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Impact of Natural Clay Deposits on Water Movement in Calcareous Sandy Soil

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*In a laboratory experiment, four concentrations of two natural bentonite clay deposits (commercial Bentonite and Aquagel) were applied to study their impact on water movement in a sandy calcareous soil. Cumulative infiltration (*D*), advance of wetting front (*Z*), and available water content (*AWC*) were measured for untreated and treated soils mixed with 1, 2, 3, and 4% of Bentonite or Aquagel. Cumulative infiltration (*D*) increased with increase in time in all of the treatments. The data tested fitted the Kostiakov equation (*$D = kt^n$*), giving highly significant correlation (*$r > 0.95$*) for all of the treatments. A marked decrease in *D, k*, and *n* values were observed with increasing concentrations of both of the clay deposits. This trend was more pronounced with Aquagel than Bentonite. Data on advance of the wetting front fitted the empirical power equation (*$Z = at^b$*), showing high correlation values (*$r > 0.95$*) for all treatments. Advance of wetting front was markedly affected by the type and the concentration of clay deposit applied. *Z* decreased and the constants *a* and *b* decreased with increasing concentrations of clay. Available water content (*AWC*) increased with increasing concentrations of Bentonite and Aquagel. The percentage increases over untreated soil were 6.66, 7.92, 8.33, and 13.33 when amended with 1, 2, 3, and 4%, respectively, of Bentonite whereas, for Aquagel the respective increases were 37.7, 51.8, 86.1, and 90.4%. This is attributed to higher clay content and the water absorbance characteristics of Aquagel. Aquagel labeled as high-grade bentonite was more effective in controlling water movement in the soil and markedly increased the AWC of a sandy soil.*

Keywords available water, bentonite, cumulative infiltration, wetting front

The productivity of calcareous sandy soils is limited by low water holding capacities, high infiltration rates, high evaporation, low fertility levels, and low organic content. The use of organic and chemical amendments could improve the chemical and physical properties of these soils. Sewage sludge along with other organic wastes is commonly used as soil amendments. Also, synthetic soil conditioners were used to improve some soil physical properties and productivity

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(Miller, 1996; Mustafa et al., 1988; Choudhary et al., 1995; Falatah et al., 1996). These materials can thus increase water supply to growing plants and improve water use efficiency (El-Hady et al., 1981, Terry & Nelson, 1986, Al-Harbi et al., 1996). Research on application of different synthetic conditioners showed that their use on a large scale in agricultural land could be unrealistic because of their high cost, insufficient longevity, and drastic reduction in efficiency with salinity (Armbrust & Dickerson, 1971; Al-Darby et al., 1993; Choudhary et al., 1998). There have been studies in some arid and semiarid areas of the world on the use of natural deposits to alleviate some of the soil constraints to crop production. The use of natural deposits may improve the above constraints and thus increase soil productivity, especially in the areas where these materials are available naturally in abundance and inexpensive. Bentonite, a natural deposit, is available in different parts of Saudi Arabia such as Khulays, 95 km north of Jeddah (Ministry of Petroleum and Minerals Resources, 1993). Atin (1986) reported that the addition of bentonite to sandy soils increased the retention and the availability of soil moisture as well as the increase of the cohesive forces among their particles. He concluded that the addition of bentonite reduced the velocity of downward water movement and restricted the deep percolation and leaching of nutrients. Das and Dakshinamurti (1975) showed that the infiltration rate and hydraulic conductivity of sandy loam soils treated with bentonite were reduced compared to untreated soils. They concluded that the horizontal infiltration as well as the diffusivity was very much reduced in the treated soils. Sallam et al. (1995) concluded that mixing shale deposits (clay content 72%, dominantly smectite) with sand at different rates improved the physicochemical properties, and in particular the soil moisture characteristics and cation exchange capacity. Abou-Gabal et al. (1990) found that the addition of local Tafla (dominantly bentonite) to the sandy soils in Egypt improved the soil texture and consequently soil-water plant relationships. El-Sherif and El-Hady (1986) revealed that mixing local bentonite with sandy soil improved its mechanical, hydrophysical, and chemical properties, and consequently increased water use efficiency. However, further research is needed to determine the effect of bentonite on physical properties of sandy calcareous soils. Hence, the main objective of this study is to investigate the effect of different rates of bentonite on infiltration, wetting front, and available water content of a calcareous sandy soil.

