Hydro-Physical Properties of Soil Treated with Rice Straw-Based Hydrogels

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Abstract: The Present work deals with evaluating rice straw (RS)-based hydrogels, as conditioners for improving the hydro-physical properties of sandy calcareous soils. In this respect, some hydro-physical properties of the soil were examined at the end of three successive growing seasons. Completely randomized field experiments, with three replications for each treatment, were conducted at El-Saff-Giza Governorate, Egypt (summer season 2010 using tomatoes v. cusstle rock, winter season 2010-2011 using wheat v. Seds 1 intercropped with onion v. Giza 20, and summer season 2011 using caw pea v. Bafb as indicator crops), The results obtained show that, applying the RS-based hydrogels provides: (a) Improving in soil structure, which was expressed by water stable structural units (> 0.25 mm in diameter), structural coefficient, dry stable structural units (> 0.84 mm in diameter) and wind erosion parameters. This improvement indicates the high resistance of the soil against both wind and water erosion, as well as destruction of the soil by tillage operations. Moreover, it leads to decrease soil bulk density and macroporosity (drainage pores) on the expense of micro ones. Therefore, water holding pores (the retained moisture in the soil) were increased. Increasing the retained moisture in the soil was noticed at all suctions under study (from 0-15atm). (B) Decreasing the mean diameter of soil pores and in turn its water transmitting properties, namely hydraulic conductivity and transmissivity for vertical flow of water through soil profile. (C) Doubling the rate of applied hydrogels from 2gkg^{-1} to 4gkg^{-1} soil leads to great improvement in hydro-physical properties of soil, whereas applying the later rate of hydrogel provides improvement in moisture retention of the treated soil to become over than the requirements of the growing plants. Also, it has adverse effect on the aeration of the root zone as a result of increasing the soil micro-porosity on the expense of its macro ones. Therefore, 2g hydrogel kg^{-1} soils is recommended dose to get use the RS-hydrogels as benefit soil conditioner, without adverse effects on growth, water and fertilizers efficiency by plants.

Keywords: Agricultural waste management, rice straw, sandy and sandy calcareous soils, rice straw-based hydrogels, soil conditioners, hydro-physical properties of soils.

1. INTRODUCTION

Sandy and sandy calcareous soils are wide spread in Egypt and other countries of the Middle East. Such soils have poor physico-bio-chemical properties, soil water plant-relationships, as well as their nutritional status. For the urgent needs to meet food and dress demands for the inhabitants of these countries, more desert areas either sandy or sandy calcareous have to be put under cultivation [1].

Incorporating gel forming materials in sandy and sandy calcareous soils become a familiar technique in conditioning such soils. In 1990, in the framework of cooperation between the International Trade Ministry and the Industrial Ministry of Japan, the Japanese Aids Program used highly water-absorbent product as a soil conditioner for sandy soil in Egypt. However, this experiment had failed because of unfixation of hydrogels toward light. Synthetic polymer (e.g., polyacrylamide) in gel form are considered as one of the most widely used soil conditioners for sandy soils, when mixed with such soils [2-4]. Although the extent of application of the synthetic soil conditioner polymers is very wide, especially in desert areas, their use in practice is not common as expected due to high cost. Also, bentonites and clays are reported as soil conditioners for stabilizing fine sands [5, 6].

On the other hand, the agricultural wastes represent an inexpensive source of lignocellulosic products, most of these wastes cause pollution because they considered good media for growing the microorganisms, or emission of toxic gases during disposal by burning. The utilization of lignocellulosic wastes, as cellulose source, for economic preparation of hydrogel was taken attention of the leader authors of this present article, since 1999. As in Egypt and other similar countries, which have huge amount of agricultural wastes (lignocelluloses), e.g., rice straw (RS), sugar-cane bagasse, cotton stalks, etc, normally they use partially in pulp and paper industries, however they are still large amounts, especially RS without any utilization and cause environmental problems. According to the periodical report of Ministry of Agriculture in Egypt for the year 2009, the accumulated

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quantities of rice straw is about 6 million ton/year. For utilizing agro-wastes, e.g., bagasse, rice straw, cotton staks and old newsprint paper (ONP) in preparing building elements (artificial wood and cemented fiberboards), and active carbon, was carried out elsewhere [7-12]. While for production of hydrogels with relatively higher water absorption capacities was only examined under laboratory and greenhouse conditions [13-16]. Also, utilizing rice straw as substrate of hydrogel, it needs to purify by pulping before synthesized the adsorbents.

