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IMPACT OF TILLAGE OPERATION ON SOIL PHYSICAL, MECHANICAL AND RHELOGICAL PROPERTIES OF PADDY SOIL

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Abstract

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Laboratory experiment was conducted on paddy soil to determine the effect of tillage operations before and after on soil physical, rheological and mechanical properties. Tillage operations play an important role to change the physical and mechanical properties of the soil. The three soil moisture content levels (27%, 30% and 33%) were used in the study to measure the effect of tillage operation on soil conditions. Results showed that soil bulk density was observed directly proportional to the soil moisture while soil porosity was inversely proportional to the moisture content. It is observed that soil requires more shear stress before tillage operation. Overall results showed that the soil water content has great impact on soil properties. A negative impact of tillage operation was found in soil bulk density and internal friction angle, while decreasing trend was found on porosity, shear stress, penetration resistance after tillage operation significantly ($P = < 0.01$). Soil water content on rheological parameters (E_m, E_k, λ_m and λ_k) were found predominantly significant ($p = < 0.01$).

Key words: Paddy soil; soil physical properties, penetration resistance, shear stress, rheological properties

Introduction

Effects of tillage tool on soil physical and mechanical properties are the main objectives of all researches which are concerned with soil physics and soil mechanics (Gupta and Surendranath, 1989; Makanga, 2010). Soil tillage is carried out with the objective of changing the soil physical and mechanical properties. The loss of the physical quality of a soil can be evaluated through the changes that occur to some of its most important physical characteristics such as density, porosity, pore size, distribution, structure, and infiltration rate (Abo Al-kheer et al., 2011).

Excessive tillage practices could destroy the soil structure and also an energy consuming process (Ali-Hassan et al., 1983). Proper use of tillage tolls enables the soil to increase its bulk density, porosity and water holding capacity which is the favourable factors for the proper growth of the crops (Changying and Junzheng, 1994). Soil proper aggregation is also an important factor for optimum growth of the plant which results in best use of the tillage tools (Archer, 1975; Arora, 1988) and proper soil aggregates' are also responsible for the soil organic carbon (SOC) retention (Carman, 1997).

Soil-tool interaction is of much concern for these top soil strata. Methods of classical soil mechanics are often applied to agricultural soil mechanics with little modification for studying soil deformation (Koolen and Kuipers, 1983). Soil mechanics mostly deal with soil failure at shallow depth with the interaction of relatively low load. Classical soil mechanics deals with mainly on the response of soil to small displacements due to loading and its behavior up to failure, whereas, tillage mechanics is concerned with the soil condition after failure. A substantial soil deformation is associated with the

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generation of nonlinearity in stress-strain relations in soil failure with tillage tool interaction (Kushwaha and Shen, 1995; Meng et al., 1996; Chandio et al., 2014; Kgun et al., 2014).

The movements of tillage tool affect soil physical properties and mechanical properties like soil erosion, soil compaction, soil bulk density, soil moisture content, soil porosity, soil texture and structure. Stand establishment failure often reflects the combined impact of soil property change on tillage tool performance.

Materials and Methods

Soil preparation

Soil was taken from Pukou Yongning in South of Nanjing from paddy field. Before conducting experiments the soil texture had been analyzed and found to be clay Zhail Lixin (2011). Paddy clay soil was prepared for measuring horizontal force on the surface of the moldboard plough. In the first step, the soil was leveled by a wooden leveler and in the second step; water was sprayed by showers on the soil, to get saturation stage. After that soil physical and mechanical properties were determined. The particle size distribution of soil, sand, silt and clay proportion was found 11%, 47% and 42% respectively.

Soil Physical properties

Soil moisture content

In the study there were three levels of soil moisture content was used to measure physical and mechanical properties before and after tillage (27%, 30% and 33%). For each test, 6 samples were randomly collected from soil bin and were kept at 105^{o}C for 24 hours and soil moisture content on wet basis was calculated according to Blake and Hartge, (1986), as follows:

$$MC = ((Mw - Md) / Mw) * 100 \quad (1)$$

Soil Bulk Density

The values of soil bulk density were determined at four different soil horizons (0.0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm) also we have followed the C. Karman (1996).

$$Db = Ws / Vt \quad (2)$$

Total porosity

Soil total porosity after and before tillage tool operation was measured with bulk density, reflects the soil condition at sampling time, and both are used to characterize soil compaction at the macroscopic scale (Blake and Hartge, 1986; Black et al. 1965). Total porosity (% per pore space) was worked out using the same samples that were collected for soil bulk density. Porosity (%) was calculated with the help of the following formula:

$$\text{Total porosity (\%)}\ P = (1 - \frac{B.D}{P.D}) \times 100 \quad (3)$$

Soil Mechanical Properties

Penetration Resistance

A digital cone penetrometer was used (Figure 1) to find out the soil penetration resistance. It was pushed by hand into the soil to a 25 cm depth and penetrometer resistance for each 5 cm depth interval was recorded directly Campbell (2001). For each experiment, soil penetration was measured at 3 points from the soil bin at different 5 depths.

