Experimental analysis of bionic rotary tillage broken stubble with universal blade

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ABSTRACT

Bionic rotary tillage universal blade is a kind of universal blade， it could complete both broken stubble and rotary tillage.In this experiment, the single-cutter torque (power consumption) of bionic rotary tillage broken stubble was tested by orthogonal test method.The main factors affecting power consumption were found out by using the method of multiple variance analysis. The rotational speed and depth of the universal blade for bionic rotary tillage were determined.The operation speed of the unit has no significant effect on the power consumption of the universal bionic rotary tillage broken stubble blade.The mathematical models of power consumption, blade speed and tillage depth are established by using regression analysis method.The power consumption of rotary tillage and broken stubble operation could be predicted by using the established mathematical model.

Keywords: General blade, working parameters, power consumption, variance analysis, orthogonal polynomial

1. INTRODUCTION

At present, rotary tillage or broken stubble was the main operation in our country, two rollers, two blades and two sets of fixed parts of tillage blades were used to complete stubble breaking and rotary tillage on the same machine tool, this increased the cost of purchasing machines and using them. In order to reduce the use cost, in recent years, after many studies and practices, some scientists and technicians had put forward the design idea of using rotary tillage-broken stubble universal cutter roll, universal cutter disc and universal blade.A new type of combined tillage and leveling machine had been successfully designed. The combined tillage and leveling machine used universal cutter rollers, universal cutter discs and blades.The general blade could complete both rotary tillage and stubble breaking operations at the same time, and its main structural parameters were basically determined[1]. The schematic diagram of the general blade was shown in Figure 1.

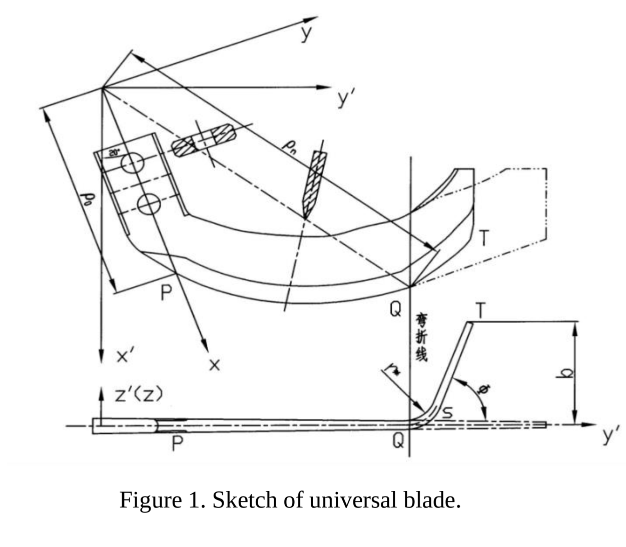

Figure 1. Sketch of universal blade.

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International Conference on Optics, Electronics, and Communication Engineering (OECE 2024), edited by Yang Yue, Proc. of SPIE Vol. 13395, 133950N · © 2024 SPIE · 0277-786X · Published under a Creative Commons Attribution CC-BY 3.0 License · doi: 10.1117/12.3050017

The general blade was installed on the combined tillage and leveling machine. In rotary tillage and broken stubble operation, the power consumption of the machine was mainly used for cutting, cutting soil ,broken stubble or throwing soil and etc. There were many factors affecting power consumption in machine operation, and mainly related to soil environment, physical characteristics of stubble, structural parameters of general blade and operating parameters of machine tools[3].When the soil environment and stubble physical characteristics were the same or the general blade structure parameters and arrangement method were basically fixed, the power consumption of blades was mainly affected by the working parameters such as operating depth, blade speed and unit operating speed[4].This paper mainly studied the influence of unit operation speed, blade rotation speed, and interaction operation between blade rotation speed and working depth on power consumption.

2. VARIANCE ANALYSIS OF TEST CONDITIONS AND RESULTS

In order to minimize the limitation of time and external conditions on the test,and facilitate repetitive test, this test was arranged in a laboratory soil tank.

