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Optimization design and experimental analysis of bionic viscosity reduction of chisel type energy saving subsoiling shovel

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Abstract—In order to solve the problems of adhesion to soil and high resistance in traditional subsoiling shovel operation, a bionic energy-saving subsoiling shovel with bionic viscosity reducing and resistance reducing chisel is designed based on the polygon geometry structure of pangolin scales. In this paper, the bionic modeling analysis of chisel type energy-saving subsoiling shovel is carried out by using 3D modeling software. According to the simulation analysis data, we optimize the key structural parameters, and try to produce the bionic energy-saving deep scarifier with reducing viscosity and resistance. In order to study the performance of the chisel type energy-saving subsoiling shovel, L9 (3^4) orthogonal test was carried out in the field with the number of bionic surfaces, coating materials and forward speed as the experimental factors, and the adhesion soil amount and traction resistance as the test indexes. The results show that the order of influence of each factor on the index is the number of subsoiling shovel bionic surface, coating material and advancing speed; the optimal horizontal combination is that the number of bionic surfaces of subsoiling shovel is 10, the coating material is UHMWPE, and the advancing speed is 6km/h.

1. Introduction

The purpose of soil subsoiling is to break the hard plough bottom formed by the long-term traditional tillage, so as to increase the depth of ploughing layer, increase the permeability and permeability of soil, and improve the growth environment of crop roots. The results show that subsoiling can increase the yield of deep root crops, and it is an important yield increasing technology[1]. It is of great practical significance to solve the problems of soil adhesion and high resistance in subsoiling shovel operation.

The results show that when UHMWPE and enamel coating are used, the adhesion and friction resistance of soil to soil contact parts are lower than that of steel[2-3].

Du Weigang[4] made UHMWPE into corrugated geometric structure unit and adhered it to the surface of ditcher. The test results show that there is little clay in UHMWPE bionic ditcher. After spraying enamel on the surface of disc opener by Zuo Chuncheng[5], the average traction resistance of disc opener is reduced by 62.1% compared with that of ordinary disc opener. It can be seen from the above that changing the surface structure of subsoiling shovel and combining with hydrophobic materials can improve the soil adhesion and resistance of subsoiling shovel. On the basis of previous work and bionic technology, a new subsoiling shovel was designed to reduce soil adhesion.

Manis pentadactyla has a symmetrical hexagonal geometry[6], as shown in Figure 1. During the digging, its scales rarely adhere to the soil. In order to solve the problem of soil adhesion of traditional subsoiling shovel, the surface of pangolin is designed from traditional plane to regular polyhedron structure after the in-depth study on the non clay characteristics of scale polygon geometry structure of pangolin body, and the bionic subsoiling shovel with the best anti clay effect is obtained through experiments. At the same time, UHMWPE and enamel coating were applied to the bionic subsoiling shovel with the best anti clay effect [7].

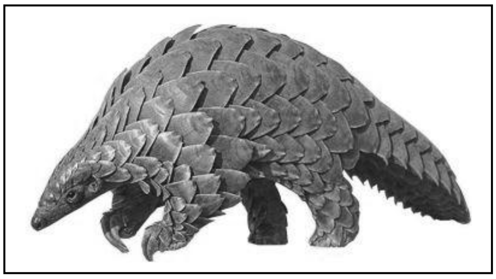

Figure 1. Manis pentadactyla

2. Design of Bionic Subsoiling Shovel

2.1 Introduction of bionic method for reducing viscosity and resistance of subsoiling shovel
In this paper, the bionic theory of reducing viscosity and resistance is used to study the bionic scale of pangolin digging holes, and the shape of cross-section of subsoiling shovel is optimized by using its polygon geometry structure [8]. The main parameters of contact surface of subsoiling shovel are analyzed, and reasonable size parameters are obtained. Then, the surface of the subsoiling shovel is designed from the traditional cylindrical surface into a regular polyhedron structure. Three kinds of bionic polyhedral geometry structures, namely, regular hexahedron, regular octahedron and regular 10hedron, are designed respectively, as shown in Figure 2. Finally, the actual operation experiments were carried out to verify the actual effect of bionic theory on soil adhesion reduction of subsoiling shovel.