Materials and Methods

A bulk surface (0–30 cm) calcareous sandy soil sample (Typic Torripsamments) was collected from the College Experimental and Research Station at Dierab (24 25′ N, 46 34′ E), 40 km southwest of Riyadh, Saudi Arabia. Two samples of natural clay deposits available in Saudi Arabia, commercially known as Bentonite (a low-grade bentonite) and Aquagel (a high-grade bentonite) were used in this study. Both of these products are soft, plastic, porous rock composed essentially of clay minerals of the smectite group with dominant exchangeable cations Na^+, Ca^{2+}, and Mg^{2+}, and with high swelling and adsorbance properties. Some physical and chemical characteristics of the soil and two natural clay deposits (Bentonite and Aquagel) used in this study are presented in Table 1.

In the infiltration experiment, air-dried < 2 mm sieved soil samples (control and treated) were packed at 1.5 g cm^{-3} bulk density in transparent sectioned lucite cylinders (5 cm internal diameter, 60 cm long). The five rates used of both natural deposits available as fine clay were 0, 1, 2, 3, and 4% (on a dry weight basis), mixed with the upper 0–10 cm of the soil columns. A flooding apparatus was designed to maintain a constant head (2.5 cm) above the soil surface by means of a bubbler tube to allow accurate measurement of infiltration data as a function of time.

TABLE 1 Physicochemic... Properties of Soil and Two Natural Clay Deposits Used in this Study

Properties	Soil	Aquagel	Bentonite
EC_e (dS m^{-1})	1.30	1.10	1.05
pH	8.00	8.80	9.00
$CaCO_3$ %	26.7	4.4	6.0
Sand %	90	1	3
	5	5	15
Clay %	5	94	82
Soil texture	Sandy	Clay	Clay
CEC, cmol$_c$ kg^{-1}	4.50	87.3	75.6
ESP	N.D.	35	23

Observations made during the infiltration included change in the bubbler reading (cumulative infiltration) and the visible wetting front advance. When the wetting front reached 40 cm depth below the soil surface, infiltration was terminated. The soil column was sectioned in 5 cm increments and water content was determined gravimetrically by drying in an oven at 105°C. Each treatment was applied in triplicate.

Available water content (AWC) curves were obtained by a pressure plate method of Richards (1948) using matric potential at −1 kPa and −1500 kPa. Treated and untreated soil samples were packed in brass rings, 5 cm in diameter and 3 cm high at 1.5 g cm^{-3} bulk density. The soil samples were saturated for 24 h before placing into the pressure plate apparatus.

Results and Discussion

Cumulative Infiltration

Cumulative infiltration depth as affected by time, when a sandy soil was amended with two natural deposits (Aquagel and Bentonite) and four concentrations, is shown in Figures 1a and 1b. The relationships between cumulative infiltration depth as a function of time was demonstrated by fitting the data in the Kostiakov (1932) equation: $D = kt^n$, where D is the cumulative infiltration depth in cm within time t in minutes, and the constants k and n are infiltration parameters. The data fitted the above equation giving correlation coefficients r ranging from 0.990 to 0.999 (Table 2). At any given concentration there was an increase in D with increase in time for both the natural deposits. However, a remarkable reduction in D between the control and the treated soils was observed with the addition of natural deposits. This decrease in D was more pronounced with increasing concentrations of the natural deposits. Aquagel was more effective in reducing infiltration when compared to Bentonite. For instance, at 2% concentration of Aquagel, the D was only 6 cm in 100 minutes, whereas for the same concentration of Bentonite the D was 25 cm in 38 minutes. This decrease in D values could be attributed mainly to the presence of high clay content in these materials, which improved the texture and structure of this sandy soil, promoted soil aggregates swelling, limited capillary rise and increased water retention, consequently decreasing D.