Previous work by the three leader authors of this paper and their collaborators at NRC-Cairo have succeeded in producing hydrogels from most available raw agricultural wastes, as raw and pulp [13-15, 17-19]. Rice straw (RS) without any pre-treatment, is also used as a substrate for synthesizing the hydrogels *via* environmentally friendly grafting and hydrolysis approach, which protected from disposal any polluted by-products [17]. The safety and economical use of these investigated hydrogels as soil conditioners were also evaluated through examining their toxicity behaviour against the most efficient micro-organisms in plants media (*rizosphere*) [18]. These RS-based hydrogel materials are succeeded for removing the heavy metal ions from municipal waste water, and used this purified water in irrigation purposes [19]. As it will be very useful. Alkali pre-treatment the cellulosic fibers leads to increase the degree of grafting onto fibers [20].

The present work aims to clarify the beneficial effects of some investigated RS-based hydrogels on hydro-physical properties of sandy calcareous soil after three successive growing seasons (summer season 2010 using tomatoes v. cusstle rock, winter season 2010-2011 using wheat v. Seds 1 intercropped with onion v. Giza 20, and summer season 2011 using caw pea v. Bafb as indicator crops),

2. MATERIALS AND METHODS

Completely randomized field experiments, with three replications for each treatment, were conducted at El-Saff-Giza Governorate, Egypt (summer season 2010 using tomatoes v. cusstle rock, winter season 2010-2011 using wheat v. Seds 1 intercropped with onion v. Giza 20, and summer season 2011 using caw pea v. Bafb as indicator crops). Two rice straw-based hydrogels (with two rates; 2 and 4 g kg^{-1} soil) were evaluated as conditioners for sandy calcareous soils, as follows;

2.1. Soil

The soil is a virgin sandy calcareous soil (90.3% sand, 9.7% silt + clay, ~12.0% $CaCO_3$, and 0.06% O.M.), with pH 7.4 and EC 2.2 dSm^{-1}. The main analytical data of the soil were carried out [21, 22], and presented in Table **1**.

2.2. Drip Irrigation Using

Two sources of water were alternatively used for irrigation (El-Saff canal water and water of a well dug

Table 1: Analytical Properties of El-Saff Sandy Calcareous Soil

1- Mechanical Analysis:

Sand%		Silt 20-2*u*%	Clay<2*u*%	Texture
Course >200*u*	Fine >200-20 *u*			
67.5	22.8	5.0	4.7	Sand

2- Chemical Analysis:

pH 1:2.5	EC 1:5 dSm^{-1}	$CaCO_3$%	CEC C mole Kg^{-1}	O.M%	Macronutrients (μg g^{-1})					
					Total			Available		
					N	P	K	N	P	K
7.4	2.2	11.95	4.48	0.06	415	738	1015	32	6	55

3- Hydro-Physical Analysis:

Bulk density Mg m^{-3}	Total Porosity%	Water* Holding Capacity, %	Field* Capacity%	Wilting* Percentage	Hydraulic conductivity m day^{-1}	Mean diameter of soil Pores *u*
1.63	38.5	22.8	7.11	1.22	7.3	16.7

*On weight basis.

