International Journal of Plant & Soil Science

16(5): 1-11, 2017; Article no.IJPSS.33388
ISSN: 2320-7035

Impact of Biogas Slurry on Some Physical Properties in Sandy and Calcareous Soils, Egypt

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Authors' contributions

This work was carried out in collaboration between both authors. Author MAB designed the study, performed the statistical analysis, wrote the protocol, managed the literature searches and wrote the first draft of the manuscript. Author ASA managed the sampling site selection, edited the data, reviewed and edited the protocol and manuscript. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2017/33388
Editor(s):
(1) Fatemeh Nejatzadeh, Department of Horticulture, Faculty of Agriculture, Khoy Branch, Islamic Azad University, Iran.
Reviewers:
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Complete Peer review History: http://www.sciencedomain.org/review-history/19505

Original Research Article

Received 12th April 2017
Accepted 21st May 2017
Published 13th June 2017

ABSTRACT

Sandy and calcareous soils in Egypt are promising for increasing cultivated area to suffice the growing food demand; however, their physical properties adverse plant growth. Hence, the current work was carried out to evaluate the effect of biogas slurry (BGS) application rates of 0, 30, 60 and 90 g kg^{-1} on physical properties in sandy and calcareous soils. Soils were incubated for six months under laboratory conditions keeping the moisture content around 70% of holding capacity. The BGS applications resulted in significant increases ($P < 0.05$) in organic matter content, total soil porosity, air-filled porosity and water holding capacities while decreased bulk density and void ratio in both soils compared to the control (untreated soils). Soil hydraulic conductivity significantly ($P < 0.05$) decreased in sandy soil but increased in calcareous soil, with the highest application rate of 90 g kg^{-1} being the most effective treatment. Generally, the BGS proved success in ameliorating soil physical properties.

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Keywords: Biogas slurry; porosity; bulk density; air-filled porosity; void ratio; hydraulic conductivity; soil moisture content.

1. INTRODUCTION

Declining the cultivated land in Nile Valley and Delta, Egypt has pushed the agricultural expansion into the wide desert to suffice the growing food demand [1]. Sandy and calcareous soils occupy the majority of the Egyptian desert lands; however, their use is limited by adverse physical properties [2]. Sandy soils have inherent low fertility and water-holding capacity [3], while high content of calcium carbonate affects negatively soil water relations and plant nutrition in calcareous soil [4]. Low organic matter content seems to be the key factor contribute such unsavory effects [5]. Thus, incorporation of organic fertilizers into the soils alleviate the negative effects and improve soil properties [6].

Under arid and semi-arid conditions, much attention has been drawn on the significance of supplementing organic materials to the soils to improve the physiochemical properties [7,8]. Organic fertilizers are the main available sources for increasing organic matter in the soil [9]. When organic solids are incorporated into the soil, a gradual assimilation occurs through chemical and biological reactions. Mineralization of nutrients releases many nutrients in the forms available for plants uptake. Organic matter amendments improve soil physical conditions [10], enhancing plant growth parameters and increase yield [11].

Soil physical properties such as bulk density, porosity, hydraulic conductivity and moisture content are important components of soil quality that affect availability and uptake of water, oxygen, and nutrients [12]. Soil bulk density is an index of the soil penetration resistance to root growth [13] and to characterize soil compaction [14]. Soil porosity expresses the amount of space available to a fluid within the body of the soil [15]. It is the fraction of the total soil volume that is taken up by the pore space [9]. By convention, the definition of pore space excludes fluid pockets that are totally enclosed within the soil solid material [16]. Porosity is mainly responsible for the exchange of gases and water in the soil. Void ratio is a characteristic of compact soil and is defined as a volumetric ratio of the volume of void-spaces to the volume of soil [17]. Soil air-filled porosity is important [16] for soil aeration and is commonly used to estimate the availability of oxygen to plant roots [18]. Hydraulic conductivity is important for soil water flow, surface water infiltration and runoff and sub-soil water recharge [19]. Soil moisture content is the primary factor that limits productivity among farming systems [20] and is a fundamental property affecting plant growth, transport, and transformation of soil nutrients [21].

