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Research paper

Image processing technique to assess the use of sugarcane pith to mitigate clayey soil cracks: Laboratory experiment

A.A. Abd El-Halim

Department of Soil and Water, Faculty of Agriculture, University of Tanta, 31527 Tanta, Egypt

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ABSTRACT

Rapid transport of water and solutes through desiccation soil cracks can lead to crop water and nutrient stress. The challenge of irrigation management of cracking soils is to take advantage of the rapid water intake rate of a dry, cracked soil, while keeping plant water stress at a minimum. Therefore, mitigation not suppression of desiccation cracks is imperative and considered our objective of this study. A laboratory experiment was carried out to investigate the effects of sugarcane pith additive on mitigating desiccation cracks, the volumetric shrinkage strain, the total porosity, and water retention at field capacity of clay soils. The clay soil was treated with the sugarcane pith at dosages of 1, 2, 3, 4 and 5% on dry weight basis. Various experimental methods were used to determine the variations in volumetric shrinkage, total porosity and water retention at field capacity. The characteristics of crack patterns were studied using an image processing technique. Compared with the untreated soil, the results showed that the sugarcane pith can increase the total porosity and water content at field capacity, while reducing volumetric shrinkage strain, and consequently, mitigating the development of desiccation cracks. Therefore, results suggested that the modification of clayey soil by the addition of the sugarcane pith by rates up to 2% on dry weight basis can be a viable and innovative method to mitigate the development of desiccation cracks. In addition, this application will enhance recycling efforts by converting sugarcane pith waste into usable amendment to mitigate cracks in clayey soil.

1. Introduction

Clay soils contain silicate clay minerals that have the potential for swelling and shrinkage under changing moisture contents. Shrinkage and swelling cause a very common field phenomenon, namely, cracks, which can negatively affect soil performance in geotechnical, agricultural and environmental applications (Jianhua et al., 2015). Specifically, the geometric structure of cracks changes the migration process of soil moisture and nutrients, leading to crop water and nutrient stress, and thus can significantly affect the growth and yield of crops (Römkens and Prasad, 2006). The challenge of irrigation management of cracking soils is to take advantage of the rapid water intake rate of a dry, cracked soil, while keeping plant water stress at a minimum (Mitchell and van Genuchten, 1993). Therefore, mitigation and not suppression of desiccation cracks is an imperative to reach this objective. Considerable work has been done to study the physical phenomenon of cracking in clay soils experimentally (e.g., Abu-Hejleh and Znidarcic, 1995; Hasibul et al., 2013; Kishné et al., 2010; Li and Zhang, 2011; Morris et al., 1992; Miller et al., 1998; Nahlawi and Kodikara, 2006; Tang et al., 2008; Tang et al., 2011a,b; Yesiller et al., 2000).

The necessary factors or the key parameters that can explain the development and extent of desiccation cracking are water loss, mechanical effect and shrinkage potential, as they control the initiation and propagation of desiccation cracks (Tang et al., 2011a, 2012; Wu, 2014). To characterize the crack patterns quantitatively, crack patterns, e.g., the number of crack intersections, the number of crack segments, the total length of cracks, the average width of cracks and surface crack ratio or crack intensity factor have been used for this purpose (Atique and Sanchez, 2011; Hasibul et al., 2013; Kodikara et al., 2002; Tang et al., 2010, 2011b, 2012).

Several chemicals such as synthetic polymer soil conditioners have been used to improve soil physical properties, namely increase the amount of water-stable aggregates, reduce tensile strength, bulk density, surface compaction and clay dispersion, consequently, mitigate desiccation cracks of clay soil (Mamedov et al., 2010; Lehrsch et al., 2012; Li et al., 2014; Inbar et al., 2015). However, synthetic polymers have not been commercially used in agriculture, partly because of economic considerations and partly as a result of the incomplete understanding of complex polymer-

E-mail address: halim.ismail@agr.tanta.edu.eg (A.A. Abd El-Halim).

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soil interactions (Sojka et al., 2007). Due to these limitations, exploring alternative methods is imperative. The use of compost derived from numerous crop residues and agricultural by-products as natural amendments offers a promising low cost alternative method and enhances recycling applications of waste materials (Aguilar et al., 2004; Anand Puppala et al., 2006; Intharasombat et al., 2007).

Sugarcane stalk consists of two parts, an inner pith containing most of the sucrose, and an outer rind with lignocellulosic fibers (Lee and Mariatti, 2008). The rind is made up of a hard fibrous substance surrounding a central core of pith, which is soft due to a spongy structured component (Wirawan et al., 2010). During sugar processing, the sugarcane stalk is crushed to extract the sucrose yielding a large volume of bagasse residue, which contains both crushed rind and pith fiber (Samariha and Khakifirooz, 2011). Bagasse, which contains about 30–40% pith, is used as an alternative to wood pulp for making fibrous products, such as paper and board (Rainey, 2012). In paper industry, depith bagasse for separating pith is a common practice that ensures clean fibers to produce paper with high quality (Xing, 2010). Therefore, the pith of bagasse has always been considered as a raw material for papermaking factories. Recently, depithing occurs at the sugar mill to reduce raw bagasse transport costs. In most cases the removed sugarcane pith is then used as fuel for the boilers in these factories (Rainey, 2012).

