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Original article

Capacity assessment of carbon-based nanoparticles in stabilizing degraded soils

Abeer AlObaid [a,*], Khalil Ur Rehman [b], Shahla Andleeb [b], Kehinde O. Erinle [c], Adeel Mahmood [b]

[a] Department of Chemistry, College of Science, King Saud University, P.O. Box 22452, Riyadh 11451, Saudi Arabia
[b] Department of Environmental Science, Faculty of Natural Sciences, GC Women University Sialkot, 51310, Pakistan
[c] School of Agriculture, Food and Wine, The University of Adelaide, SA 5005, Australia

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ABSTRACT

Nano particles were already being used in various sectors like engineering, industry, information technology and security; and have gained attention in field of environment for pollution remediation and soil quality improvement since last decades. It was the need of hour to investigate nano materials to improve soil quality sustainably. In this scenario, present study was designed and conducted to check the capacity of carbon based nano fibers and nano tubes to stabilize degraded soils. Study investigated that carbon nano fibers and carbon nano tubes caused decrease in soil specific gravity (g/cm^3) from 2.6 to 2.53 and 2.54, respectively in presence of 0.2% of selected carbon nano materials. However, increase in soil pH value from 6.9 to 7.2 was observed with this improvement. Soil dry density increased from 1.48g/cm^{3}to 1.99g/cm^3 in presence of 0.05% of carbon nano fibers and from 1.48g/cm^{3}to 1.49g/cm^3 in the presence of 0.05% of multiwalled carbon nano tubes. Both carbon nano fibers and multiwall carbon nano tubes enhanced soil plastic and liquid limits. Results concluded that carbon nano fibers and carbon nano tubes have good potential in stabilizing degraded soils.

1. Introduction

Literature represented "nanotechnology" as the control and comprehension for reformation of nano materials to develop modified methods for solving prolonged environmental degradation problems. By putting forth this aspect, nanotechnology proved to be a unique and innovative discipline in all the related sciences (Mahmood et al., 2020; Ullah et al., 2019; Tabinda et al., 2019; Roco, 2005). Studies were also alerting about sustainable soil stabilization by using nano materials. In this scenario, many methods were investigated but two basic methods for the application of nanotechnology in soil stabilization were found effective; one method was the utilization of nanotechnology in preferable comprehension of soil nature at nano scale in soil structure study along with better perception of soil performances while interacting with several nanostructures. Second way of nanotechnology utilization in soil improvement was the study of soil performance at atomic or molecular level when the soil was rigged by the external factors of nano particles (Roco, 2011). For many decades, soil stabilization was the finest method for enhancing performance of sub graded soils; but soil desiccation cracking was the main problem being faced. Studies investigated that compressed and cohesive soils contained low hydraulic conductivity and were considered best for landfills covers or as bottom liners (Cuisinier et al., 2011); but the most essential and relevant undertaking in prolonged conduction of cover barrier system was the desiccation factor; as desiccation caused the moisture leakage from the landfill cover barrier; and compressed clay originated the decline in sealing capacity of cover soils (Tang et al., 2012). Moreover, desiccation cracking was observed three times more responsible of an increase in hydraulic conductivity values. Some researchers contemplated that soil additives i.e. lime, sand and cement could strengthen soil and found them beneficial in providing resistance to cracking (Adaska and Luhr, 2004). However, previous studies also indicated that lime or cement was not that beneficial in stabilizing soil desiccation cracking as clayey soil has lower permeability and hold greater water concentrations. Some researchers also experimented and observed the effectiveness of quick lime addition for artificial

* Corresponding author at: Department of Chemistry, College of Science, King Saud University, P.O. Box 22452, Riyadh 11451, Saudi Arabia.
E-mail addresses: aaalobaid@ksu.edu.sa, abeeralobaidksu@gmail.com (A. AlObaid).