Biogas slurry (BGS) raises agricultural productivity and enhances soil fertility. It is a product of the anaerobic digestion of organic materials. Such product includes methane gas along with traces of H_2S, CO_2, NH_3, H_2, CO besides BGS [22]. Organic materials obtained as a by-product from biogas slurry technology are used as organic fertilizers. The slurry produced by the biogas is effective as a soil conditioner [23]. Biogas contains many rich nutrients including nitrogen, phosphorous, potassium, iron and trace elements [24]. The anaerobic digestion of organic matter using biogas slurry technology produces materials that are utilized as crop nutrients which are free of weed seeds [25]. The effect of BGS on soil physical properties largely depends on the rate of decomposition and its contribution to soil organic content. Factors affecting the rate of decomposition include; chemical composition of the BGS, soil temperature, soil moisture, method of BGS application (surface-applied or soil-incorporated) and rate of application [26]. Soil applications of BGS at different rates were evaluated by previous studies in Egypt [27,28]. They indicated the effectiveness of BGS in improving soil physical properties and enhancing crop yield. BGS improves aggregation, water-holding capacity, pore size distribution, hydraulic conductivity and porosity [29,30].

The objective of the current study is to evaluate the changes of soil physical properties; bulk and particle density, porosity, hydraulic conductivity, and water content in sandy and calcareous soils as affected by different application rates of biogas slurry to determine the possibility of using such material in improving the aforementioned properties of newly reclaimed soils.

2. MATERIALS AND METHODS

2.1 Biogas Slurry (BGS)

The BGS used for the current study was from anaerobic digestion of organic materials obtained from the training center for biogas and recycling of agricultural waste (TRRAR), Moshtohor, Qalubiya Governorate, Egypt. The biogas slurry was air-dried and passed through a 2-mm sieve before mixing with the soils. The main composition of the BGS is shown in Table 1.

Table 1. Main properties of biogas slurry (on dry weight basis) applied to the soil

Properties	Unit	Value
pH (1:10 BGS : water)	- log [H^+]	7.54
EC (1:10 BGS : water)	dS m^{-1}	2.53
Organic matter	g kg^{-1}	408.10
Bulk density	Mg m^{-3}	0.387
Moisture content	%	23.64
Total N	g kg^{-1}	8.20
Total P	g kg^{-1}	9.50
Total K	g kg^{-1}	16.30

2.2 Soils

Two soils were tested; the first is sandy soil taken from Wadi El-Natrun region, the Western Desert of Egypt, classified as Typic Torripsamments, and the second is calcareous sandy loam soil taken from El-Nubaria region near Cairo-Alexandria desert road, classified as Typic Haplocalcids [31]. Soil samples were collected from the surface layer (30 cm). The soils were of low organic matter, low water retention and low fertility. The soils were air-dried, passed through 2 mm sieve. Particle size distribution was determined by the pipette method, using sodium hexametaphosphate as a dispersing agent [32]. Organic matter was determined by using the modified Walkley and Black method [33]. The pH, EC, and $CaCO_3$ were also estimated [34]. Main properties of the soils are given in Table 2.

2.3 Experimental Design

A laboratory experiment was performed using a completely randomized design with 5 replicates. There were eight (8) treatments as follows: 0, 30, 60 and 90 g kg^{-1} for sandy soil and 0, 30, 60 and 90 g kg^{-1} for calcareous soil (total number of treatments 40 experimental units). Three kilograms each of sandy and calcareous soils were thoroughly mixed with 0 (control), 90, 180 and 270 g BGS, and moisture was kept 70% of water holding capacity using distilled water. Soils were covered with polyethylene sheets and water content was maintained constant by weighing the pot weekly and bringing it to its initial weight by adding distilled water. The prevailing ambient room temperature during incubation period ranged from 24 to 30ºC.