2.1 Experimental Equipment

The test soil tank was located in the Key Laboratory of engineering bionics Education Ministry of Jilin University. The experimental device consisted of a tucking trolley, a universal blade test bench and a testing system.The tested universal blade test-bed was fixed on the trolley, and the required speed of the test was provided by the trolley, and the speed of advance could be adjusted.The rotating speed of the measured blade was provided by Y112-M motor, and the rotating speed of the motor was controlled by frequency converter. The measured blade torque was displayed by AKC-205B sensor through TS-5HM intelligent instrument.

The soil in the trough was northeast yellow clay. Before broken stubble operation, maize straw was first compacted and buried into the soil along the ditch. The buried depth is 6-7 cm, and the stubble spacing is 40 cm.The stubble spacing could ensure the blade cut stubble or corn straw every time,it could effectively reduce the test error and make the test data fluctuating less.Previous test results showed that the results of stubble crushing and stubble cutting were similar, so the experiment adopted the cutting operation instead of the stubble crushing operation.The average moisture content of soil (0-15 cm) was 17%, the average firmness content was 0.78 MPa, the moisture content of stubble was 41.5%-75%, and the moisture content of straw was 52.4%-79.1%.

2.2 Test Method

L9 (34) orthogonal table was used to arrange the experiment[5]. The purpose of the experiment was to investigate the effect of working parameters on the power consumption of general blade single-cutting tillage. Found out the primary and secondary factors affecting power consumption, established the mathematical model of single tool power consumption and operation parameters, and used this mathematical model to study and analyze power consumption.The single-tool torque was used as the test index (power=torque*speed)[6-7], and the test was repeated three times. See Table 1 for the specific test arrangements.The results of variance analysis were shown in Table 2.

Table 1. The experimental factors and levels of a single blade's torque of the university blade for stubble cutting and rototilling.

Factor	**Level**		
	1	2	3
Speed/ $r \cdot \min^{-1}$	380	420	460
Working Depth/CM	6	9	12
Forward Speed/ $r \cdot \min^{-1}$	0.5	0.7	0.9

Table 2. The experimental results.

Number	Factor				Single tool unit width torque M
	A（x）	B（y）	E	C（z）	
1	1(380)	1(6)	1	1（0.5）	45.7
2	1	2(9)	2	2(0.7)	47.2
3	1	3(12)	3	3（0.9）	49.0
4	2(420)	1	2	3	50.2
5	2	2	3	1	51.1
6	2	3	1	2	52.5
7	3(460)	1	3	2	53.1
8	3	2	1	3	54.2
9	3	3	2	1	55.9
$\sum M'_{1j}$	-8.1	-1	2.4	2.7	$T=\sum_{i=1}^{3}\sum_{j=1}^{3}(M_{ij}')=8.1$
$\sum M'_{2j}$	3.8	2.5	3.3	2.8	$T=\sum_{i=1}^{3}\sum_{j=1}^{3}(M_{ij}')=8.1$
$\sum M'_{3j}$	13.2	7.4	3.2	3.4	$T=\sum_{i=1}^{3}\sum_{j=1}^{3}(M_{ij}')=8.1$
1	1(180)	1(10)	1	1(0.35)	28.8
2	1	2(13)	2	2(0.5)	31.1
3	1	3(16)	3	3(0.65)	32.3
4	2(220)	1	2	3	33.4
5	2	2	3	1	34.0
6	2	3	1	2	35.6
7	3(260)	1	3	2	37.9
8	3	2	1	3	39.3
9	3	3	2	1	40.5
$\sum M'_{1j}$	-9.2	-1.9	2.3	1.3	$T=\sum_{i=1}^{3}\sum_{j=1}^{3}M_{ij}'=8.1$
$\sum M'_{2j}$	1	3.6	3.6	3.2	
$\sum M'_{3j}$	16.3	6.4	2.2	3.6	

From the range line $\overline{R_j}$ in Table 2, it could be seen that the blade speed had the greatest influence on the torque (power consumption), followed by the plough depth.The forward speed had little effect on the torque (power consumption). The optimal combination[8-10] was universal blade speed 380, tillage depth 6 and advance speed 0.5.

