
The rotary tillage energy and tillage-induced soil structure affected by blade geometry and rotary speed

Yanshan Yang^a, Chengsheng Dong^b, Qishuo Ding^{a,*}, Tingfeng He^a, Lianfei Huo^a

^a College of Engineering, Nanjing Agricultural University, Nanjing, Jiangsu 210031, China

^b Agricultural Machinery Technology Extension Station, Danyang, Jiangsu 212300, China

* Qishuo Ding, E-mail: qsding@njau.edu.cn

Abstract

Rice-wheat (RW) rotation was characterized as one of the most important intensive agricultural systems in Asian countries. The desired yield of the RW system directly affects the national food security of these countries. The key factors affecting food production is the soil structure. However, the soil structure in the RW system is destroyed by the paddling and wet-dry alternation. The required level of the soil structure can be only achieved by using complex agricultural machinery. Rotary tiller are used to achieve better soil structure and many different shapes blades were produced by local manufacturers, this study was aimed to find out which type of rotary blades is more satisfied to the paddy soil. An in-situ test rig was used to evaluate the performance of the rotary blades in paddy soils. The in-situ test rig allows a wide range of rotary speed from 0 to 600rpm, providing a possibility for high-speed rotary tillage research. The effect of two blade geometries (namely, conventional blade and type G blade) at four rotary speeds (180, 280, 380, and 510 rpm) on the energy consumption and tillage-induced soil structures was investigated using the in-situ soil tillage test. The soil structures were evaluated on the basis of the flatness and pulverization. The flatness was analyzed by the image processing tool. Results proved that the torque, specific work requirement and pulverization were mainly affected by the rotary speed. The flatness was significantly affected by blade geometry. The flatness induced by Conventional blade was much higher than the G blade. Both considering the tillage-induced soil structures and energy requirement, the G blade would be the preferred option when undertaking rotary tillage on the wet paddy soil.

Key words: Paddy soil, In-situ test, energy consumption, soil structural, Image processing

1. Introduction

The rice-wheat rotation is widely distributed in Asia countries, including Japan, Korean, China, and south Asian countries like India, Nepal, and Sudan etc. China has 4.8 million ha rice-wheat rotation (RW) cultivation area, the farmland contributes to 55% of the nation's grain food supply (Li et al., 2012). The key factors affecting food production is the soil structure (Barzegar et al., 2004; Altikat et al., 2011; Bronick et al., 2005; Carter et al., 2004). However, the soil structure in the RW system is destroyed by the paddling and wet-dry alternation.

The required level of the soil structure can be only achieved by using complex agricultural machinery (Carter et al., 2004, Aluko et al., 2000). As a conservation tillage tool, rotary tiller is becoming a more widely used worldwide. In the last 20 years rotary tiller was used to replace mouldboard ploughing for seedbed preparation in many places in China rice-wheat system. Recent year experiments have shown that improved tool design or selection of particular working parameters can reduce energy consumption and improve soil structures. Ponjican et al., 2011 analyzed the influence of rotary tiller rotor rotation direction on specific work requirement and determined the tillage quality. They found that better soil structure and lower specific work

requirement was observed with the reverse rotor rotation direction. Matin et al., 2014's research showed that the level of soil pulverisation increased with rotary speed. Kushwaha 96 conducted a field experiments to determine the draft-speed relationships, the results showed that the draft increased less above a critical speed range of 3 to 5m/s. Salokhe et al., 2002 evaluated the power-take-off (PTO) power consumed of a rotary tiller in a Bangkok clay soil, discovering that the power consumption increased as the increase of forward speed. Sirisak et al., 2010 also found that the shape of the rotary blade influenced the torque characteristic and the specific tilling energy. The cyclic variation in torque could be observed distinctively, especially, for both European blades. The investigations indicated that the specific tilling energy of the Japanese C-shaped blade was the highest while the specific tilling energy of European L-shaped blade was the lowest. The tillage process of a rotary tiller was investigated by Takashi et al., 2002, they found that the crack formation is helpful to produce a better soil structure and reduce the energy consumption. The down-cut process of rotary tiller was recommended by Lee et al. 2003 for preparing a desired rice seedbed.

