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Environmentally Friendly Soil Water Conservation Techniques

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Abstract: ***The conservation of water resources through their optimal use is a compulsory for countries with water shortages in the arid and semi-arid regions, and it should be in an environmentally friendly manner to avoid the serious consequences of the use of environmentally harmful substances, the implications of which are currently evident from climate change, pollution of water bodies, soils, etc. Since Egypt is one of those countries suffering from water scarcity and uses about 82.5 percent of its water consumption in agriculture, according to data of the Ministry of Irrigation in 2010, so this research is focusing on the use of new methods to increase the efficiency of irrigation water, to achieve high productivity of agricultural crops with less water use that will certainly help to alleviate or solve the water scarcity issue. The study used a physical based model, to simulate the methods used to increase sand soil properties to ensure larger water retention index. Within this work, soil have been sampled from different areas, to simulate the behavior of arid lands, under different water retention techniques. Soil was exposed to different techniques, as it was mixed with soil additives in different quantities and different types. Physical barriers of cohesive soil and polyethylene sheets were used in addition to studying the effect of mulch on water storage capacity in non-cohesive soil. Water retention have been measured using the direct method of determination soil water content by oven drying and the volumetric water content ($\boldsymbol{\theta}_v$) with time graphs have been plotted in groups, as well as the cultivated plants have been monitored as to measure the influence on plants growing and irrigation efficiency. And the experiment showed that the use of rice straw (RS) and wheat straw (WS) in the powder condition have a significant effect in increasing in the soil water content and even to the plant growth, the WS obtained $\boldsymbol{\theta}_v$ values approaching the loam soil at times and slightly less in the case of RS, when the percentage of RC and WS was 30% to the sandy soil volume/volume (v/v). Also the use of mulch of RS showed a noticeable increase in $\boldsymbol{\theta}_v$ and significant improvement of plant growth to that without mulch. These proven technologies can be used in sandy land targeted for reclamation to reduce water use in agriculture.***

Keywords: ***Agriculture Waste, Environmentally Friendly, Soil Water Conservation, Sustainability.***

I. INTRODUCTION

Limited water resources in many countries of the world especially, that suffering from arid climate, increase of local population, and encroachment of refugees, such as in Jordan, Lebanon and Egypt is threatened the water security in these lands. In addition, Egypt located in the downstream of the Nile River is influenced greatly by any large scale irrigation projects in the upstream countries (i.e., the Renaissance Dam, in Ethiopia). And as Egypt, is the leading country in Africa, it always encourages development of their neighbors, and consequently will never hinder water projects that may serve them, and even will help in it (i.e., the new dam in Tanzania). Therefore, Egypt must find new sources of water and work on the optimal use of water resources to overcome water shortage. Since agriculture consumes about 82.5 percent of total water consumption, the optimal use of agricultural water realizing the highest irrigation efficiency is mandatory. Food and Agriculture Organization (FAO) states that the number of people that expected to face absolute water scarcity (from 500 m^3/capita/year to less [1]) will be 1.9 billion, and two third of global population will be under stress conditions [2]. In Egypt that almost entirely relies on renewable water sources from neighboring countries. In 2014, Egypt's renewable water resources reached 700 m^3/capita/year [3]. By the next decade, and as a result of the huge increase in population it is expected to reach absolute water scarcity [3], [4]. Consequently, the use of agricultural irrigation new techniques that conserve water in soil must be explored to cope with the lack of water supply in addition to the food demand growth [5]. In the last 50 years, a lot of technologies to retain more quantities of water in soil for longer periods of time had been explored through innovative researches [5].

Thousands of years ago, attempts were made to conserve water in the root zone of the plant, so olla irrigation system was created in North Africa by buried pottery pots, and also traces from 4,000 years ago found in China. This method relies on the porosity of pottery pots filled with water to get out the water to feed the soil [6]–[9], but by the time the system pores are clogged due to plankton, which leads to lack of efficiency [10], this is in addition to the wasted area of agricultural land. Also mixing permeable soils like sandy soil with other types of soil that have lower permeability than the sand. Beside that the use of synthetic additives such as polyacrylamide proved great efficiency in improving the holding capacity of soil water, as the soil treated with 0.07% polyacrylamide can store more water than the soil with no additives and this water is available for plants, thereby increasing the irrigation efficiency and crop production [11], but polyacrylamide is non-biodegradable material that harms the environment.

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During the past few years, scientists have tried to focus on finding environmentally friendly solutions while achieving high efficiency, they were resorted to the use of agricultural residues by conducting some chemical reactions on them to be introduced into different efficient organic products [12], [13], such as cellulose-based hydrogel. Initially, superabsorbent cellulose based hydrogel was considered as totally biodegradable which has the ability to swill and hold water in soil [14], [15]. The cellulose-based hydrogel is synthesized beginning from the extraction of cellulose from biomass (lignocellulose material) and then fulfilment the polymerization process with a cross-binding agent such as N-N Methylenebisacrylamide (MBA) [13]. Hydrogels in the polymerized form can be non-toxic, pH-neutral, and environmentally friendly materials, but after a certain period of time (five years substantially) de-polymerization take place to all hydrogels naturally, and this is in contrast to the public's belief that hydrogels are fixed forever, however the hydrogels release acrylamide when they break down which is lethal neurotoxin that can be inhaled as dust, enters the body through the skin and they have been shown to causes cancer. Surely, once these substances are degraded in the soil, they become toxic and endanger the workers in the cultivation of these lands and animals that are in touch with these toxic compounds and the surrounding ecosystem as a whole [16].