2.3 Variance analysis of power consumption in cutting test of general blade for rotary tillage and broken stubble

Range analysis was relatively intuitive and simple, the primary and secondary factors could be excluded according to the magnitude of range, but range analysis could not estimate the magnitude of experimental error.Therefore, it was impossible to distinguish,whether the difference between the test results corresponding to the factor level was really caused by the different levels or by the test errors, so the range analysis could not know the accuracy of the analysis.Next, we use variance method to overcome the shortcomings of range analysis.

From the variance analysis method of orthogonal table[6], we can know the square sum and the feasible formula of each factor:

$$S_j^2 = \frac{1}{3}\left[\left(\sum M'_{1j}\right)^2 + \left(\sum M'_{2j}\right)^2 + \left(\sum M'_{3j}\right)^2\right] - \frac{T^2}{9} \quad (j = 1,2,3,4) \tag{1}$$

To calculate (here, $S_A = S_1$, $S_B = S_2$, $S_E = S_3$, $S_C = S_4$). The sum of squares of total deviations was:

$$S_T^2 = \sum_{i=1}^{3}\sum_{i=1}^{3} M_{ij}^{'\,2} - \frac{T^2}{9} \tag{2}$$

The experimental error could be estimated from the corresponding data of column 3 (blank column) in variance analysis of Table 2. Specific calculation results were listed in Table 3 of ANOVA.

Table 3. ANOVA table.

Source of variance	Sum of squares	Freedom	Mean square sum	F value	critical value	Saliency
Factor A	75.9622	2	37.9811	468.3243	$F_{0.01}(2.2)=99$	**
Factor B	11.8689	2	5.9344	73.1739	$F_{0.05}(2.2) = 19$	*
Factor C	0.0956	2	0.0478	0.5894		
Factor E	0.1622	2	0.0811			
Sum	88.0889					

From Table 3, we knew that factor A was very significant, factor B was significant, and factor C was not significant. It could be concluded that the main factor affecting the power consumption of general purpose blades was the blade speed, followed by the depth of cultivation, and the forward speed had little effect on the power consumption of general purpose blades.

3. MATHEMATICAL MODEL OF POWER CONSUMPTION IN COMMON BLADE STUBBLE TEST

In order to study the relationship between power consumption and blade speed and tillage depth of general-purpose blades in stubble breaking. We established an approximate function relationship between power consumption of general blade and blade speed or tillage depth.In the above variance analysis, it could be seen that in the cut-off test, the blade speed (set as) had a significant effect on power consumption at $\alpha = 0.01$ significant level.The effect of tillage depth on power consumption was significant at $\alpha = 0.01$ significant level.This shown that power consumption M (torque) was interdependent with blade speed X and tillage depth y, it was a functional relationship.In addition, if the third column in ANOVA Table 3 was considered as the interaction effect column $A \times B$ of factor A and factor B, so the sum of squares of the interaction between A and B was $S_{A\times B}^2 = S_E^2 = 0.1622$.Therefore, there was no interaction between factor A and factor B. That was to say, the influence of general blade speed and ploughing depth on power consumption of general blade was independent, so we could establish the functional relationship between blade speed and power consumption, and between ploughing depth and power consumption respectively.

3.1 Functional relation between speed and power consumption of general blade

According to the test results in Table 3, when the blade speed was $x_1 = 380, x_2 = 420, x_3 = 460$, the corresponding torques were $M_1 = 47.3, M_2 = 51.27, M_3 = 54.4$ respectively.It could be seen that with the increase of blade speed x, the torque M increased linearly, so it could be assumed that there was a linear function relationship between the torque M and x.

$$M = a + bx \tag{3}$$

The least square method can be used to estimate $a = 13.8453$, $b = 0.08844$, and the linear function between the torque M and x is obtained as follows.So the linear function between the torque M and x was:

$$M = 13.8453 + 0.08844x \tag{4}$$

Substitute $x_1 = 380, x_2 = 420, x_3 = 460$ into formula (1) respectively.

$M(380) = 47.45$, $M(420) = 51$ and $M(460) = 54.5$ could be got.The correlation coefficient was $r = 0.994$.It could be seen that the accuracy of function (1) was relatively high. Therefore, function (1) could be used to study the relationship between power consumption and blade speed in broken stubble.For example, took $x = 340$ and get $M(340) = 43.9$,took $x = 400$ and get $M(400) = 49.2$,took $x = 500$ and get $M(500) = 58.1$.The graph of linear function (1) was shown in Figure 2.