Despite this large number of studies, a better understanding of the relationships existing between tillage-induced soil structure and energy consumption and tool parameters has not been elucidated particularly in paddy soils. This study was aimed to find out which type of rotary blades is more satisfied to the paddy soil through comparing the tillage-induced soil structure and energy consumption.

2. Materials and methods

2.1 Study site and soil

Field experiment was conducted between Dec. 9 and Dec. 19 2015 in Babaiqiao, Nanjing city, Jiangsu Province in China, during the short window period of rice-to-wheat transition. According to the international soil textural triangle; experimental field soil was clay loam having clay (<0.002 mm) 35.55%, silt (0.2-0.002) 40.39%, sand (>0.2mm) 24.06% and organic matters 2.27%. Soil plastic limit was 25.18% and liquid limit was 41.94%. The soil of the experimental area has a long history of rice-wheat rotation. Soil physical properties are presented were measured at the depth 0 to 10cm. (as shown in Table 1)

Table1 The physical and mechanical properties of paddy soil

Soil depth(cm)	Water content (%)	Dry bulk density (g cm ⁻³)	Cohesion (kPa)	Internal friction angle (°)	Cone Index (kPa)
0-10	31.83	1.25	30.91	13.12	348.05

2.2 Construction of the test rig

A Platform of 7m length and 1.2m width test rig was developed for ease of in-situ testing (Fig.1). The system was constructed with a tool trolley sitting on short rails with track cart spans of 6 m. A 7.5kW rotary tiller was installed on the tool trolley and the working depth of the tiller was adjustable by three screw mechanisms. The rotary tiller equipped had 6-speed gears, two clutches and a throttle. The combination of the gear and the engine throttle provides rotary speed adjustable from 0 to 600 rpm. The test rig could be moved along the two rails with four support wheels. Four 0.75Kw motor were used to control the four support wheels up and down according to where the experiment should be conducted or when the rig should be shifted. The driving draft was supplied by a 7.5Kw motor to allow the rotor speed to be adjusted. Power is transmitted through a mechanical coupler to a pulley wheel installed on the motor. A break is used at the other end of the tool trolley.

Thus a consistent driving speed can be obtained which can also be adjusted from 0.1 to 0.5 m/s during the experiment. All the electricity power is provided by a 13.5kw generator and all the motor was controlled by a control panel.

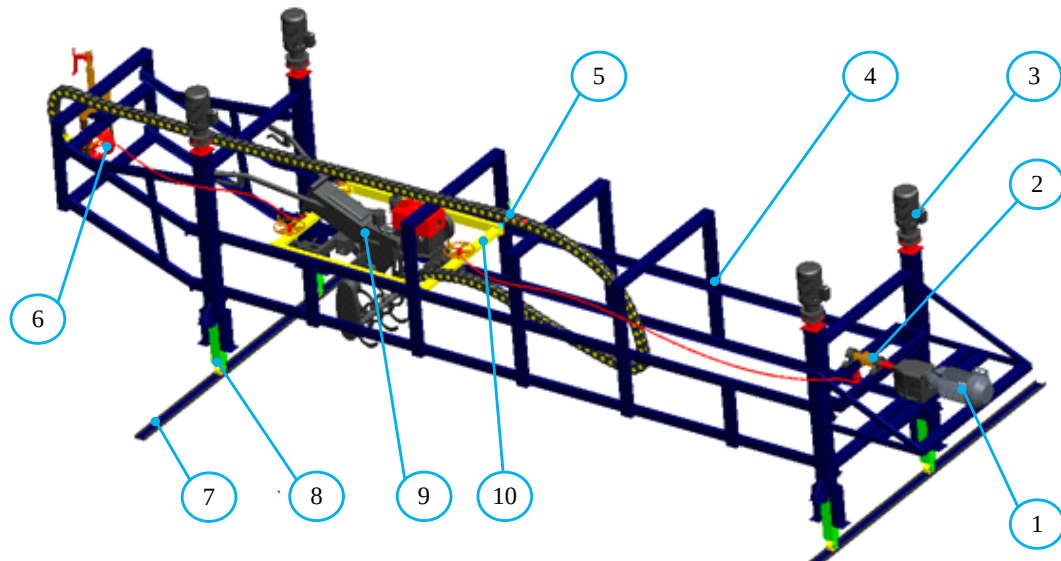


Fig.1 Schematic of in-situ experimental platform

- 1) 7.5Kw motor 2) mechanical coupler 3) 0.75Kw motor 4) frame 5) plastic chain 6) brake 7) rail 8) support wheel 9) rotary tiller 10) the tool trolley

