Article

Investigating the role of diatomite admixing on the water absorption and retention capacity of the soil

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Abstract
Diatomite is a unique natural material with interesting features including very fine structure, low mass density, high porosity, high specific surface, chemical neutrality and high silica content. In this work, the effects of diatomite on water absorption and water retention capacity of soil are studied. For this purpose, sandy soil samples from a farm were first prepared. Different amounts (0-10-20-40-80 g) of fragmented diatomite with the different particle size (0-2, 2.36-4.75, 4.75-12.5, 12.5-19 mm) added to the pots of 1-kilogram soil. After four months, the effect of adding raw and calcined diatomite on parameters such as soil bulk density, water absorption capacity, and water retention capacity was studied. By adding 10g/kg of diatomite to the soil, approximately 1.25% enhancement to the amount of soil saturated moisture occurred. Use of calcined diatomite, in contrast to raw diatomite, adds about 20% more to the water absorption capacity of the soil. With the addition of diatomite particles larger than 4.75 mm, the water absorption capacity increased significantly. Regarding the water retention capacity, adding about 10 g/kg of diatomite to the soil would add up to 0.6% to the 48-hours soil moisture content. The use of calcined diatomite did not affect the water retention capacity, but the use of coarse particles of raw diatomite increased the water retention capacity of the soil. Adding diatomite to soil decreases bulk density and significantly increases water absorption and water retention capacities. In this regards, the use of untreated raw diatomite particles with the size of 4.75-19 mm is most effective.

Keywords diatomite; soil amendment; water absorption capacity; water retention capacity.

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1 Introduction

One of the key characteristics of suitable soil for agriculture is its high water absorption capacity. Soil that cannot absorb much water cannot provide enough water to the plant. As water absorption capacity is essential in plant nutrition, water retention capacity is also necessary. If soil absorbs enough water, but cannot maintain it until the next irrigation, the plant will suffer from water shortages and drought stress. Properties such as clay percentage, clay type, organic matter content, and pore size are useful on soil water absorption and retention capacity. The higher the clay content in the soil, the more will be its water absorption and storage capacity. Organic matter in the soil plays a similar role with clay but with less impact. The disadvantage of organic material is that it decomposes quickly and its effect is eliminated. The soil porosity increases the water absorption capacity but increases the water retaining capacity only if the pores are microscopic.

The search for materials that, by adding a small amount of them to a granular soil, significantly increase soil water absorption and storage capacity is a big challenge in counteracting the decline in agricultural production, which has been the result of severe drought in recent years. One of the solutions is to find materials such as natural or synthetic super-absorbents that, by absorbing water and gradual providing it to the plant, can help the plant to withstand the water stress. Diatomite is a natural material with these characteristics that is recently being considered. It has numerous microscopic cavities and therefore has the potential to eliminate water shortages and cope with drought stress. The term diatomite is applied to the nearly pure sedimentary accumulation of the microscopic skeletons of unicellular aquatic algae belonging to the class of golden brown algae, Bacillariophyceae. The sediments are fine-grained, highly siliceous, and consist primarily of amorphous opaline silica with only minor amounts of organic residue, secondary minerals, and codeposited nondiatomaceous or crystalline debris (Breese and Bodycomb, 2006). Although diatomite is found in most places, reserves with high purity and commercial value are scarce. The physical properties of the diatomite, which adds value, include a very fine structure, low density, high porosity and high specific surface area. Other important factors are high absorption capacity, neutrality, and high silica content.

Research on the application of diatomite to soil amendment and its impact on drought stress and salinity is quite new. According to Breese and Bodycomb (2006), calcined diatomite grains are increasingly being used as a high-end soil amendment. Important properties are granule durability and the ability to store and release water. Studies have shown that the addition of 10% volumes of diatomite to soil reduces the plant's irrigation requirement by 50%. As a soil amendment, diatomite is used to prevent soil compaction, improve root development and reduce water consumption in sports fields and ornamental applications. New uses include adding diatomite to create specialty soil blends for hanging basket soil and rooftop garden soil.

