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Analysis Of The Causes Of Cutter Loss In Mechanized Oilseed Rape Harvesting And Experimental Research

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Abstract:
Aiming at the problem of high loss of rapeseed mechanized harvesting, this paper analyzes the biological properties and physical properties of rapeseed, and gets that the main part of rapeseed generating loss is the angular fruit layer, and the main form is the angular fruit blowing up and seed dropping, and the main reason is that the key parts of the cutting table have the flapping effect on the angular fruit layer as well as the vibration effect on the rapeseed during the work of the harvester; The key components of the cutting table were analyzed in terms of their working mechanism to understand the process of each component's influence on oilseed rape harvesting, and the key influencing factors were selected for field tests to obtain the significance of each factor's influence on the loss rate of the longitudinal cutter. To provide reference for reducing mechanized harvesting loss of oilseed rape, adjusting operating parameters of harvester, and optimizing structural design of key components of cutting platform.

Keywords: *oilseed rape; harvester cutter; loss rate.*

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I. Introduction

Oilseed rape as an important oilseed crop, its mechanized harvesting methods can be divided into two-stage harvesting and joint harvesting, two-stage harvesting is the first oilseed rape cut down for drying, drying after manual threshing and picking up harvesting methods, this way of consuming manpower and material resources, and the rate of loss is high, the operating time is long. Therefore, joint harvesting is more suitable for the development of oilseed rape mechanization, joint harvesting is the harvester one-time completion of the cutting, threshing, separating and cleaning process of operation, impurities can be discharged directly out of the machine, to get a low impurity rate of crop seeds[1].

At present, compared with rice, wheat, corn, the degree of mechanization of oilseed rape is still low, restricting its development is the main reason for the high harvest loss, in order to reduce the harvest loss, improve the quality of harvesting machine operations, research scholars at home and abroad from the agro-mechanical and agro-technical aspects of the research. On the agronomic side, the biological characteristics of oilseed rape itself, such as stalks and angiosperms, are analyzed to find the biological characteristics suitable for mechanized operations; On the farm machinery side, losses are reduced by adding longitudinal cutters on both sides or one side of the rice-wheat cutting table to reduce splitting losses, lengthening the cutting table to collect the fallen grains, and adjusting the speed and position of the paddle wheel [2-5].

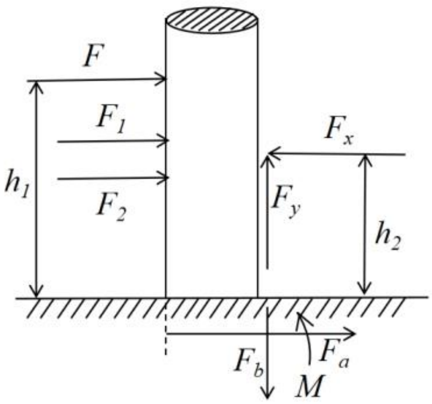
II. Oilseed rape characterization

Oilseed rape belongs to the cruciferous family of herbaceous plants with thick and well-branched stalks at maturity, and the harvesting process produces a large amount of grain loss due to vibration [6]. Therefore, analyzing the biological characteristics of oilseed rape and the stresses on its harvesting process is essential for the study of damage reduction techniques.

Biological properties of rape stalks

Carry out oilseed rape harvesting operations, oilseed rape stalks are cut when one end is fixed to the ground, one end of the free and unfixed state, the cross-section of the stalks as a circle, the stalks are considered to be cylindrical, and the force is shown in Figure 2.1. Keeping the static state of the stalk by the impact of the cutter, will produce the opposite direction of the inertia force F. The shear force of the cutter can be decomposed into the horizontal direction component force F_x and the vertical direction component force F_y, the fixed knife support force F_1, F_2, and the ground fixation force on the stalk can be decomposed into the horizontal direction component force F_a, the vertical direction component force F_b, and the moment M [7], and its force equilibrium equations are:

$$\begin{cases} F_x - F_a - F - F_1 - F_2 = 0 \\ F_y - F_b = 0 \\ F_x h_1 - F h_2 - M = 0 \end{cases} \tag{2-1}$$