2.3 Measuring system

The torque required for tilling with the rotary blades was measured using the test carriage system as shown in Fig. 2. Strain gauges were attached to the driving shaft of the rotary tiller (Sirisak et al., 2010). The torque measuring system included a slip ring, Bridge measurement, resistance strain gauge and computer-based data acquisition system. During tilling, the soil reaction force (torque) was sensed by the strain gauged torque transducer and recorded on a computer. Signals were analyzed at a sampling rate of 500 Hz.

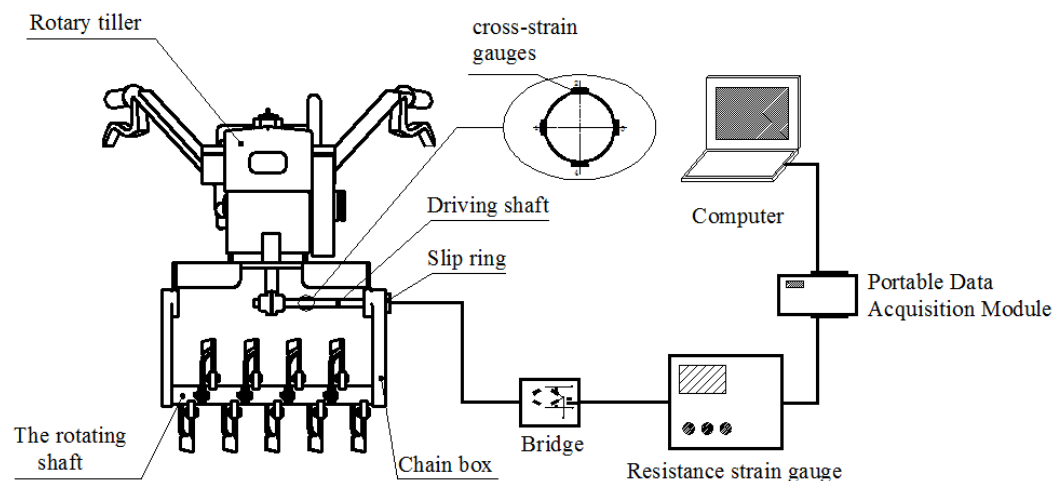


Fig.2 Measurement system

2.4 Rotary blades

Three different types of rotary blades (namely, conventional, C-type blades) were used in the experiments shown in fig 3. The rotary radius is 225mm and 18 blades were mounted on the rotor

shaft and the tillage width was 0.8m.



C-type blade

Conventional blade

Fig. 3 Rotary blades

2.5 Test conditions and data analysis

The experiment was studied in paddy soil, two blade geometries (namely, conventional blade and type G blade) were chosen in the experiments. And the tilling depth was 10 cm, the forward speeds were 0.3m/s, and the rotational speeds were 180, 280, 380, and 510 rpm. To evaluate the tillage quality, the Mean Weight Diameter (MWD) and the flatness on the shaft was determined. Soil was sampled by a $\Phi 300 \times 200$ mm after tillage and brought back to lab for sieving. Air-dried soil samples were graded by a series of sieves, i.e. <4, 8, 16, 32, 64 and 128 mm in sizes and weighed respectively (Dexter et al., 2004; Arvidsson et al., 2010). Classically, a synthetic descriptor of SDA the Mean Weight Diameter (MWD) was used shown in equation (1) (Caruso et al., 11)

$$MWD = \sum_{R=rmin}^{rmax} W_R R \quad (1)$$

Where R is the sieve size and WR is the weight ratio of the material retained on the sieve of size R

To evaluate the shape of the block produced by different rotary blade, the flatness was proposed. As shown in fig 4, 10 blocks were selected after sieving randomly and Taking pictures vertically and horizontally. The vertical and horizontal projected area were calculated by the Adobe Photoshop software. The flatness is defined as the vertical projected area divides the horizontal projected area as shown in Eq. (2), the F is more close to 1 ,the block structure is better. This method is just suitable for the larger clods(MWD >8mm).

$$F = \frac{S_v}{S_h} \quad (2)$$

Where S_v is vertical projected area, S_h is horizontal projected area.