Aksakal et al. (2012) studied the effects of diatomite on soil physical properties and proved that diatomite application limited large aggregate formation in clay-textured soils, increased aggregate stability in all aggregate size fractions, and soil penetration resistance decreased with diatomite application. Angin et al. (2016) studied effects of diatomite application on physical properties of soils subjected to freeze-thaw cycles. The results showed that diatomite application decreases bulk density of soils subjected to the same number of freeze-thaw cycles and increase of diatomite application rate reduces the negative effect of freeze-thaw cycles on aggregate stability. Effects of diatomite on soil consistency limits and soil compactibilty was studied by Aksakal et al. (2013). The results presented in this study indicated that application of diatomite increased liquid and plastic limit values, decreased the maximum dry bulk density, and increased optimum moisture content. Application of diatomite will cause the soil more easily tilled. These results were also affirmed by the study of Qu and Zhao (2016).

Antonides (1998) and Hellal et al. (2012) showed that diatomite has neutral pH and is stable and will not contribute to change in PH, a useful feature that eliminates concerns about pH changes when diatomite is being used. The positive effect of diatomite on hydrophysical properties and soil aeration has been indicated. The pore size is an important physical property that affects the absorption of water and nutrition by the roots of the plant. Caron and Nkongolo (1999) showed that in light textured soils diatomite can be used as an agent for increasing water holding capacity. The existence of a sufficient amount of coarse to fine grains is necessary for drainage, water retention, and soil aeration. Angin et al. (2011) noted that increasing Diatomites in mixture increased meso, micro and ultra-pores, which are important for plant water requirements, however, it also increased macropores which are desired for optimum plant growth and root distribution. Sayyari-Zahan et al. (2015) investigated the potential of using Birjand diatomite as a non-chemical mineral fertilizer for agricultural soil in a laboratory study. The results showed that the effects of diatomite were significant on EC, K and P concentrations in soil, but did not have much effect on soil pH. In this work, a comprehensive laboratory study is conducted to investigate the effects of different parameters including percentage, size, and calcination of diatomite particles on water absorption and water retention capacity of a granular soil.

2 Material and Methods

The soil sample required to study the effect of diatomite on water absorption and storage capacity was taken from a depth of 0-30 cm of an agricultural farm. It was a sandy soil with a low water absorption capacity. According to Sayyari Zahan et al. (2015), this soil has a pH of 7.8 and EC = 1 dS / m with a moderate texture. The field capacity moisture content of this soil is about 18%.

The diatomite sample used in this study was taken from diatomite deposits located near Birjand, Iran. Azimi Pirsaraei et al. (2015) studied the chemical components, surface area, pore size, total pore volume, and other features of this material through X-ray diffraction method and scanning electron microscope. The chemical composition of the Birjand diatomite obtained from the X-ray fluorescence spectroscopy is shown in Table 1. This analysis revealed that the diatomite of Birjand contain more than 82 wt.% of silica and their chemical composition is formed mainly by silica and aluminum oxides. Other important components include iron, potassium, calcium, and manganese. The microscopic structure of the Birjand diatomite obtained by scanning electron microscopy (SEM) is presented in Fig. 1. Porosity at diatomite surface is visible in Fig. 1. The results obtained from the specific surface area and the pore volume distribution of diatomite samples are given in Table 2.

After preparing the soil and diatomite samples, soil samples were passed through a 2 mm sieve. Then, treatments were made of one kilogram of soil and transferred to plastic pots. Laboratory filter paper was used on the floor of the pots to prevent soil withdrawal (with drainage water). The treatments consisted of five levels of diatomite application: 0, 10, 20, 40 and 80 g/kg dry soil. The experiments were carried out in a completely randomized design with three replications. Four different sizes of diatomite particles including 0-2, 2.36-4.75, 4.75-12.5 and 12.5-19 mm were investigated to study the effect of particle size. It should be noted that for particles larger than 2 mm, only 40 g/kg treatment with two replications was used. In addition to raw diatomite, calcined diatomite was used in the treatment of 20 g/kg soil. The process of calcining the raw diatomite was carried out during 4 hours without a fluxing agent at 900° C. The raw diatomite was pretty white but turned to brown color after calcining. A total of 24 treatments were prepared.

In all of the treatments, diatomite particles were mixed entirely with one kilogram of dry soil and then the soil moisture content was reached to field capacity moisture content, i.e., 18%. Irrigation of pots was performed every ten days after weighing and determining the amount of moisture reduction for different treatments. For some time, the pots were kept saturated at field capacity moisture content. After four months, the following factors were measured: soil bulk density, saturated water content, and water retention capacity. The dry bulk density, the saturated unit weight and the porosity of the pure diatomite sample were also measured for use in later analyzes. Laboratory data were analyzed and interpreted using statistical software. In the next section, the results are presented and discussed.

