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Transitions of soil failure patterns as affected by various moisture contents

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Abstract
To better understand the soil tilth modified by tillage, it is important to study the soil failure patterns and the conditions at which the transition of soil failure pattern takes place. This study has investigated the transitions of soil failure patterns as affected by various moisture contents in dry land and paddy soils. The soil failure patterns were observed and recorded using a digital camera, the recorded failure patterns were then converted into snapshots. The results revealed that two soils have same textural class as well as soil genesis, but the transitions of failure patterns corresponding to moisture contents were not the same.

Keywords: Soil failure patterns, moisture content, genesis, texture.

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Introduction

To better understand the soil tilth modified by tillage, it is important to study the soil failure patterns [1, 2] and the conditions of soil and tool in which one form of soil failure pattern changes into another. There are mainly four types of soil failure patterns including, collapse (pulverizing by shear), brittle (fracturing), chip forming, and flow [3-5]. The collapse failure occurs in dry soils, due to the collapse of the soil structure when a mass of a soil in front of the tool is crushed [6]. It is similar to the shear plane type failure as described by Elijah and Weber [7]. Brittle failure occurs in moist soils due to the propagation of tensile cracks [8, 9]. This type of failure is mostly desired to achieve better soil tilth [10-13]. The chip forming failure occurs in wet unsaturated clay in which soil is removed in the form of chips depending on the width of tool [1]. Flow failure occurs in wet saturated clay due to mere physical displacement of the soil [1].

The soil failure patterns are affected by soil and tool parameters [7, 14-16]. During the past decades, the numbers of studies have been conducted to evaluate the effects of these parameters on soil failure patterns [4, 16-21]. Stafford [15] concluded that soil failure pattern changed from shear to flow failure corresponding to increase in the implement speed. This is consistent with Karmakar [20] who indicated that at slow speed, soil failed to create some soil segments in terms of blocks and at higher velocities; the soil failure was like a flow failure. Aluko and Seig [19] concluded that at 25-40^o soil failed in brittle failure and as the angle increased from 40^o, same soil failed in shear failure. O'Callaghan and Farrelly [22] stated that the transition from one mode of soil failure to the other occurred when the aspect ratio was 0.6. Moreover, Godwin and Spoor [14] concluded that there is critical depth and above this depth, soil failed in a crescent failure pattern, and below this depth, soil failed in lateral failure. In contrast, Elijah and Weber [7]; Stafford [15, 23] and Rajaram and Gee-Clough [4] reported the identification of distinct soil failure patterns in all major soil types with the change of soil moisture content. They concluded that the nature of soil failure depends on the soil moisture level. In addition, Rajaram and Erbach [1] attributed that soil moisture content determines the way the agricultural soils fail.

The objective of this study was to investigate the conditions of soil and tool parameters at which one form of soil failure pattern changes into another form of soil failure pattern as affected by various moisture contents in dry land and paddy soils.

Materials and methods

The experiments were carried out in an indoor soil bin test rig developed at the Department of Agricultural Mechanization, College of Engineering, Nanjing Agricultural University, China. The soils used in the experiment were dry land soil and paddy soil. The soil textural class was determined by Hydrometer Method [24]. Dry bulk density was measured using gravimetric method [25]. The dry bulk density at various moisture contents in both dry land and paddy soil is shown in Table 1. Organic carbon content was determined using the Walkley and Black [26] method. The soil physical properties of soil, corresponding to ten different moisture contents for dry land and paddy soils are shown in Table 2.

Table 1 Dry bulk density at various moisture contents

Type of soil	Moisture content (%)	Dry bulk density (Mg m^{-3})
Dry land soil	10	1.22
	12	1.21
	15	1.20
	17	1.24
	19	1.25
	22	1.32
	25	1.33
	28	1.34
	29	1.33
	32	1.30
Paddy soil	10	1.20
	13	1.22
	17	1.25
	22	1.26
	26	1.25
	29	1.32
	33	1.40
	36	1.39
	37	1.38
	45	1.40

Soil preparation

The experimental soil was air dried for two to three weeks, ground, and sieved through a 4 mm sieve. Soil samples were taken from the sieved soil to determine the existing moisture content in the soil, and then on the basis of existing moisture content, a calculated amount of water was added to the soil according to Eq. 1.

$$W_a = W_{req} - W_{ex} = \left(M.C_{req} \times WS\right) - \left(M.C_{ex} \times WS\right) \quad (1)$$

Where W_a is the amount of water added (ml), W_{req} is required water (ml), W_{ex} is existing water (ml) and $M.C_{req}$ is required moisture content, $M.C_{ex}$ is existing moisture content and WS is weight of soil (gm).

The soil was then mixed well, covered with a polyethylene sheet, and left for 24 hours. It was transferred to a metal-framed mold (300 mm × 100 mm × 100 mm) and then compacted to the ideal bulk densities i.e., 1.20-1.4 Mgm^{-3} for sandy clay loam soil using hydraulic press [27].

