Article

Lodging Resistance as Related to Root Traits for Mechanized Wet Seeding of Two Super Rice Cultivars

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Abstract: The mechanical hill wet-seeded rice machine is benefits to establish uniform seedling, and ditches were established by using this machine. However, little knowledge is known on the effect of the establishment of ditches on growth, lodging and yield, and their relationship with root traits. In this study, two field experiments were conducted during 2012 and 2013 with using two super rice varieties (i.e. hybrid rice 'Peizataifeng' and inbred rice 'Yuxiangyouzhan') grown under three ditches establishment treatments (i.e. T1: both water ditches and seed ditches were established by the machine, T2: seed ditches were established by the machine, T3: neither water nor seed ditches were established by the machine). The lodging index and lodging resistance traits, the grain yield and above-ground dry weight and the root traits were measured. The results showed that the lodging index was significantly affected by the treatments with ditches. The strongest lodging resistance was detected in mechanical hill wet-seeded rice with ditches treatment in both 2012 and 2013. The lodging resistance was strongly related to the breaking resistance, the root volume and root superficial area at the heading stage and maturity stage and the total root length at the heading stage. No significant difference was investigated in grain yield or dry weight of mechanical hill wet-seeded rice. Yuxiangyouzhan showed higher grain yield, dry weight and better lodging resistance but unfavorable root growth attributes than Peizataifeng. Therefore, the mechanical hill wet-seeded rice with ditches treatment increased rice lodging resistance is related to root traits.

Keywords: ditches; grain yield; lodging resistance; root traits; wet-seeded rice

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1. Introduction

Rice is an important food crops for over half of the world population. Rice planting methods differ in the production cost, gross return, and beneficial cost ratio etc.[1-3]. Among the two principle rice planting methods, direct-seeding shows high efficiency than transplanting [4]. The direct-seeding method is difficult to be implemented because of its particularity of susceptible to adverse environment. Machine for wet seeded rice has been developed by Luo, and is currently widely used in China and many other Asian countries, such as Thailand, Laos, and Vietnam [5]. This machine established water ditches and seed ditches as shown in Figure 1, the pre-germinated rice seeds are uniformly sown in the expected positions in the seed ditches by the mechanical hill wet-seeded rice machine [6-8]. How the performance of the mechanical hill wet-seeded rice machine in the paddy field in affecting of rice plant growth is still need to be further investigated.

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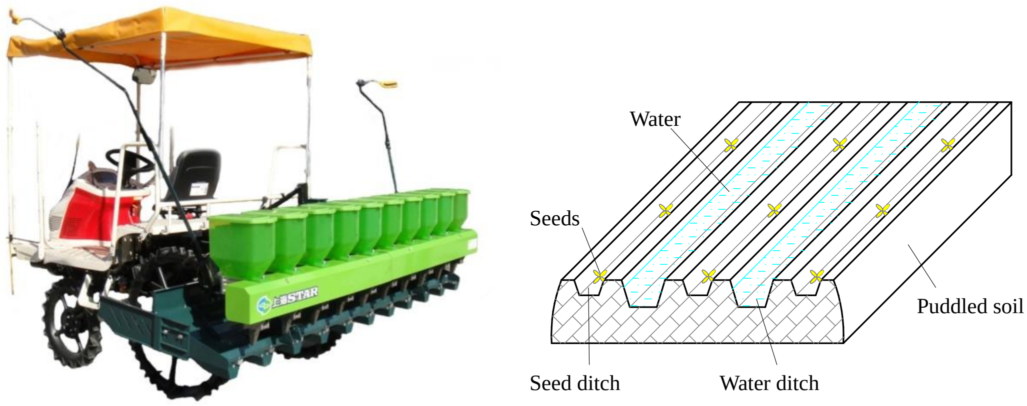

Figure 1. Mechanical hill wet-seeded rice machine and its performance in the paddy field.

Lodging could led to reduction in grain yield, quality and trade price in rice [9-13]. Generally, root lodging and stem lodging have been known as the two main lodging types for rice plant [14]. Among the two lodging types, the stem lodging is the main lodging type happened in rice production that commonly accompanies reductions in grain yield and quality [9, 15-17]. Genetic characteristics, crop management practices (i.e. planting methods, plant growth regulators, irrigation and fertilization) and environmental condition (i.e. the soil temperature, the level of CO_2 and O_3, and ultraviolet light) have been reported to be strongly related to lodging resistance in rice [18-39]. Besides, within the planting methods, the direct-seeded rice method is generally detected as higher in lodging than transplanting [40, 41]. However, the direct- seeded rice by the machine developed by Luo increased lodging resistance in rice [5, 42, 43]. For wet seeded rice, the water ditches and seed ditches established by the machine may contribute to better lodging resistance in rice, but the mechanism is still remains unknown.