Different types of Physical barriers to be installed at a certain depth from soil surface could retain the water in the root zone of the plant such as thin clay layer, thin asphalt layer and polyethylene sheets. Using a thin layer of natural low permeable soil to be placed at a certain depth from high permeable soil surface cause in maintaining soil water in addition to nutrients [17], the use of asphalt layer can sustain moisture in near surface horizons and the volumetric water content ($\boldsymbol{\theta}_v$) percentage can be doubled in the root zone above the continuous physical barrier of asphalt [18], Also polyethylene sheets have been used to improve water holding capacity of permeable soil [19], [20], but the soil continuous physical barriers have a restrictions of that the plant roots cannot penetrate the physical barrier to root growing, in case of excess precipitation causing of root submergence that results in crop loss, fluctuating water table that cause lack of oxygen which leads to restricted root development [21], in addition to installation difficulties in the land. For these problems of the physical barrier, experts at Michigan State University designed a mechanical installation cultivators to install contoured polyethylene sheets that can double $\boldsymbol{\theta}_v$ within the upper 50 cm, these Soil Water Retention Technology achieved the balance between capillary water retention and gravitational water drainage even during intensive rainfall storm due to the designed spatial arrangement of impermeable sheets [22], but it is still using polyethylene which is one of the most harmful materials on the environment.

Mulch the surface of the cultivated land is also has an effect in increasing retention of water in soil in the areas with high evaporation rates, as solar energy on agricultural land results in the evaporation of soil water that ascends to the surface by capillary action, in addition it reduces the surface temperature of the soil [23], but agricultural machinery is unable to perform its functions in sowing seeds in mulched lands [24].

Despite all these attempts, scientists are still looking for new ways to meet the increasingly difficult requirements of the times by obtaining products that meet the criteria of high efficiency, easily implementable and environmentally friendly impact.

II. EXPERIMENTAL

A. *Materials*

Sandy soil (sample 1) from Petrified Forest Protectorate, Cairo, Egypt, loamy soil from the garden of faculty of engineering, Ain Shams University (ASU), silt loam soil (sample 2) from a farm in Dakahlia, Egypt. Plastic containers with 15 cm depth and capacity of 2,000 cm³ as a boundary condition. Different types of additives used from the agriculture crops waste "Rice Straw (RS), Wheat Straw (WS), Beans Straw (BS) and Alfalfa Straw (AS)" in the raw condition [Rice straw is provided in two forms, the first one is cut in 3 cm average length and the second one is in powder form after grinding the first one] provided by farmers in Dakahlia, Egypt. Bleached crude cellulose (B-Cellulose) extracted from the agriculture waste of rice straw by pulping with 2% KOH at 90 °C, alpha cellulose extracted from the B-Cellulose using 17.5% KOH at 20 °C. Commercial materials "polyacrylamide and Carboxy Methyl Cellulose (CMC)" used for improving water retention in sandy soil from the local market.

B. *Methods*

1) Physical soil characterization

The soil types have been classified the soil texture according to the FAO triangle shown in **Fig. 1** based on the main soil classes' grain sizes. The soil grading was tested using sieve analysis for coarse-grained soil and hydrometer for fine-grained soil and classified as shown in **Table- I**, and the physical properties of the three soil types presented in Table- II had been determined in the soil lab of the faculty of engineering, ASU.

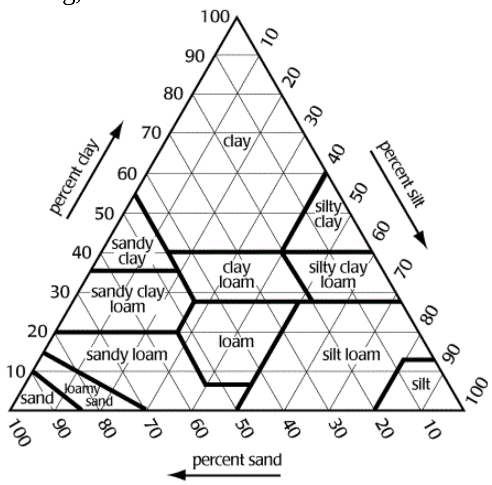

Fig. 1: FAO's soil classification triangle [25]

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Table- I: Used soils classifications

Sample	% Soil Content				Type
	Gravel	*Sand*	*Silt*	*Clay*	
1	13.96	86.04	-	-	Sand
2	-	54.44	38.68	6.88	Loam
3	-	20.89	64.72	14.4	Silt Loam

Table- II: Soils physical properties

Sample	Density (gm/cm^3)	Specific gravity	Permeability (cm/s)
Sand	1.681	2.624	5.962
Loam	1.353	2.742	$1.156*10^{-3}$
Silt loam	1.294	2.632	$8.836*10^{-5}$

