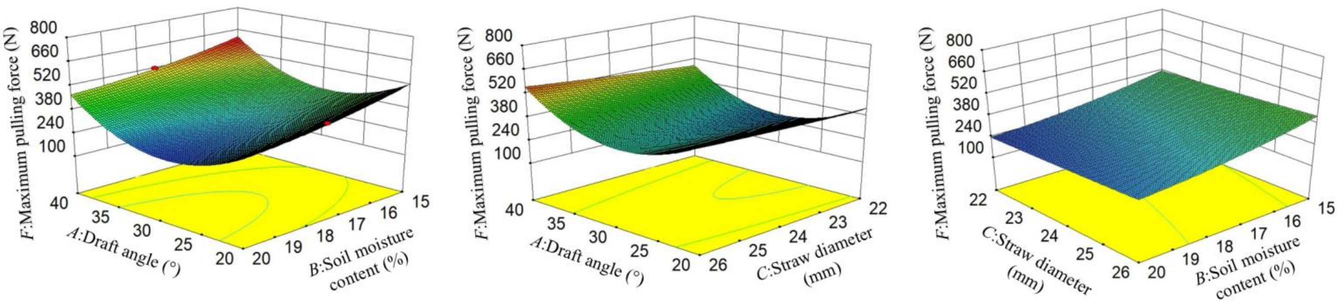
TABLE 4. Analysis of variance of the maximum pulling force regression equation.

Source of variance	Sum of squares	Degree of freedom	Mean square	*P*-value	Significance
Model	1.979E+005	9	21984.16	0.0002	***
A	11478.27	1	11478.27	0.0109	*
B	45013.22	1	45013.22	0.0003	***
C	6213.79	1	6213.79	0.0393	*
AB	57.39	1	57.39	0.8149	ns
AC	451.56	1	451.56	0.5173	ns
BC	81.76	1	81.76	0.7801	ns
A^2	1.304E+005	1	1.304E+005	<0.0001	***
B^2	2708.32	1	2708.32	0.1389	ns
C^2	27.36	1	27.36	0.8715	ns
Residual	6800.75	7	971.54		
Lack of fit	4979.56	3	1659.85	0.1218	ns
Pure error	1821.19	4	455.30		
Total	2.047E+005	16			
R^2=0.9668；$R^2_{,adj}$=0.9240；Adeq precision=15.9360					

***: Significant at 0.1% probability (p<0.001); **: Significant at 1% probability (p<0.01); *: Significant at 5% probability (p<0.05); ns: non-significant (p>=0.05);

Optimization of the regression model

The response surface diagram was drawn by Design-Expert 8.0 software to analyze the influence of each factor on the pulling force, and by fixing one factor, the influence law of the other two factors on the pulling force was investigated. The results are shown in FIGURE 8. It can be seen from FIGURE 8a and FIGURE 8b that with the increase in the draft angle, the maximum pulling force decreases first and then increases (Dai, 2015). It can be seen from FIGURE 8a and FIGURE 8c that with the increase in soil moisture content, the maximum straw pulling force gradually decreases, which is mainly due to the decrease in the friction coefficient between roots and soil caused by the lubrication of water (Hu, 2018). It can be seen from FIGURE 8b and FIGURE 8c that with the decrease in straw root diameter, the maximum straw pulling force gradually decreases (Ji et al., 2017).



a. Interaction between *A* and *B* b. Interaction between *A* and *C* c. Interaction between *B* and *C*

FIGURE 8. Optimization of parameter groups based on the response surface method.

Optimal parameter solution and verification

In the Design-Expert 8.0 software optimization module, the range of test conditions and the objective function were limited, as shown in Equation 15, and the minimum tensile force value (*F*) was selected as 189.635 N, the draft angle was 28.5°, the soil moisture content was 20.47%, and the straw diameter was 22 mm. To test the accuracy of the model prediction, the response surface optimization results were verified by experiments. Due to the accuracy limitation of the test conditions, the optimal conditions were set as a draft angle of 28.5°, a soil moisture content of 20.5%, and a straw diameter of 22 mm. Under these conditions, five repeated tests were carried out; the results showed that the average pulling force was 178.15 N, and the error with the theoretical prediction was 6.05%, indicating that the model was reliable.

$$\begin{cases} \text{Min}F \\ 20 \le A \le 50 \\ 15.23 \le B \le 20.47 \\ 22 \le C \le 26 \end{cases} \quad (15)$$

CONCLUSIONS

Through the force analysis of the straw cutting process of the flail knife-type stem cutting device, it is concluded that the angle between straw and ground, soil moisture content, and straw root diameter will affect the straw root-soil interaction. The straw pulling force was directly proportional to the straw root diameter and inversely proportional to the soil moisture content. The straw pulling force first decreased and then increased with increasing draft angle. When the draft angle was 28.5°, the soil moisture content was 20.47%, the root diameter was 22 mm, and the minimum pulling force of straw was 189.635 N.