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improvement of soil micro texture (Chen and Wang, 2006); along with this, they also observed the mineralogy of marine clay congregation. The consequence indicated that utilization of lime only caused sudden agglomeration of clay particles whereas showed no impact on flocculated formation of soil creating cementations bonds. Studies also concluded that platy minerals improved through lime stabilization caused inter aggregate space of soil particles which resulted in volume enhancements of micro pores of soil (Kamon and Nontananandh, 1991). Furthermore, soil structural deformity formation was experienced with the addition of lime. Many studies investigated the mechanical behavior of the soil by applying cemented material in order to achieve soil stability but did not found this environmental friendly (Cuisinier et al., 2011). Cement material was altering soil composition which resulted in alteration of soil microbial activities. Most of the studies were using Portland cement as soil stabilizer but this was normal in construction activities; however, this kind of soil stabilization caused impact on soil ecological health (Ghadir and Ranjbar, 2018). Although some additives were being changed in soil stabilization experiments but these replacements were taking in account the soil conditions which needed for essential technological and financial benefits. Some of the studies focused on nano particle addition in soil stabilization process to maintain soil basic properties. Addition of nano particles in cementations substances proved to be beneficial in altering physical condition of soil along with associating chemical procedures occurring in cement curing process (Ghasabkolaei et al., 2017); and some of the carbon based nano materials showed good tendency towards successful soil stabilization with normal soil activities. It was important to understand that carbon based nano particles were not cemented in nature. Furthermore, Carbon nano tubes itself were not the cementations substances, but they help and support in the formation of more compact, rigid, and solid soil structure by suppressing. Carbon nano tubes along with cementations substances enhance the mechanical characteristics of soil (Taha and Alsharef, 2018). In utilization of Carbon nano tubes as additive, the significant opposition expressed was its ability of aggregation which overshadows its other essential characteristics. Anyhow, to solve this issue, surfactants or ultrasonic energy was added with the nano particles to scatter in suspension condition (Majeed and Taha, 2013; Bisinoti et al., 2019). Various additives were previously used to stabilize chemical and physical conditions of soil; but cemented additives could not improve soil hydraulic capacity and moisture percentage (Mahmood et al., 2020; Mahmood et al., 2020; Mahmood et al., 2015). Nevertheless, nano articles were found better to stabilize weaker soils ecologically in all aspects. Present study aimed to examine behavior of nano particles specifically multiwall carbon nano tubes (MWCNTs) and Carbon nano fibers (CNFs) in soil stabilization as these were reported beneficial (Mahmood and Malik, 2014; Majeed and Taha, 2013; Bisinoti et al., 2019; Mahmood et al., 2020; Mahmood et al., 2020; Mahmood et al., 2015; Mahmood et al., 2012). MWCNTs have much potential of distinguished physical properties containing ultrahigh specific surface, extremely high yield strength and modular of elasticity and elastic behavior (Bisinoti et al., 2019; Mahmood et al., 2020; Mahmood et al., 2020; Mahmood et al., 2015; Mahmood et al., 2012; Mahmood and Malik, 2014).

2. Materials and methods

2.1. Sampling location

Samples were collected from six different places (Fig. 1) to make a homogenous sample and were selected on the bases of soil uses in district Faisalabad, Province of Punjab. Sampling location was divided in two zones 'agricultural land' and industrial land'. Three points were in agricultural lands and three were in industrial area.

2.2. Study design

All collected soil samples were mixed to get an average soil quality for conducting experiment to check the capacity of carbon-based nano mateials named 'carbon nano fibers' and multi-wall carbon nano tubes' for soil stabilization. Properties of nano particles used in this study are given in Table 1. Schematic diagram of the study design is given in Fig. 2.

2.3. Sample preparation

Soil was grinded and sieved with 2 mm sieve to attain fine grain soil particles. 1 kg of soil was taken in each of earthen pots and added carbon nano fibers and carbon nano tubes which were already mixed with water in a 150 ml beaker. Five experiments were conducted for each parameter for one type of carbon nano particles. Each experiment was run in triplets in earthen pots to give total number of 15 experiments against one type of carbon nano particles and one parameter to avoid ambiguities. Five soil stabilization parameters soil specific gravity, pH, compaction, hydraulic conductivity and Atterberg's limits were selected to analyze; and 0.05%, 0.75%, 0.1% and 0.2 % of selected multiwall carbon nano tubes and carbon nano fibers added in soil by mixing in distilled water. A control sample with zero percentage of carbon nano tubes and carbon nano fibers were also experimented.

2.4. Experimental work

Basic soil parameters were determined in departmental laboratory. Soil pH of composite sample used for further experiment was 6.9. Hydraulic conductivity of the sampled soil was 53 mm/hr. Soil texture was sandy, clayey and loam from which sand, silt and clay percentage was 46, 30 and 25 respectively. Specific gravity was 2.6; organic matter of the sample soil was ranged between 4.3 and 4.8%. Two types of carbon based nano particles "multiwall carbon nanotubes" and carbon nano filters were used to identify their impact on soil stabilization. Further procedures for studying impact of carbon based nano particles on soil stabilization were given below:

2.4.1. Specific Gravity.

This was ratio between soil weights and water contents at specific volume. We can define it as average soil particle concentration in sample test. 50 g of soil sample was separated and oven dried at 105 to 110 °C. For further processing 5 g of sample was used. Specific gravity of soil was calculated byadopting IS: 2720 (Part III/Sec 1) – 1980 (Wasim et al., 2019).

Specific gravity of soil was calculated by using following formulae;

$G=(W_2 - W_1) / [(W_{4-1})-(W_3-W_2)]$where W1 is weight of density bottle, W2 is weight of density bottle with dry soil sample, W3 is weight of bottle with soil and water, and W4 is weight of density bottle and water sample.