Previous studies have assessed the methods in evaluating of the crop plant lodging [44, 45]. There were many aspects in plant were reported to highly related to plant lodging. For example, Hu et al. reported the lodging was related to the plant morphology indices (i.e. plant height and leaf morphology) [31]. Additionally, reports indicated that the lodging was strongly associated with the stem morphological characteristics (i.e. matter accumulation, length of the internode, element and starch content) [27, 33, 39, 46-52]. Moreover, the lodging were reported to be significantly affected by the content of cellulose, hemicellulose and lignin as well as the physiological attributes related to cellulose, hemicellulose and lignin synthesis [53, 54]. In addition, hormones, such as the GA3 content, were strongly related to the rice plant lodging [23, 34]. Although, Wang et al. had indicated that lodging resistance is affected by the water ditches and seed ditches which were established by the hill direct seeded machine but no data supported [35]. Therefore, the relationship between lodging and root traits of the mechanical hill wet-seeded rice is rarely studied.

Therefore, in this study, two field experiments were conducted by using two super rice cultivars to i) investigate the lodging resistance of the mechanical hill wet-seeded rice under different ditches establishment treatments, ii) observe root growth of the mechanical hill wet-seeded rice under different ditches establishment treatments, and iii) estimate the relationship between lodging resistance and root traits of the mechanical hill wet-seeded rice.

2. Materials and methods

2.1. Experimental description

The field experiments were conducted in the Experimental Research Farm in the College of Agriculture at South China Agricultural University in Guangzhou, China (113.18 E, 23.10 N at 18 m elevation) during 2012 and 2013. This region has a sub-tropical and monsoon type of climate, and the mean monthly air temperature, precipitation, mean daily radiation, and average humidity during the

 doi:10.20944/preprints201911.0128.v1

rice growing seasons is presented in Table 1. The experimental soil was sandy loam with medium soil fertility [55].

Table 1. Mean monthly air temperature, mean sunshine hours, precipitation, and average humidity in 2012 and 2013.

Time	2012				2013			
	Temperature (ºC)	Sunshine hours (hour)	Precipitation (mm)	Average humidity (%)	Temperature (ºC)	Sunshine hours (hour)	Precipitation (mm)	Average humidity (%)
July	28.6	204.2	165.8	78.0	27.9	177.3	273.3	82.0
August	28.8	181.9	158.5	77.0	27.9	162.3	396.6	83.0
September	26.7	191.8	102.3	73.0	27.0	176.1	203.7	79.0
October	24.0	197.5	62.7	71.0	23.6	224.4	5.9	66.0
November	19.5	86.2	178.7	78.0	19.5	150.1	40.3	71.0

2.2. Experimental treatments and design

The experiments were arranged in split plot design in 2012 and 2013, with rice cultivars as main plot and the ditches establishment treatments as sub plot. The three ditches establishment treatments were i) both water ditches and seed ditches were established by the machine (T1), ii) seed ditches were established by the machine (T2), iii) neither water nor seed ditches were established by the machine (T3). The ditches establishment treatments were conducted by the mechanical hill wet-seeded rice machine developed by South China Agricultural University. The plot size for each treatment was 300 m^2.

Two locally popular super rice cultivars, Yuxiangyouzhan and Peizataifeng were grown under three ditches establishment treatments in both the 2012 and 2013. The rice cultivar Yuxiangyouzhan is an inbred super rice cultivar developed by Guangdong Academy of Agricultural Sciences with growth period of 127 d, and plant height of 105 cm. The rice cultivar Peizataifeng is a hybrid super rice cultivar developed by South China Agricultural University with growth period of 126 d, and plant height of 108 cm. They are high-yielding and with strong resistance capacity. The pre-germinated seeds of Yuxiangyouzhan and Peizataifeng were hill-seeded with the mechanical hill wet-seeded rice machine at a density of 25 × 15 cm with 3–5 seeds per hill on July 29th and August 5th for 2012 and 2013, respectively. The seeding effect is shown in Fig. 2. The field preparation and water management in both years was conducted according the specification reported by Pan et al. [8]. During the entire growth period, the commercial compound fertilizer (N: P: K = 15:15:15) was manual applied at 600 kg/ha and 150 kg/ha at three leaf stage and at panicle initiation stage, respectively. The crop management practice was implemented according to the local high-yield cultivation methods. The weeds and insects were effectively controlled to avoid yield loss.