2.4 Soil Measurements and Data Analysis

After six months of incubation, the following determinations were carried out on the treated soil: soil bulk density (BD) was determined on undisturbed soil samples using a steel cylinder of 100 cm^3 volume. On the other hand, the particle size density (PD) was measured by a pycnometer. From both BD and PD the total porosity (TP), the void ratio (VR) and air-filled porosity (AFP) were calculated as follows [35]:

$$TP = \frac{PD - BD}{PD} \times 100 \quad (1)$$

$$VR = \frac{TP}{(1 - TP)} \quad (2)$$

$$AFP = TP - S \quad (3)$$

Where *S* is saturation degree

Soil cores were sampled by a cylinder to measure the saturated hydraulic conductivity in the laboratory using the constant-head method. Water holding capacity at 0.33 bar (field water capacity) and at15 bar (wilting point) were determined in undisturbed samples. Available water capacity (AWC) was then determined considering the difference between water retained at 0.33 and 15 bars [36]. Data were all analyzed using analysis of variance at a 0.05 level, using SPSS19.0 for Windows (SPSS Inc., Chicago, USA). A correlation matrix of different properties was based on linear correlation coefficients ($p < 0.05$ and $p < 0.01$).

3. RESULTS AND DISCUSSION

3.1 Soil Organic Matter, Bulk Density and Particle Size Density

Results in Table 3 show the effect of different application rates of BGS on soil organic matter (SOM), bulk density (BD) and particle size density (PD) in sandy soil and calcareous soil. Treating the soils with BGS resulted in a significant increase in SOM ($P < 0.05$) with slight differences among the applied rates. Insignificant differences were identified in both soils between the applied rates of 60 and 90 g kg^{-1}, which increased SOM by 26% and 33% for the sandy soil respectively, and 9.23% and 13.07% for the calcareous soil respectively compared to the control. On the other hand, the lowest application rates of 30 g BGS kg^{-1} had an insignificant effect. This result is in agreement with [37,38] who reported that applications of BGS increased soil organic matter. Generally, organic fertilizers enhance organic carbon storage in soil and improve soil fertility [39,40]

The bulk density (BD) of the sandy and calcareous soils significantly ($P < 0.05$) decreased with the BGS applications with slight differences among the applied rates. The application rates of 30, 60 and 90 g kg^{-1} decreased soil BD at the sandy soil by 4.17, 8.92 and 11.90%, respectively compared to the control. Treating the calcareous soil with the same rates resulted in decreases by 5.03, 10.07 and 13.67% respectively compared to the control.

The highest application rate of 90 g kg^{-1} resulted in significant decrease in soil particle density (PD) by 0.10 Mg m^{-3} in both soils compared to the control. Also, the application rate of 60 g kg^{-1} decreased PD significantly by 0.05 Mg m^{-3} in both soils compared to the control; however, soils received 30 g kg^{-1} showed an insignificant decrease. Soil density is inversely related to the changes in soil organic matter [41], thus significant decreases in soil BD and PD have been reported in different soils upon application of BGS at different rates [42-44]. Organic materials have low density, thus mixing these less dense materials with denser mineral fractions of soils induce a dilution effect, decreasing both bulk and particle density [45].

3.2 Soil Total Porosity, Air-Filled Porosity and Void Ratio

Results in Table 4 illustrate the effect of BGS at different rates on soil total porosity (TP), air-filled porosity (AFP) and void ratio (VR) in soils. The BGS application resulted in a significant increase ($P < 0.05$) in TP for both soils with slight differences among application rates. The application rates of 60 and 90 g kg^{-1} had the same effect in the two soils and induced significant increase by 13.05 and 15.32%, respectively in sandy soil and 9.36 and 11.50% in calcareous soil compared to the control. On the other hand, the application of 30 g kg^{-1} had an insignificant effect in the two soils. The BGS increased AFP with slight differences among application rates.