Table 1 Chemical composition of Birjand Diatomite (Azimi Pirsaraei et al., 2015).

Constituent	Value, %
SiO_2	82.27
Al_2O_3	4.97
Fe_2O_3	1.81
CaO	1.47
MgO	1.29
K_2O	0.90
Na_2O	0.54
TiO_2	0.23
P_2O_5	0.17
L.O.I	6.27

Table 2 Microscopic physical properties of Birjand Diatomite (Azimi Pirsaraei et al., 2015).

Specific surface area, m^2/g	Pore volume, cm^3/g	Average pore radius, Å
29.14	0.04319	29.65

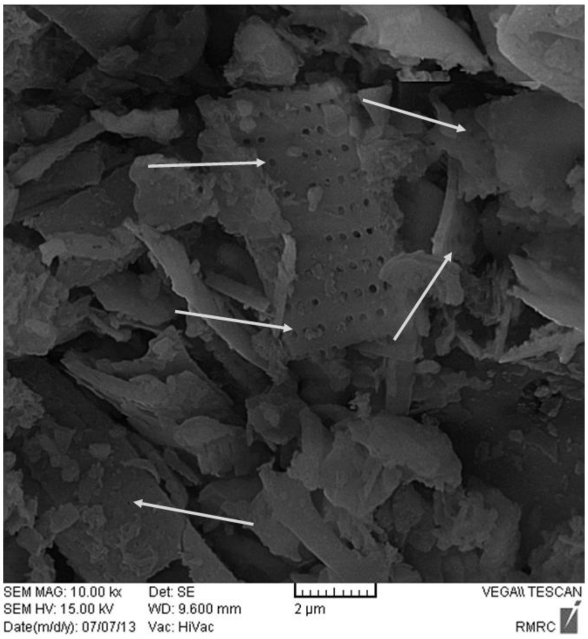

Fig. 1 Scanning electron micrograph with a magnification of 10000X of Birjand Diatomite (Azimi Pirsaraei et al., 2015).

3 Results and Discussion

3.1 Physical properties of the raw diatomite

The dry unit weight, saturated unit weight and porosity of the diatomite sample were measured in the laboratory as 0.65 g/m^3, 1.3 g/m^3, and 65% respectively. In this way, it became clear that the studied diatomite has a water absorption capacity almost equivalent to its weight. It is noteworthy that these figures were obtained on average. In some diatomite samples, the percentage of clay was high, and therefore the water absorption capacity was lower. Dry diatomite floats on water due to its small gravity, but after some time the water penetrates into it and causes it to settle.

3.2 Density of the soil

The treatments prepared in this study were kept for 18 months in greenhouse conditions and maintained at 18% moisture content so that all possible reactions between soil and diatomite occur. At the end of this period, the dry bulk density of soil of each pot was measured. Fig. 2 depicts the effect of adding diatomite to soil on the amount of soil dry bulk density. The overall impact of increasing diatomite percent on the soil would be to reduce its bulk density. However, it should be noted that for small amounts of diatomite there is not much change in the soil bulk density.

Reducing soil bulk density is a positive effect for diatomite, which is also reported by Aksakal et al. (2013), and Qu and Zhao (2016).

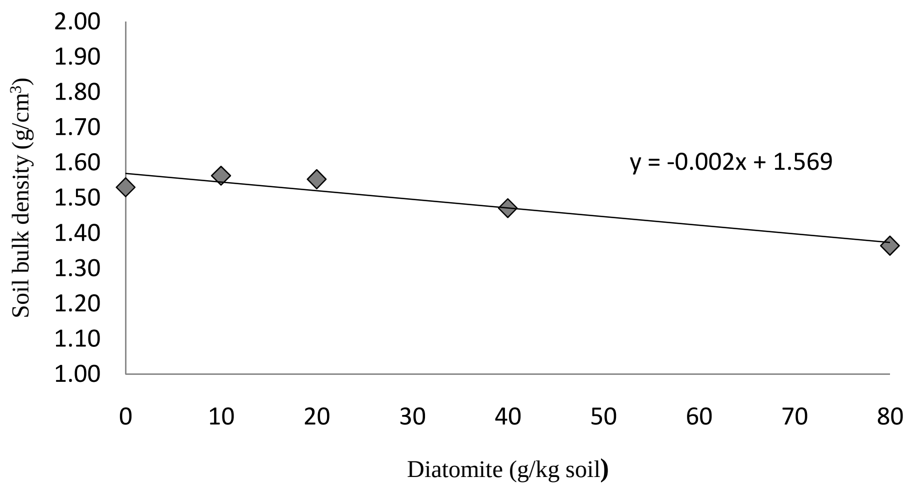

Fig. 2 The effect of diatomite treatment on the bulk density of the soil.