F - Inertia force; F_x - Horizontal force of shear; F_y - Vertical force of shear;

F_1, F_2 - Fixed knife support force; F_a - Ground-fixed horizontal force;

F_b - Ground-fixed vertical force; M - Ground fixing moment;

h_1 - Distance from the ground to the center of mass of the stalk; h_2 - Cutting height

Figure 2.1 Stress diagram of rapeseed stem

Physical characteristics of rape stalks

The plant height, plant type, branching characteristics, water content of stalks and carob, maturity and harvesting period of oilseed rape all have an important influence on the mechanized harvesting effect. Therefore, both the physical properties of oilseed rape and the biology of oilseed rape are important to study.

(1) oilseed rape plant type, plant height and branching

Due to the differences in variety types, growing environment, cultivation methods, geographic location and field management, oilseed rape varies greatly in plant type, plant height and branching [8]. Taking the oilseed rape "Qingyou 331" in Weiyuan Town, Mutual Assistance County, Haidong City, Qinghai Province as an example, its plant height, plant type and branching are shown in Table no 1.

Table no 1 : Plant type, plant height and branch situation

Parameter	Unit(of measure)	Numeric value
Oilseed rape variety	/	Qingyou331
Plant height	cm	163
Minimum branch height	cm	50
Number of primary branches	pcs	8
Number of secondary branches	pcs	5
Number of tertiary branches	pcs	1
Carpophore thickness	cm	62
Canopy diameter	cm	47

(2) Carob and Seed

The yield of oilseed rape is made up of the number of angiosperms per acre, the number of grains per angiosperm and the grain weight, which is calculated by the formula: oilseed rape yield (kg/acre) = Number of horn beams per acre × Number of grains per horn × Thousand grain weight (g). One of the factors that has the greatest impact on yield is the number of angular fruits per acre, which can vary from 1 to 5 times under different cultivation conditions. In this study, five mature oilseed rape plants were collected randomly from different areas of the experimental field and the angiosperms and seeds are shown in Table no 2.

Table no 2 : Number of rape carobs and number of seeds

Serial number	Number of angiosperms per plant /(pcs)	Number of grains per angiosperm /(grains)
1	316	28
2	297	31
3	308	22
4	322	25
5	288	27
Average value	306.2	26.2

(3) Moisture content of stems and grains

Rapeseed grows from green ripening stage to finish ripening stage, the water content of stalks and seeds is gradually reduced, these two factors are important indexes to test whether rapeseed is at the right time for harvesting, and the level of water content directly affects the quality of the harvester's harvest. When the moisture content is high, the moisture in the stalks is released during the striking and crushing process of the threshing drum of the harvester, and the impurity clusters formed by sticking together with dust and fine impurities are easy to be blocked on the surface of the clearing sun, which increases the clearing loss. Therefore, before harvesting operations, the moisture content of the stalks and seeds should be checked to see if they meet the harvesting requirements, and according to the oven-drying method, the moisture content is calculated as follows: (Wet weight－Dry weight)/Wet weight × 100%. The stalk moisture content and seed moisture content measured before harvest of the experimental oilseed rape in this study were 17% and 12%, respectively, which already met the harvest requirements.