2.4.2. Dry density and water contents Measurement

Measurement of dry density and water contents of soil was normally called compaction analysis. For this reason proctor compaction test was adopted; and three layers of soil sample were analyzed, top, middle and bottom.

Following formulae was used to determine water contents.

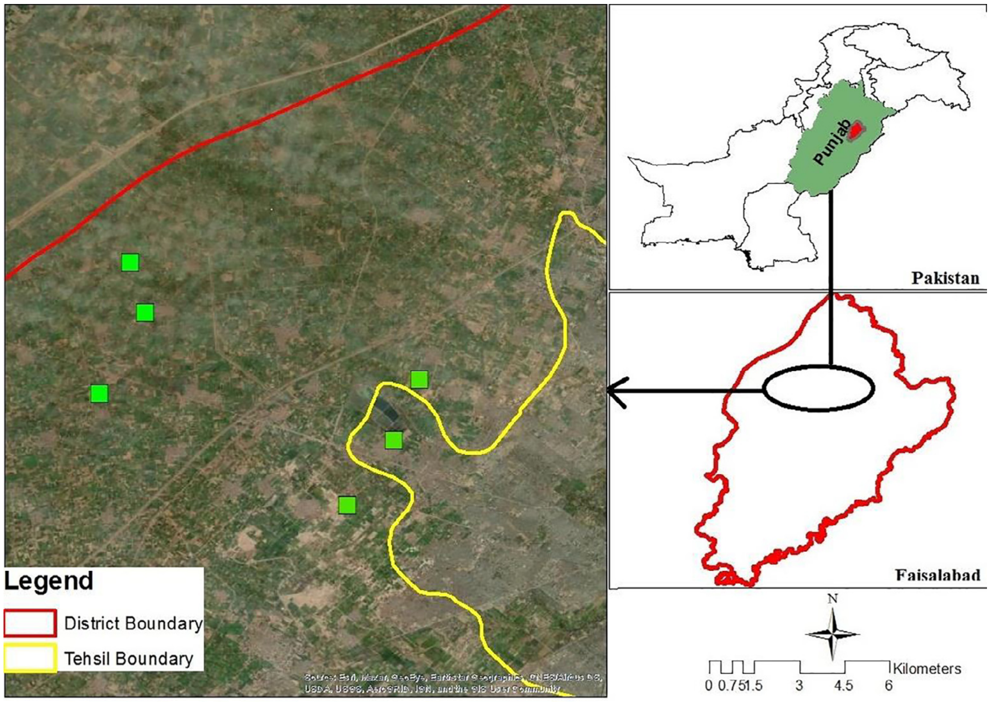

Fig. 1. Sampling Location Map.

Table 1
Properties of carbon based nano-particles used in study.

Properties	MWCNTs value	CNFs value
Average diameter (nm)	13–16	180–200
Carbon concentration (%)	>97	>99
Aspect ratio	595–700	1280–1500
Average length (um)	0.5–10	45–200
Apparent density (kg/mc)	40–145	35–320

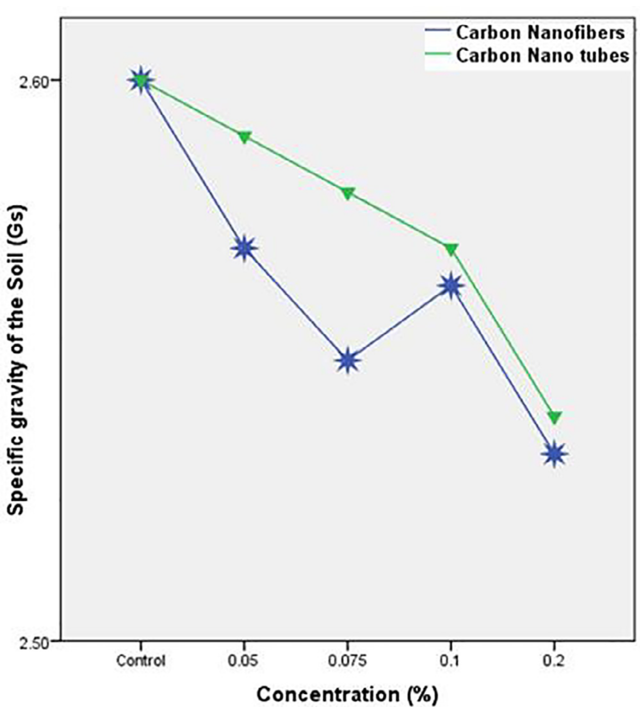

Fig. 2. Schematic Diagram.