3.3 Saturated water content

Water was added to the soil pots till the saturation point. By measuring the weight of saturated soil, the saturated water contents of each pot, and the average saturated water content for each series of treatments were calculated. Fig. 3 shows the effect of adding diatomite on soil saturation water content. It is seen that increase of diatomite in the soil has a significant impact on the rise of soil saturated water content. Approximately 1.25% increase in soil water content has been observed by addition of every 10 g/kg of raw diatomite per kilogram soil. In Section 3.1, it is noted that Birjand diatomite has a water absorption capacity equivalent to its weight. Thus 10 grams of added diatomite per kg of soil should absorb 10 grams of water and hence increase soil moisture by 1 percent. The 1.25% increase in soil moisture content is more than the theoretically expected

1%. This is an ambiguous issue but is probably because the addition of diatomite to soil has altered its structure as well and increased its porosity.

Since the amount of saturated water content in an agricultural soil is equivalent to the water absorption capacity, the results of this study show the positive effect of diatomite on increasing the water absorption capacity of gravelly and sandy soils. In many industries, calcined diatomite is used because of superior properties to raw diatomite. As mentioned in section 2, 20 g/kg treatment was prepared in both natural and calcined form. In Figure 4, the effect of calcined diatomite on soil saturated water content is compared with natural raw diatomite. The use of calcined diatomite has a much higher effect on increasing soil water absorption capacity compared to raw diatomite and roughly increased it by 20% in treatment 20 g/kg.

Because the diatomite is a highly porous material, crushing the diatomite is likely to destroy part of its porosity. Therefore, in the present study, the effect of diatomite particle size on soil absorption capacity was investigated (Fig. 5). The use of coarser particles has increased the absorption capacity of the soil. A detailed examination of Fig. 5, shows that the soil saturated water content with a diatomite size of 2.36-4.75 mm has a slight increase of about 1% compared to finer than 2mm treatment. However, use of coarse particles with a size of 4.75-12.5 mm caused a significant increase of about 5% in saturation water content and increased it from about 27% to 32%. Interestingly, the use of coarser particles, i.e., 12.5-19 mm, did not have much effect compared to the size of 4.75-12.5 mm, but only increased the soil saturation water content by 1%.

Based on the results of the diatomite size study, it is inferred that the crushing of diatomite causes the loss of a significant part of its internal space which has water absorption capacity. Therefore, to improve the agricultural soils with a low water absorption capacity, it is recommended that coarse diatomite particles with a size of 5-12 mm or 12-20 mm should be used. Another factor that will be very effective is the use of calcined diatomite.

The addition of diatomite develops the microscopic cavity to the fine soil and thereby increases its water storage capacity. Meanwhile, diatomite increases the coarse cavities that play an essential role in improving plant growth and root distribution (Angin et al., 2011). In the present study, it has shown that for increasing soil water content, more diatomite, bigger diatomite particles or calcination of diatomite can be used.

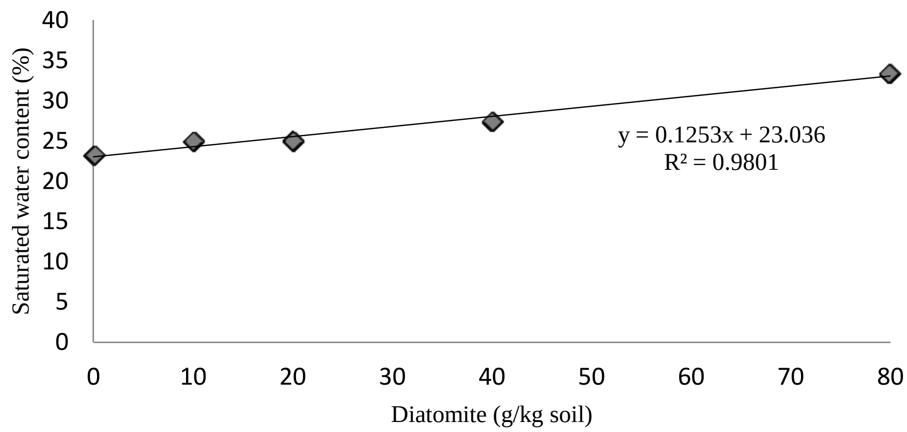

Fig. 3 The effect of diatomite treatment on the saturated water content of the soil.