III. Key components of the header

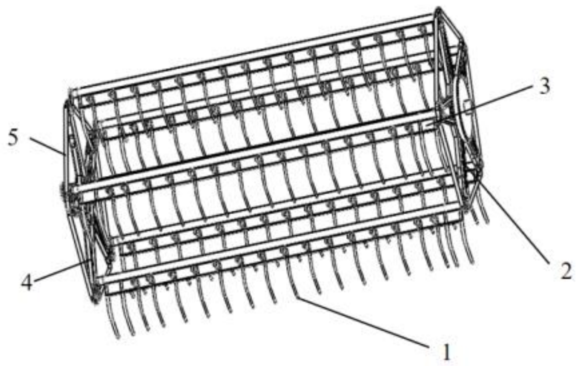
Paddle wheel

(1) Role of the paddle wheel

The main function of the pivoting wheel is to pivot the stalks of the crop to be cut towards the cutter, and at the same time to pick up the fallen crop and push it towards the cutting table, so as to make the cutter convenient for the cutting work and to prevent the cutting table from blocking the knife phenomenon [9-10]. In order to adapt to different states of crops, the horizontal position and vertical position of the paddle wheel relative to the cutting platform and the paddle wheel rotation speed can be adjusted, and when harvesting wheat and other crops growing upright, the paddle wheel spring teeth are vertically downward to avoid the loss of the spring teeth on the crop spike head striking; When harvesting crops with inclined seed pods, such as oilseed rape, the bullet teeth can be adjusted to a suitable inclination angle to avoid losses from insertion of the bullet teeth into the angular fruit.

(2) Principle of operation of the paddle wheel

At present, the combine harvester harvesting rice, wheat, oilseed rape and other crops mostly use eccentric paddle wheel, its structure sketch shown in Figure 3.1. It mainly includes eccentric wheel, elastic teeth, wheel axle and other components.



1. Bullet teeth 2. Eccentric wheel 3. Wheel axle 4. Spokes 5. Tension bar

Figure 3.1 Schematic diagram of the structure of the plucking wheel

The eccentric paddle wheel has a simple structure, complex principle, high adaptability, simple maintenance and high reliability level, and its working principle is shown in Figure 3.2. B is the spoke plate on the shaft of the fixed toggle wheel, B1 is the eccentric ring for adjustment, A-A is the pipe shaft, fixing the elastic teeth K. The whole eccentric wheel consists of 5 sets of parallel four-link mechanism OO1A1A. During the working process of the paddle wheel, the eccentric ring B1 can rotate around the axis O. When the position of the eccentric ring B1 is adjusted, the relative position of OO1 and the axis OA and the angle of the crank AA1 will be changed accordingly, but the AA1 and OO1 always remain parallel, and the elastic teeth K always maintain the adjusted inclination angle, and the inclination angle adjustment range is generally from vertically downward to 30°tilted forwards or backwards [11].

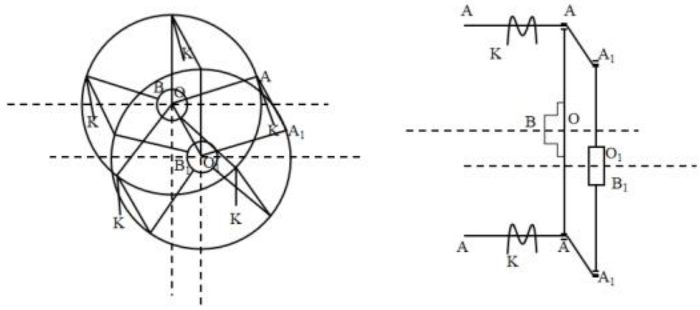


Figure 3.2 Working principle diagram of eccentric reel

Cutter

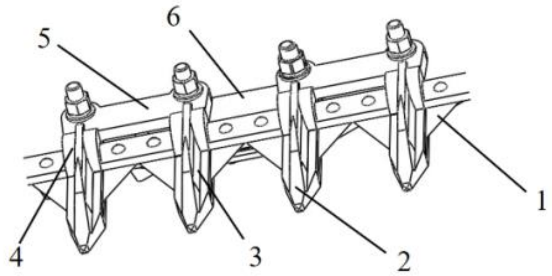
The cutter is one of the important general-purpose parts on the harvester, and its cutting performance directly affects the harvesting quality of the harvester, so the agricultural technology requires that the cutter must meet the following requirements:

(1) Do not miss cuts or block knives. Leakage and blockage will increase crop loss and reduce the quality of harvesting. Therefore, to avoid the occurrence of these two harvesting conditions is to ensure that the harvesting operation is carried out smoothly important conditions.

