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Iron and magnesium nano-oxide effects on some physical and mechanical properties of a loamy Hypocalcic Cambisol

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ABSTRACT

Nanoparticle effects on mechanical and physical properties of soil have rarely been investigated, particularly those of iron and magnesium nano-oxides. This study investigated the effects of the application of nano-oxides on total porosity, mean weight diameter (MWD) of aggregates, volumetric water content at a matric potential of −100 kPa, penetration resistance, and saturated hydraulic conductivity. Nanoparticle type (two types comprising iron and magnesium nano-oxides), application dosage (four dosages of 0, 1, 3, and 5% by weight), and incubation period (40 and 100 days) comprised the factors considered. The magnesium nano-oxide treatments increased ($P < 0.05$) total porosity by reducing soil bulk density due to the smaller size of magnesium compared with iron by 0.04 $cm^3\ cm^{-3}$. After both incubation periods, each application dosage of magnesium nano-oxide increased ($P < 0.05$) the *MWD* of the aggregates, ranging from 0.47 to 2.91, compared with the control and all of the iron nano-oxide dosages because of the large flocculation capacity of magnesium nano-oxide. The 1 and 3% applications of magnesium nano-oxide increased ($P < 0.05$) the water content, ranging from 0.01 to 0.02 $cm^3\ cm^{-3}$ compared with the control and 1 and 3% of the iron nano-oxide dosages, possibly by increasing the specific surface, stabilizing the soil structure, and increasing the microporosity. Penetration resistance increased ($P < 0.05$) about 0.14–0.28 MPa under the iron nano-oxide treatments whereas penetration resistance decreased ($P < 0.05$) about 0.21–0.33 MPa under the magnesium nano-oxide treatments. The saturated hydraulic conductivity decreased ($P < 0.05$) after both incubation periods with iron (24–61%), and after incubation for 40 days with magnesium (38–56%). However, the saturated hydraulic conductivity increased ($P < 0.05$) from 46 to 61% after incubation for 100 days with magnesium. It was concluded that magnesium nano-oxides can improve selected soil physical and mechanical properties due to their large adhesivity, specific surface, activity, and reaction ability.

1. Introduction

Numerous indicators have been suggested to evaluate the soil physical quality for water and solute transport and crop production. These indicators should comprise soil properties that affect the plant and root growth, such as water and oxygen storage, mechanical resistance and temperature (Letey, 1985). Indicators related to soil structure including soil total porosity, mean weight diameter (MWD), penetration resistance, water-holding capacity, and saturated hydraulic conductivity, which integrates three of those soil properties, namely water, air and mechanical resistance to root penetration, have been shown to be correlated with productivity of different crops and root growth. In contrast, indicators related to soil structure affect the management practices required to maintain soil water, oxygen, and mechanical resistance in a range suitable for good production. In other words, choosing the appropriate management method is required to improve soil physical properties for reducing potential problems in crop production and environment.

Nanotechnology is a current novel research area. Nano-related applications are ubiquitous in soil science and have been investigated in various areas. Nanomaterials have applications in management of farm practices due to their small size, large reactivity, and large specific surface area (Ghormade et al., 2011). Moreover, nanomaterials can affect soil structural properties. For example, Ben-Moshe et al. (2013) reported that a large application rate of copper (CuO) and iron (Fe_3O_4) nano-oxides to soil and their subsequent accumulation could reduce soil porosity. Igwe and Mbagwu (1995) expressed that the specific surface of nanoparticles is harnessed as a linking factor in the formation of

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aggregates. When the particle size increases, the specific surface decreases as well as the surface energy. For nanoparticles, larger values of surface energy, as compared to the bulk material, have been reported from the size-dependent lattice parameter (Berry, 1952). Nanda et al. (2003) reported that the large specific surface of nanoparticles, such as silver nanoparticles ($5.37\,m^2\,g^{-1}$), generates a large surface energy ($7.2\,Jm^{-2}$) among the particles and leads to very strong flocculation. Nanoparticles can affect the soil penetration resistance by decreasing or increasing swelling, shrinkage, and the elasticity index. Taha and Taha (2012) reported that an appropriate optimum percentage of nanoparticles, such as aluminum and copper nano-oxides, can reduce the soil swelling index and the shrinkage potential of a soil. Nanoparticles might also affect the saturated hydraulic conductivity because of their size, large adsorption surface, and the capacity for the accumulation of particles, and by increasing porosity.

Several studies have investigated the effects of nanoparticles on agricultural soils, but they were not sufficiently comprehensive. For example, Jiang et al. (2014) determined the effects of dithionite–citrate–bicarbonate and oxalate extractable metal oxides, such as iron oxy-hydroxides, Al, and Si on the specific surface area and pore structure of water-dispersible colloids from silt-loam soil. Taha and Taha (2016) evaluated the effects of nano-copper and nano-alumina on potential and hydraulic conductivity in a compacted soil-bentonite mixture with different plasticity indexes. Taha et al. (2015) determined the effects of nano-magnesium oxide on the geotechnical properties of a local soil. Fang et al. (2009) investigated the stability of TiO_2 nanoparticles in soil suspensions and their transport behavior through saturated homogeneous soil columns. Gao et al. (2018) studied the relationship between magnesium nano-oxide (MgO) and soil shear property. He et al. (2011) investigated the impact of iron nano-oxide (Fe_3O_4) on the soil bacterial community. Martínez-Fernández et al. (2016) assessed root water transport of *Helianthus annuus* L. under an iron nano-oxide. Bayat et al. (2018) focused on the effects of MgO and Fe_3O_4 nanoparticles on soil properties, such as tensile strength of aggregates and compression characteristics of a soil. Gao et al. (2015) applied magnesium nano-oxide as a new type of additive for clay and carried out unconfined compressive strength tests. Mahdavi et al. (2013) evaluated heavy metals removal from aqueous solutions using TiO_2, MgO, and Al_2O_3 nanoparticles.