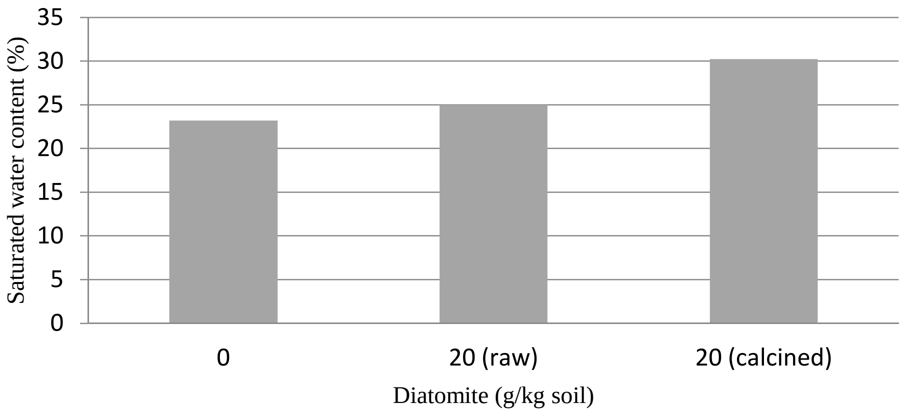

Fig. 4 Comparing the effect of raw and calcined diatomite in 20g/kg treatment on the saturated water content of the soil.

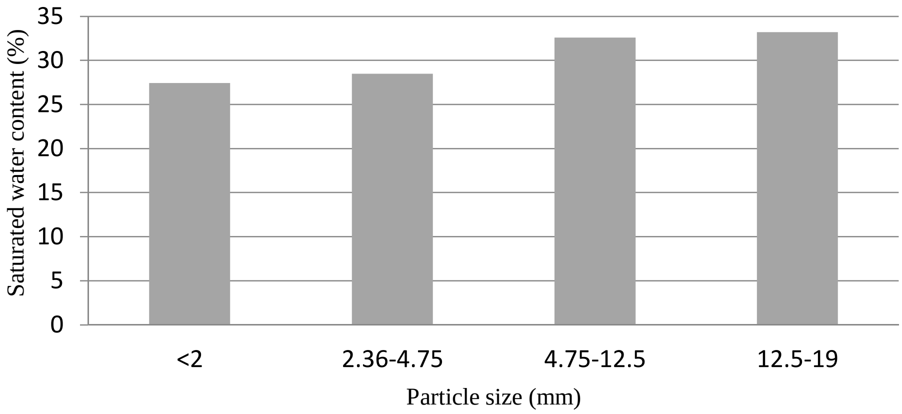

Fig. 5 The effect of diatomite particle size in 40g/kg treatment on the saturated water content of the soil.

3.4 Water retention capacity

As mentioned in the previous section, Water was added to the soil pots till the saturation point to measure soil saturated water content. The soil water content of each pot was re-measured 48 hours after the saturation moment to estimate the soil water retention capacity. Fig. 6 shows the effect of diatomite on the soil water content after 48 hours. It is observed that the increase of diatomite in the soil has a significant effect on increasing the water holding capacity of the soil. Almost every 10 g/kg of raw diatomite to the soil added 0.6% to its 48-hour water content. Since the 48-hour water content is an indicator of water holding capacity in the soil, the results show the positive effect of diatomite on increasing water retention capacity in sandy soils.

In Fig. 7, the effect of raw and calcined diatomite on the 48-hour soil water content has been compared. As seen, the use of calcined diatomite does not have an impact on increasing the water holding capacity in the soil and even compared to raw diatomite a reduction in water content is observed. Referring to section 3.3 and recalling that soil modified with calcined diatomite has a higher saturated water content than raw diatomite, it is questioned why the reverse condition exists for the 48-hour water content of the same soil. In other words, the effect of calcined diatomite, in contrast to raw diatomite, is the increase of the soil water absorption but the decrease of soil water retention capacity. It should be noted that according to Breese and Bodycomb (2006) the calcination process, due to the onset of internal fusion, causes the microscopic structure of the diatomite to disappear. Since the microscopic pores play a significant role in maintaining and improving the water holding capacity, it is clarified why thermal treatment reduces the quality of calcined diatomite. Therefore, to improve the soil water retention capacity, it is better to use natural raw diatomite, and calcined diatomite is not recommended.