(2) Simple structure and strong adaptability. The cutter is a perishable part, the field harvest environment is complex, the soil stones and other hard objects will wear the blade; hard objects and blade collision process will cause blade loosening, bending, edge guards, blade riveting device, etc. have some damage. Therefore, the cutter is required to have a simple structure, easy to manufacture, and to have good versatility and adaptability.

(3) Less power consumption and less vibration. Less power consumption of the cutter is to reduce the power consumption of the whole machine, reduce the supporting power of the premise. Small vibration can effectively reduce crop harvesting losses, for rape a kind of crops, after the completion of ripening period of the fruit is easy to explode, the vibration amplitude and frequency of harvesting losses for the impact is very large.

Currently widely used on the combine harvester cutting table is the reciprocating cutter, mainly composed of reciprocating movement of the cutter and fixed immobile support part, its structure sketch shown in Figure 3.3.



1. Dynamic blade 2. Fixed blade 3. Presser 4.Guard 5. Guard beam 6. Toolholder

Figure 3.3 Schematic diagram of the structure of the reciprocating cutter

According to the installation distance between the fixed blade and the moving blade, the reciprocating cutter can be divided into three types: standard, low-cutting type and double-pitch stroke type, whose main difference lies in the relationship between the straight-line motion stroke s of the moving blade and the installation spacing t between adjacent moving blades and the installation spacing t0 between adjacent fixed blades. Most of the cutter blades currently used in combine harvesters are standardized for the installation of a Standard II reciprocating cutter, as shown in Figure 3.4, with a structural dimension relationship of s=t=t0=76.2 mm [12].

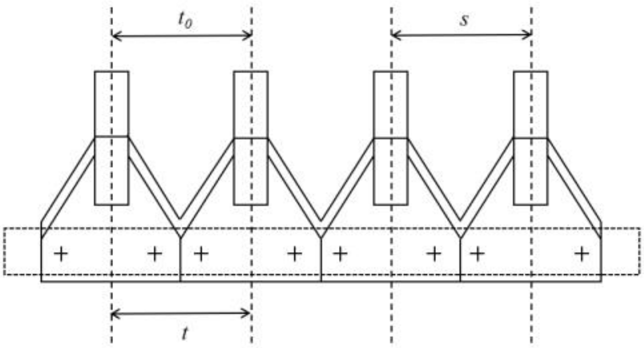


Figure 3.4 Standard Type II reciprocating cutter

Cutting machine work knife on the one hand relative to the machine for reciprocating motion, on the one hand with the machine forward to do straight-line motion, cutter trajectory for the synthesis of these two movements [13]. The relationship between the speed of the cutter and the forward speed of the machine can be expressed in terms of the feed distance, i.e., the distance the machine advances in the time it takes for the cutter to complete one stroke, as in Equation 3-1.

$$H = v_m \frac{60}{2n} = \frac{30 v_m}{n}$$

or $$H = \frac{\pi v_m}{\omega} \qquad (3\text{-}1)$$

Where: V_m - Machine forward speed, m/s;

n - Cutter crank speed, r/min;

ω - Cutter crank angular speed, rad/s.

The size of the cutter feed distance directly affects the scanning area of the moving blade on the ground, which has a greater impact on the performance of the cutter. Figure 3.5 shows the cutting diagram of the standard cutter, from the figure, it can be seen that the crop within the trajectory line of the fixed blade will be pushed to the two sides by the edge guards and the fixed blade, and the area between the two adjacent fixed blades is the cutting zone.