Table 2: Analyses of Irrigation Water Used

Source	pH	EC dsm^{-1}	Soluble Cations (meq/l)				Soluble Anions (meq/l)			
			Na^+	K^+	Ca^{++}	Mg^{++}	CO_3^{--}	HCO_3^{--}	Cl^-	SO_4^{--}
Canal	7.53	0.47	1.36	0.07	3.36	2.04	0.3	-	0.36	2.17
Well	7.05	1.35	8.3	0.2	9.0	6.5	0.02	3.6	5.4	14.6

Fe = traces < 3 $\mu g\ g^{-1}$.

inside the study area). Analysis of irrigation water used is presented in Table **2**. Water was classified as none and slight to moderate restriction on use for the Nile and Well water, respectively [23].

2.3. Absorbent Materials (Hydrogels)

Two prepared RS.-based hydrogels (El-Saied *et al.*, 2011), were examined. Description of the preparation conditions, are given below;

- Gel #1, was prepared under grafting conditions: 0.12 H_2O_2/RS ratio, 0.1% ferrous ammonium sulfate, and 2 acrylonitrile/RS ratio, for 3 h, at 50°C followed by KOH hydrolysis, using AcOH for neutralize the pH-value to~6-7.
- Gel #2, was prepared by grafting the partially cyanoethylated RS, under the same conditions of hydrogel # 1, using AcOH for neutralize the pH-value to~6-7.
- These examined hydrogels were coded as G1 and G2, and their water absorption capacities, i.e., Sat /Dry x 100 (w/w) were 7610, and 7061 in distilled water; while 6107, and 3789 in Nile water, respectively.

2.4. Experimental Treatments for Examined Crops

Each experiment consisted of the following treatments:

- **Irrigation regime:** Three irrigation regimes were examined, i.e., 60 %, 80%, and 100% of the water requirements of each crop.
- **Conditioning treatments**: five conditioning treatments were examined for each irrigation regime.

- Treatment no. 1: non conditioned soil,
- Treatments no. 2 and 3: for soils conditioned with hydrogel G_1 at the rates of 2 and 4 g kg^{-1} dry soil, and
- Treatments no. 4 and 5: for soils conditioned with hydrogel G_2 at the rates of 2 and 4 g kg^{-1} dry soil.

2.5. Evaluation Parameters

At the end of the 3rd growing season (December, 2011), the following hydro-physical properties of the soil (for each treatment), were determined, as the methods reported elsewhere [5, 24-25]. Water stable structural units >0.25 mm in diameter and structure coefficient,

- Dry stable structural units >0.84 mm in diameter and wind erosion parameters,
- Soil bulk density, total porosity and pore size distribution,
- Moisture retention at different tensions and available moisture, and
- Hydraulic conductivity, mean diameter of soil pores and transmissivity for vertical flow of water through the soil profile.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Effect of Irrigation Regime Treatments

Regarding the effect of water regimes on soil properties, it was noticed that, at the same treatment conditions, the differences in the obtained results, using different water regimes were insignificant (i.e., in the range ± 4%). Therefore, for each treatment this value was taken into consideration.

3.1.2. Effect of Conditioning Treatments

The hydro-physical properties of the sandy calcareous soil conditioned with the investigated RS-based hydrogels, under different irrigation regimes, are recorded in Tables **3** and **4**. The studied properties were structural stability, porosity, pore size distribution, moisture retention and water transmitting properties.

Table 3: Effect of RS-Based Hydrogels on Soil Structure and Pore Size Distribution of a Sandy Calcareous Soil after Three Successive Growing Seasons

Treatments			Water stable structure units (>0.25mm) %	Structure Coefficient (Cr)	Dry stable structural units (>0.84 mm) %	Wind Erosion Parameter	Bulk density (Mg m^{-3})	Total porosity %	Macro pores (drainable pores >28.8μ%	Micro pores (< 28.8 μ)		Micro/ Macro
No.	Hydrogel /kg dry soil									Water holding pores (28.8-0.19μ) %	Fine capillary pores (<0.19μ) %	
1	-	-	50.5	1.02	10.90	1.00	1.59	40.04	30.50	6.2	3.4	0.31
2	G_1	2	74.7	2.96	26.5	0.38	1.54	41.85	29.00	9.1	3.7	0.44
3	G_1	4	81.1	4.30	41.7	0.24	1.53	42.11	22.70	15.5	4.0	0.85
4	G_2	2	71.3	2.48	21.7	0.47	1.55	41.58	29.40	8.5	3.6	0.41
5	G_2	4	77.5	3.44	36.8	0.28	1.54	41.96	24.70	13.4	3.8	0.70

