Field experimental study on pullout forces of rice seedlings and barnyard grasses for mechanical weed control in paddy field

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Abstract: Pullout forces of rice seedling and barnyard grass were tested by universal testing machine controlled by WDW-5 type microcomputer to obtain the pullout forces of rice seedling and barnyard grass. The measured pullout force was used to improve the weeding rate and reduce the rice seedling damage rate caused by mechanical weeding device. According to the measured continuous curve of pullout forces of rice seeding and barnyard grasses in weeding period, the best range of force required to pull out barnyard grasses from soil with no injury and damage to rice seedlings was discussed. Reasons for the difference in the pulling force were analyzed. Results show that, with the increment of the number of single cell rice seedlings the pullout force increases. The pullout forces of single cell rice seedlings and barnyard grasses at first increased slowly reaching the maximum value followed by rapid drop and finally it remained steady. The minimum pullout forces recorded during rice seedlings at the first and the second weeding periods were 2.57 N and 9.70 N, respectively, while the minimum forces during the first and second weeding periods were recorded as 1.24 N and 7.51 N, respectively, for barnyard grasses. The results show that the pullout forces of weeding to rice seedlings and barnyard grasses should be within 1.24 N to 2.57 N and 7.51 N to 9.70 N respectively in the first and second weeding periods.

Keywords: paddy field, mechanical weed control, pullout force, rice seedlings, barnyard grasses, field test

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1 Introduction

Mechanical weed controller loosens soil around seedling roots, improves the physical properties of soil and reduces environment pollution compared to chemical weed controllers. Mechanical weed control has become the main weeding method in recent years. It is an effective approach to replace chemical and manual weed control[1-12]. However, the study of weeding machine is still in the research phase. The field test on the previous weeding equipment show that inter-row weeding rate can reach 70%, but intra-row weeding rate is very low and rice-injuring rate is high[13-15]. And the pullout forces of rice seedlings and barnyard grasses are the key to determining the optimal operation parameters of mechanical weeding device[16-18].

Most of the studies related to pullout force of crop at home and abroad are mainly concentrated in wheat, barley, alfalfa, sugar cane, corn stalks etc[19-21]. A work by an American scholar Wright reported compression, tension and bending of wheat, barley and maize[13]. Similarly a German scholar O'Dogherty[15] studied maximum shear force, shear strength, and tension of wheat. Similarly mechanical property of corn stalk during reciprocating cutting was studied and analyzed [16]. Researchers have also reported their work on mechanical properties of rice seedlings. Studies on mechanical properties of rice seedlings are mainly concentrated on the seedling disc hole[22-25]. Ma et al.[21,22] measured rice seedlings’ fracture force and pulling force sprouted in

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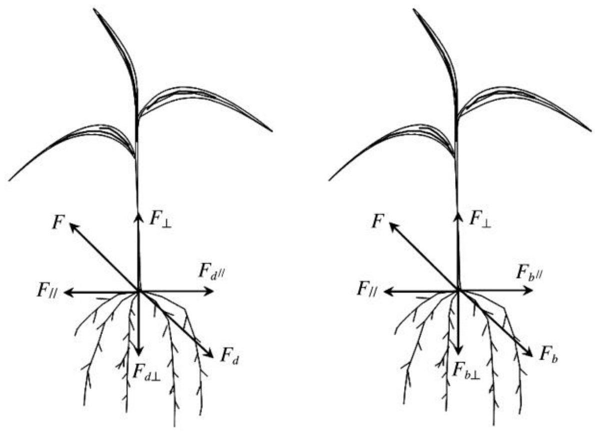
plastic cell-trays using self-regulating measuring system. Song et al.[23] studied tensile strength of rice seedling and the ability of pulling seedling from trays using a universal testing machine. However, study on mechanical properties of rice seedling and barnyard grass during weeding period has seldom been reported in literature.

In the process of mechanical weed control, hardware parts of weeding device are in direct contact with rice seedlings or barnyard grasses. Thus, it is very important to design the weeding device such that barnyard grasses are removed without injuring rice seedlings. Rice seedling pulled completely out from soil is one of the common injuries that requires attention during weeding. Therefore this work aimed to study the pullout forces of rice seedlings and barnyard grasses and seek the optimal force range for removing barnyard grasses without injuring the rice seedlings, so as to provide a theoretical basis for designing and controlling mechanical weeding device.