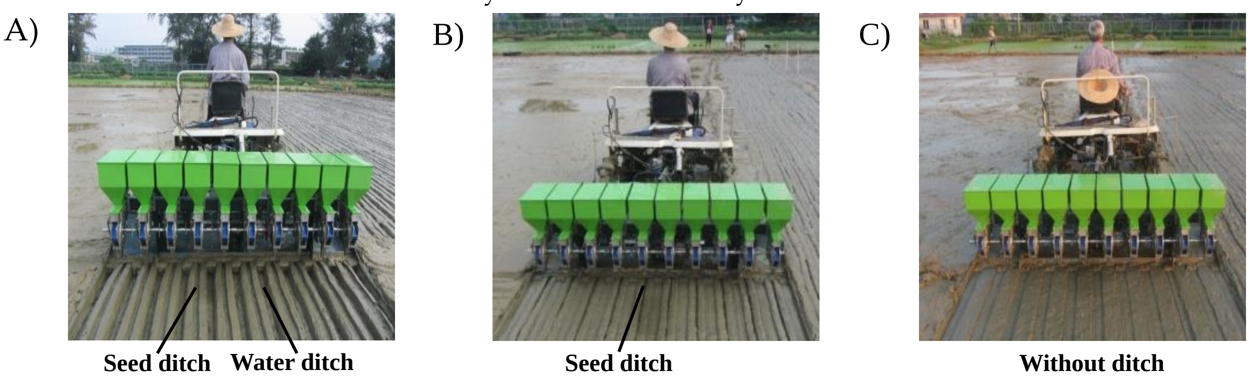

Fig. 2. The water ditches and seed ditches establishment treatments in the field. A) Both water ditches and seed ditches were established by the machine; B) Seed ditches were established by the machine; C) Neither water nor seed ditches were established by the machine.

2.3. Measurements

2.3.1. Lodging index and lodging resistance traits

At the Heading stage, 10 main stems were sampled to measure the lodging index and lodging resistance traits. The lodging index and lodging resistance traits were determined according to the method of Islam et al. [56].

The first (N_1) and second (N_2) internodes were numbered from the plant base. The culm height (length between the plant base and the panicle neck node), the height of the gravitational center, the length from the lower joint of N_2 to the top of the plant and the fresh weight of the upper portion of the plant from the lower joint of N_2 to the top of the panicle with leaf and leaf sheath (W) were measured. Then, N_1 and N_2 were cut at their upper joints. The breaking resistance strength of the middle point of N2 with the leaf sheath was measured using a three-point bend test machine (YYD-1A, Tuopu yunnong technology, China). The center of the internode, where the breaking resistance was measured, was aligned horizontally with the middle point between the two joints. The bending moment at N_2 was calculated using the following formula:

Bending moment = length from the lower joint of N_2 to the top of the panicle (cm) × W (g);

Lodging index = bending moment (cm·g) / Breaking resistance (g·cm) × 100.

2.3.2. Grain yield

At the mature stage, the effective panicle number of each plot was calculated using 50 hills in each plot, and the mean value was recorded as the effective panicle number of the plot. The mature rice plant samples in 1 m^2 were harvested to measure the total grain number, seed setting rate and 1000-grain weight of each plot. The grain yield was harvested from 3 m^2 in each plot. The sample was manually threshed, and then sun dried and weighed to record the grain yield (the moisture of the grains was adjusted to ~140 mg/g).

2.3.3. Above-ground dry weight

At the mature stage, 4 representative rice samples were harvested from each plot, and the roots, stems and leaves were separated; the plant samples were oven dried at 105 °C for 30 minutes then at 80 °C to a constant weight. The dry samples were weighed to measure the above-ground dry weight.

2.3.4. Root morphological traits

The roots were completely cleaned and neatly placed in utensils. The root scanner EPSON V700 (Seiko Epson Corporation, Tokyo, Japan) and software WinRHIZO Reg (Regent Instruments Inc., Quebec, Canada) were used to measure the root volume, total root length, root average diameter and root superficial area. During scanning, the roots did not overlap. The cleaned roots were refrigerated to maintain freshness, and the scanning process was finished in 5 days. After scanning, the dry matter test was carried out.

2.4. Statistical analysis

The data were analyzed with Statistix version 8 (Analytical Software, Florida, USA). The figures were created with Microsoft Excel Software (Microsoft Office Professional Plus 2010, Microsoft Corporation, Washington, USA).

3. Results

3.1. Lodging index and lodging resistance traits of rice

The analysis of variance on height of gravitational center and lodging index between years was significant. Variety significantly affected breaking resistance and lodging index. The furrowing and ridging treatment obviously affected lodging index. Y×V and Y×T significantly affected the height of gravitational center and lodging index respectively. V × T significantly affected height of gravitational center, breaking resistance and lodging index. Height of gravitational center and breaking resistance was significantly affected by Y×V×T. The T1 treatment had the lowest lodging index in both 2012 and 2013. The average lodging index for Peizataifeng was higher than that of Yuxianyouzhan, and the lodging index for both Peizataifeng and Yuxiangyouzhan in 2012 was higher than that in 2013. The breaking resistance was affected by the furrowing and ridging treatment in 2013 (Table 2).