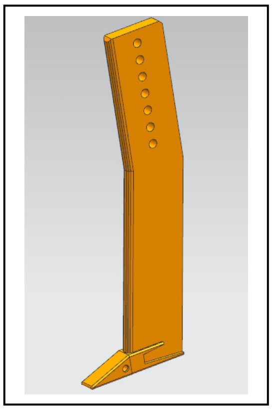

Figure 2. Bionic subsoiling shovel model

2.2 Modeling and material properties

According to the polygonal geometry of pangolin scales, the parameters of subsoiling shovel were designed, and the corresponding 1:1 subsoiling shovel model was established in the 3D modeling software UG. The material of this subsoiling shovel is defined as a rigid body, and its characteristic parameters are set according to 65Mn manganese steel.

TABLE I. THE MATERIAL PROPERTY OF 65MN

Grades	Poisson's ratio	Young's modulus (MPa)	Yield Strength (MPa)	Tensile strength (MPa)	Density ($kg·m^3$)
65Mn	0.3	$2.06×10^5$	≥430	≥735	7850

2.3 Manufacturing process and technical conditions

1) The edge of subsoiling shovel needs heat treatment to improve the hardness and wear resistance of subsoiling shovel. The width of quenching zone is 20 mm ~ 30 mm, the temperature is 830 ℃ ± 20 ℃, and the hardness is 48 HRC ~ 56 HRC.

2) When installing the center plane of the deep loosening shovel handle, the symmetry of the longitudinal central plane of the rectangular part of the upper part of the deep loosening shovel handle is 1.0 mm.

3) The surface of subsoiling shovel shall be flat and free of burr and crack.

4) The assembly surface of subsoiling shovel and subsoiling shovel handle shall be flat within the length of 80 mm, and the flatness shall be 0.5 mm, and there shall be no bulge.

3. ANALYSIS OF FIELD EXPERIMENT

3.1 Test conditions

The experiment was carried out in a sugarcane field of the third team of Huguang farm in Zhanjiang City, Guangdong Province. The area of the plot is 7.2 hm^2. The soil is red soil, and the texture is between clay and sand. It has the advantages of both clay and sand. It has good ventilation, water permeability, water retention and heat preservation. It is an ideal agricultural soil. The soil firmness was measured by TE-3 soil hardness meter and soil moisture content was measured by TS-3 soil moisture meter. In the area of 50m × 30m, the soil firmness and soil moisture content were measured by five point method. The average soil firmness was 1780kPa and the average soil moisture content was 17.6%.

Figure 3. Tension pressure sensor

3.2 Test equipment

In this test, Dongfanghong 1204 wheeled tractor was selected with engine power of 88.2KW. CFBLZ column tension pressure sensor (0.2-10T) and corresponding test and acquisition system are adopted, as shown in Figure 3. The sensor adopts column S-type structure and has the characteristics of high precision, good strength and good stability. In order to firmly connect the sensor between the tractor three-point suspension bracket and subsoiler, a suitable hanging and fixed installation mechanism for working parts is also designed, as shown in Figure 4.

Figure 4. Field test Locomotive Group

3.3 Orthogonal experimental design

According to the analysis of the working process and mechanism of the subsoiling shovel, it is necessary to further determine the influence of the number of bionic surfaces, coating materials and forward speed on the visbreaking performance of the subsoiling shovel and the optimal level combination. The number of bionic surface, coating material and advancing speed of subsoiling shovel are selected as test factors, and the factor levels are shown in Table II. Traction resistance and soil adhesion are selected to measure the performance of subsoiling shovel, and the smaller the test index value, the better. L9 (3^4) orthogonal table was selected to arrange the experiment and 9 groups of experiments were carried out. The results are shown in Table III. A. B and C are the factor level values.