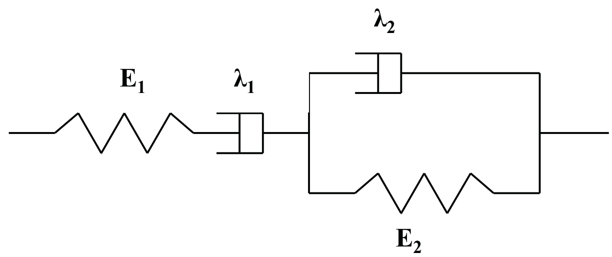

Fig. 1. Digital cone penetrometer

Direct Shear Stress Soil Sample Preparation

Soil mechanical properties including cohesion, adhesion, internal and external friction angles were measured in the laboratory. A direct shear test apparatus having shear box surface area of 100 cm^2 was employed to measure these values under three different moisture content levels 27%, 30%, and 33% before and after tillage operation. Three different normal shear stress levels were applied to find out the impact of the mould board plough on shear stress of paddy soils before and after tillage Fredlund et al. (2002).

$$\tau = c + \tan \varphi, \quad (4)$$

where: τ = Shear stress; c - Soil cohesion; φ - Friction angle of soil.

Soil Rheology

A Four-element Burgers rheological model H. Lee, 1955, Pan Junzheng (1986) shown in Figure 2 were used in this research to study soil rheology. Burgers model of stress-strain equation for the operator is used for this purpose asunder,

$$\alpha = \frac{\lambda_1 \frac{d}{dt} + \frac{\lambda_1 \lambda_2}{E_2} \frac{d^2}{dt^2}}{1 + \frac{\lambda_1 + \lambda_2 \quad E_1 + \lambda_1 E_2}{E_1 E_2} \frac{d}{dt} + \frac{\lambda_1 \lambda_2}{E_1 E_2} \frac{d^2}{dt^2}} \varepsilon \qquad (5)$$

If the arithmetical symbol of above equation can be indicated by D,

$$\sigma = D\varepsilon \qquad (6)$$

A displacement sensor was used to measure the soil rheological properties at different moisture content. The sensor was calibrated before the experiments, followed the Lixin (2011) and Chandio (2013). While after completing all procedure, two LabView programs were developed (National Instruments, Austin, Texas, USA) 8.2 (computer software) for JP-1 force sensor and LD-80 octagonal ring transducer to get output from sensors through USB-4716 data acquisition card.

Results and Discussions

Soil Bulk Density After and Before Tillage

Before and after tillage in all treatments an average bulk density is given in Figure 3. A significant effect of soil bulk density was found (P < 0.01). It was found that tillage increases the bulk density of paddy soil. Minimum bulk density before tillage was 1.54 g/cm^3 on 27% moisture content and after tillage bulk density was observed 1.6 g/cm^3. The highest average changes were found in soil bulk density at 30% moisture content after the tillage operation. Similar results were drawn by C. Carman (1996).

Soil Porosity Before and After Tillage

Results showed that soil porosities before and after tillage operations decreased. Minimum porosity before tillage was 34.9% on 33% moisture content while after tillage, it was reported 34.1% at the same moisture content which was slightly decreased after tillage operation results are shown in Table 1.

Effect of Shear Stress and Soil Moisture Content on Tillage

Figure 4 (a) shows the soil, average shear stress, which was finding out before and after tillage. It was found the rate of increasing normal load the soil shear stress increases significantly (P < 0.01), while decreasing trend was found with increasing moisture content result are agreeing with (Aluko and Seig, 2000; Tagar et al., 2014).