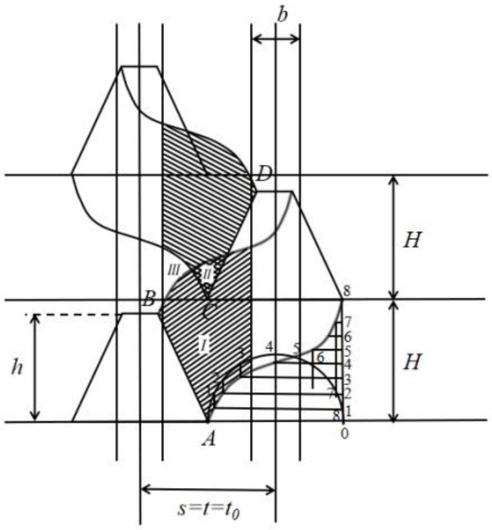


Figure 3.5 Cutting diagram of the standard cutter

(1) Primary cutting zone (I): the crop in this zone is pushed to the edge line of the fixed blade by the moving blade and cut with the support of the fixed blade, in which most of the stalks are tilted along the direction of the cutter movement, but the amount of tilting is small and the stubble is low.

(2) Recutting zone (II): The blade line of the cutter passes through this zone twice, and the stubble that has been cut may be cut again, thus repeated cuts in this zone result in wasted power.

(3) Blanking zone (III): the cutter blade line does not pass through this zone, the crop in this zone is pushed forward by the cutter into the next primary cutting zone, and is cut off in the next cutting, the longitudinal tilt of the stalks in this process is larger in amount, the stubble is higher, and due to the higher concentration of the cutting, and the cutting resistance is larger, and if the blanking zone is too long, it will lead to a portion of the stalks to be pushed back or even cause leakage of the cutting [14].

From the above analysis, it can be seen that: the blank area and the re-cutting area have a direct relationship with the cutter feed distance that affects the cutting pattern, therefore, efforts should be made to reduce the area of these two areas. When the feed distance increases, the cutting diagram graph becomes longer, the area of the blank area increases, and the area of the recut area decreases; conversely, the opposite is true. In addition, the height h of the cutting edge of the moving blade affects the shape of the cutting diagram. When h increases, the blanking zone decreases and the recut zone increases; the opposite is true. Therefore, it is particularly important to choose the correct cutter feed distance and the ratio between feed distance and blade height.

IV. Field trial

Combined with the growth characteristics of oilseed rape itself and harvesting machine cutting platform key components of the working mechanism of the two aspects of the analysis can be summarized that, the maturity period of oilseed rape fruits are intertwined with each other and difficult to share the harvesting, and fruits are more fragile, the stalk is subjected to the force of the interference, will cause the fruits layer greatly pulling, beat the role of the paddle wheel on the loss of oilseed rape loss of the impact of the paddle wheel is mainly concentrated in the paddle popping teeth into the fruits layer of oilseed rape fruits, fruits by the teeth of the popping and bombing pods fall grains; The effect of cutters on losses in oilseed rape comes from two aspects, on the one hand, the transverse cutter cuts the stalks causing disturbed grain drop on the angular layer, and on the other hand, the longitudinal cutter acts directly on the angular fruits of oilseed rape, which causes losses mainly in the form of angular fruits blowing up, repetitive cuts, or missed cuts, etc. [15]. Analyzing the oilseed rape harvesting process, it can be seen that the cutter has a greater impact on the oilseed rape harvesting loss, therefore, this study aims to reduce the loss rate of the longitudinal cutter, and the three indicators of harvester forward speed, transverse cutter cutting height, and longitudinal cutter cutting speed were selected for the field test.

The same lot of experimental field was selected for the field test, and there was no great difference in the growth of oilseed rape in all the test lots, with a light breeze and a temperature of about 17° at the time of the test, so that the environmentally induced loss of angiosperm frying pods was negligible. The harvester used in the experiment was a Dongfeng 4LZ-5.2AJ(G4) full-feed combine harvester with specific parameters shown in Table no 3.

