Science of the Total Environment 568 (2016) 480–488

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Comparative research on tillable properties of diatomite-improved soils in the Yangtze River Delta region, China

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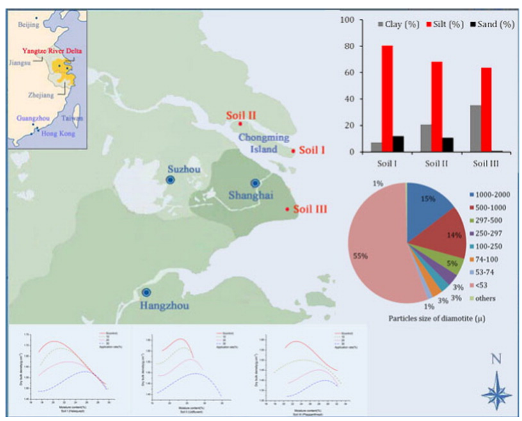
HIGHLIGHT

- Diatomite applications significantly ($p < 0.05$) increased liquid limit values.
- Effects of diatomite on PL and AS were also significant ($p < 0.05$).
- Increase in diatomite application decreased the MBD values.
- Increase in diatomite application increased the OMC values.
- Diatomite application made soil more easily tilled.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 8 April 2016
Received in revised form 9 June 2016
Accepted 9 June 2016
Available online xxxx

Editor: Jay Gan

Keywords:
Diatomite-improved soil
Consistency limits
Maximum dry bulk density (MBD)
Optimum water content (OMC)

ABSTRACT

To improve soil texture and structure, techniques associated with physical, biological or chemical aspects are generally adopted, among which diatomite is an important soil conditioner. However, few studies have been conducted to investigate the physical, hydraulic and tillage performance of diatomite-improved soils. Consistency limits and compaction properties were investigated in this study, and several performance indicators were compared, such as the liquid limit, plastic limit and compactability, of silt, silt loam and silty-clay loam soils to which diatomite was added at volumetric ratios of 0%, 10%, 20%, and 30%. The results showed that diatomite significantly ($p < 0.05$) improved the consistency limits, with the most preferred effects in the silt soil. The liquid limits were increased by 53.9%, 27.3%, and 14.7%, in the silt, silt loam and silty-clay loam soils, respectively, when the volumetric ratio was 30%. While diatomite lowered the maximum dry bulk density (MBD) of the classified soils, the optimum moisture content (OMC) was increased overall. The trend was consistent with the proportion of diatomite, and MBD decreased by 8.7%, 10.3%, and 13.2% in the silt, silt loam and silty-clay loam soils when 30% diatomite was mixed, whereas OMC increased by 28.7%, 22.4%, and 25.3%, respectively. Additionally, aggregate stability was negatively correlated with MBD but positively correlated with OMC. Diatomite exerts positive effects on soil mechanical strength, suggesting that soils from sludge farms are more tillable with a larger stabilized and workable matrix.

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http://dx.doi.org/10.1016/j.scitotenv.2016.06.056

1. Introduction

Various investigations have been conducted to improve the tillable and mechanical properties of soil materials for greater applicability in both agricultural engineering and construction projects (Ferrero et al., 2007; Lipiec et al., 2009; Król et al., 2013; Król et al., 2015). Generally, there are three categories of techniques, namely physical, biological or chemical approaches. Among these, physical approaches use organic or inorganic conditioners, achieving the dual goal of higher soil fertility and better soil structure without the introduction of chemical materials or biological species. Previous investigations have indicated that the tillable properties of agricultural soils are impacted by various factors such as soil texture, consistency limits, bulk density, water content, and organic matter, all of which vary considerably among soils in different regions (Wagner et al., 1994; Dexter and Bird, 2001; Mueller et al., 2003; Mosaddeghi et al., 2009; Koolen and Kuipers, 2012; Keller et al., 2013; Leroueil and Hight, 2015; Otalvaro et al., 2016).

An indicator that affects the stability of the soil structure is water-stable aggregates, which can be used to predict crop yield and soil fertility. Investigations have indicated that various factors influence aggregate formation, characteristics and function, from the composition of the soil parent material to human activities (Liu and Wang, 2005). Tisdall and Oades (1982) noted that water-stable aggregates were strongly associated with the organic carbon content and organic binding agents. Therefore, in agricultural practice, soil management (in terms of fertilizer and tillage) would impact the distribution of both aggregates and organic carbon (Liu et al., 2015; Singh et al., 2016). Beare et al. (1994) compared soil aggregates and the organic matter content under conventional and no-tillage conditions and found that aggregates under conventional tillage were more likely to be damaged, resulting in lower organic matter content and soil stability. Mikha and Rice (2004) stated that both tillage and fertilizer amendment improved macro-aggregates, which improved the organic carbon content and effectively reduced soil degradation. In addition, it has been shown that soil conditioners (organic fertilizer, inorganic fertilizer, rice-husk ash and diatomite) can influence water-stable aggregates in soils (Liu et al., 2010; Aksakal et al., 2012, 2013; Qu et al., 2014; Hontoria et al., 2016).