Over the past decades, for measurements of crack patterns, most studies focused on measurements at the field scale (Ringrose-Voase and Sanidad, 1996; Novak, 1999), but with the development of computers, opportunities have become available for analyzing measurements using image processing techniques because they imply advantages based on rapid, accurate and non-destructive quantification (Tang et al., 2010, 2011b, 2012; Jianhua et al., 2015; Liu et al., 2013; Vogel et al., 2005; Yan et al., 2002).

Identifying better utilization of sugarcane pith instead of combustion is necessary. Therefore, it is hypothesized that sugarcane pith is one of the recycled materials that can provide benefits on the physical properties similar to compost materials and stabilize clay soils in order to mitigate desiccation cracks, since it is rich in nutrients. Moreover, as a spongy material, exhibiting moisture affinity characteristics, it offers numerous advantages in comparison with other crop residues because its ash content (about 2.4%) is low (Pandey et al., 2000). Moreover, the sugarcane pith has a large surface area, and consequently, is a very hygroscopic material, able to absorb water up to 20–30 times its own weight (Lois-Correa, 2012; Rainey, 2012). In addition, the sugarcane pith is available in large quantity and free or at a low price (the local price is 13 $ ton^{-1}) at sugar factories or sugarcane juice shops. However, no studies were either available or conducted to address this application of sugarcane pith to stabilize clay soils in order to mitigate surface desiccation cracks. In this research, an attempt was made for the first time to quantify experimentally the beneficial effect of applying the sugarcane pith as an organic amendment on mitigating desiccation cracks of clayey soil under proper laboratory environment.

2. Materials and methods

2.1. Soil samples

Clay soil samples were collected from the top soil layer (20 cm) on January 2015 from Desouk city. It belongs to Kafr el-Sheikh Governorate, Egypt, (latitude 31°8′32″N, longitude 30°38′42″E, and the altitude is nine meters above sea level). The main clay minerals composition of the studied soil is smectite (Na-montmorillonite) and kaolinite. The smectite ranges from 62.68% to 85.04% with an average of 73.42%, while Kaolinite varies from 14.96% to 37.32% with an average of 26.43% (Azam, 2014; Abd-Allah et al., 2009). The soil samples were collected, air-dried, crushed, and sieved through a 2 mm sieve (ASTM No. 10). The primary chemo-physical properties of the studied soil are illustrated in Table 1, and were determined using the appropriate methods as described in (Haluschak, 2006).

2.2. Sugarcane pith

The sugarcane pith was obtained locally from sugarcane juice shops after separating the outer rind. Then it was air dried, gently crushed, passed through a 1-mm sieve (ASTM No. 18), and stored in airtight containers to avoid pre-hydration until usage. The primary chemo-physical properties of the studied sugarcane pith are illustrated in Table 1, and were determined using the appropriate methods as described in (Estefan et al., 2013).

2.3. Preparation of soil-pith mixture treatments

The sugarcane pith was blended with the soil to prepare five soil-pith mixtures (each mixture one kilogram). The soil-pith mixture treatments were 1, 2, 3, 4, and 5% on a dry weight basis, respectively, in addition to 0% of the sugarcane pith, which refers to the soil not treated with sugarcane pith (the control treatment). All mixtures were prepared manually and proper care was taken to homogenize mixtures.

2.4. Laboratory analyses

2.4.1. Water retention at field capacity (FC)

Water retention at field capacity (FC) was determined at 0.33 bar using the pressure plate apparatus (Soil Moisture Equipment Corp., Santa Barbara, CA, USA) (Estefan et al., 2013).

2.4.2. Volumetric shrinkage strain (V_s) and total soil porosity(P_t)

Volumetric shrinkage strain (V_s) tests were conducted using the American Society for Testing and Materials (ASTM, 2007) standardized method D4943-02 with some modifications as follows: Approximately 150 g of the natural soil or soil-pith mixture samples were mixed with distilled water until the mass became a smooth thick homogeneous paste. After that, it was placed in an airtight container for 24 h to enable the water to penetrate through the sample. The prepared sample was placed in a greased aluminum cylinder with a volume of 50 cm^3 in three

Table 1
Primary physical and chemical properties of the study clayey soil and sugarcane pith.

Soil		Sugarcane pith	
Property	Value	Property	Value
Bulk density (g cm^{-3})	1.27	Bulk density (g cm^{-3})	0.43
Particle density (g cm^{-3})	2.78	Particles size (mm)	<1
Total porosity (%)	54.32	pH (Soil paste)	6.64
Field capacity (%)	37.57	EC (dS m^{-1})	1.44
pH (soil paste extracts)	7.76	Total N (%)	0.48
Electrical conductivity (EC) (dS m^{-1})	1.23	Total P (%)	0.39
Consistency limit		Total K (%)	0.99
Liquid limit, w_L (%)	68.57	Organic carbon (%)	56.55
Plastic limit, w_P (%)	34.63	C/N ratio	118:1
Shrinkage limit, w_S (%)	20.37		
Plasticity index, PI (%)	33.94		
Mechanical analysis			
Sand (%)	18.66		
Silt (%)	34.23		
Clay (%)	47.11		
Soil type	Clay		