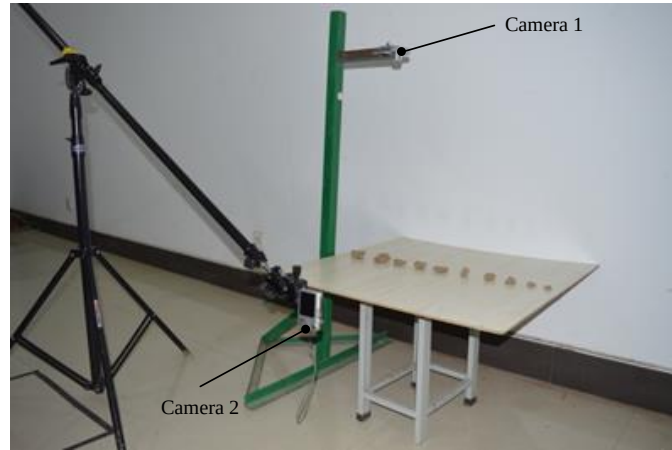


Fig 4. Image acquisition device

camera 1: taking vertical photo, camera 2: taking horizontal photo

In order to evaluate the energy consumption of these two blades, the torque and Specific work requirement was determined. The torque data and the value was calculated using the relationship between torque and output voltages shown in equation (3). Specific work requirement was calculated based on the Equation (4) (Ondrej et al., 2011).

$$y = 93.356x + 0.4973 \quad (R^2 = 0.999) \quad (3)$$

where y is torque value (N m) and x is output voltage(V).

$$SW_{pto} = \frac{M \cdot n \cdot \pi}{30 \cdot v_f \cdot B \cdot a} \quad (Jm^{-3}) \quad (4)$$

Where: M is PTO torque (Nm), n is rotor speed (min^{-1}), v_f is driving speed (m s^{-1}), B is working width (m), a is working depth (m).

3. Results and Discussion

3.1 Tillage-induced soil structure

Tillage is conducted to improve the soil functions in regard to water and air regulation and flow, to enhance the water storage capacity of the soil, and to create a desirable aggregation size distribution conducive for seed-soil contact (Carter et al., 2004). For determining the aggregate size distribution and level of tillage quality. The Mean Weight Diameter (MWD) and the flatness were calculated, respectively as shown in fig5 and fig6. The mean weight diameter was not significantly affected by the blade geometry, but by the rotary speed. This result is similar to that observed by Sirisak et al., 2010, Matin et al., 2014 who did not find any significant difference in soil fragmentation by comparing tillage performance of different geometries of rotary blades. The rotary speed of the blade influences soil pulverization by affecting the bite length and soil acceleration (Matin et al., 2015). The volume of tilled soil per bite will be increased with the increasing of bite length, and the larger MWD will be produced. Higher rotary is helpful to improve the tillage pulverization. The shape of the block was significantly affected by the blade geometry and the cutting style during tillage. The tillage process was different, the narrow tip of the C-type blade penetrated into the soil and dugged the soil out. The contact area between tilled soil and C-type blade was small (just the tip area), the crack was caused by tensile force. Therefore the block produced by C-type blade was closed to the sphere and the flatness was closed to 1. In contrast, the soil was cut and the slice was tilled by the conventional blade during tillage. The flatness was much higher as shown in fig 6. The slice soil was smeared and compact hard by the conventional blade. The structure of the tilled soil was poor and is not suitable for seed germination and growth.