The increases in sandy soils were 1.53, 2.11 and 2.29 folds for soils treated with 30, 60 and 90 g kg^{-1}, respectively; while in the calcareous soil, the corresponding increases were 1.54, 2.15 and 2.41 folds, respectively for the same rates. The VR decreased in sandy soil in response to BGS applications; however, the decreases were slight. On the other hand, the applied BGS rates did not significantly affect VR in calcareous soil. These results are in agreement with [43,46] who found that application of BGS improved soil aeration by increasing total porosity and air-

Table 2. Physiochemical properties of the studied soils

Soils	pH*	EC** dSm^{-1}	OM g kg^{-1}	$CaCO_3$ g kg^{-1}	Texture (USDA)	Particle size distribution, %			
						Fine sand	Coarse sand	Silt	Clay
Sandy soil	8.14	2.18	2.20	22.30	Sand	38.0	55.5	2.5	4.0
Calcareous soil	8.09	1.25	4.50	221.10	Sandy loam	36.1	37.1	8.0	18.8

*Note: * pH of 1 : 2.5 soil : water suspension **EC of soil past extract*

Table 3. Effect of BGS applications on soil organic matter (SOM), bulk density (BD) and particle size density (PD) under sandy soil and calcareous soil

Soils	BGS (g kg^{-1})	SOM(g kg^{-1})	BD(Mg m^{-3})	PD(Mg m^{-3})
Sandy soil	0	2.20b	1.68a	2.60a
	30	2.51ab	1.61b	2.58ab
	60	2.99a	1.53bc	2.55b
	90	3.30a	1.48c	2.50c
	Mean	2.75	1.57	2.55
Calcareous soil	0	4.50b	1.39a	2.63a
	30	4.75ab	1.32b	2.60ab
	60	4.98a	1.25bc	2.58b
	90	5.20a	1.20c	2.53c
	Mean	4.86	1.29	2.58

Note: Values followed by the same letter within a column indicate no significant difference at 0.05 level

Table 4. Effect of BGS on soil total porosity (TP), air-filled porosity (AFP) and void ratio (VR) in sandy soil and calcareous soil

Soils	BGS (g kg^{-1})	TP (%)	AFP (%)	VR
Sandy soil	0	35.38b	4.18c	1.029a
	30	37.59ab	6.39b	1.027ab
	60	40.00a	8.80ab	1.025b
	90	40.80a	9.60a	1.025b
	Mean	38.44	7.24	1.026
Calcareous soil	0	47.14b	3.84c	1.021a
	30	49.23ab	5.93b	1.020a
	60	51.55a	8.25ab	1.019ab
	90	52.56a	9.26a	1.019ab
	Mean	50.12	6.82	1.019

Note: Values followed by the same letter within a column indicate no significant difference at 0.05 leve

filled porosity, and decreased void ratio. The observed changes go beyond the fact that application of BGS improved soil structure by better aggregation of individual soil particles and decreased BD [47,48].

3.3 Soil Saturated Hydraulic Conductivity

The BGS applications resulted in significant decrease ($P < 0.05$) in saturated hydraulic conductivity (*Ks*) in sandy soils (Fig. 1). The greatest reduction related to the highest application rate of 90 g kg^{-1}, which caused a 34.91% decrease compared to the control. The application rate of 60 g kg^{-1} caused a decrease of 25.90%, while soil amended with 30 g kg^{-1} showed an insignificant decrease. On the other hand, the applied BDS rates increased Ks in calcareous soil and the highest increase associated with the highest application rate of 90 g kg^{-1}. The increases were 2.56 and 1.93 folds for soils amended with 90 and 60 g kg^{-1}, respectively; however, the application rate 30 g kg^{-1} had no significant effect.