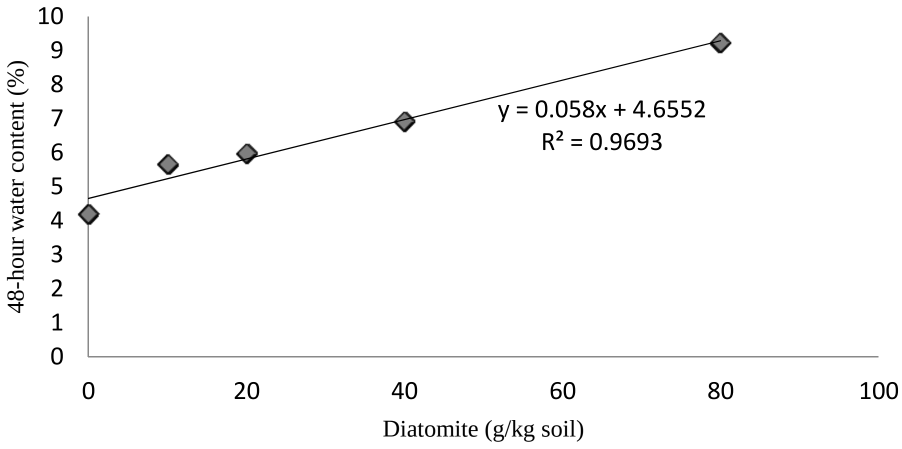

Fig. 6 The effect of diatomite treatment on the 48-hour water content of the soil.

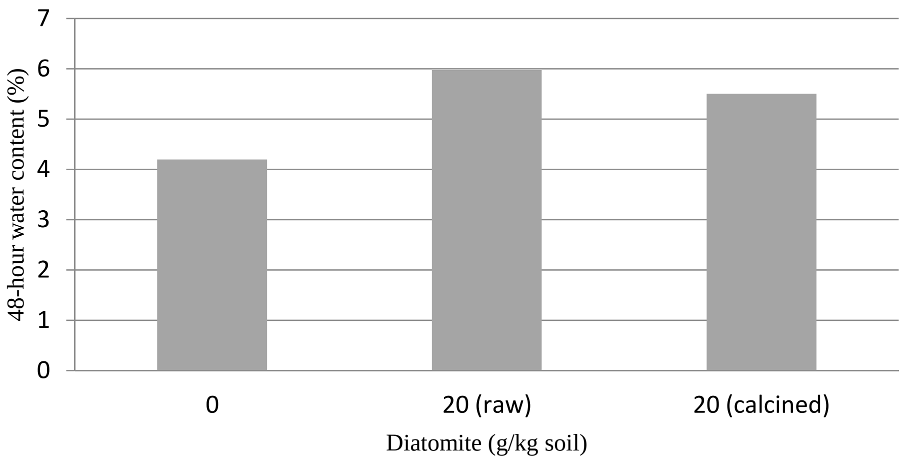

Fig. 7 Comparing the effect of raw and calcined diatomite in 20g/kg treatment on the 48-hour water content of the soil.

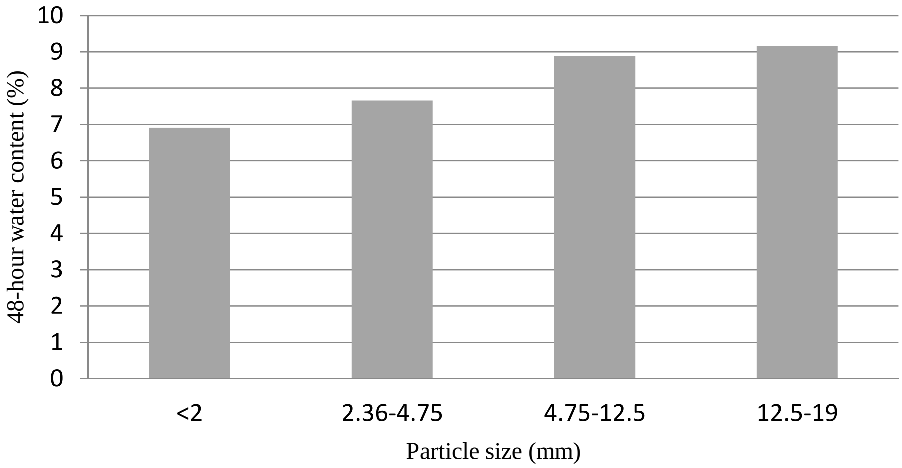

Fig. 8 The effect of diatomite particle size in 40g/kg treatment on the 48-hour water content of the soil.