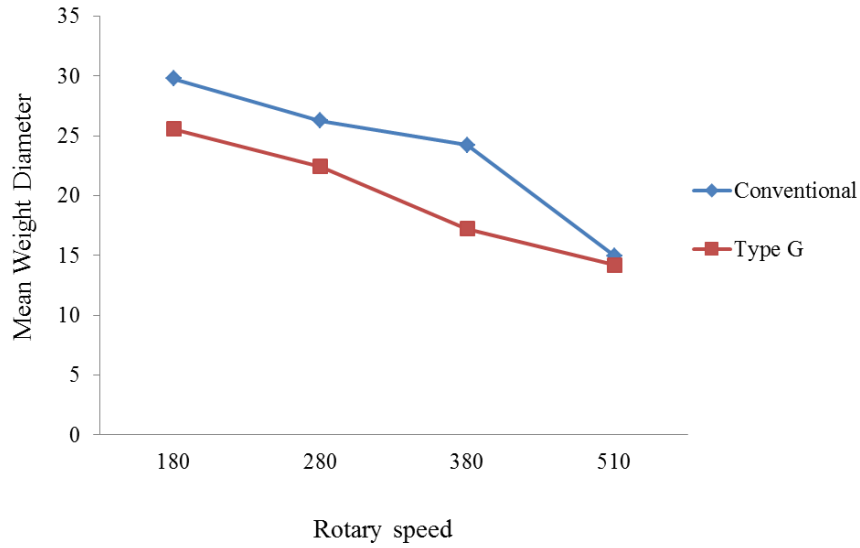


Fig 5. Effects of different rotary speed on MWD

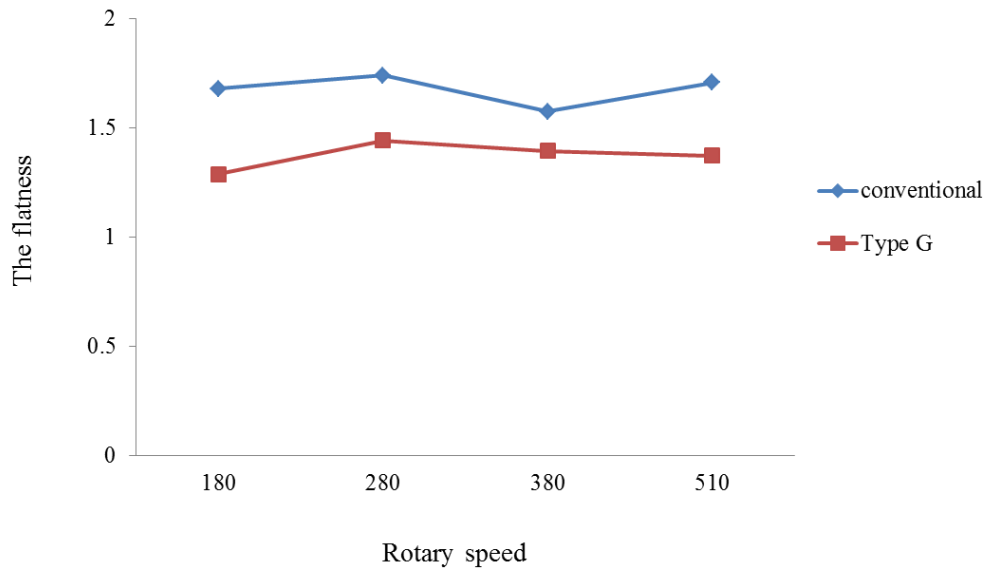


Fig 6. Effects of different rotary speed on flatness

3.2 Energy consumption

The variations of the torque and SWPTO values with the rotary speeds are shown in Fig 7 and Fig 8 respectively. As Fig 7 shown, the torque decreased at an increasing in rotary speed. The reason being that at lower rotary speed more soil volume is considered and the torque will be increased at the cutting and holding stage (Takashi et al., 2002). SWPTO varied in a range of 63.5 to 131.2kJ/m³ as shown in Fig.8. This is because for the constant forward speed as the bite length increased, in each blade thrust more soil was tilled and consequently the torque increased significantly calculated based on the Equation (4). Kheiralla et al., 2004 and Sirisak et al., 2010 also got the same conclusion. From the above analysis, we can see there is no significant difference in energy consumption between the C-type blade and conventional blade. The optimization of the rotary speed needs further investigation.