2 Theoretical basis

In the growth process, the roots of rice seedlings and barnyard grasses are engraved in soil, when pulled out from soil, contact surfaces are stressed by adsorption force of water, cohesion and cementation force of organic and inorganic colloform, friction between root and soil surface, shear force when relative movement occurs, etc. These forces are collectively called the resistance of soil to rice seedlings F_d and resistance of soil to barnyard grasses F_b, as shown in Figure 1.



a. Rice seedling b. Barnyard grass

Note: F_d is the static resistance for rice, N; F_b is the static resistance for barnyard grasses , N.

Figure 1 Diagram of forces for pulling out seedlings

When smaller external force F is applied, rice seedlings and soil remain relatively static. there must be a F_d balanced with F at the moment. Only relative motion tendency exists between rice seedlings and soil rather than relative motion, the resistance between rice seedlings and soil at this point is termed as static resistance. Static resistance in general increases with the increase in external force. With gradual increase in the external force F, rice seedlings begin to move, at this time the resistance of soil to rice seedlings is called the maximum static resistance F_{dmax}. When external force F exceeds F_{dmax}, rice seedlings are pulled out from soil.

However, until the F_{dmax} is greater than the applied external force F, the rice seedlings are not pulled out (Equation (1)).

$$F_{\perp} < F_{d\perp\max} \tag{1}$$

Similarly, the condition that barnyard grasses could be pulled out from soil is

$$F_{\perp} \geq F_{b\perp\max} \tag{2}$$

Considering both Equation (1) and Equation (2), the condition that barnyard grasses could be pulled out from soil without causing any injury to rice seedlings is

$$F_{d\perp\max} > F_{\perp} \geq F_{b\perp\max} \tag{3}$$

3 Materials and methods

3.1 Test materials

Rice variety 'Longyang 12' was used as samples in this study. As reported in previous literature, two experiments on pullout forces of rice seedlings and barnyard grasses were carried out on the 7th days and 14th days after transplantation[26-29]. Heights and diameters of 10 rice seedings and barnyard grasses were measured. The result (Table 1) shows that in the first weeding period, the average height of rice seedlings was 226.5 mm, the average diameter was 2.1 mm; the average height of barnyard grasses was 110.4 mm, the average diameter was 1.7 mm. In the second weeding period, the average height of rice seedlings was 300.5 mm, and the average diameter was 2.9 mm; the average height of barnyard grasses was 156.3 mm, and the average diameter was 2.7 mm.

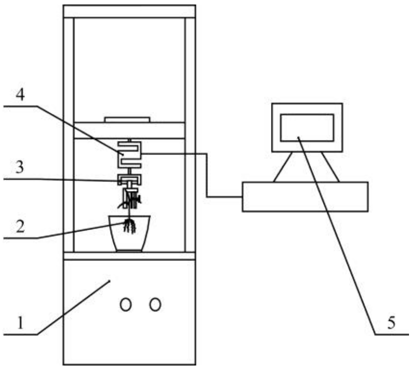
Table 1 Test results of height and diameter of rice seeding and barnyard grasses mm

No.	7th day				14th day			
	Rice seeding		Barnyard grasses		Rice seeding		Barnyard grasses	
	Diameter	Height	Diameter	Height	Diameter	Height	Diameter	Height
1	2.3	216.3	0.91	110	2.7	298.5	2.69	160
2	2.2	221.6	1.27	150	2.6	306.5	1.98	110
3	1.9	231.2	1.53	90	2.8	294.6	3.03	170
4	1.9	236.4	2.29	103	2.9	306.8	2.82	165
5	1.8	220.7	2.51	120	3.1	295.6	2.25	150
6	2.4	216.4	2.18	100	3.2	302.4	2.85	140
7	2.3	231.2	1.47	80	3.1	304.2	2.96	175
8	2.1	238.5	1.63	120	2.9	295.4	3.21	180

3.2 Test device

WDW-5 type microcomputer control electronic universal testing machine (Jinan Test Instrument Co., Ltd.) was used for the test.