Fig. 2. Four element Burgers model

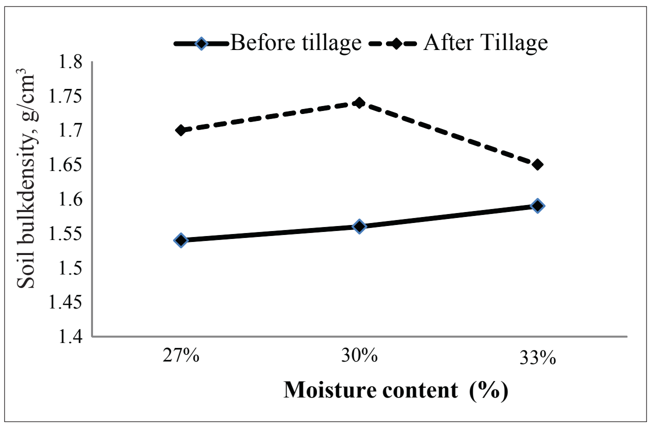

Fig. 3. Relationships between soil moisture content and soil bulk density

Table 1
Effects of porosity (%) before and after tillage

Moisture content, %	before	after	Treatment mean
27	48.8	47.4	48.2
30	39.5	35.4	37.4
33	34.9	34.1	34.5
mean	40.8	39	

Results also show a negative impact of tillage tool (Aluko and Chandler, 2004). The greatest changes were found in soil shear stress at same normal load, a decrease of 50% with before tillage. Similar findings were found by Tagar et al. (2014). Overall in all treatments an average decrease 42% of soil shear stress were found in paddy soil after tillage.

Figure 4 (b) showed a negative impact of moisture content on soil cohesion. Results show that soil cohesion slightly decreased from before to after tillage: from 3 to 1.89 kPa in the paddy soil similar trend where found by Jayasuriya and Salokhe (2001). Comparatively, 44% of the decreasing ratio of soil cohesion was found from before to after tillage on paddy soil.

Figure 4 (c) shows that the internal friction angle also decreases when soil moisture content increase over all, 27% of internal friction angle variation was found due to moisture content changes. The internal friction angle before to after tillage slightly increased in the soil bin from 5.5° to 6.71° in the soil bin at 27% of moisture content similar results were found at high moisture content by A. A Tagar et al. (2014).

Plowing impact on penetration resistance

Soil penetration resistance depends on its operating condition (depth) and changes of soil properties. Figure 5 shows an increasing trend of penetration resistance was found due to increasing the operating depth was significant ($P < 0.01$). Results showed highest penetration resistance 693 Pa was observed at the depth of 25 cm under 27% of moisture content which was reduced to 303 Pa when moisture content was in-

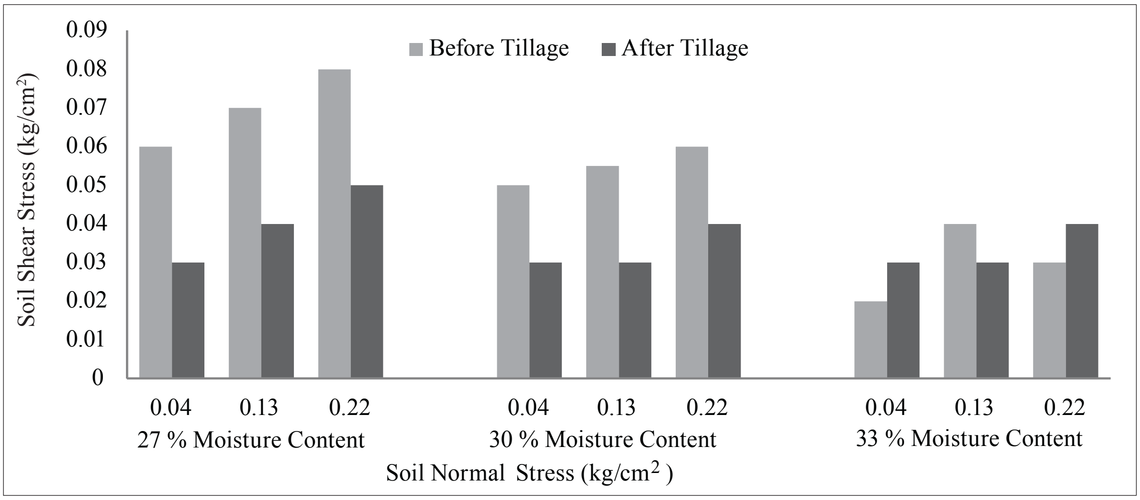

Fig. 4 (a). Soil shear stress before and after tillage at various moisture content