Changes in soil hydraulic conductivity in response to the organic matter application have been reported [49-51]. The observed Ks decrease in sandy soil based on the dispersion and expansion of soil colloid particle enhanced by BGS applications, and thus blocking macro-pores. Moreover, BGS can adsorb and fix various inorganic ions as well as polar or nonpolar organic compounds, thereby forming stable aggregates in the sandy soil, thus possibly filled pore spaces, which means a reduction in soil hydraulic conductivity [43,52]. On the other hand, Ks increase in calcareous soil is a result of improving soil structure due to decreased bulk density and increased porosity. These positive changes enhanced the resistance to soil compaction results from the cementing agent; calcium carbonate and led finally to increase soil hydraulic conductivity [50,53,54].

3.4 Soil Moisture Characteristics

Data illustrated in Figs. 2, 3 and 4 show that treating the two soils with the BGS had significant effects ($P < 0.05$) on moisture constants with slight differences among application rates. The field water capacity (FWC) in sandy soil increased by 43.17, 60.77 and 86.63% for soils amended with 30, 60 and 90 g kg^{-1}, respectively (Fig. 2). With the calcareous soil, the application rate of 30 g kg^{-1} had no significant effect ($P < 0.05$) on FWC, while no significant differences were observed between the application rates of 60 and 90 g kg^{-1}, and caused 9.21 and 14.05%, respectively increases compared to the control. Likewise, the wilting point (WP) increased in sandy soil by 1.85, 2.01 and 2.20 folds in response to application rates of 30, 60 and 90 g kg^{-1}, respectively (Fig. 3). Contradictory, the WP in calcareous soil did not show the same trend, since the application rates of 60 and 90 g kg^{-1} decreased WP by 21.07 and 27.08%, respectively; however, the application rate of 30 g kg^{-1} showed insignificant effect. The BGS application rates of 30, 60 and 90 g kg^{-1} increased available water content (AWC) by 32.34, 50.43 and 77.94%, respectively in sandy soils and 11.47, 25.21 and 35.77%, respectively in calcareous soil. Several researchers [18,19,55] reported improved water holding capacity at field water capacity and wilting point, with the application of the organic material. It is well known that water holding capacity is an important soil property that is directly related to soil porosity; micro and macro pores [56]. Water capacity of soils with high micro-pores was reported to be higher than the soils with low micro-pores [57]. This can give an interpretation for increased water holding capacity with the BGS applications due to increasing small pores while decreasing large pores [58]. The humic substances and other organic compounds such as polysaccharides and bacterial gums augment the binding force between particles, enhancing formation of soil aggregates. Moreover, organic materials have usually a large surface area that enables adsorbing more water [59].

The different effects resulted from the BGS on water content in the two soils could be due to one or more of the followings: a) The BGS particles can retain more water due to their large surface area which adheres water films; b) The BGS particles may fill the pore space between soil particles, thus reducing its volume, which results in pores with smaller radius holding more moisture at relatively highly amount [16]. The effect of BGS application on the calcareous soil was influenced by its high $CaCO_3$ content as well as its heavier texture in comparison with the sandy soil [29]. Islam et al. [60] found that addition of BGS to sandy and highly calcareous soils improved their physical properties.

3.5 Correlation among Soil Properties

As shown in Table 5, the BD showed a negative correlation with Soil OM in both soils, which indicates that organic matter, caused a decrease in BD. Also, there was a negative correlation between the VR and SOM, indicating that the VR decreased with increased organic matter content; indicating that decreases in BD and VR improved the soil structure. The VR showed a negative correlation with the AWC, and this AWC showed a significant negative correlation with the *Ks* in calcareous soil. The high negative correlations observed between the SOM and the BD and the VR are due to the increase in the labile fraction of the organic carbon released through the microbial decomposition of organic matter and deposited on the soil as a surface coating, causing aggregation [61]. The *Ks* showed a negative correlation with the SOM and a positive correlation with BD and VR in the sandy soil, therefore improving water holding capacity. In calcareous soil, the *Ks* showed a significant negative correlation with the BD and VR, and a positive correlation with SOM, therefore, improving hydraulic properties.