During the test, computer displayed and stored the collected data in real time. Two elastic rubber pads with 3 mm thickness were fixed inside the fixture to avoid injuring rice seedlings and barnyard grasses due to hard metal fixture.



1. Mainframe 2. Rice seedling 3.Fixture 4. Tension sensor 5. Computer

Figure 2 Diagram of test device

The tension sensor with a range of 0-100 N with a measuring accuracy of 0.02 N was used. To eliminate the system error, force measuring system of the universal testing machine was calibrated. The calibration curve is shown in Figure 3.

The regression equation of the calibration curve is

$$y = 2.8999x - 0.1044 \quad (4)$$

where, y is the predicted value displayed by computer, N; x is actual weight, N.

After the value is displayed by computer, the pullout forces of rice seedlings and barnyard grasses were obtained using Equation (4).

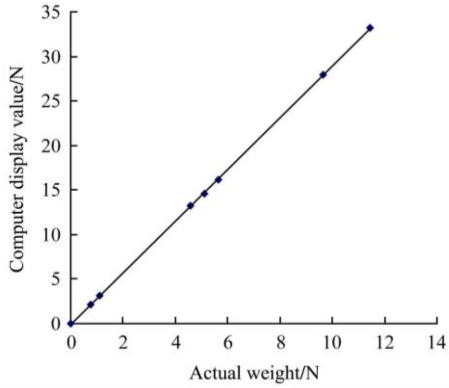


Figure 3 Calibration curve of force measuring system of universal testing machine

The influence of leaves and stalk on pullout force being very small, the leaves were separated from plant before the test for the convenience of fixing rice seedlings and barnyard grasses. The loading rate was 20 mm/min. Figure 4 represents the testing device during the test.

Figure 4 Device in testing process

3.3 Test method

Experimental field was in Houzhangjia Village, Xingfu Town, Harbin City of China. Rice transplantation was performed manually. Before rice transplantation, the field was not treated with fertilizers and chemical herbicides. Other paddy field managements were in accordance with the local actual conditions of agricultural production, as shown in Figure 5. In order to make the test more convenient, the test seedlings were transplanted to flowerpots with 200 mm in height and 220 mm in diameter before test. In the process of transplantation, enough soil was put around roots of rice seedlings and barnyard grasses from beginning to end ensuring roots growth environment consistent with that in the field.

Figure 5 Rice seedling situation in the first weeding period

According to pre-experimental study, the roots number, single root diameter and rooting depth of rice seedlings with the same age were not different. In a cell, the number of rice seedlings does not affect single root diameter and rooting depth, but the root number rises with the increase in the single cell seedlings number and *vice versa*. Different single cell seedlings number leads to differences in contact area between roots and soil, thus causes change of pullout force. For statistical convenience, this work studied the influence of different single cell rice seedlings number on pullout force. In order to determine each cell rice seedlings number, 115 cells of rice seedlings were randomly checked and counted in the first weeding period. The results (Figure 6) showed the rice seedlings number ranged from 3 to 9. Rice seedlings were at tillering stage in the second weeding period, and the tillering seedlings were gracile, the seedlings number per cell did not include the tillering seedlings number. So the rice seedling number ranging from 3 to 9 was repeatedly tested (n=6) in the first and the second weeding periods. As the growing way of barnyard grasses was single, barnyard grasses number was not counted. The repeated number of barnyard grasses test was 8.

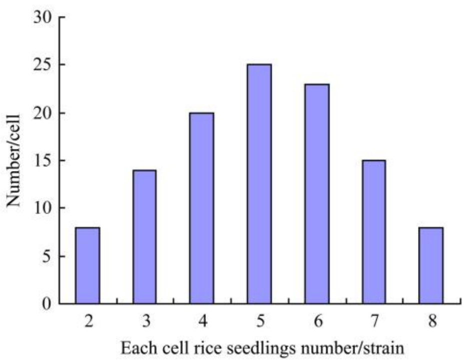


Figure 6 Statistical figure of seedling number in single cell

4 Results and analysis

4.1 Force-displacement curve

A case test was conduct to analyze the mechanical property of rice seedlings or barnyard grasses. The sample was in the first weeding period and the rice seedlings number was 9. The average height was 223 mm, stalk average diameter was 1.95 mm, new root average length was 42.53 mm and new root average diameter was 0.32 mm. In the test process, the data were stored in real time and processed using Excel software. Figure 7 represents the force-displacement curve of pulling out the single cell rice seedlings.