$$\gamma_d = \frac{W - W_m}{(1 + w) * V}$$

A formula was used to determine dry density given below: (David Suits et al., 2005)

$$\gamma_d = \frac{G_s - \gamma_w}{(1 + w) * G_s}$$

2.4.3. Hydraulic conductivity

Hydraulic conductivity is generally represented by "k". Hydraulic conductivity was calculated by maintaining a straight hydraulic gradient against soil sample. This helped to attain equal flow rate; influent and effluent. Then water concentration in the sample was computed and calculated by following formulae:(Gallage et al., 2013)

$$k_w = \left(\frac{Q}{At}\right)\left(\frac{d}{(h_1 - h_2) + d}\right)$$

2.4.4. Atterberg limits

Atterberg limits were defined as liquid limits, plastic limits and plastic index of soil. Liquid limit was denoted by LL, plastic limit was denoted by PL and plastic index was denoted by PI. Liquid limit was calculated by Casagrande cup method and plastic limit was calculated by ASTM Standard test procedure (Di Matteo, 2012). Then plastic index was calculated by subtracting plastic limit from liquid limit.

2.5. Statistical analysis

Results of present study were analyzed by using IBM SPSS statistical analysis version 20. All data was subjected by descriptive statistics and statistical graphs were prepared. And a location ma was developed by using Arc GIS and entering location latitudes and longitudes.

3. Results

3.1. Specific gravity

Specific gravity of soil decreased with increased concentration of Carbon nano fibers and carbon nano tubes (Fig. 3); addition of Soil specific gravity decreased from 2.6 to 2.57 and 2.59 at 0.05% concentration of carbon nano fibers and carbon nano tubes respectively. Specific gravity decreased up to 2.53 and 2.54 at 0.2% concentrations of Carbon nano fibers and carbon nano tubes respectively. Nano materials have lower specific gravity; and this result was expected. This indicated that specific gravity of soil decreased in samples with higher concentrations of nano fibers and nano tubes. But concentration of both carbon nano materials were lower and decrease in specific gravity is notable. CNTs were from Kaolinite minerals and its specific gravity is already lower and being used in various medicines.

3.2. pH test

It was observed that soil pH was increased by utilizing both types of carbon based particles as represented in Fig. 4. Control showed 6.9 pH and it has been increased on application of 0.05%, 0.75%, 0.1% and 0.2% of carbon nano fibers (7, 7, 7.2, and7.2) and carbon nano tubes (7, 7, 7, 7.2 and 7.2). pH is slightly increased with addition of cabon nano tubes and carbon nano fibers. Normally, pH showed significant impact on soil properties but minor increase was considered insignificant (Ullah et al., 2019).

3.3. Soil compaction

Soil compaction was consisted of soil dry density and water contents. Small amount of carbon nano tubes could cause increase in soil dry density but have not any significant impact on soil water contents as given in Figs. 5 and 6. Soil samples with zero addition of nano materials showed insignificant change in dry density and moisture contents. But addition of carbon nano tubes and carbon nano fibers caused increased in soil dry density; however, water contents remained unchanged or showed minor change.

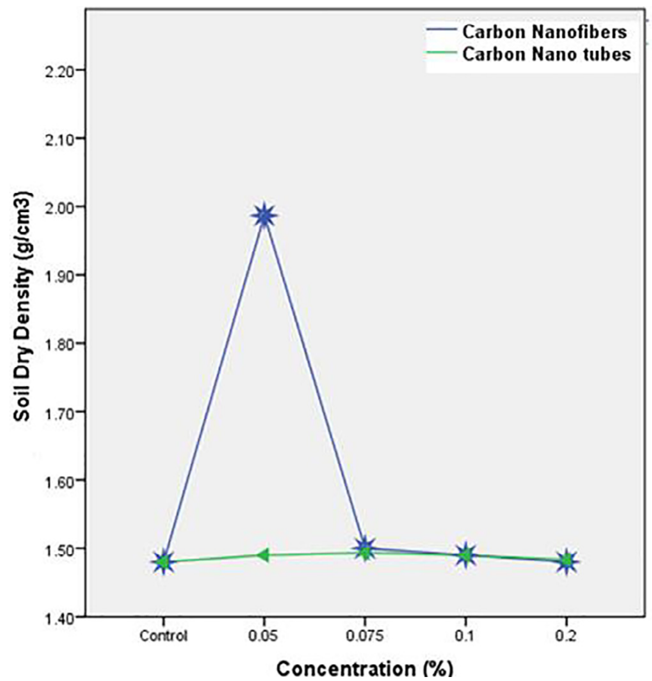

Fig. 4. Impact of carbon nano fibers and tubes on pH.

3.3.1. Dry density

Sudden increase was observed in soil dry density by applying 0.05% of carbon nano fibers (1.99 g/cm^3) while in presence of 0.05% of carbon nano tubes dry density increased up to 1.49 g/cm^3;However,dry density become same as with of control with higher concentrations of carbon based nano materials as given in Fig. 5. Highest concentrations of both nano particles were 0.2% and both maintained soil dry density 1.48 g/cm^3.