Wet sieve analysis was used to ensure that the percent of water stable fraction is > 0.25 mm in diameter, and this fraction was taken as a reflection of soil aggregate stability [5]. Table **3** shows that, addition of either G_1 or G_2 resulted in an increased percent of water stable fraction. This fraction being higher with increasing the application rate of applied hydrogel conditioners. Applying G_1 provided higher stable fraction than G_2. Whereas, the water stable fraction > 0.25 mm in diameter was higher than that of the non-conditioned soil by 47.9, 60.6, 41.2 and 53.5% for conditioning treatments, using 2 and 4 g/kg dry soil, of hydrogel G_1 and the same rates of hydrogel G_2, respectively.

In order to find out the aggregation capacity and to compare quantitively between the different treatments, structural coefficient (Cr) was calculated. This coefficient, as suggested by El-Shafei and Ragab [26], is the ratio between the percentage of the total amount of fraction having the diameter less than 0.25 mm in diameter and the percentage of fraction having the diameter greater than 0.25 mm. It is well known that the higher value of this index is noticed as a result of applying the studied hydrogels, which reveals the more structural stability of the soil. For the case of conditioning with G_1 at the rates of 2 and 4 g kg^{-1} dry soil, the structural coefficient values were about 2.9 and 4.2 times that of the untreated soil, respectively; while applying G_2 at the same rates provided increase of Cr to be about 2.4 and 3.4 times, respectively (Table **3**).

For the case of dry stable structural units > 0.84 mm in diameter, Table **3** shows also improvement in this property. This property was measured as criteria to evaluate soil mechanical stability and the resistance of the structural units of sandy calcareous soil against breakdown by tillage or by wind erosion [27]. As can be seen that, under the condition of the research, the increase in dry stable structural units > 0.84 mm in diameter were 159.8 and 308.8 % with 2 and 4 g G_1 kg^{-1} dry soil, respectively. Relevant values for G_2 were 112.7 and 260 % with 2 and 4 g/kg soil.

For the case of wind erosion parameter, Table **3** shows that, the percentages of reduction in this parameter due to incorporating 2 and 4 g of G_1 kg^{-1} soil were 62 % and 76 %, respectively, based on non-conditioned soil. While, for the case of applying the same rates of G_2, the wind erosion parameter of the soil was lower than that of non conditioned soil by 53% and 72%, respectively. This property was calculated as the ratio between the percentages of the structural units >0.84 mm in diameter of the untreated soil and those of treated ones. The low calculated parameter refers that the soil become more stable [5].

Values of soil bulk density, soil porosity and pore size distribution as affected by conditioning the soil with the RS-based hydrogels reveal that, soil conditioning led to decrease the bulk density of the soil, as well as the macroporosity (drainable pores having the diameter of > 28.8μ), relative to those of unconditioned soil (Table **3**). Similar to the foregoing parameters, the hydrogel G_1 provided higher improvement (decrease) in bulk density and macro-porosity than hydrogel G_2. Increasing the rate of both hydrogels provided also higher reduction in these parameters. For the case of G1, increasing the rate of applied hydrogels from 2g kg^{-1} soil to 4kg/kg soil led to decrease the bulk density and macroporosity from 3.0% to 3.5%, and from 4.9% to 25.6%, respectively. While, increasing the rate of G_2 hydrogels led to higher decreasing in bulk density and macro-porosity from 2.6% to 3.6% and from 3.2% to 19%, respectively. It is interesting to mention that, the macroporosity was taken as the air filled porosity, when the soil water system was in equilibrium with 100cm suction [25].