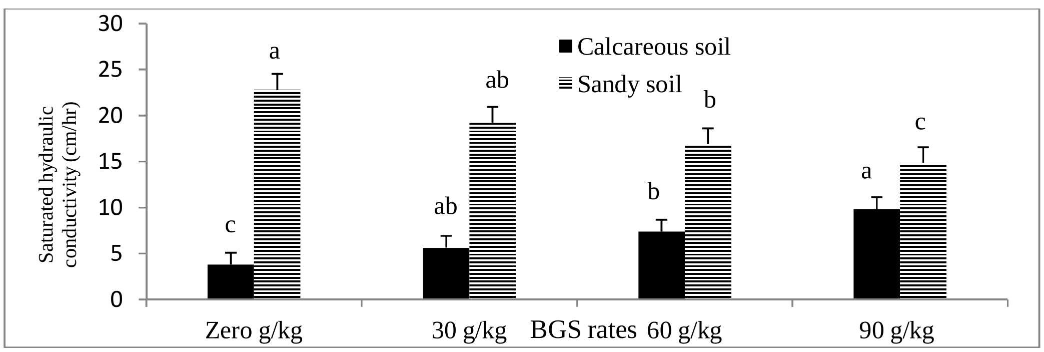

Fig. 1. Effect on BGS applications on saturated hydraulic conductivity (*Ks*) under sandy and calcareous soils. Vertical bars indicate mean ± 1 standard error

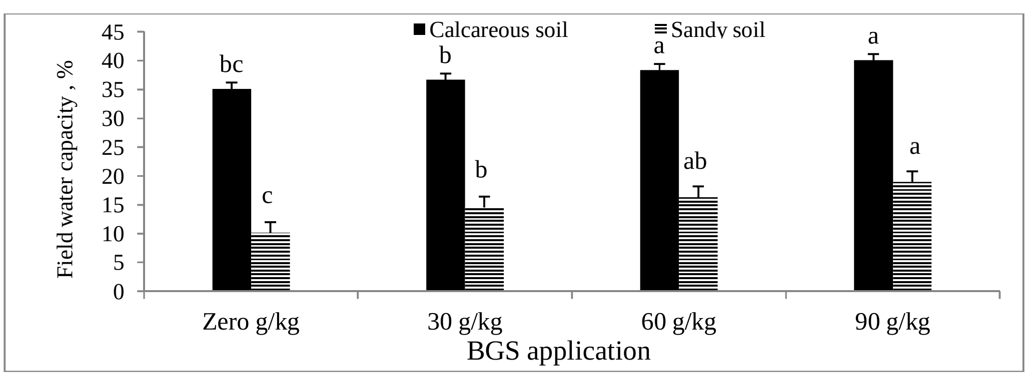

Fig. 2. Effect on BGS applications on field water capacity (FWC) under sandy and calcareous soils. Vertical bars indicate mean ± 1 standard error

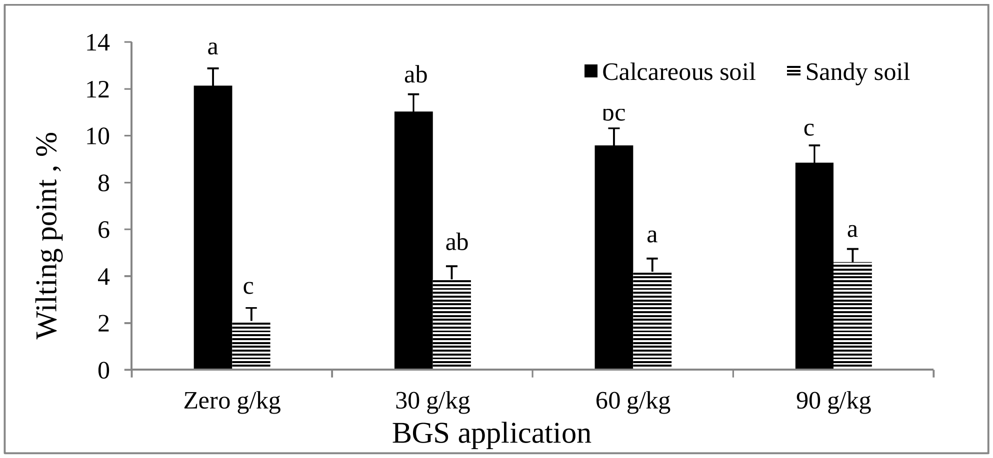

Fig. 3. Effect on BGS applications on wilting point (WP) under sandy and calcareous soils. Vertical bars indicate mean ± 1 standard error