Table 2. Lodging index and lodging resistance traits of rice.

Treatment	Height of gravitational center (cm)	Breaking resistance (g cm)	Lodging index
2012			
Peizataifeng			
T1	42.28 a	985.14 a	153.25 b
T2	43.76 a	1103.92 a	177.27 a
T3	42.68 a	885.44 a	189.03 a
Yuxiangyouzhan			
T1	42.46 a	1483.62 a	143.51 b
T2	41.30 a	1325.68 a	153.60 a
T3	41.50 a	1462.50 a	149.22 a
2013			
Peizataifeng			
T1	41.16 a	1216.00 a	146.35 b
T2	39.34 b	1014.44 b	178.64 a
T3	37.32 c	819.86 c	163.75 ab
Yuxiangyouzhan			
T1	38.80 b	1468.52 a	124.21 b
T2	39.76 b	1460.90 a	142.61 a
T3	41.46 a	1551.02 a	131.87 b
Analysis of variance			
Year (Y)	15.37 *	0.40 ns	45.94 **
Variety (V)	1.56 ns	605.94 **	97.34 **
Treatment (T)	0.79 ns	2.87 ns	27.93 **
Y×V	31.42 **	1.44 ns	1.03 ns
Y×T	0.35 ns	0.67 ns	3.82 *
V×T	8.58 **	7.33 **	5.85 *
Y×V×T	16.20 **	3.90 *	1.93 ns

Means in the same column followed by different lower case letters for the same variety indicates significantly different at 5% level by LSD tests. * and ** indicates significant difference at 5% and 1%, respectively; ns, nonsignificant.

3.2. Grain yield and above-ground dry weight of rice

Grain yield and above-ground dry weight differed significantly between the cultivars and years. Y×V and Y×V×T significantly affected grain yield and above-ground dry weight, respectively. The furrowing and ridging treatment had no obvious effects on grain yield or above-ground dry weight

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in either 2012 or 2013. The furrowing and ridging treatment had no obvious effects on the rated yield traits (data not shown) (Table 3).

Table 3. Grain yield and above-ground dry weight of rice.

Treatment	Grain yield g/m^2		Dry weight g/m^2	
Peizataifeng	2012	2013	2012	2013
T1	705.64 a	564.39 a	1055.91 a	1247.53 a
T2	704.79 a	575.17 a	1100.01 a	1216.12 a
T3	696.74 a	556.42 a	1163.18 a	1236.5 a
Yuxiangyouzhan				
T1	781.98 a	767.62 a	1682.03 a	1551.87 b
T2	723.40 a	758.47 a	1333.77 b	1763.55 a
T3	761.58 a	735.05 a	1396.19 b	1674.06 ab
Analysis of variance				
Year (Y)	8.13 *		13.48 *	
Variety (V)	86.11 **		180.58 **	
Treatment (T)	0.14 ns		0.17 ns	
Y×V	26.92 **		1.23 ns	
Y×T	0.15 ns		2.58 ns	
V×T	0.15 ns		0.74 ns	
Y×V×T	0.07 ns		5.00 *	

Means in the same column followed by different lower case letters for the same variety indicates significantly different at 5% level by LSD tests. * and ** indicates significant difference at 5% and 1%, respectively; ns, nonsignificant.

3.3. Root dry weight

Root dry weight at tillering stage and booting stage was significantly differed between years. The root dry weight of rice differed significantly between the cultivars. The furrowing and ridging treatment had no obvious effects on the root dry weight of rice. Y×V significantly affected root dry weight at tillering stage and booting stage. Y×T significantly affected root dry weight at booting stage (Table 4).

Table 4. Root dry weight of rice (g/m^2).

Treatment	**Tillering stage**	**Booting stage**	**Heading stage**	**Maturity**
2012				
Peizataifeng				
T1	82.00 a	118.51 a	101.75 a	75.10 a
T2	83.34 a	92.36 b	87.22 a	76.63 a
T3	64.99 a	81.10 b	94.97 a	82.66 a
Yuxiangyouzhan				
T1	63.43 a	90.58 a	85.84 a	80.76 a
T2	58.02 a	68.34 b	75.69 a	55.96 b
T3	53.55 a	66.89 b	81.81 a	60.49 b
2013				