Table no 3 : Dongfeng 4LZ-5.2AJ(G4) fully fed combine harvester parameters

Item	Unit(of measure)	4LZ-5.2AJ(G4)
Overall dimensions (L×W×H)	mm	5100*2530*2850
Matching power	kW	92
Machine mass	kg	3730
Working width of cutting platform	mm	2200
Minimum ground clearance	mm	315
Feeding capacity	kg /s	5.2
Operating speed	km/h	0~7.4
Productivity	hm^2/h	0.35~0.75

The detection method of the vertical cutter branch loss is as follows: before the start of the test, the actual total loss per square meter in the normal harvest section is measured by the three-point averaging method, without the need to subtract the loss of falling grains, the loss of separation and cleaning, etc., and the calculation formula is as shown in Equation 4-1. Three 1.5 m × 0.3 m × 0.06 m receiving tanks were placed at equal intervals along the outside of the vertical cutter operation area in the measurement area, with the long side in the same direction as the forward direction of the harvester, as shown in Fig. 4.1, to catch the seed splash loss caused by the vertical cutter branches, and the seeds, horn shells and broken horns that had not been removed from the tanks at the end of the trial were separated and cleaned by manual seed separation and the seed quality of each receiving tank was The mass of seeds in each receiving slot was weighed and labeled. The rate of vertical cutter branch loss within the test area was then calculated according to Equation 4-2.

$$W = \frac{(W_1 + W_2 + W_3)}{3} \tag{4-1}$$

Where: W_1，W_2，W_3 - Actual loss at three measurement points, g.

$$S = \frac{W(B \times L)}{M} \times 100\% \tag{4-2}$$

Where: S - Vertical cutter branch loss rate, %；

W - Actual total loss per square meter of the survey area, g;

B - Actual average cutting width, m;

L - Length of the measurement area, m;

M - Total weight of seeds received in the receiving slot, g.

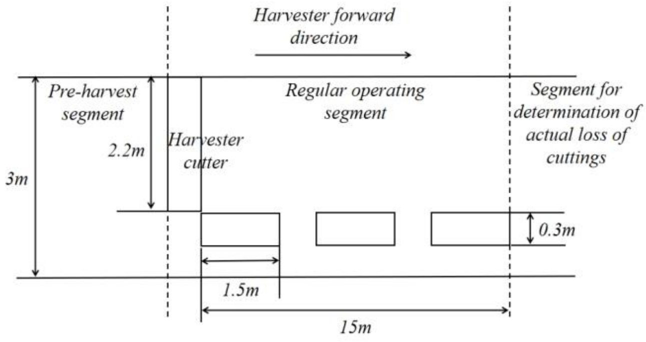
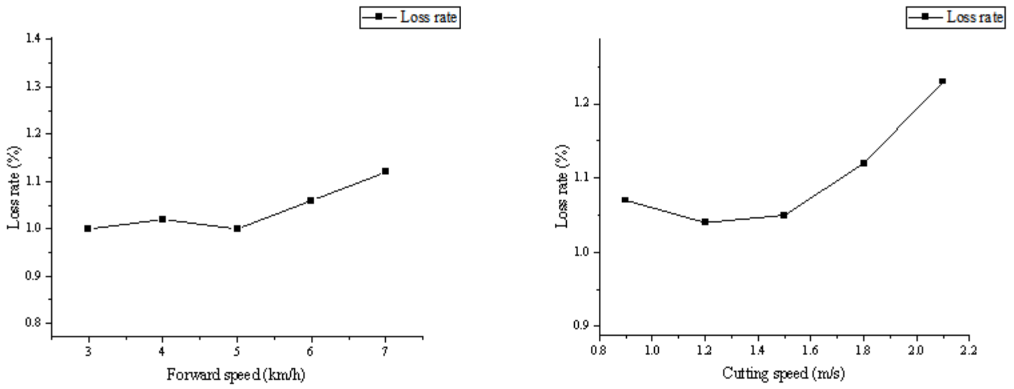