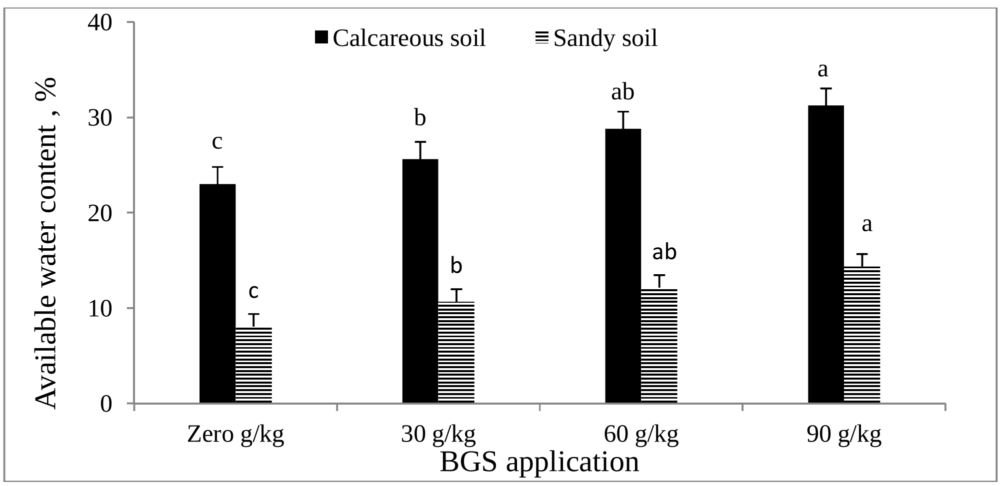

Fig. 4. Effect on BGS applications on available water content (AWC) under sandy and calcareous soils. Vertical bars indicate mean ± 1 standard error

Table 5. Correlation coefficients among soil organic matter (SOM), bulk density (BD), void ratio (VR), saturated hydraulic conductivity (*Ks*) and available water content (AWC) in sandy and calcareous soils

	Sandy soil			
	BD	**VR**	***Ks***	**AWC**
SOM	-0.95**	-0.70*	-0.85**	0.94**
BD		0.71*	0.84**	-0.87**
VR			0. 81**	-0.73*
Ks				-0.88**
	Calcareous soil			
SOM	-0.94**	-0.66*	0.88**	0.89**
BD		0.62*	-0.85**	-0.88**
VR			-0.67*	-0.68*
Ks				0.87**

*Note: *, **Significant at p< 0.05 and p< 0.01, respectively*

4. CONCLUSIONS

The BGS can serve as valuable organic input for improving adverse physical properties in sandy and calcareous soils. The BGS application increased soil organic matter and decreased soil bulk and particle size density. The increases accompanied with BGS application in soil total porosity and air-filled porosity, and the decrease in void ratio, improved soil aeration, especially in calcareous soil. The BGS improved water holding capacity by increasing field water capacity and available water content in both soils. The highest BGS application rate of 90 g kg^{-1} caused positive changes in hydraulic conductivity for the two soils, as it caused a decrease in sandy soil and an increase in cemented calcareous soil. Finally, the BGS can be used intensively in the reclamation of sandy and calcareous soil covering large wide areas in Egyptian deserts.

ACKNOWLEDGEMENTS

The authors express their deep thanks to Prof. Dr. Ali Abdel Salam, Soil and Water Department, Faculty of Agriculture, Moshtohor, Benha University, Egypt for his valuable comments and help during the study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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