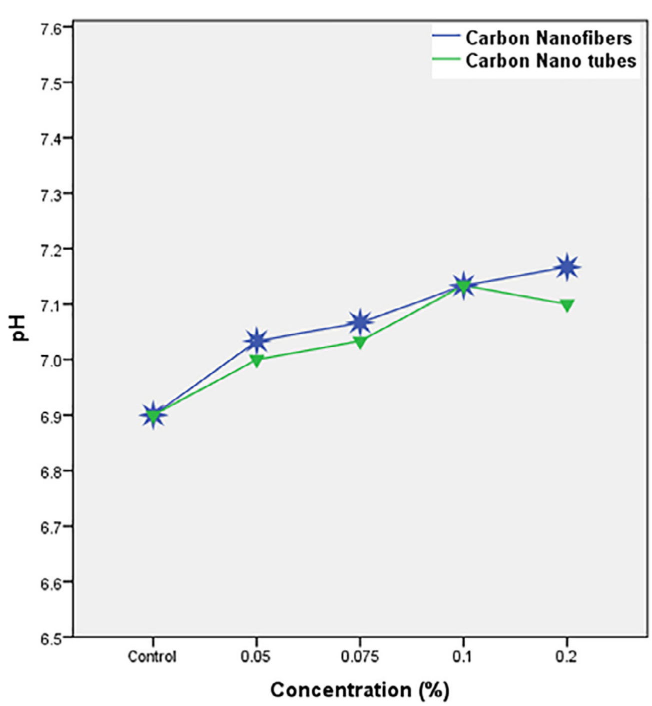

Fig. 3. Impact of carbon nano fibers and tubes on soil specific gravity.

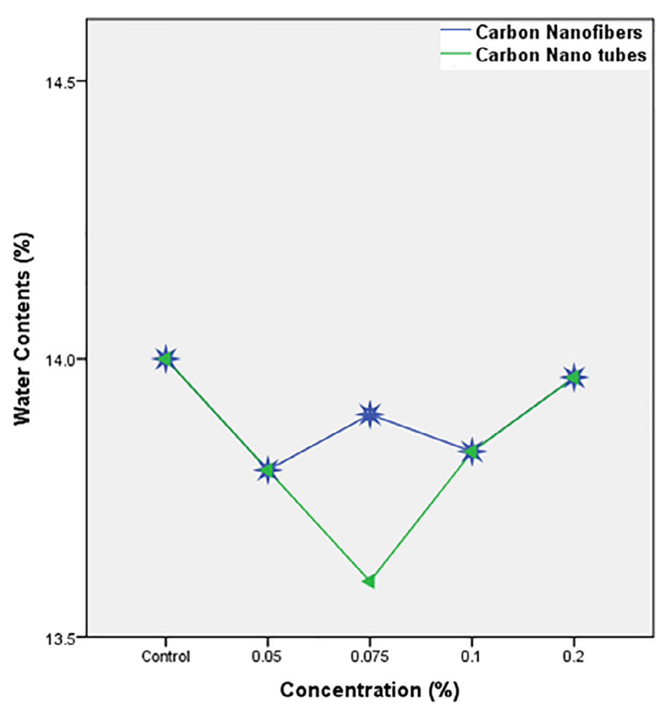

Fig. 5. Impact of carbon nano fibers and tubes on soil density.

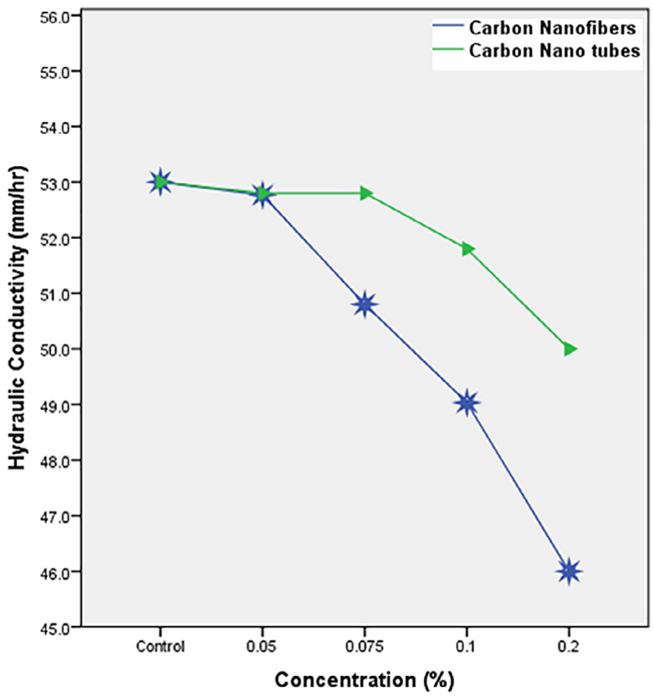

Fig. 6. Impact of carbon nano fibers and tubes water contents.