TABLE II. FACTORS AND LEVELS OF ORTHOGONAL TEST

level	**Factor levels**		
	The number of bionic surface	advancing speed /(km·h^{-1})	Coating material
1	6	2	Q235
2	8	4	UHMWPE
3	10	6	Enamel

4. TEST RESULTS AND ANALYSIS

Through the range analysis of the test results, it is found that the order of influence on traction resistance is A, C and B. the optimal level of each factor is A_3, B_3 and C_2 respectively, so the optimal combination is A_3, B_3 and C_2. Similarly, the order of influencing soil adhesion is A, C and B. the optimal levels of each factor are A_3, B_3 and C_2, and the optimal combination is A_3, B_3 and C_2.

TABLE III. RESULTS OF ORTHOGRAPHY EXPERIMENT AND RANGE ANALYSIS

Number	**Factor**			**Traction resistance /kN**	**Soil adhesion /g**
	A	B	C		
1	1	1	1	45.4	470.60
2	1	2	2	40.5	418.35
3	1	3	3	42.3	425.66
4	2	1	2	38.6	431.22
5	2	2	3	41.5	446.98
6	2	3	1	38.7	465.35

7		3	1	3	36.8	391.34
8		3	2	1	38.2	421.54
9		3	3	2	37.4	368.48
Traction resistance	k_1	42.73	40.27	40.77		
	k_2	39.60	40.07	38.83		
	k_3	37.47	39.47	40.20		
	R	5.27	0.80	1.93		
	Better level	A_3	B_3	C_2		
	Primary and secondary factors	$A>C>B$				
Soil adhesion	k_1	438.2	431.1	452.5		
	k_2	447.9	429.0	406.0		
	k_3	393.8	419.8	421.3		
	R	54.1	11.2	46.5		
	Better level	A_3	B_3	C_2		
	Primary and secondary factors	$A>C>B$				

Through the analysis of variance, the significance test of each factor influencing traction resistance and soil adhesion was carried out, as shown in Table IV and Table V.

TABLE IV. VARIANCE ANALYSIS OF TRACTION RESISTANCE

Source of variance	**Sum of squares**	**Freedom**	**Mean square**	***F***	***F* Critical value**	**Significance**
A	42.11	2	21.05	3.59	$F_{0.05}(2,6)=5.14$	*
B	1.04	2	0.52	0.09	$F_{0.01}(2,6)=10.92$	*
C	5.93	2	2.96	0.51		*
Error	11.73	2	5.87			
Sum	60.8	8				

Note: * * * means extremely significant, * *means significant, * means not significant, the same below.

TABLE V. VARIANCE ANALYSIS OF OF SOIL ADHESION

Source of variance	**Sum of squares**	**Freedom**	**Mean square**	***F***	***F* Critical value**	**Significance**
A	4988.74	2	2494.37	234.78	$F_{0.05}(2,2)=5.14$	***
B	213.66	2	106.83	10.06	$F_{0.01}(2,2)=10.92$	**
C	3366.36	2	1683.18	158.43		***
Error	21.25	2	10.62			
Sum	8590.00	8				

It can be seen from Table III and Table IV that the number of bionic surfaces, forward speed and coating material of subsoiling shovel have no significant effect on traction resistance. The number of bionic surfaces and coating materials have significant effects on soil adhesion, the forward speed has a significant effect on soil adhesion. This is consistent with the conclusion of primary and secondary factors in range analysis. Therefore, the number of bionic surfaces and the selection of coating materials are very important for soil adhesion.

5. Conclusion

1) The bionic method of reducing viscosity and resistance is used to optimize the design of a deep loosening shovel, which has the ability of reducing viscosity and resistance and meets the requirements of subsoiling operation.

2) According to the range analysis of the test results, the order of influence on traction resistance and soil adhesion is the number of subsoiling shovel bionic surface, coating material and advancing speed; The optimal horizontal combination is that the number of subsoiling shovel bionic surface is 10, the coating material is UHMWPE, and the advancing speed is 6km / h.

3) The results of orthogonal test were analyzed by statistical analysis software. The results showed that the number of bionic surfaces, forward speed and coating materials had no significant effect on the traction resistance; the number of bionic surfaces and coating materials had a significant effect on soil adhesion; the forward speed had a significant impact on soil adhesion.

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