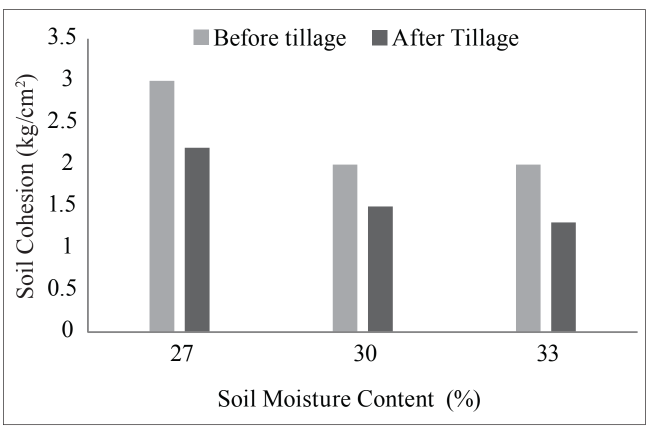

Fig. 4 (b). Soil Cohesion before and after tillage at different moisture content

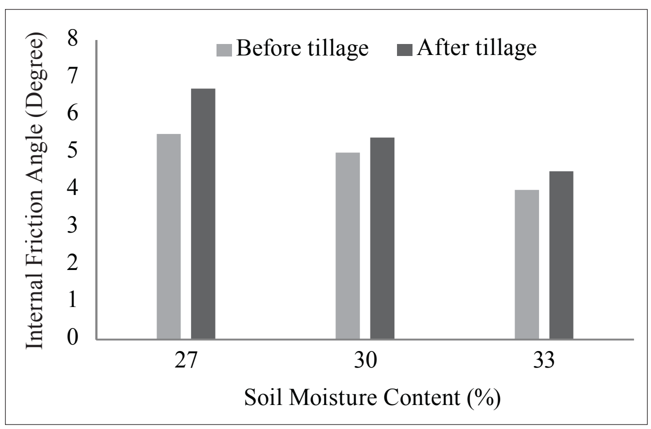

Fig. 4 (c). Internal friction angle before and after tillage at different moisture content

creased 33%, resulting in a negative impact of moisture content (Adam and Erbach, 1992; Mari et al., 2014).

A negative impact of tillage operation was found in penetration resistance 186 Pa before the tillage was observed at 5 cm under 27% of moisture content which was reduced 103 Pa after tillage operation shown in figure 5. Over decreasing trend of penetration resistance was found at the changes of moisture content and after tillage. Results are agreeing with Carman (1996), Mari (2008), Tagar et al. (2014).

Measurement of Some Soil Rheological Properties

According to the equation (5), we can measure the relationship between the displacement and the time on the condition of the under static and dynamic loading at different soil moisture content. Static load conditions, the rheological parameters are used in static load conditions, the measured creep curve obtained in the soil. Test, the computer automatically collected by the pressure and subsidence of soil volume, and after this, we can work out the rheological parameters of the paddy clay loam soil at different soil moisture content which are shown in Table 2.

Soil moisture content was 27%, 30% and 33% as we can see from figure 6 the measure with theoretical curve. This shows that the system used to measure the paddy clay loam soil rheological parameters under dynamic loading is quite good.

The experimentally determined rheological parameter gathered could be used in predicting soil strain and resulting changes in hydraulic properties during compaction of agricultural soil. Soil rheological parameter under steady state and oscillatory stress conditions of paddy clay loam soil were measured using a paddy soil rheometer with a displacement sensor in different soil moisture content. The displacement was measured at different pressure, soil moisture content levels from 27% to 33%. In the study of soil physical/mechanical properties it was observed that moisture content has long been found as one of the numerous factors influencing the rheological behavior of paddy soils. Significant changes on rheological behaviour of paddy soil were recorded due to the changes in the water moisture content (Mari et al., 2009; Lixin et al., 2010; Mari et al., 2014). When the vertical load effects on the soil whose water moisture content is high, the