Test rig

A soil cutting test rig was developed for the study (Fig. 1), it consisted of a soil bin, tool bearing, cutting tool and hydraulic system. A soil bin (500 mm long and 300 mm wide) with two supports (90 mm × 40 mm × 50 mm) at the right side and one at the front was mounted on the test rig. The soil molds were transferred to the soil bin. To move soil in order to perform cutting operations, soil bin was attached to a hydraulic system. The speed of the soil bin was kept constant at 10 mm s^{-1} in all experiments to allow for a clear observation and recording of soil failure patterns [16, 21].

Table 2 The physical properties of dry land and paddy soils

Type of soil	Sand (%)	Silt (%)	Clay (%)	Textural class	Organic carbon (g kg^{-1})
Dry land soil	67	5	28	Sandy clay loam	8.4
Paddy soil	50	26	24	Sandy clay loam	9.6

Test procedure

The soil cutting test was performed at ten different moisture contents (10%, 12%, 15%, 17%, 19%, 22%, 25%, 28%, 29% and 32%) for dry land soil and (10%, 13%, 17%, 22%, 26%, 29%, 33%, 36%, 37% and 45%) for paddy soil at 15^{o} rake angle and 30 mm operating depth. A flat triangular shaped tool was used in all experiments (Fig. 2). Soil failure patterns were observed and recorded using a digital camera; the recorded videos were then converted to snapshots.

Results and Discussion

The brittle failure, chip forming failure and flow failure patterns of dry land soil are shown in Fig. 3 and for paddy soil are portrayed in Fig. 4. In this study collapse (pulverize by shear) failure pattern was not observed; possibly, because the minimum moisture content in the study was 10%. This is consistent with Rajaram [28] who observed collapse type failure pattern at 5.2% moisture content in Bangkok clay soil as well as Makanga et al [21] who witnessed the progressive shear type (collapse) failure at 5.2% moisture content in dry loam soil. A brittle failure pattern was observed at 10-18% moisture content in dry land soil and 10-25% in paddy soil, respectively. The transition of brittle failure pattern to chip forming failure occurred at 19% moisture content in dry land soil and 26% moisture content in paddy soil, respectively. However, Stafford [15] observed brittle failure pattern at 18% to 28% moisture content in clay soil. This is consistent with Rajaram and Gee-Clough [4] who observed brittle failure or cracking at 18.3% moisture content in clay soil. In contrast, Harison [29] observed progressive shear type failure at 18% to 20% moisture content in silty loam soil. Moreover, Makanga et al [21] found progressive shear type failure pattern at 21% moisture content in loam soil.

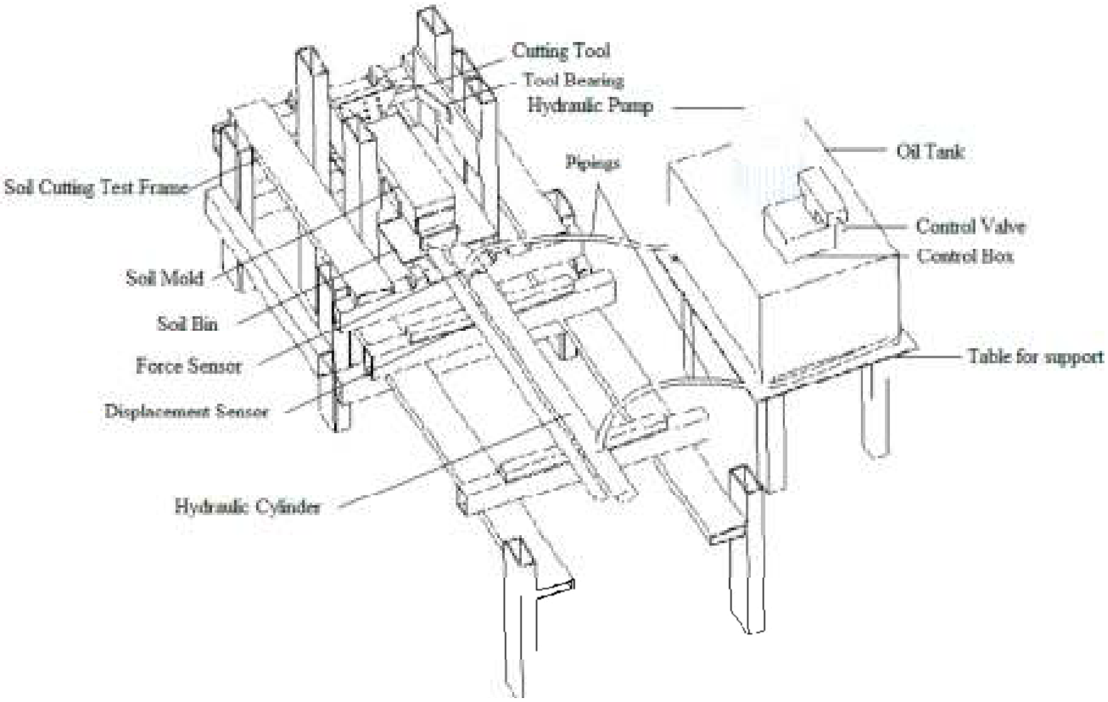

Fig. 1 Sketch of soil cutting test rig.