Figure 4.1 Distribution of sample slots for vertical cutting knife loss test slots

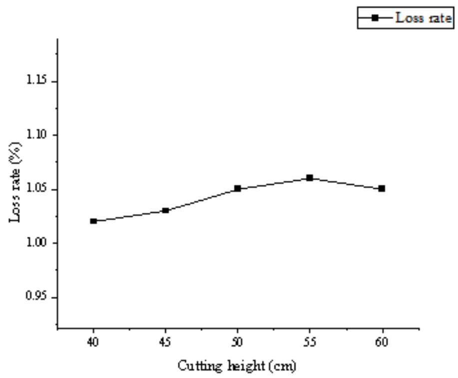
The range of test factors was determined as shown in Table no 4, and five levels were selected for a one-way test of the three factors, and the effect of each factor on the rate of loss of longitudinal cutter branches is shown in Figure 4.2.

Table no 4 : Range of operating parameters of test factors

Parameter	Unit(of measure)	Adjustment range
Harvester forward speed	km/h	3~7
Cutting height of transverse cutter	cm	40~60
Longitudinal cutter cutting speed	m/s	0.9~2.1



(a)Forward speed in relation to branch loss rate （b）Cutting speed in relation to branch loss rate



(c) Cut height in relation to branch loss rate

Figure 4.2 Effect of factors on the loss rate of vertical cutting knife branches

Comparing the results of three single-factor tests, it can be seen that the significance of the effect of cutting height on branch loss rate is significantly lower than that of the other two factors, in order to further explore the order of significance of the effect of each factor on the branch loss rate, each factor is selected to carry out a three-factor, three-level quadratic regression orthogonal test for three-factor and three-level quadratic regression, and obtain the results of the analysis of variance as shown in Table no 5.

Table no 5 : Analysis of variance result

Source	SS	DF	MS	F - value	P - value
Model	0.38	9	0.042	96.06	<0.0001
x_1	0.0072	1	0.0072	16.36	0.0049
x_2	0.005	1	0.005	11.36	0.0119
x_3	0.0018	1	0.0018	4.09	0.0828
x_1x_2	0.000	1	0.000	0.000	1.0000
x_1x_3	0.0001	1	0.0001	0.23	0.6481
x_2x_3	0.0001	1	0.0001	0.23	0.6481
x_1^2	0.06	1	0.06	135.51	<0.0001
x_2^2	0.27	1	0.27	617.38	<0.0001
x_3^2	0.01	1	0.01	22.98	0.0020
Residual	0.00308	7	0.00044		
Lost proposal	0.0008	3	0.0002667	0.47	0.7206
Inaccuracies	0.00228	4	0.00057		
Aggregate	0.38	16			

From the ANOVA results, the p-value of the primary term x_1, the secondary terms x_1^2, x_2^2 and x_3^2 is <0.01, which indicates a highly significant effect on the branch loss rate, and the p-value of the primary term x_2 is <0.05, which indicates a significant effect on the branch loss rate, while the other factors are not significant.

Comparison of the p-value magnitude was able to determine the order of significance of the effects as: forward speed x_1 > cutting speed x_2.

V. Summary

The high loss rate of oilseed rape harvesting is an important problem faced during the development of oilseed rape mechanization, and it is of great significance to understand the characteristics of oilseed rape and the key harvesting techniques to reduce the loss of oilseed rape.

(1) This paper analyzes the biological and physical characteristics of oilseed rape to understand the stress processes and the effects of disturbances at harvest;

(2) Analyze the key components of the cutting table to understand how they work and how they affect the oilseed rape, and explore the effects of the structural and operating parameters of each component on the loss rate;

(3) The significance of the effects of forward speed of the harvester, cutting speed of the longitudinal cutter and cutting height of the transverse cutter on the rate of branch loss was verified in the following order of significance: Forward speed>Cutting speed>Cutting height.

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