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Peizataifeng				
T1	31.79 a	78.07 b	89.74 a	70.03 a
T2	29.49 a	98.46 ab	93.96 a	71.37 a
T3	27.63 a	119.25 a	98.83 a	74.71 a
Yuxiangyouzhan				
T1	30.29 a	91.53 a	76.41 a	69.00 a
T2	24.74 b	95.27 a	76.70 a	75.23 a
T3	27.48 ab	96.48 a	86.11 a	68.60 a
Analysis of variance				
Year (Y)	520.79 **	12.89 *	0.16 ns	0.02 ns
Variety (V)	16.13 **	26.57 **	26.57 **	5.54 *
Treatment (T)	2.75 ns	0.45 ns	1.97 ns	0.52 ns
Y×V	9.88 *	12.35 **	0.03 ns	3.90 ns
Y×T	1.46 ns	8.91 **	2.69 ns	2.02 ns
V×T	1.31 ns	0.38 ns	0.03 ns	2.37 ns
Y×V×T	0.46 ns	1.88 ns	0.17 ns	2.21 ns

Means in the same column followed by different lower case letters for the same variety indicates significantly different at 5% level by LSD tests. * and ** indicates significant difference at 5% and 1%, respectively; ns, nonsignificant.

3.4. Root volume of rice

The root volume of the rice was not affected by the furrowing and ridging treatment. The rice root volume differed significantly between the cultivars. Significant differed in root volume at tillering stage and booting stage was observed. Y×V and Y×T significantly affected root volume at booting stage (Table 5).

Table 5. Root volume of rice (cm^3).

Treatment	Tillering stage	Booting stage	Heading stage	Maturity
2012				
Peizataifeng				
T1	30.89 a	43.88 a	35.08 a	28.35 a
T2	31.89 a	35.22 b	31.88 a	28.19 a
T3	24.50 a	27.08 c	34.09 a	28.24 a
Yuxiangyouzhan				
T1	25.25 a	26.60 a	31.35 a	25.37 a
T2	21.56 a	21.29 a	27.89 a	22.24 a
T3	21.07 a	20.99 a	29.05 a	21.39 a
2013				
Peizataifeng				
T1	11.49 a	26.49 b	30.53 a	27.59 a
T2	11.62 a	33.13 a	32.86 a	27.53 a
T3	10.28 a	35.61 a	35.81 a	27.18 a
Yuxiangyouzhan				

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T1	11.21 a	30.51 a	23.61 a	22.15 a
T2	8.69 b	31.62 a	25.17 a	22.75 a
T3	10.27 ab	33.63 a	25.70 a	22.94 a
Analysis of variance				
Year (Y)	349.52 **	8.50 *	4.53 ns	0.47 ns
Variety (V)	9.31 *	76.38 **	21.47 **	44.77 **
Treatment (T)	2.64 ns	1.07 ns	1.03 ns	0.38 ns
Y×V	4.77 ns	80.86 **	2.19 ns	0.09 ns
Y×T	1.46 ns	12.41 **	3.25 ns	0.60 ns
V×T	1.68 ns	0.58 ns	0.49 ns	0.21 ns
Y×V×T	0.26 ns	2.99 ns	0.08 ns	0.69 ns

Means in the same column followed by different lower case letters for the same variety indicates significantly different at 5% level by LSD tests. * and ** indicates significant difference at 5% and 1%, respectively; ns, nonsignificant.

3.5. Average root diameter

The average rice root diameter was significantly affected in both cultivars at the tillering stage, booting stage and at maturity. The average rice diameter at the tillering was significantly affected by the furrowing and ridging treatments and Y×V. Y×T and V×T significantly affected the average rice root diameter at the tillering stage and booting stage (Table 6).

Table 6. Average root diameter of rice (mm).

Treatment	Tillering stage	Booting stage	Heading stage	Maturity
2012				
Peizataifeng				
T1	0.390 a	0.472 a	0.466 a	0.536 a
T2	0.378 a	0.470 ab	0.458 a	0.523 a
T3	0.390 a	0.436 b	0.469 a	0.523 a
Yuxiangyouzhan				
T1	0.409 a	0.448 a	0.479 a	0.484 a
T2	0.379 a	0.434 ab	0.457 b	0.488 a
T3	0.371 a	0.397 b	0.457 b	0.485 a
2013				
Peizataifeng				
T1	0.417 b	0.436 a	0.480 a	0.551 a
T2	0.396 b	0.464 a	0.472 a	0.607 a
T3	0.448 a	0.487 a	0.450 a	0.581 a
Yuxiangyouzhan				
T1	0.379 a	0.437 a	0.466 a	0.504 a
T2	0.349 a	0.443 a	0.463 a	0.504 a
T3	0.377 a	0.403 a	0.470 a	0.507 a
Analysis of variance				
Year (Y)	2.22 ns	0.28 ns	0.12 ns	4.67 ns

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Variety (V)	14.15 **	24.20 **	0.02 ns	18.47 **
Treatment (T)	7.02 **	2.48 ns	0.97 ns	0.55 ns
Y×V	16.44 **	0.08 ns	0.00 ns	1.61 ns
Y×T	4.98 *	3.36 *	0.20 ns	1.34 ns
V×T	3.38 *	4.01 *	0.13 ns	0.37 ns
Y×V×T	0.01 ns	2.24 ns	1.55 ns	1.63 ns

Means in the same column followed by different lower case letters for the same variety indicates significantly different at 5% level by LSD tests. * and ** indicates significant difference at 5% and 1%, respectively; ns, nonsignificant.