There were several limitations with the previous investigations. First, previous studies did not investigate the effect of nano particles on some soil physical and mechanical properties. To address this limitation, in the present study, we explored the effects of nanoparticles on various soil properties, mostly different from those previously investigated. Former studies correlated improvements in soil physical and mechanical properties with the addition of nanoparticles (Ben-Moshe et al., 2013; Taha et al., 2015; Taha and Taha, 2016), but none examined the effects of magnesium and iron nano-oxides on the MWD of soil aggregates, penetration resistance, soil total porosity, volumetric water content at the matric potential of −100 kPa, and saturated hydraulic conductivity. Second, the optimum amount of nanoparticle addition to soils to avoid potential environmental damages has not been determined. Consequently, effects of applying different dosages of nanoparticles on soil properties could be assigned as the environmental implications of nanoparticles in the present study. Third, the effects of nanoparticles on calcareous soils have not been studied. With respect to this problem, the soil used in this study was a calcareous soil with loam texture.

Adding nanoparticles may improve soil physical, chemical and biological properties. For example, addition of nanoparticles may increase soil porosity and hydraulic conductivity and decrease soil penetration resistance, therefore nanoparticles can be used to improve compacted soils. This case could be assigned as a practical implication of nanoparticles for soil remediation.

It was hypothesis that nanoparticle type, application dosage, and incubation period would have different effects on soil physical and mechanical properties. Therefore, the objective of this study was to identify the effects of applying iron and magnesium nano-oxides at different dosages on soil total porosity, MWD, volumetric water content at the matric potential of −100 kPa, penetration resistance, and saturated hydraulic conductivity.

2. Materials and methods

A soil sample was collected from the top 30 cm of the surface horizon of a loamy, Hypocalcic Cambisol (Ochric) from an agricultural field from Qie-Ali Bulaq, a village in Hamedan province, west Iran (35°1′26″N, 48°19′14″E), where about 1 ha of wheat (*Triticum aestivum L.*) was cultivated. The soil was mixed uniformly before conducting any initial measurements and/or imposing any treatments. The soil sample was air-dried for 7 days at about 30 °C and passed through a 4.75-mm mesh by hand. The soil pH was 7.7, which indicated a balanced alkaline soil (Thomas, 1996). The electrical conductivity was $0.3\,dS\,m^{-1}$ which indicated the soil was not saline (Rhoades, 1996), and the average cation exchange capacity was $17\,cmol_c\,kg^{-1}$ (Rayment and Higginson, 1992). However, soil was classified as a poor soil due to low organic matter concentration (Nelson and Sommers, 1982), i.e., $11\,g\,kg^{-1}$. Based on large calcium carbonate equivalent (CCE) ($165\,g\,kg^{-1}$), the soil was also classified as a calcareous soil (Page, 1982).

A factorial design was used with three replicates, where the factors were comprised of nanoparticle type at two levels (iron and magnesium nano-oxides), application dosage (0, 1, 3, and 5% by weight), and incubation period (40 and 100 days). Thus, the total number of experimental units used in this study was 42 ([(2 types of Nps × 3 application dosage × 2 incubation period) + (2 control)] × 3 replicates = 42) for each soil property assessed.

2.1. Sample preparation and treatments

To prepare the samples containing nanoparticles, approximately 300 g of the air-dried soil was mixed with the nano-oxides at 0 (control), 1, 3, and 5% by weight, as suggested in a previous study by Taha and Taha (2012). These dosages were selected in order to perform a laboratory-scale study of the effects of iron and magnesium nano-oxides on soil physical and mechanical properties. The field capacity (FC) gravimetric moisture content was determined for all of the treatment groups and then water was spread on thin layers of the air-dried soil with about 3 mm thickness, in trays with 50 × 30 cm dimensions, before mixing the soil. A fine spray of distilled water was applied three times, where one-third of the calculated water required was added to the soil each time, before leaving for several hours to allow the added water to be distributed in the soil. Then, the mixture of soil, nanoparticles and water was placed in cubic plastic boxes with length = 13.5 cm, width = 9 cm and height = 6 cm. The soil container (plastic boxes) was covered to minimize evaporation and incubated for 40 or 100 days. During incubation, samples were kept at the FC moisture content and 22 ± 5 °C to simulate favorable conditions for microbial activity, aeration, and plant growth. The ± 5 value related to temperature variations. In the field condition, the temperature variations are greater than this range. Therefore, to simulate the field condition, the laboratory temperature variation was not controlled in the narrower range. The prepared mixtures were weighed every three days and the water lost by evaporation was added to keep them at FC. To add the calculated amount of distilled water, a wet cloth was put on the soil in the plastic boxes and the distilled water was spread on the wet cloth. During the water addition, the soil was weighed several times to control the amount of water addition exactly.

After incubating for 40 or 100 days, steel cylinders, measuring 5.1 cm in diameter and 3.5 cm in height, were used to collect an undisturbed sample from each box, and the remaining soil was treated as a disturbed sample. The incubation periods were considered suitable for allowing the nanoparticles to affect soil properties.