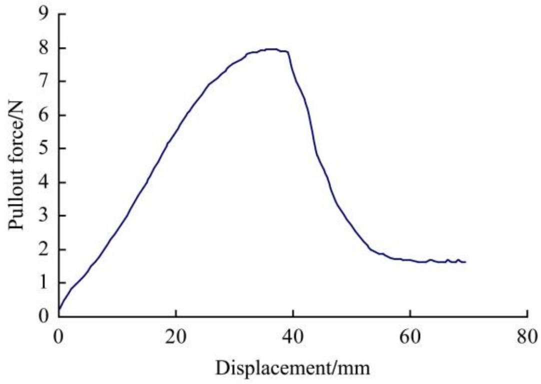
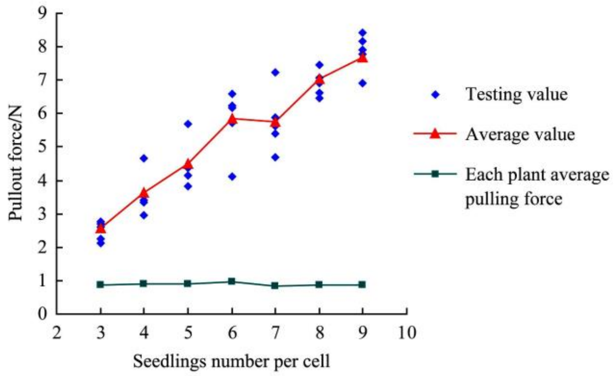


Figure 7 The force-displacement curve of pulling out the single cell rice seedlings

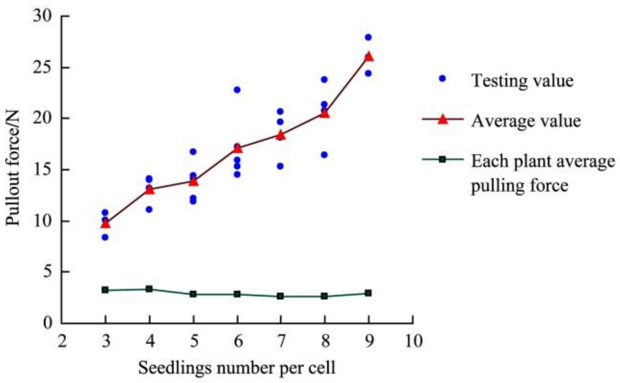
Figure 7 shows that the pullout force of rice seedlings increased to the maximum and then rapidly decreased, finally came to steady state. When the pullout force was small, rice seedlings roots stayed still because of the soil resistance on rice roots. When pullout force reached the maximum, the soil resistance on rice roots also attained the maximum. The phenomenon was followed by dislodging the original soil by rice seedlings. The soil resistance on rice roots during this phenomenon was the same as that of the maximum static resistance. Hereafter, as the roots dislodged original soil, the soil resistance on rice roots and pullout force rapidly decreased at the same time and finally reduced to the weight of rice seedlings and the soil adhered on roots. When external force was greater than the soil resistance on rice roots, rice seedlings were pulled out from soil. So the maximum force as shown in Figure 7 was the critical value which could pull the rice seedlings out from soil.

4.2 Pullout force of rice seedlings

The test results of pullout forces of rice seedlings in the first and the second weeding period are shown in Figure 8.



a. Test results of pullout force of rice seedlings in the first period



b. Test results of pullout force of rice seedlings in the second period

Figure 8 Test results of pullout forces of rice seedlings

Following conclusions can be drawn from Figure 8:

1) Average value of each group test shows that the pullout force increases with the increase in single cell rice seedlings number.

2) In the first weeding period, the minimum value of rice seedlings pullout force was 2.57 N, and in the second weeding period, the minimum value was 9.70 N. The reason for this significant difference is that rice seedlings rapidly grow in recovery period and roots become longer and thicker, thus the soil resistance on rice roots increases.