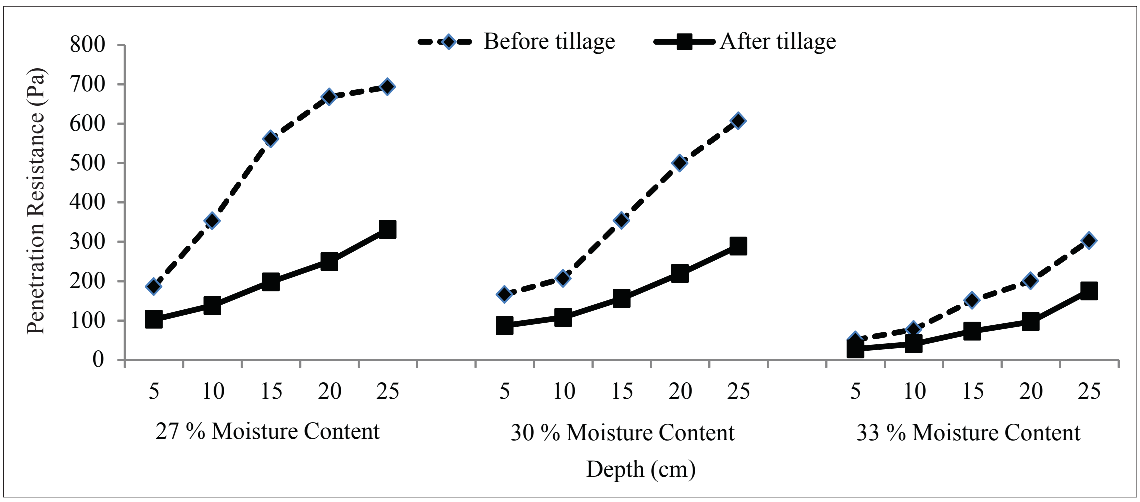

Fig. 5. Penetration resistance (PR) in the plow layer before and immediately after plowing

Table 2
Testing result of rheological parameters at different water content (27%, 30% and 33%)

S.No	Soil water content, %	E1/ N/cm^2	λ1/ N s/cm^2	E2 / N/cm^2	λ2/ N s/cm^2	Different pressure, N/cm^2
1	27%	146.133	1962.5	33.75	23.31	20.32
2	30%	139.1	1001.15	21.11	25.74	20.32
3	33%	400.85	2021.85	39.23	48.7	20.32

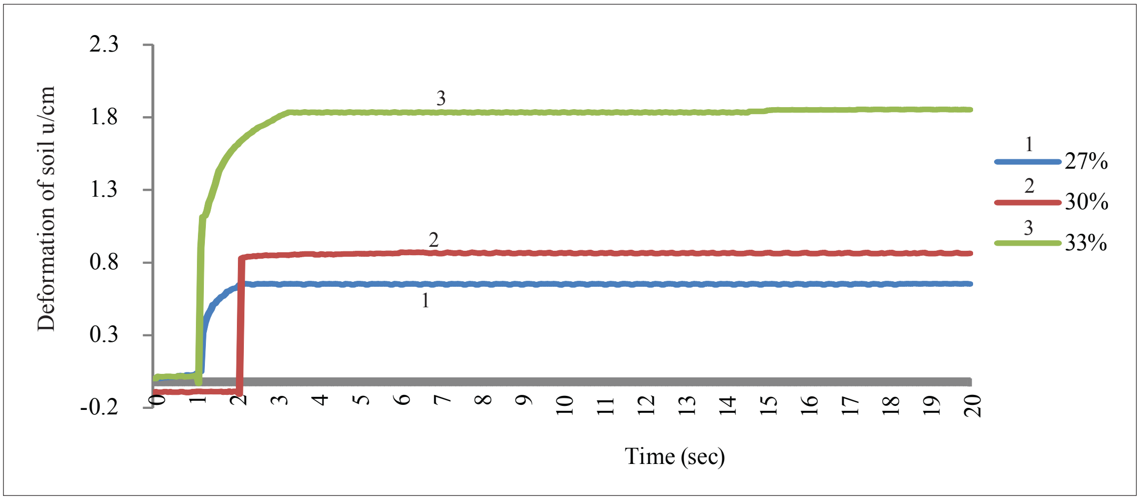

Fig. 6. Different soil moisture content and time of the creeping curve

displacement may appear the case of step or sudden change which are shown in Figure 6. So, through the experiment, we can anises the law that water moisture content affects on the rheological parameters, it can help us to know the rheological properties and the law of displacement (Irshad Ali Mari et al., 2009).

Conclusions

- A negative impact of tillage operation was found in soil bulk density, while soil porosity is inversely proportional to the moisture content.
- Soil represents more shear stress before the tillage operation and less shear stress after the tillage operation, before and after the tillage operation; it was observed that shear stress is inversely proportional to the soil moisture content.
- An increasing trend of soil penetration resistance was found with increasing depth, however, before and after tillage penetration resistance was decreased.
- This research shows that the rheological behaviour of paddy soil changes significantly according to the change of the moisture content in the soil. When the vertical load effects on the soil whose water, moisture content is high, the displacement may appear in the case of step or sudden change.

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