Across different regions, soil properties have been studied following the addition of different soil conditioners. Alhassan (2008) collected lateritic soil samples from Nigeria for the determination of British standard light compaction and found that both MBD and OMC increased with the amount of rice husk ash. Herath et al. (2013) collected silt loam soil from two sites in New Zealand to investigate corn stover-improved soil properties and reported that biochar application could improve the water-holding capacity and drainage ability of the soil. Parvage et al. (2013) analysed phosphorus contents in silt loam, clay loam and silty clay loam soils in Swedish agricultural lands amended with wheat residue char, and the water-soluble phosphorus concentrations increased with wheat conditioner. On the contrary, Borchard et al. (2014) reported that sandy and silty soils amended by slow-pyrolysis charcoal, gasification coke and flash-pyrolysis char barely increased maize yield in practice. However, few studies have examined the properties of reinforced soil in China. It has been shown that diatomite, a type of soil conditioner widely available in Chin (USGS, 2008) a, can enhance the drainage capacity, structural strength, tillable quality, acid-base balance and salinity (Wang et al., 2016). This article is the first to report on the influence of diatomite on the physical, hydraulic and tillage performance of soils in the Yangtze River Delta Region, China.

In regard to the effects of diatomite on soil properties, Aksakal et al. (2012, 2013) collected agricultural soil samples in Turkey to assess their physical and mechanical performance and provided some experimental reference for studies in other regions. However, the same soil conditioners exert distinct effects in different soils extracted from various geographical regions (Rahman, 1987); this has been shown in rice husk ash and cement-reinforced soils. Rahman (1987) reinforced Nigerian lateritic soils using rice husk ash and cement and reported that 18% rice husk ash and 9% cement resulted in the maximum unconfined compressive strength. Basha et al. (2005) added both cement and rice husk ash to Malaysian residual granitic soils and stated that 10–15% rice husk ash and 6–8% cement was the optimum proportion to enhance unconfined compressive strength. Kolias et al. (2005) stabilized clay soil in Greece using rice husk ash and cement materials; these authors concluded that 20% rice husk ash and 4% cement generally improved the unconfined compressive strength. Therefore, rice husk ash and cement reinforcement exert diverse effects on soil physical, mechanical tillage and structural aspects, even for the same soil conditioner. Therefore, the conclusions reached by Aksakal et al. (2012, 2013) for Turkish soils might not indicate actual effectiveness of improved soils in other regions.

This article was designed to investigate the effects of diatomite on the tillable properties of three soils in the Yangtze River Delta Region, China. The tillable properties include the consistency limits and plastic index, Proctor compaction test parameters (OMC, MBD) and water-scale aggregates. A series of liquid-plastic limit combined tests, compaction tests, and wet sieving were carried out on all soil samples. The consistency limits, OMC, MBD and water-scale aggregates were observed in silt, silt loam and silty clay loam soils to which diatomite was added at volumetric ratios of 0%, 10%, 20% and 30%.

Table 1
Physical and chemical properties of the collected soils.

Properties	Materials		
	Soil I	Soil II	Soil III
Clay (%)	7.37	20.85	35.50
Silt (%)	80.58	68.35	63.58
Sand (%)	12.05	10.80	0.92
Textural class	Silt	Silt loam	Silty-clay loam
Great soil group	Halaquept	Udifluvent	Plagganthrept
pH[a]	8.00	8.1	7.8
EC[a] ($mScm^{-1}$)	0.25	0.21	0.15
CEC($cmol_{(+)}kg^{-1}$)	12.94	15.00	16.73
$CaCO_3$ (%)	4.32	7.0	5.3
Organic matter (%)	0.97	1.59	1.36
Bulk density ($g\ cm^{-3}$)	1.53	1.26	1.21

2. Research methodology

2.1. Soil characteristics

According to soil-forming conditions, soils are divided into fluvo-aquic soil (calcareous alluvial soil, salinized moist soil) and coastal Solonchakin Yangtze River Delta soil. To investigate the effects of diatomite on soil properties such as physical, hydraulic and mechanical properties in the Yangtze River Delta Region, three types of agricultural soils, i.e., silt (Soil I), silt loam (Soil II) and silty clay loam (Soil III) soils, were collected in Shanghai, China (31° 14′ N, 121° 29′E). To ensure representativeness and effectiveness of soil samples, all sampled were collected over a depth of 0 to 15 cm based on large groups of uniform soil. According to the Keys to Soil Taxonomy issued by the United States Department of Agriculture (2006), these soils could also be classified as Halaquepts, Udifluvent and Plagganthrepts. The general physical and chemical properties of these soils are provided in Table 1, and all methods used to determine the specific values of these properties can be found in our previously published article (Qu et al., 2014).

Soil I, which was collected from Shanghai Qianshao Farm, belongs to Shanghai coastal Solonchak, mainly distributed in seaside areas, and the specific sites are presented in Fig. 1. The Solonchak contains high amounts of silty sand with better tillage and more working days. However, it suffers several disadvantages such as soil hardening, salinization and poor water and nutrient retention capacity. It is therefore necessary to accelerate the desalination process and block the salinization process