The empirical constants k and n were affected by both the type and the concentration of natural deposits (Table 2). K values decreased with increasing concentrations of Bentonite and Aquagel. Compared to untreated soil, the percentage decreases in k values were 12, 27, 43, and 63 when soil was mixed with 1, 2, 3, and 4% Bentonite, respectively. The respective decrease in k when soil was applied with

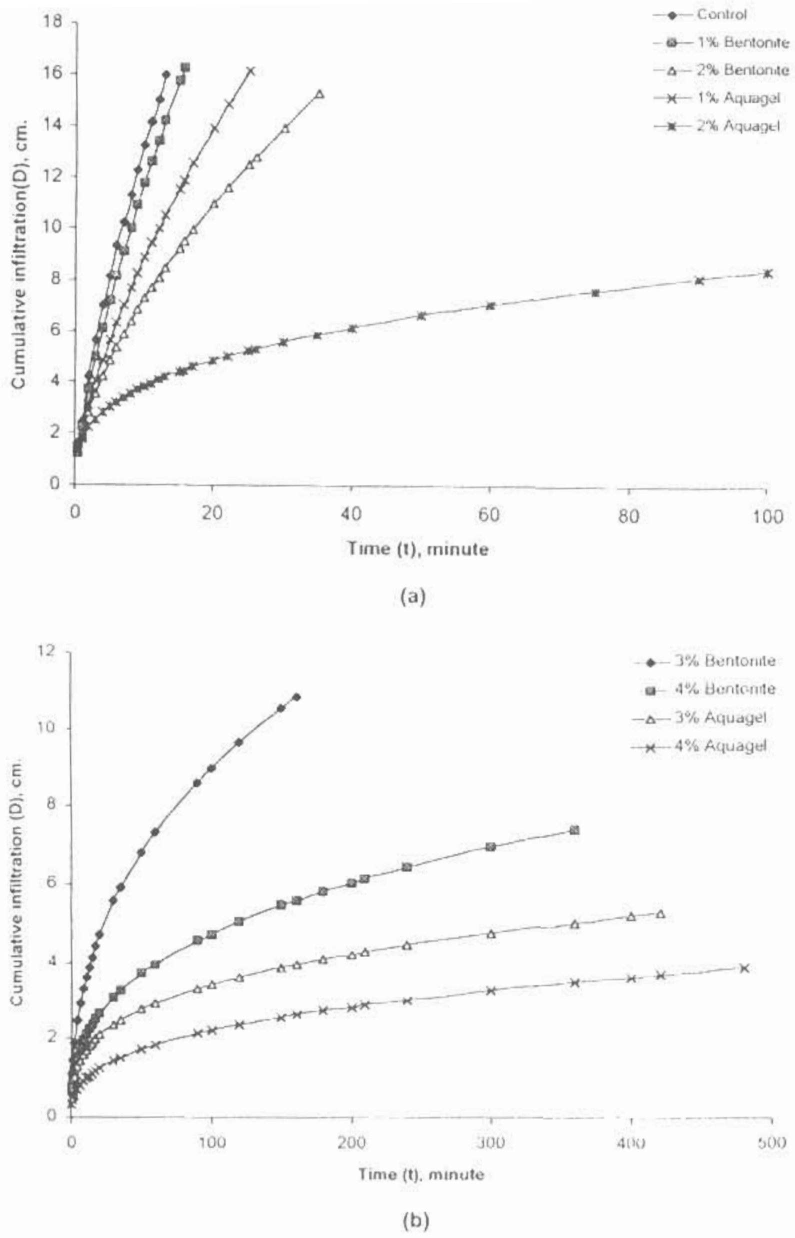

FIGURE 1 (a) Cumulative infiltration as a function of time as affected by 0, 1, and 2% concentration of two clay deposits; (b) cumulative infiltration as a function of time as affected by 3 and 4% concentration of two clay deposits.

TABLE 2 Effect of Natural Clay Deposits and Concentration on Empirical Constants of the Kostiakov Equation, $D = kt^n$

Natural deposit concentration (%)	Kostiakov empirical constant		Correlation coefficient r^2
	k	n	
Bentonite			
0	2.556	0.719	0.999
1	2.245	0.716	0.999
2	1.854	0.594	0.990
3	1.448	0.394	0.994
4	0.945	0.350	0.961
Aquagel			
0	2.556	0.719	0.999
1	1.963	0.655	0.998
2	1.738	0.343	0.988
3	0.857	0.301	0.975
4	0.645	0.251	0.997

Aquagel was 23, 32, 66, and 75. The trends in decrease in n values were very much similar to that discussed for k. At any given concentration, k and n values for Aquagel were always lower than Bentonite. This may be attributed to higher percentage and high-grade quality of clay in Aquagel compared to Bentonite.