ACKNOWLEDGMENTS

The research was funded by the Inner Mongolia Special Project for Transformation of Scientific and Technological Achievement (No. 2019CG034), the National Natural Science Foundation of China (No. 51765055).

REFERENCES

Azadbakht M, Asl RA, Zahedi TK (2014) Energy Requirement for Cutting Corn Stalks (Single Cross 704 Var.). World Academy of Science, Engineering and Technology International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering 8(5): 479-482.

Cao YS, Chen LH, Liu XG, Yang YJ (2014) The influence factors of plant root-soil interface friction. Tribology 34(05): 482-488. DOI: https://doi.org/10.16078/j.tribology.2014.05.002

Cui M, Zhang DL, Bu LG, Jia CY, Wang LX (2015) Comparison of corn stalk cutting device. Agricultural Engineering 5(03): 9-12.

Dai ZW (2015) Design and research on cotton stalk drawing institutions of pull-out cotton stalk mechanism. Master's Thesis, Changsha, Hunan Agricultural University.

Dam VV, Cong NH, Tuan NQ (2019) Parameter optimization of cutting force in corn stalk chopping. International Journal of Mechanical and Production Engineering Research and Development 9(3): 655-664.

Dias FS, Rezende WM, Zuffo LT, Caixeta DG, Massensini MA, Ribeiro Junior JI, DeLima RO (2019) Agronomic Responses of Maize Hybrids to Row Spacing and Plant Population in the Summer and Winter Seasons in Brazil. Agronomy Journal 111(6): 3119–3129. DOI: https://doi.org/10.2134/agronj2018.12.0765

Gao ZP, Ni JB, Li NN (2022) Research on the quantity and utilization of crop straw resources in China. Journal of Agricultural Mechanization Research 44(04): 1-6+25. DOI: https://doi.org/10.13427/j.cnki.njyi.2022.04.001

Hu SH (2018) Pull-out study of soil-reinforcement in the roots of trees and shrubs. Master's Thesis, Changsha, Changsha University of Science & Technology.

Igathinathane C, Womac AR, Sokhansanj S (2010) Corn stalk orientation effect on mechanical cutting. Biosystems Engineering 107(2): 97-106. DOI: https://doi.org/10.1016/j.biosystemseng.2010.07.005

Ji XD, Chen LH, Zhang A (2017) Anchorage properties at the interface between soil and roots with branches. Journal of Forestry Research 28: 83–93. DOI: https://doi.org/10.1007/s11676-016-0294-2

Jiang DL, Wang HW, Jiang J, Shi ZS, Li FH, Lv ZY, Li K (2014) Correlations between characters of roots and those of aerial parts of maize in different plant type. Seed 33(07): 94-96. DOI: https://doi.org/10.16590/j.cnki.1001-4705.2014.07.061

Jia ZB, Hou JL, Liu JW, Shao W, Wu YQ, Niu ZR (2019) Design and experiment of system for pulling force of scallion. Journal of Agricultural Mechanization Research 41(02): 109-133. DOI: https://doi.org/10.13427/j.cnki.njyi.2019.02.020

Li CH, Wang XX, Wang Q, Hao SP (2007) Effect of different textural soils on rhizosphere microorganisms and enzyme activities in maize. Scientia Agricultura Sinica 40(2): 412-418.

Li Y, Zhang GZ, Zhou Y, Ji WF, Li ZD, Zhang YX, Zai KY (2013) Design and field experiment of drawing resistance measurement system for cotton stalk. Transactions of the Chinese Society of Agricultural Engineering 29(18): 43-50. DOI: https://doi.org/10.3969/j.issn.1002-6819.2013.18.006

Lu YX, Wei M, Li WM, Xue LH, Yang T, Shi NQ, Zhang ZY (2020) Influencing factors and experimental study on cotton stalk pullout force. Journal of Agricultural Mechanization Research 42(03): 153-158. DOI: https://doi.org/10.13427/j.cnki.njyi.2020.03.026

Mathankera SK, Grifta TE, Hansenab AC (2015) Effect of blade oblique angle and cutting speed on cutting energy for energycane stems. Biosystems Engineering 133: 64-70. DOI: http://dx.doi.org/10.1016/j.biosystemseng.2015.03.003

National Bureau of Statistics. China Statistical yearbook 2021. China Statistics Press.