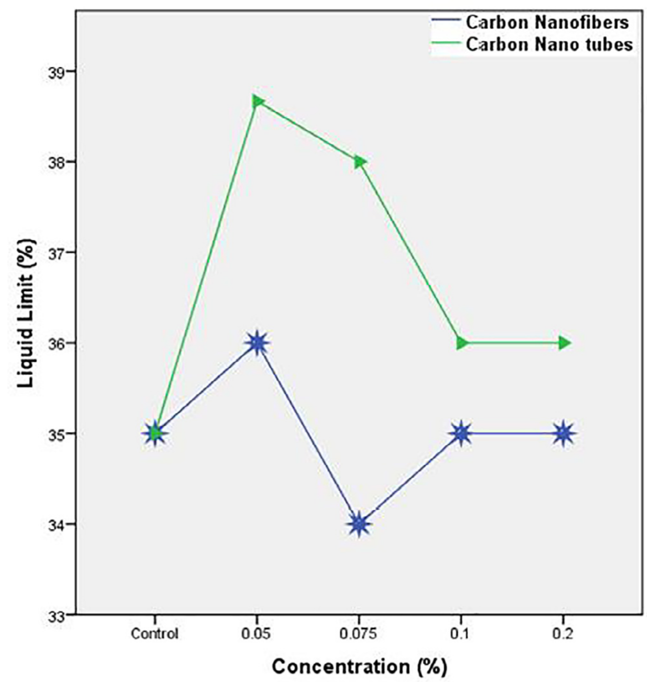

Fig. 7. Impact of carbon nano fibers and tubes on hydraulic conductivity.

3.3.2. Water contents

Fig. 6 represented impact of carbon nano fibers and carbon nano tubes on soil water contents. No significant impact on soil water contents was observed. It was almost same as was observed in control sample (14%) with zero percent application of carbon nano particles.

3.4. Hydraulic Conductivity.

Hydraulic conductivity was decreased with increased concentration of carbon nano fibers and carbon nano tubes as shown in Fig. 7. This result showed that some additives needed to add in the experiment to maintain hydraulic conductivity; as Control samples have 53 mm/hr hydraulic conductivity. But samples with addition of carbon nano tubes and carbon nano fibers caused decrease in hydraulic conductivity. In this experiment carbon nano fibers decreased soil hydraulic conductivity (46 mm/hr) more than the soil teated with carbon nano tubes (50 mm/hr) in presence of 0.2% of both carbon nano fibers and carbon nano tubes. Addition of some additives could be helpful in solving this issue (Chen and Wang, 2006).

3.5. Atterberg Limits.

Atteberg's limits were consisted of three basic parameters. Liquid limits, plastic limit and plastic index. These are important parameter in measuring soil stabilization. Impact of both carbon nano fibers and nano tubes were given in Fig. 8, 9 and 10. Atterberg's limits were found very important in improving degraded soils. Liquid limits of soil remained almost insignificant but plastic limits of soil decrease with increased concentration of nano fibers and tubes. This helps in strengthening soil quality without disturbing its ecological capacities (Kreyling et al., 2010).

3.5.1. Liquid limit

Liquid limits were calculated in percentage. Control samples have 36% liquid limit. Liquid limit in presence of 0.05%, 0.75%, 0.1% and 0.2% of carbon nano fibers was observed 36%, 34%, 35% and 35% against each concentration respectively (Fig. 8). Liquid limit of soil sample treated with 0.05%, 0.75%, 0.1% and 0.2% of carbon nano tubes was 39%, 38%, 36% and 36% respectively.

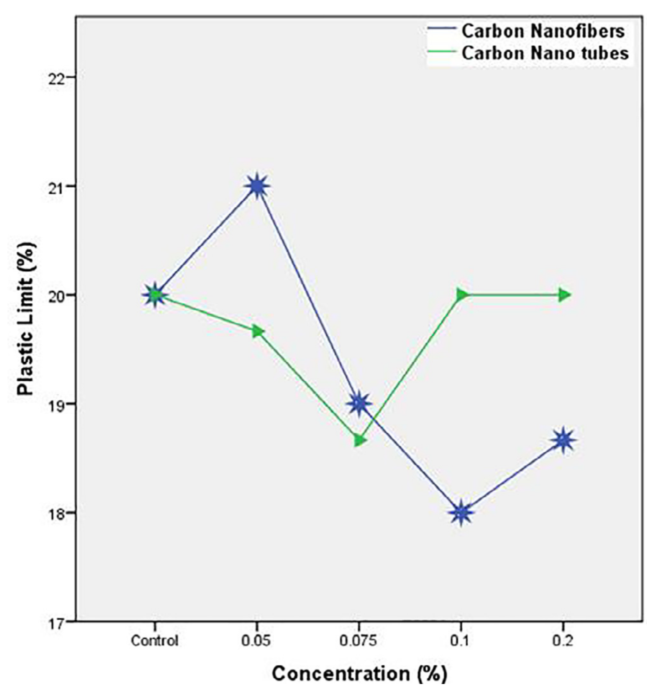

Fig. 8. Impact of carbon nano fibers and tubes on liquid limits.