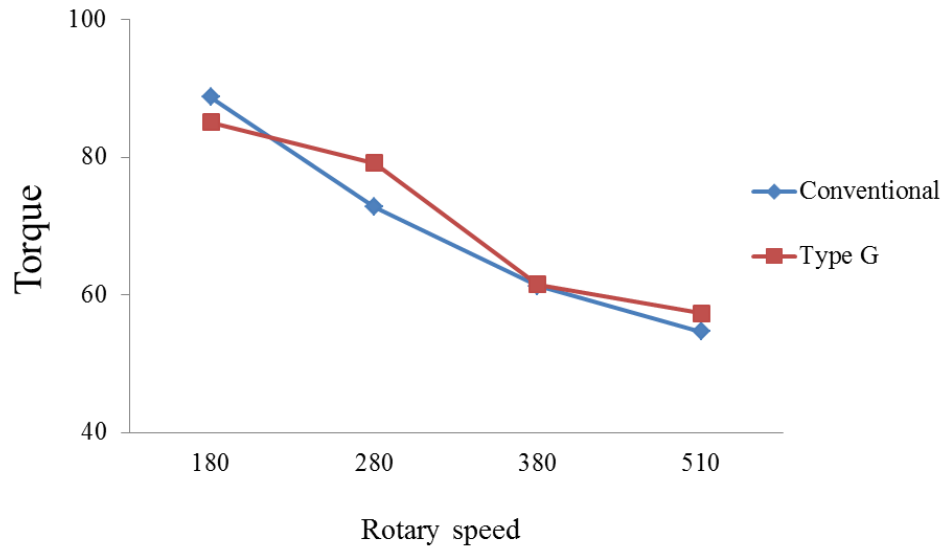


Fig 7. Effects of different rotary speed on tillage torque

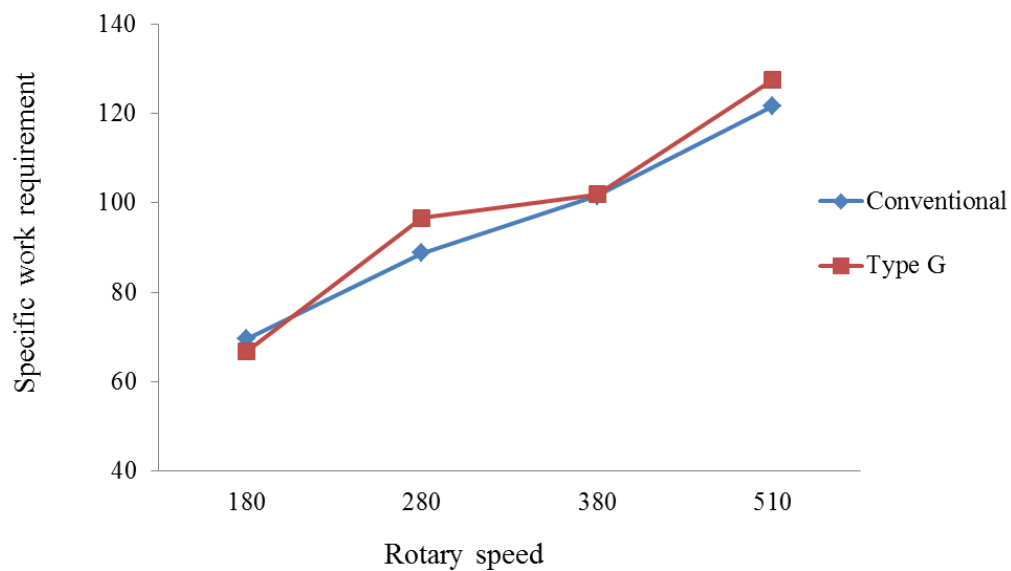


Fig 8. Effects of different rotary speed on specific work requirement

4. Conclusions

The main purpose of tillage is to create a favorable soil structure for crop growth, furthermore promoting seed germination and increasing yield (Yousef et al., 2009, Sirisak et al., 2010, Salokhe et al., 2002, Altikat et al., 2011, mark et al., 2005). This study recommends the use of C-type blades operated at 510rpm as a more suitable tillage blade in paddy soil comparing the pulverization, flatness and energy consumption. This recommendation is based on:

- The pulverization increased significantly with the increase of rotary speed which would create a desirable aggregation size distribution conducive for seed-soil contact and enhance the water storage capacity of the soil, furthermore improve the yield of crops.
- The block produced by C-type blades was less smearing and compaction and the flatness was much lower. The lower destruction of soil structure and soil porosity was caused by C-type

-
- blades. Therefore the C-type blades is more suitable for rotary tillage in paddy soil
- There is no significant difference in energy consumption between the C-type blade and conventional blade. The application of C-type blade did not cause more energy consumption, but improved the soil structure.

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