The effect of diatomite particle size on water holding capacity by soil was investigated in the treatment of 40 g/kg (Fig. 8). It is observed that the use of coarser particles of diatomite increases the water holding capacity of the soil. A detailed examination of Fig. 8 shows that the 48-hour water content of the studied soil, with the diatomite particle size of 2.36-4.75 mm, increases by about 0.8% in comparison to the particles smaller than 2 mm. With the use of coarse particles with a size of 4.75-12.5 mm, a significant increase of about 2% was observed in the 48-hour soil water content. In the same way, as observed for the soil saturation water content (section 3.3), the use of coarser particles, i.e., 12.5-19 mm, has a minimal effect and only increased the 48-hour water content of the soil by 0.3%.

The positive effect of diatomite on water holding capacity of light textured soils is consistent with the findings of similar studies such as Caron and Nkongolo (1999), and Breese and Bodycomb (2006). But, in the present study, it has shown that use of diatomite particles larger than 5 mm further improves the water holding capacity of the soil.

4 Conclusions

The Birjand diatomite is a relatively pure diatomite mainly composed of silica (about 80%) and aluminum oxide. Other important components include iron, potassium, calcium, and manganese. The dry unit weight, saturated unit weight and porosity of Birjand diatomite were measured as 0.65 g/m^3, 1.3 g/m^3, and 65% respectively. In this way, it became clear that the Birjand diatomite has a water absorption capacity almost equivalent to its weight. The value of the specific surface area of Birjand diatomite according to Azimi Pirsoraie et al. (2015) is 29.24 m^2/g, the total pore volume is 0.04319 cm^3/g, and the mean radius of the microscopic pores is 29.65 Å. In the present study, different amounts of crushed diatomite (10-20-40-80 g) with the different particle size (0-2, 2.36-4.75, 4.75-12.5, 12.5-19 mm) were added to 1 kg of soil. After four months of storage of treatments in field moisture capacity, the effect of adding diatomite on parameters such as soil bulk density, soil water absorption capacity, and water storage capacity was measured. Also, the effect of calcination of diatomite on absorption capacity and water holding capacity by soil was studied in the treatment of 20 g/kg.

Based on the results of this study, it was determined that adding diatomite to soil decreases its bulk density. Reducing soil bulk density is a positive effect, which improves soil aeration and increases water absorption capacity. The addition of diatomite to soil increased the saturated water content of the soil. Approximately 1.25% increase in soil water content has been observed by addition of every 10 g/kg of raw diatomite per kilogram soil. The use of calcined diatomite rather than natural raw diatomite has a significantly higher positive effect on the water absorption capacity, whereas, compared to raw diatomite, the soil saturation water content was increased by about 20%. The use of coarser particles of diatomite increased the water absorption capacity of the soil. On this basis, it was found that crushing diatomite in dimensions of less than 4.75 mm would cause the loss of a substantial part of its internal porosity. Therefore, to improve agricultural soils with low water absorption capacity, it is recommended to use coarse diatomite particles with a size of approximately 4.75 to 19 mm.

Regarding water holding capacity by soil, the results of this study showed that the addition of diatomite to soil has a significant positive effect. Almost adding up to 10 g/kg of raw diatomite to the studied soil added 0.6 percent to its 48-hour water content. The use of calcined diatomite did not affect water holding capacity in the soil and even reduced the 48-hours soil water content, as compared to raw diatomite. Therefore, to improve the soil water retention capacity, it is better to use natural raw diatomite. The effect of diatomite particle size on water holding capacity by soil was also studied. The results showed that the use of coarser particles of diatomite increases the water holding capacity of the soil. Thus, it was determined that the use of diatomite particles with the size of 4.75-19 mm is most effective in increasing the water absorption and storage capacity in granular soils.

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