3) There is only slight change in average pullout force of rice seedling in each plant. In the first weeding period, the average pullout force is between 0.82 N and 0.94 N, and in the second weeding period, the pullout force is between 2.57 N and 3.30 N.

4) From view of measured values, there are some unexpected differences in terms of some data in the same group test. The reason behind the differences may be due to difference between rice seedlings selves as well as some manual errors.

4.3 Pullout force of barnyard grasses

Tables 2 and 3 represent the test results of pullout forces of barnyard grasses in the first and the second weeding periods.

Table 2 Test results of pullout forces of barnyard grasses in the first weeding period

No.	Single root length /mm	Stalk diameter /mm	Height /mm	Pullout force /N
1	60	0.91	110	1.12
2	110	1.27	150	1.24
3	70	1.53	90	0.58
4	100	2.29	103	1.76
5	95	2.51	120	1.49
6	80	2.18	100	1.68
7	94	1.47	80	1.22
8	86	1.63	120	0.81
Average	86.88	1.72	110.38	1.24

Table 3 Test results of pullout forces of barnyard grasses in the second weeding period

No.	Single root length /mm	Stalk diameter /mm	Height /mm	Pullout force /N
1	130	2.69	160	7.22
2	90	1.98	110	4.61
3	150	3.03	170	8.58
4	135	2.82	165	8.20
5	100	2.25	150	6.48
6	110	2.85	140	7.13
7	120	2.96	175	8.92
8	145	3.21	180	8.96
Average	122.50	2.72	156.25	7.51

Following conclusions can be drawn from Table 2 and Table 3:

1) The pullout forces of barnyard grasses are relatively smaller compared to those of rice seedlings. This is due to the presence of only one thin tap root in young barnyard grass which causes small soil resistance.

2) In the first weeding period, the average value of barnyard grass pullout force was 1.24 N, and in the second weeding period, the average value was 7.51 N.

3) There is only small change in pullout force of barnyard grasses in the same weeding period. In the first weeding period, the barnyard grasses pullout force was observed to be between 0.58 N and 1.68 N, and in the weeding period, the pullout force was between 4.61 N

and 8.96 N.

By the comprehensive analysis of Figure 6, Figure 7, Table 2 and Table 3, conclusions can be drawn as below.

In the first weeding period, the rice seedlings pullout force is bigger than that of barnyard grasses; the foremost reason is due to the difference in their growth time. Rice seedlings growth time includes sprout cultivation period (which is approximately one month) and growing period in field (a week). While, barnyard grasses growth time is less than a week. After seven days of rapid growth to the second weeding period, barnyard grasses pullout force is still less than that of rice seedlings. This can be reasoned as presence of only one root in barnyard grass during initial growth stage. Contrary to rice seedlings which have plenty of roots and the roots often closely interwoven resulting in the large pullout force.

In conclusion, the direct reason that causes difference in pullout force between rice seedlings and barnyard grasses in two weeding periods is the difference in the maximum static resistance of the plants. And there are two aspects that lead to the difference of the maximum static resistance, the first one is resultant force effect and the second one is contact area.

5 Conclusions

1) In the pullout process, the pullout forces of single cell seedlings and barnyard grass increased at first until reached the maximum value, and then dropped rapidly, finally reaching steady value. The maximum value is the critical value that can pull the rice seedlings out from soil.

2) The rice seedlings number in a single cell has significant impact on pullout force. In order to avoid injuring rice seedlings, in the first and second weeding periods, the external forces of weeding part to rice seedlings should be less than 2.57 N and 9.70 N, respectively.

3) In weeding period, barnyard grasses have only one root because of short growth time, and the pullout force is small. Therefore, in order to effectively control barnyard grasses, the external forces of weeding part to barnyard grasses should be greater than 1.24 N and 7.51 N, respectively, in the first and second weeding periods.

4) In the two weeding periods, the force of weeding component to rice seedlings and barnyard grasses should be controlled to be in the range of 1.24 N to2.57 N and 7.51 N to9.70 N, respectively. Test results of this study can provide theoretical references for the design and control of mechanical weed control device, achieving the purpose of controlling weed but not injuring rice seedlings.

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