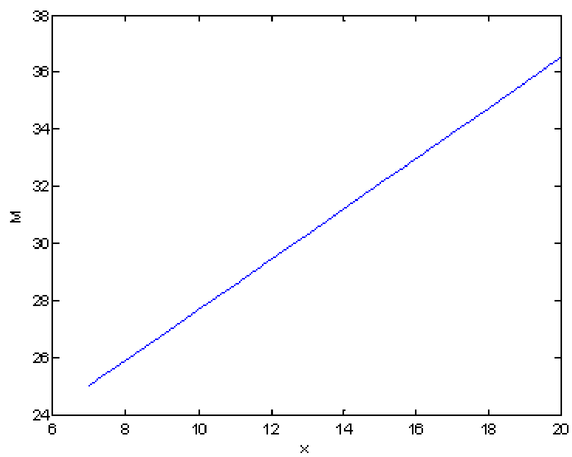

Figure 2. Linear Function Graph

Function (1) shown that the blade speed should be reduced as much as possible during broken stubble operation.

3.2 Functional relationship between power consumption and tillage depth of general purpose blades

From the experimental data in Table 3, it was known that the tillage depth was $y_1 = 6, y_2 = 9, y_3 = 12$,the corresponding torques was $M_1 = 49.67, M_2 = 50.83, M_3 = 52.47$.

According to $M_2 - M_1 = 1.16$ and $M_3 - M_2 = 1.64$, the relationship between tillage depth and torque M was linear, that is, the torque increased linearly with the increase of tillage depth.Therefore, the function relationship between torque M and tillage depth y could be set as follows:

$$M = a + by \tag{3}$$

The least square method can be used to calculate $a = 46.7899$ and $b = 0.46667$,the correlation coefficient between M and y was obtained as $r = 0.995$.It could be seen from that the fitting accuracy of straight line (2) was very high, so it could be used formula (2) to study the relationship between tillage depth and torque in broken stubble.For examples,took $y = 3$ and got $M(3) = 48.19$,took $y = 8$ and got $M(8) = 50.52$, took $y = 15$ and got $M(15) = 53.79$.It was known from function (2) that the tillage depth could be reduced in broken stubble operation. This reduced power consumption, linear graph as shown in Figure 3.

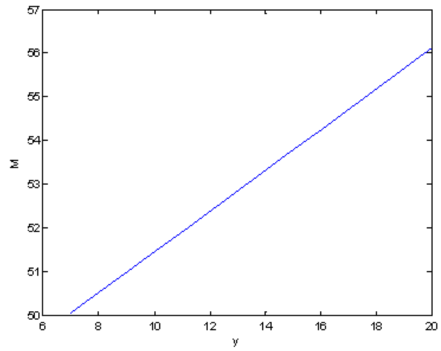

Figure 3. Linear Function Graph

4. CONCLUSION

In the broken stubble operation, the main factor affecting power consumption was the speed of the general blade, so when the broken stubble operation, the general blade should be as small as possible, for example, it could be controlled below $380r/\min$ in order to reduce power consumption.

In the broken stubble operation, tillage depth was the secondary factor affecting the power consumption of general purpose blade. With the increase of tillage depth, the power consumption of general purpose blade increased linearly, so the tillage depth should be as small as possible in stubble breaking operation. For example, it was controlled below 18 cm.

The advance speed of the machine had no effect on the power consumption of the general blade. Therefore, the advance speed of the machine could be increased in the broken stubble operation.In order to improve production efficiency, power consumption per unit area can be reduced.

The main factor affecting power consumption was the speed of blade, so in rotary tillage operation, the speed of cutter roll operation should be controlled below $180\backslash r\cdot\min^{-1}$.

Tillage depth was the secondary factor affecting power consumption of general blades. In rotary tillage operation, the tillage depth could be controlled below 18 cm.

Forward speed had no effect on power consumption of general blade. In rotary tillage operation, the speed of advance could be increased to improve productivity, thereby reduced power consumption per unit area.

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