It was observed that, conditioning of soil by hydrogels provided an increase in total porosity and micro-porous (especially water holding pores having the diameter of 28.8-0.19 µ), relative to unconditioned (Table **3**). The percentages of increasing the total pores and micro-pores on applying 2 and 4g G_1 were 4.5-5.2% and 46.8 - 150%, respectively. For condoning with the same rate of G2, the increase in these parameters was 3.8-4.8% and 37.1-116.1%, respectively.

When the ratio between micro and macro pores is of great importance in revealing the rate of water retention and water movement in the soil. Therefore, it is interesting to observe the beneficially improvement of this ratio *via* the investigated hydrogels. Where, micro to macro-porosity in the non-conditioned soil was 0.31; while these ratio became 0.44 and 0.85 by applying 2 and 4g G_1 kg^{-1} soil; while became 0.41 and 0.7 for the same two rates of G_2, respectively. It is well known that the increase in micro /macro porosity ratio indicates slow water movement and more water retention in the soil.

From Table **4** it is clear that, the retained moisture in the soil, under different suctions, was influenced by applying the investigated hydrogels (G_1 and G_2). These hydrogels provided improvement in the retained moisture in soil, at all suctions under study. Increasing the retained moisture accompanied the increase in hydrogels rate from 2 to 4g, based on dry weight of soil. At saturation (i.e., at pF =0) and applying 2 and 4g of $G_{1,}$ the total water holding capacity (WHC) of the soil was increased by 28.1% and 45.7%, respectively; while became 23.6% and 37.2% on applying the same rates of G_2. At field capacity (FC), i.e., at pF = 2.0, the values of retained moisture show increments of 38.3, 111.7%, on applying the two rates of G1, respectively, relative to that of non-conditioned soil. While, conditioning the soil with the two rates of hydrogel G_2 also raised the amounts of moisture retained in calcareous sandy soil, over that of non-conditioned soil, by 31.7 and 86.7%, respectively.

Since the increase in water retained at soil field capacity (FC) is far beyond that at wilting percentage (WP), i.e., at pF =4.2, therefore the available water (FC-WP) increased. In this respect, incorporating 2 and 4 g G_1 kg^{-1} soil raised available moisture to be 1.5 and 2.6 times that of non-conditioned soil, respectively. The increase in available moisture for applying the two rates of G_2 was lower than G_1, where the available moisture of conditioning by G_2 rates was 1.4 and 2.2 times, respectively (Table **4**).

Table **4** also shows a decrease in water transmitting properties of hydrogel-treated soil, with respect to non-conditioned soil. The decrease in water transmitting properties of the soil due to addition of 2 g G_1 kg^{-1} dry soil, reached 33.2, 18.0 and 17.6%, for the hydraulic conductivity, mean diameter of soil pores and transmissivity for vertical flow of water through the soil profile, respectively. While, addition of 4g G_1 kg^{-1} dry soil, these decrement were 50.0, 29.0 and 31.3 %, respectively. Regarding the effect of incorporating G_2, at the rates of 2 and 4g, the reduction in the water transmitting properties of the soil were 15.7 and 41.3% for the hydraulic conductivity, 8.2 and 23.0% for the mean diameter of soil pores and 9.8 and 25.8% for the transmissivity for vertical flow of water through the soil profile.