Advance of the Wetting Front

Figures 2a and 2b depict the relationships between the advance of the wetting front (Z) in cm and time (t) in minutes as affected by the type and concentration of natural deposits. These relationships fitted in following empirical power equation giving highly significant correlation coefficient (Table 3): $Z = at^b$, where Z is the depth to wetting front in cm, t is time in minutes, and a and b are parameters dependent on soil treatment. The results in Figures 2a and 2b showed that Z was strongly influenced by the type and concentration of natural deposits. Generally, Z decreased with an increase in concentration of natural deposit. The results indicated that, in untreated soil (control), the time required to reach the depth 40 cm was 20 minutes, whereas for the soil treated with Bentonite at the concentration of 1 and 2% the times were 25 and 60 minutes, respectively. The time for the respective depth and concentration for Aquagel were 25 and 200 minutes. However, for the higher concentration of 3 and 4% of both natural deposits, the time required to wet 10 cm soil column ranged from 20 to 1,000 minutes. The results in Table 3 indicated that both values a and b in the equation decreased with increasing concentration of natural deposits. The results also showed that the a and b values for Bentonite were higher than those of Aquagel for the same concentration. This was mainly due to higher clay content in Aquagel compared to Bentonite. The decrease in Z might be due to higher swelling nature of clay present in these deposits.

Available Water Capacity (AWC)

Evaluation of available water content is essential for soil-water plant relationship for proper plant growth. The available water capacity of soil studied as affected by two clay deposits applied at various concentrations was calculated as. $AWC = \Theta_{0.1} - \Theta_{15.0}$, where $\Theta_{0.1}$ is the water content at 1 kPa, and $\Theta_{15.0}$ is the