3.6. Total root length

The total root length per hill of rice at tillering stage, booting stage and maturity stage differed significantly between years. The total root length per hill of rice differed significantly between the cultivars at the tillering stage and Heading stage. The furrowing and ridging treatment and V×T significantly affected the total root length per hill at the tillering. Y×V significantly affected the total root length per hill at the tillering and booting stage while Y×T significantly affected the total root length per hill at the booting stage (Table 7).

Table 7. Total root length per hill of rice (10^3 cm).

Treatment	Tillering stage	Booting stage	Heading stage	Maturity
2012				
Peizataifeng				
T1	28.40 a	26.20 a	20.13 a	12.59 a
T2	27.76 a	20.40 b	20.03 a	12.87 a
T3	21.18 a	17.66 b	20.19 a	13.52 a
Yuxiangyouzhan				
T1	19.50 a	17.33 a	17.86 a	14.35 a
T2	19.03 a	15.15 a	17.58 a	11.76 b
T3	19.69 a	16.58 a	18.04 a	11.69 b
2013				
Peizataifeng				
T1	8.31 ab	18.25 a	18.13 a	9.79 a
T2	9.74 a	20.48 a	19.18 a	9.92 a
T3	6.99 b	20.25 a	20.26 a	11.92 a
Yuxiangyouzhan				
T1	10.22 a	21.39 a	15.12 a	11.21 a
T2	9.21 a	20.97 a	15.44 a	12.08 a
T3	9.44 a	26.94 a	17.31 a	12.49 a
Analysis of variance				
Year (Y)	365.72 **	27.27 **	2.81 ns	27.39 **
Variety (V)	16.80 **	0.83 ns	13.55 **	0.41 ns
Treatment (T)	3.41 *	0.50 ns	0.94 ns	0.54 ns
Y×V	37.81 **	22.59 **	0.40 ns	1.32 ns
Y×T	0.84 ns	3.53 *	0.69 ns	1.63 ns

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V×T	3.81 *	1.95 ns	0.06 ns	1.18 ns
Y×V×T	1.58 ns	0.51 ns	0.01 ns	0.86 ns

Means in the same column followed by different lower case letters for the same variety indicates significantly different at 5% level by LSD tests. * and ** indicates significant difference at 5% and 1%, respectively; ns, nonsignificant.

3.7. The root superficial area

The superficial area of the rice root at tillering stage, booting stage and maturity stage was significantly different between the years. Variety significantly affected the superficial area of the rice root at tillering stage, booting stage and Heading stage. The superficial area of the rice root at tillering stage and booting stage was significantly affected by Y×V. Y×T significantly affected the superficial area of the rice root at booting stage (Table 8).

Table 8. Rice root superficial area (cm^2).

Treatment	Tillering stage	Booting stage	Heading stage	Maturity
2012				
Peizataifeng				
T1	3198 a	3742 a	2942 a	2032 a
T2	3388 a	2964 b	2788 a	2084 a
T3	2523 a	2414 c	2898 a	2436 a
Yuxiangyouzhan				
T1	2407 a	2359 a	2610 a	2116 a
T2	2299 a	1947 a	2446 a	1792 b
T3	2295 a	2067 a	2518 a	1764 b
2013				
Peizataifeng				
T1	1088 a	2429 a	2370 a	1665 a
T2	1178 a	2898 a	2793 a	1870 a
T3	937 a	2951 a	2739 a	2029 a
Yuxiangyouzhan				
T1	1186 a	2830 a	1982 a	1748 a
T2	996 a	2837 a	2175 a	1864 a
T3	1093 a	3335 a	2275 a	1952 a
Analysis of variance				
Year (Y)	215.18 **	18.47 *	5.11 ns	56.12 **
Variety (V)	9.61 *	15.85 **	10.82 *	2.86 ns
Treatment (T)	2.58 ns	0.55 ns	0.89 ns	1.31 ns
Y×V	11.01 *	46.65 **	0.29 ns	2.87 ns
Y×T	1.05 ns	6.79 **	3.26 ns	1.15 ns
V×T	2.66 ns	1.45 ns	0.18 ns	2.32 ns
Y×V×T	0.65 ns	1.16 ns	0.18 ns	0.99 ns

Means in the same column followed by different lower case letters for the same variety indicates significantly different at 5% level by LSD tests. * and ** indicates significant difference at 5% and 1%, respectively; ns, nonsignificant.

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3.8. Correlation analysis

Lodging index was strongly and positively associated with RV and RSA at both heading stage and maturity and TRL at heading stage, but negatively associated with breaking resistance (Fig. 3).