Table 4: Effect of RS-Based Hydrogels on Water Retention and Transmitting Properties of a Sandy Calcareous Soil after Three Successive Growing Seasons

Treatments			Water holding capacity (WHC)* %	Field capacity (FC)* %	Wilting percentage (WP)*%	Available moisture* %	Hydraulic conductivity m.day^{-1}	Mean diameter of soil pores (µ)	Transmissivity (Σk /D) day^{-1}
No	Hydrogel								
1	-	-	19.9	6.0	2.1	3.9	8.8	18.3	93.9
2	G_1	2g kg^{-1}	25.5	8.3	2.4	5.9	5.88	15.0	74.4
3	G_1	4g kg^{-1}	29.0	12.7	2.6	10.1	4.40	13.0	64.5
4	G_2	2g kg^{-1}	24.6	7.9	2.4	5.5	7.42	16.8	84.7
5	G_2	4g kg^{-1}	27.3	11.2	2.5	8.7	5.17	14.1	69.7

*On dry weight basis.

4. DISCUSSION

Sandy soils with sand and loamy sand texture deserve special consideration since they have large percentages of sand fractions that adversely influence their agricultural potentialities. Most of the soil separates are non-coherent and remain as single grain, especially in the absence of organic matter and other soil conditioners, such as hydrogels.

High $CaCO_3$ content in the soil causes many difficulties, e.g., surface crusting, cracking and susceptibility to erosion. The high bulk density (apparent specific gravity) of the soils (1.55-1.80 Mg m^{-3}) is reflected by lowering their total porosity (32-42%), which is less than that of fine textured soils. The relative distribution of the pore sizes, which is more important than the total porosity itself, shows that, such soil has a large number of macro- pores, which is responsible for good aeration from one hand and rapid loss of water through the soil profile (i.e., rapid loss of water by deep percolation) from the other hand. Since sandy and sandy calcareous soils are low in clay and organic matter contents, and most of their pores are relatively large in a great portion, therefore the retained moisture is easily lost at tensions below one bar. Moreover, their available water range (FC-WP) will be rather narrow (4-6%), and the infiltration rate of sandy soils is usually high. High infiltration rates leads to increase water losses during irrigation, both in the convenience system and in the fields. Therefore, infiltration rate may be an important constraint in designing efficient irrigation system for such soils [28]. Another factor that has adverse effects on the agricultural potentialities of sandy soils is the great loss of water through evaporation.

The water transmitting properties of sandy soils encourage upward water movement when they are wet [1, 29]. As previously mentioned, the water retention of sandy soils is low and irrigation water moves easily downward, and consequently the soil requires frequent irrigation at short intervals. Such conditions aggravate the loss of fertilizer nutrients *via* the water.

The investigated RS-based hydrogels have high affinity to absorb water, due to the formation of hydrogen bonds between the water molecules and hydrophilic groups containing the hydrogels, resulting in amorphous gelatinous mass or discrete gel particles. This is ascribed to further deformation of the gel structure. The resulted peak storage condition is actually defined by the weight for absorption of deionized water that reach in applied hydrogels >7000. The variation in the molecular structure of the hydrogel molecules through chemical structure of the polymeric chain (nature and amount of hydrophilic, ionizing groups and degree of hydrolysis), may be reasons that greatly affect the swelling ratio of such materials [17].

Incorporating the synthesized RS-based hydrogels in sandy and sandy calcareous soils improved most of the foregoing agronomic problems of the soil. Based on the data in Tables **3** and **4**, the efficient of these investigated hydrogels includes: (a) higher ability of the soil to retain water, due to swelling behavior of the hydrogel particles on one hand and its effect on pore size distribution towards water holding pores (fine pores), on the other hand. Thus the total available water in soil increases (Table **3**), (b) Improving the dynamic soil water characteristics through decreasing the hydraulic conductivity values. This is related also to the swelling of investigated RS-based hydrogels and lowering the amounts of drainable pores on the expense of the micro ones (Tables **3** and **4**).

From all the foregoing results, it could be recommended that, the investigated RS-based hydrogels, especially G_1 with 2g kg^{-1} dry soil rate for improving the hydro-physical properties of sandy calcareous soil. These promising results persuade us to further evaluate the behavior of the investigated low cost RS-based hydrogels towards the bio-chemical properties of the soil through increasing the low exchange capacity of the soil and their effect on activating other chemical relations of inert sands. This study is in preparation to be published [30].

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