Ouédraogo K, Zaré A, Korbéogo G, Ouédraogo O, Linstädter A (2021) Resilience strategies of West African pastoralists in response to scarce forage resources. Pastoralism 11(1): 1-14. DOI: https://doi.org/10.1186/s13570-021-00210-8

Qin C, Bi YY, Gao CY, Wang YJ, Zhou K, Wang Y (2019) Management and effect of straw burning prohibition in China. Journal of China Agricultural University 24(07): 181-189. DOI: https://doi.org/10.11841/j.issn.1007-4333.2019.07.21

Srivastava AK, Goering CE, Rohrbach RP, Buckmaster DR (2006) Engineering principles of agricultural machines. 2nd ed. ASAE Publication

Tan Q, Sun SL, Li JZ, Chen K, Gao XY, Quan W (2013) Relationship between harvest tobacco stem pullout force and related factors. Journal of Hunan Agricultural University (Natural Sciences) 39(03): 319-322. DOI: https://doi.org/10.3724/SP.J.1238.2013.00319

Tao HY, Cao W (2020) Principle and application of polynomial regression and response surface analysis. Statistics & Decision 36(08): 36-40. DOI: https://doi.org/10.13546/j.cnki.tjyjc.2020.08.007

Tian KP, Li XW, Zhang B, Chen QM, Shen C, Huang JC (2017) Design and test research on cutting blade of corn harvester based on bionic principle. Applied Bionics and Biomechanics 2017: 6953786. DOI: https://doi.org/10.1155/2017/6953786

Unal O (2016) Optimization of shot peening parameters by response surface methodology. Surface & Coatings Technology 305: 99-109. DOI: https://doi.org/10.1016/j.surfcoat.2016.08.004

Wang JW, Tao GX, Liu YJ, Pan ZW, Zhang CF (2014) Field experimental study on pullout forces of rice seedlings and barnyard grasses for mechanical weed control in paddy field. International Journal of Agricultural & Biological Engineering 7(6): 1-7. DOI: https://doi.org/10.3965/j.ijabe.20140706.001

Wang Y, Yang Y, Zhao HM, Liu B, Ma JT, He Y, Zhang YT, Xu HB (2020) Effects of cutting parameters on cutting of citrus fruit stems. Biosystems Engineering 193: 1-11. DOI: https://doi.org/10.1016/j.biosystemseng.2020.02.009

Zhang DB, Shu CS, Zhang YC, Zhang YF, Wei JY (2019) Improved design and parameter optimisation of the transmission mechanism of a tobacco stalk pull-out crusher. The Journal of Engineering 2019(13): 37-44. DOI: https://doi.org/10.1049/joe.2018.8983

Zhang G, Lu F, Zhao H, Yang GB, Wang XK, Ouyang ZY (2017) Residue usage and farmers' recognition and attitude toward residue retention in China's croplands. Journal of Agro-Environment Science 36(05): 981-988. DOI: https://doi.org/10.11654/jaes.2016-1505

Zhao JL, Huang DY, Jia HL, Zhuang J, Guo MZ (2017) Analysis and experiment on cutting performances of high-stubble maize stalks. International Journal of Agricultural and Biological Engineering 10(1): 40-52. DOI: https://doi.org/10.3965/j.ijabe.20171001.2589

Zhao QY, Xu SJ, Zhang WS, Zhang Z, Yao Z, Chen XP, Zou CQ (2020) Spatial regional variability and influential factors of soil fertilities in the major regions of maize production of China. Scientia Agricultura Sinica 53(15): 3120-3133. DOI: https://doi.org/10.3864/j.issn.0578-1752.2020.15.012

Zhong L, Li GY, Chen GY, Wang YZ, Chen HY, Wu WZ, Li JL, Song YJ, Yan BB (2021) Research progress on the distribution characteristics of crop straws and the preparation and application of straw carbon-based fertilizers in China. Journal of Agricultural Resources and Environment 1-15. DOI: https://doi.org/10.13254/j.jare.2021.0070