3.5.2. Plastic limit

Trend was remained same for plastic index of soil in presence of both carbon nano fibers and carbon nano tubes. Plastic limits of soil treated with 0.05% of carbon nano tubes and carbon nano fibers were 21% and 20% respectively (Fig. 9). Highest concentra-

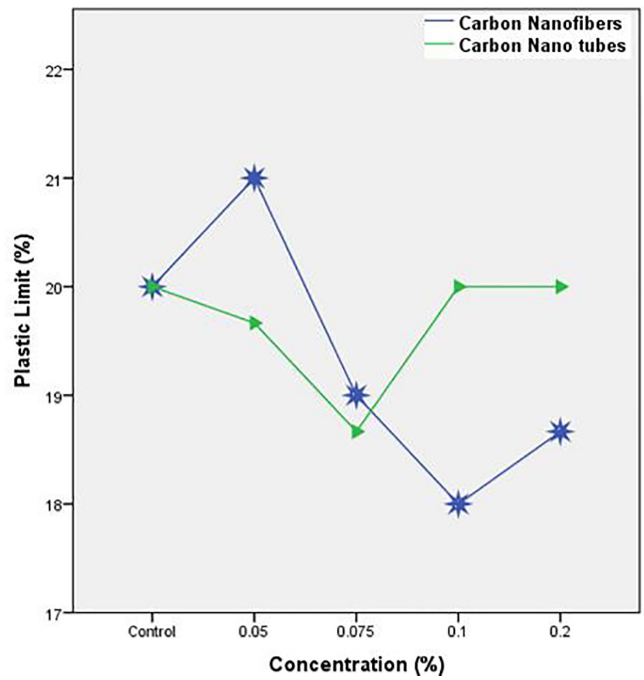

Fig. 9. Impact of carbon nano fibers and tubes on plastic limits.

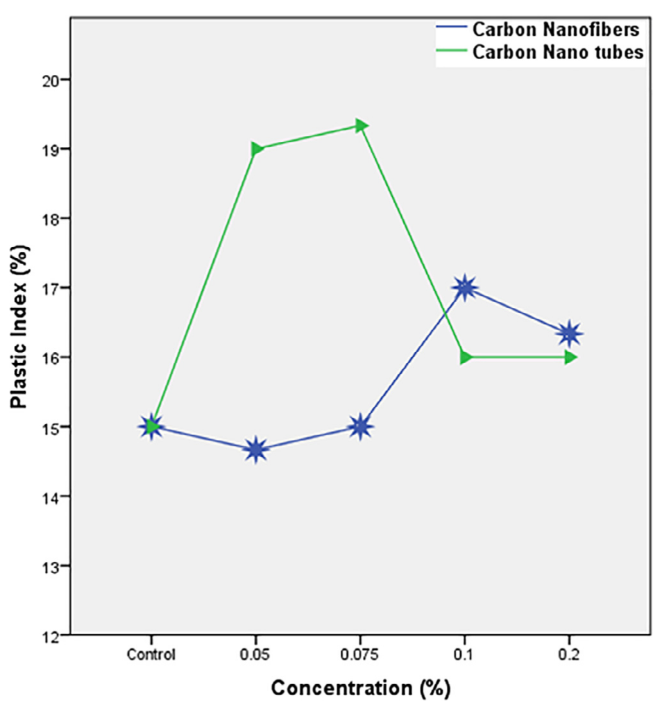

Fig. 10. Impact of carbon nano fibers and tubes on plastic index.

tion of both nano particles was 0.2%; and soil plastic limit was observed 19% and 20% in presence of 0.2% carbon nano fibers and tubes receptively.

3.5.3. Plastic index

Fig. 10 represented the plastic index of soil in presence of different concentrations of carbon nano fibers and carbon nano tubes. This was calculated by subtracting plastic limits from liquid limits; and same trend was observed as was in liquid limits.