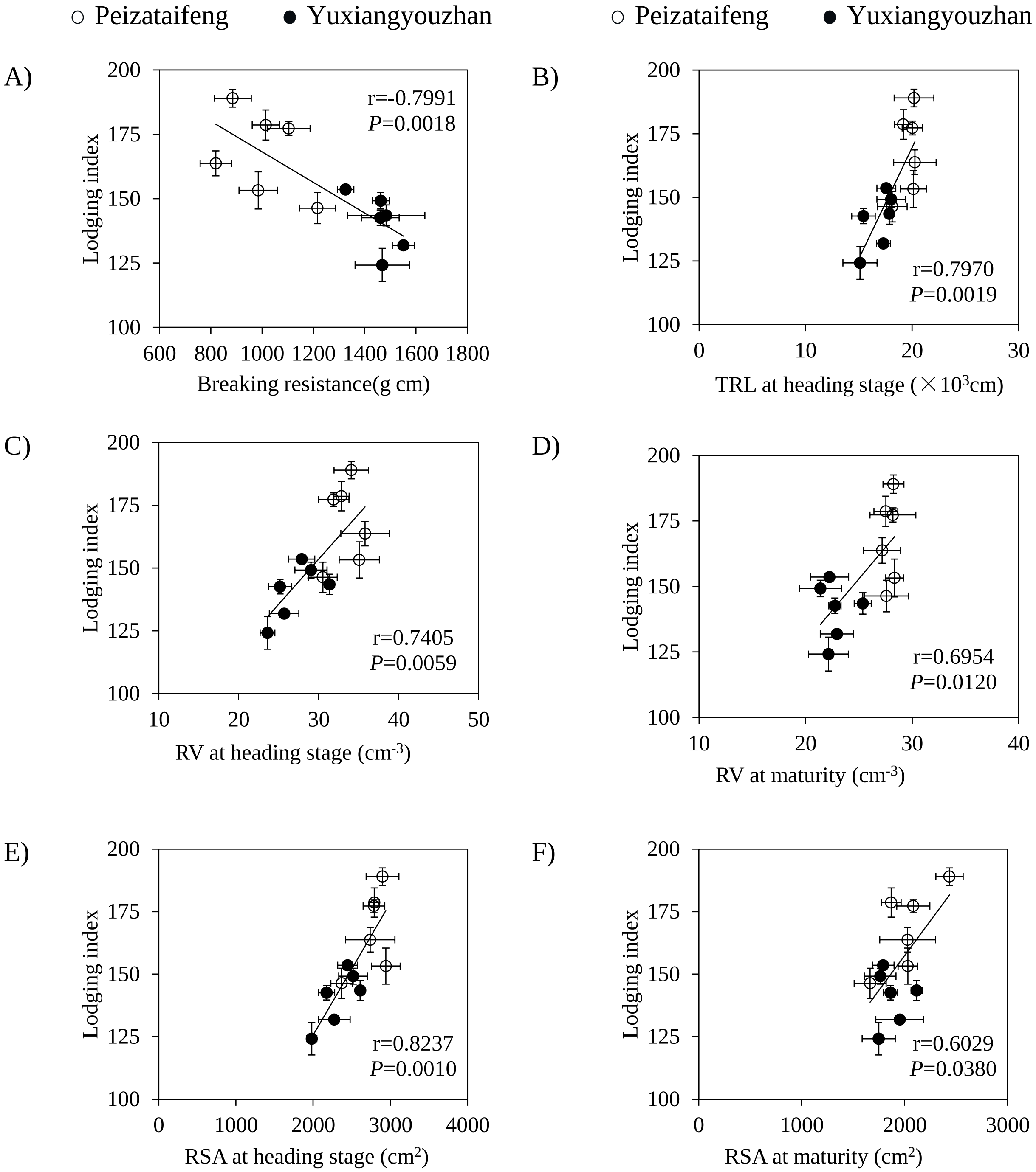

Figure 3. Relationship between the lodging index and breaking resistance and the root growth of the two super rice cultivars. Total root length= TRL, Root volumn=RV, Root surface area=RSA.

4. Discussion

It is no doubt that mechanical hill wet-seeded rice performance better lodging resistance than manually wet seeded rice, it may not only the reason of hill wet seeded but also the reason of the water ditches and seed ditches that established by the mechanical hill wet-seeded rice [5, 42, 43]. In this study, we confirm that the lodging index of mechanical hill wet-seeded rice was significantly decreased under the ditches establishment treatments than the treatment of without any ditch in both 2012 and 2013 (Table 2).