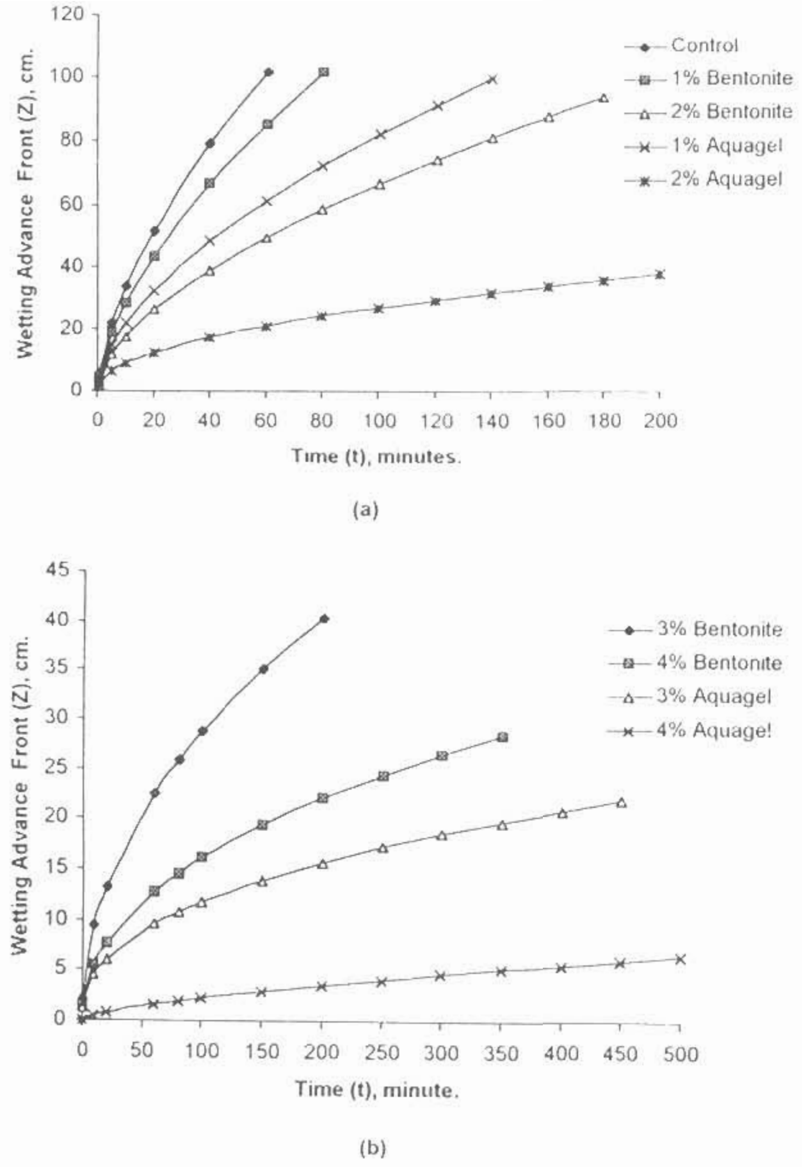

FIGURE 2 (a) Wetting advance front as a function of time as affected by 0, 1, and 2% concentration of two clay deposits; (b) wetting advance front as a function of time as affected by 3 and 4% concentration of two clay deposits.

TABLE 3 Effect of Natural Deposits and Concentration on Empirical Constants of the Power Equation ($Z = at^b$) used for Describing the Relationship of Wetting Front as a Function of Time

Natural deposit concentration (%)	Empirical constant		Correlation coefficient r^2
	a	b	
Bentonite			
0	8.247	0.614	0.997
1	7.094	0.608	0.986
2	4.676	0.577	0.977
3	3.064	0.487	0.977
4	1.927	0.460	0.921
Aquagel			
0	8.247	0.614	0.977
1	5.901	0.572	0.978
2	2.854	0.490	0.977
3	1.762	0.413	0.968
4	0.521	0.333	0.981

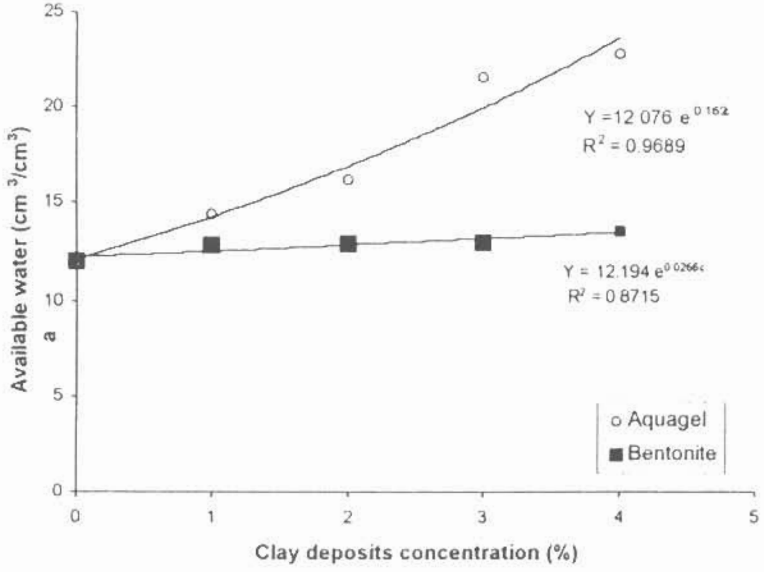

FIGURE 3 Available water capacity (AWC) of a sandy soil as affected by four concentrations of clay deposits.

water content at −1500 kPa. The relationships between AW d the concentration of two clay deposits were found to be exponential functions with a slope of 0.169 for Aquagel and 0.0266 for Bentonite and were highly correlated (Figure 3). The percentage increases in AWC over untreated soil when amended with increasing concentration of Bentonite were 6.66, 7.92, 8.33, and 13.33, whereas the respective increases with Aquagel were 37.25, 51.83, 86.17, and 90.42. This manyfold increase in soil available water, particularly in Aquagel, may be attributed to the higher content of clay and higher water absorbance characteristic of clay deposits. It is evident that AWC of the sandy soil can be increased substantially with application of Aquagel, even when applied at the lowest rate of 1% compared to Bentonite

Conclusions

Natural bentonite clay deposits were useful in improving hydrophysical properties of the sandy calcareous soil. Both Bentonite and Aquagel reduced infiltration losses and increased AWC. However, high-grade bentonite (Aquagel) was more effective than Bentonite. These observations could have important practical implications in using clay deposits of high quality. Additional work is recommended to evaluate these results under field conditions

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