4. Discussion

Major difference between nano material and bigger scale materials was that nano material holds large surface area which resulted in providing substantial substance reactivity along with imposing alterations in its physical characteristics (Kreyling et al., 2010). These properties have been exploited in most technical fields of knowledge such as electronics, computer science, manufacturing, medicine, etc. Over the years, nanotechnology proved to be an effective field of science and its enormous, rapid and modern utilization was due to its remarkable integration in various fields of science, material science, and designing streams (Pokropivny and Skorokhod, 2007). However, stabilization was most suggested method in upgrading degraded soils. For example, those clays which were compressed and had low hydraulic conductivity due to it, often utilized as waste containment material (Abdeldjouad et al., 2019). An important property of compacted clay was desiccation cracking as it cracked the soil liners which conclusively reduce the sealing and upholding impact of the degraded system as present study investigated the impact of carbon nano fibers and carbon nano tubes on soil specific gravity, which was decreased with increased concentrations of carbon nano particles (Fig. 3). It was suggested that desiccation cracking was the reason of three orders of magnitude enhancement in hydraulic conductivity (Pokropivny and Skorokhod, 2007). Some studies have concluded that addition of several soil additives of lime, sand, and cement resulted in soil strengthening along with enhancing its resilience towards the phenomena of cracking; nevertheless, lime or cement didn't prove to be effective regarding the desiccation cracking phenomena; that could not address the higher permeable capability of clay soils with high water contents (Taha and Taha, 2012). However, some additives could improve the deficiencies remained in soils treated with carbon nano fibers and tubes (Taha and Alsharef, 2018).

Till date, one of the most auspicious group of substances appeared from nanotechnology was Carbon Nanotubes (Pokropivny and Skorokhod, 2007). Fullerene structural family holds the class nanotubes and its name was derived from its structure which was elongated and hollow from inside along with its thick sheet grapheme walls, as grapheme were one atom thick sheets (Negi et al., 2013). This family caused decrease in specific gravity of soil as they have low specific gravity but addition of some additives could improve the quality. Carbon molecules of cylindrical structure comprise of various beneficial properties in many fields of science like its utilization in nanotechnology, electronics, optics, and other relevant science and technology. Nano carbon filament specifically CNTs and CNFs hold various astounding properties; some of them were high tensile strength, elastic modulus, hardness, and electricity (Negi et al., 2013). They have a history from more than a century. Literature showed many studies conducted to investigate the impact of carbon nanotube i.e. a multiwalled carbon nanotube (CNT) on the physical properties of soil as used in present study as given in Table 1. To compare the effectiveness of MWCNTs with another nano material of same carbon family named carbon nano fiber was also used in many studies (Thostenson et al., 2001). These nano materials were inexpensive and with good quality products available in market. Researchers used soil normally from indigenous area to check the proper implementation of the experiment. Common parameters like compaction, pH, hydraulic conductivity, liquid limits, plastic limits and plastic index were recommended in many studies for enhancing the soil stabilization (Taha and Alsharef, 2018)as discussed earlier in methodology section of current study. Furthermore, CNTs have ability to produce powerful and resilient composites due to its astonishing mechanical characteristics along with high ratios as no significant impact of carbon nano fibers and tubes was observed on water contents (Fig. 6) in present study; but minor increase was observed in soil dry density in treating soil with 0.05% of carbon nano fibers as shown in Fig. 5. Many studies has been conducted to identify the possible use of CNT for the protection of the environment, it was observed that CNT were selective sorbent to eliminate any kind of biological or associating biological contaminants from water bodies (Gottschalk et al., 2009; Blandine et al., 2016; Alsharef et al., 2016; Pascal et al., 2011). Furthermore, the CNTs hold a large amount of hydrogen and proved to be an effective source. Many important prospects have been obtained by study nano particles in detail, one of them was its adsorption property which resulted on account of its large surface area which is about 50–1315 m2/g. The fundamental reason of nano particle study's conduction was to explore the kind and extend of their effects could imply on physical characteristics of soils and other environmental factors. Previously, a study investigated the impacts of carbon-based nano particles on Atterberg limits, optimum water content, maximum dry density, specific gravity, pH, and hydraulic conductivity. Same trend was observed in current study as minor decrease in plastic limit (Fig. 9) was observed but no significant change was observed in liquid limits (Fig. 8) of the soil in presence of carbon nano fibers and tubes. Mainly Nanocarbon fibers used in industries for example in automotive, marine, concrete, electronics, and sports but it demonstrate its effectiveness in agriculture and construction business.

5. Conclusion

Present Study was conducted to assess the capacity of carbon based nano particles in soil stabilization. Two nano particles 'cabon nano fibers' and 'multiwall carbon nano tubes' were used. Results showed that both have tendency to cause decrease in soil specific gravity and both can cause increase in soil pH; and addition of any suitable additives makes them accurate in improving soil quality. Minor addition of carbon nano fibers and tubes have imact on soil dry density and don't have significant effect on soil moisture contents. Furthermore, selected cabon nano-particles improved water retention time as it cause minor reduction in hydraulic conductivity. Atterberg's limits were represented that cabon nano fibers and nano tubes caused increase in liquid and plastic limits of the experimented soil but cause decrease in plastic index as shown in Fig. 8, 9, and 10. Overall selected carbon nano fibers and tubes were found suitable for soil stabilization. Addition of any suitable additive could stabilize soil ecologically. These can be used in conserving embankments. Furthermore, carbon nano-particles showed tendency to be used in improving soil quality in sensitive areas for soil conservation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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