A chip forming failure pattern was found at 19-28% moisture content in dry land soil and 26-36% moisture content in paddy soil, respectively. The transition from chip forming failure to flow failure occurred at 29% moisture content in dry land soil and 37% moisture content in paddy soil. This is consistent with Rajaram [28] and Rajaram and Gee-Clough [4] who also observed chip forming failure at 28.6% moisture content in Bangkok clay soil. Flow failure was experienced at 29-32% moisture content in dry land soil and 37-45% moisture content in paddy soil, respectively. The flow type failure pattern was also observed by Wang [30] at 44% and 52% moisture contents and Rajaram and Gee-Clough [4] at 42% in Bangkok clay soils. In contrast, Wang and Gee-Clough [18] found brittle failure and shear failure patterns at 44% moisture content.

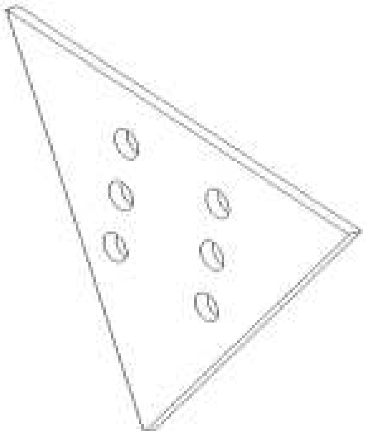

Fig. 2 Sketch of soil cutting tool.

This study has shown that two soils have same textural class and soil genesis, but the transitions of soil failure patterns corresponding to moisture contents were not the same in both dry land and paddy soils. This is attributed to the different proportions of soil separates (sand, silt and clay). It is evident from the study that the soil failure patterns have no direct relationship with the moisture content levels alone. This is in agreement with Jayasuriya and Salokhe [31] who conducted many studies and ascribed that the numerical values of the moisture content does not show any direct relationship with the change of soil failure patterns in different soils.

Conclusions

This study has shown that two soils have same textural class and soil genesis, but the transitions of soil failure patterns corresponding to moisture contents were not the same. The collapse type (pulverize by shear) failure pattern was not found in this study. A brittle failure pattern was observed at 10-18% moisture content in dry land soil and 10-25% in paddy soil, respectively. The transition of brittle

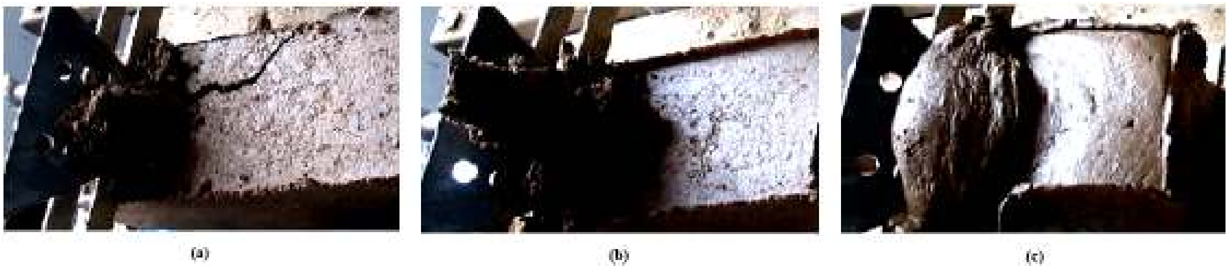

Fig. 3 Soil failure patterns in dry land soil: (a) brittle failure; (b) chip forming failure; (c) flow failure.

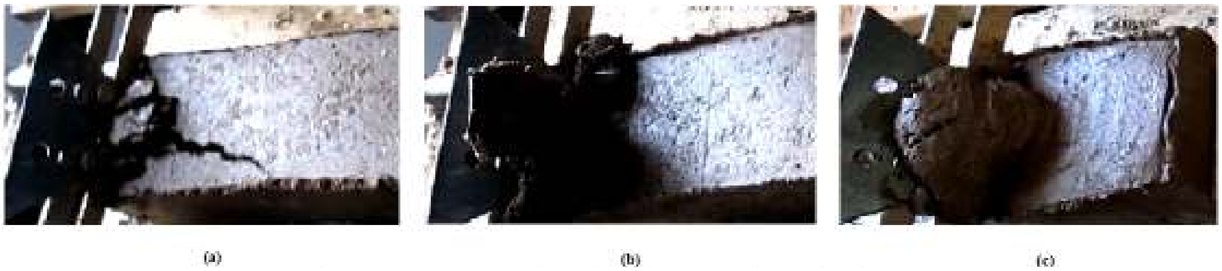

Fig. 4 Soil failure patterns in paddy soil: (a) brittle failure; (b) chip forming failure; (c) flow failure.

failure to chip forming failure occurred at 19% moisture content in dry land soil and 26% moisture content in paddy soil, respectively. The chip forming failure to flow failure occurred at 29% moisture content in dry land soil and 37% moisture content in paddy soil. Therefore, this study suggests investigating the true relationship of soil failure patterns.

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