It is well known that the plant height [57], leaf morphology [31], and stem morphological characteristics are strongly related to lodging particularly stem lodging [38, 46, 48]. In this study, the breaking resistance was significantly affected by cultivar and the ditches establishment treatments, besides it was confirmed that lodging resistance in super rice was strongly related to the breaking resistance (Table 2, Figure 3A), while the bending moment of the plant is not significantly closely related to the lodging (data not shown). The root -shoot communication is common recognized with the supplement of sufficient nutrients and the application of plant growth regulators [58, 59]. The crop root system plays a critical role in regulating the plant growth even the yield and quality formation [60]. The strong relationships between the root system and shoot performance were well detected by Ling et al. [61], Zhang et al. [62] and Gregory et al. [63]. In this study, significant cultivar and ditches establishment treatment effects on root traits various from stages, Peizataifeng showed unfavorable lodging resistance but better root growth attributes than Yuxiangyouzhan, further, the strong relationship between the lodging resistance in super rice and the root volume (RV) at the heading stage and at maturity, the total root length (TRL) at the heading stage, and the root superficial area at the heading stage and at maturity had also been assessed (Table 4-8, Fig. 3B-F). These results enriched the view of Wang et al. who proposed that the improvement of lodging resistance in mechanical hill wet-seeded rice was related to rice root growth [35].

Many other previous studies have reported the yield improvement of mechanical hill wet-seeded rice as compared to manual wet seeded and transplanting under different plant density, water management and fertilization conditions [8, 64, 65]. In this study, we try to assess the effect of the establishment of the water ditches and seed ditches on two super rice cultivars. Generally, better root growth attribute to better shoot growth and resulted in higher grain yield. Therefore, supplemental of appropriate nutrients to the rhizosphere to build ideal plant morphology performance was a feasible approach to avoid crop lodging and increase yield [17, 66-69]. Even, Zhang et al. had reported that the improvement in root and shoot growth could contribute to higher grain yield and the grain yield was related to the enhancement of the grain filling due to the increase in root activity [62]. However, we observed that the root morphological traits were improved in precision mechanical hill wet-seeded rice under the establishment of the water ditches and seed ditches treatments, but no significant difference was observed in grain yield and dry weight (Table 3). No visible rice lodging was detected in the experimental field in both 2012 and 2013, therefore, no significant influence of the establishment of the water ditches and seed ditches treatments on yield were investigated. Yuxiangyouzhan showed higher grain yield and dry weight than Peizataifeng. Besides, apart from the root morphological traits, the root activity has been regarded as an important attribute of root growth [70-73]. Higher root activity is necessary to yield root and shoot biomass and improve the ion uptake [70, 71, 73]. The established of water ditches and seed ditches may benefits for crop root growth by affecting the rhizosphere soil. However, further study to evaluate the root activity under mechanical hill wet-seeded rice is needed. Moreover, it is necessary to investigate the application of appropriate water and fertilization managements to the mechanical hill wet-seeded rice due to the establishment of the water ditches and seed ditches.

5. Conclusion

The lodging index was significantly affected by the mechanical hill wet-seeded rice due to the establishment of the water ditches and seed ditches. The establishment of the water ditches and seed ditches treatment had the lowest lodging index in both 2012 and 2013. The lodging index was strongly associated with the breaking resistance, the root volume and root superficial area at the heading stage and maturity, the total root length at the heading stage. The establishment of the water ditches and seed ditches treatment did not significantly affected the grain yield or the dry weight of mechanical hill wet-seeded rice for no visible lodging detected during the study. Yuxiangyouzhan showed higher grain yield, dry weight and better lodging resistance but unfavorable root growth attributes than Peizataifeng. Further study to assess the lodging and yield performance of mechanical hill wet-

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seeded rice with the establishment of the water ditches and seed ditches under various crop management and adverse environment conditions is needed.

Author Contributions: Zaiman Wang designed the experiments; Minghua Zhang, Zhaowen Mo, Juan Liao and Xiongfei Chen and Le Zheng investigated the traits; Minghua Zhang, Zhaowen Mo and Zaiman Wang analyzed the data and wrote the manuscript; Minghua Zhang, Zhaowen Mo, Zaiman Wang, Shenggang Pan and Xiwen Luo revised and edited the manuscript. All authors read and approved the final manuscript.

Funding: Please add: "This research received no external funding" or "This research was funded by NAME OF FUNDER, grant number XXX" and "The APC was funded by XXX". Check carefully that the details given are accurate and use the standard spelling of funding agency names at https://search.crossref.org/funding, any errors may affect your future funding.

Acknowledgments: The authors wish to acknowledge funding provided by the National Postdoctoral Program for Innovative Talents (BX201700083), the Commonweal Project (Project No. 201203059), and the National Key Research and Development Program of China (2018YFD0100800), as well as support from the earmarked funds for the China Agriculture Research System (CARS-01-41).

Conflicts of Interest: We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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