2) Application of Different Techniques of Increasing Soil Water Retention

The techniques used were carried out in a coordinated location with latitude 30° 02' 58.19" N and longitude 31° 19' 41.76" E, with an average daily high temperature of 32.6 °C and an mean daily temperature of 26.6 °C, with an evaporation rate of 60 mm/day. A three-step procedure for obtaining $\boldsymbol{\theta}_v$ was followed. Firstly, each sample irrigated with certain amount of water until the water drained from the bottom drainage holes in the pot. Secondly, the water content of the soil pots had been determined daily by the gravimetric method (The direct method) [26] at the same time every day. The samples were weighed immediately after have been taken at a precision of 1 mg to get the sample wet weight (m_w) oven dried and re-weighed again to get the sample dry weight (m_d) and the mass water content ($\boldsymbol{\theta}_m$) has been calculated using (1). Finally, $\boldsymbol{\theta}_v$ has been calculated by (2) for each sample.

$$\theta_m = \frac{m_w - m_d}{m_d} \qquad (1)$$

$$\theta_v = \frac{\gamma_d}{\gamma_{water}} \times \theta_m \qquad (2)$$

Where γ_d is the soil dry density and γ_{water} is water density.

The samples were divided into three control samples represented by the three soil types used and 10 groups representing the techniques implemented to increase water retention of sandy soils. The samples have been numbered and summarized in a matrix form in Appendix- I.

Group A: Three samples all of which consisted of a mixture of sand and 20% loam soils as a ratio between the additive volume to the total sample volume (v/v) one of which was mulched with 3 cm rice straw (C-RS) (Sample 4), other one was mulched with powder RC (Sample 5) and the last without mulching (Sample 20).

Group B: Samples of sandy soil were mixed with rice straw in different conditions and proportions, one mixed with 30% C-RS (v/v) (Sample 6), other one mixed with 10% (v/v) powder RC (Sample 7) and the last one mixed with 30% (v/v) powder RC (Sample 8).

Group C: Samples of sandy soil mixed with different types of agriculture wastes of (RS, WS, BS and AS) (Samples 8, 9, 10 and 11 respectively) with the same proportions (30% v/v) and at the same condition (powder).

Group D: Samples of sandy soil mixed with 1, 2 and 3% of the additive weight to the total weight of the sample (w/w) Bleached Cellulose (B-Cellulose) (Samples 12, 13 and 14 respectively).

Group E: Samples of sandy soil mixed with 1, 2 and 3% (w/w) Alpha Cellulose (α-Cellulose) (Samples 15, 16 and 17 respectively).

Group F: Samples of sandy soil mixed with 10, 15 and 20% (v/v) loam (Samples 18, 19 and 20 respectively).

Group G: Samples of sandy soil mixed with 10, 15 and 20% (v/v) silt loam (Samples 21, 22 and 23 respectively).

Group H: A sample of sandy soil mixed with 15% (v/v) loam and 15% (v/v) silt loam (Sample 24) compared to two samples containing 15% (v/v) from loam (Sample 20) and another with 15% (v/v) silt loam (Sample 23).

Group I: Samples of sandy soil with a physical barrier, two were formed from a silt loam at depths 5 and 10 cm from the soil surface (Samples 25 and 26), and the third one is an U-shape impermeable staggered polyethylene membranes (supported with silt loam for installation) (Sample 27).

Group J: Two samples of sandy soil one mixed with 1% (w/w) Polyacrylamide (Sample 28) and the other one is mixed with 1% (w/w) CMC (Sample 29).

3) Determination of Soil Samples' Water Limits

Hygroscopic limit: Since the hygroscopic water is formed on the surface of the soil granules once exposed to moisture of air and can only be disposed of by drying in the oven, the content of the hygroscopic water was determined by drying the samples in the oven and measuring dry weight and then the samples were left in the air for 4 hours, they were weighed again and the percentage of soil weight gain was determined.

Wilting Limit: Since the determination of the water limit at which plant wilt in the soil is not constant and depends on many factors, including the type of soil (where the ability of the plant to absorb water varies due to different strength of water cohesion with the soil granules), the type of crop and temperature [27]. So the wilting limit was determined by monitoring the plant until its wilting and determining the corresponding water content in addition to the use of the average values mentioned in the previous researches [28], and indicative values as in Northeast Region Certified Crop Adviser (NRCCA)-Cornell University. (The wilting limit determined roughly, just to give an indication for the available water content for the plant by using each technique).

Field Capacity Limit: Field capacity limit had been determined by measuring the water content in the soil sample when it reaches almost to the equilibrium state after irrigation (when no water infiltration was observed).

Available Water Content: The available water content had been calculated as the difference in water content between wilting limit and field capacity limit.

The water limits presented in Appendix- II.

III. RESULTS AND DISCUSSION

After obtaining the volumetric water content of each sample, it was plotted against time, where the three control samples were drawn and the limits of the soil water on these curves were illustrated, showing the different plant-soil-water limits from one soil type to another as shown in **Fig. 2**:**Fig. 4.**

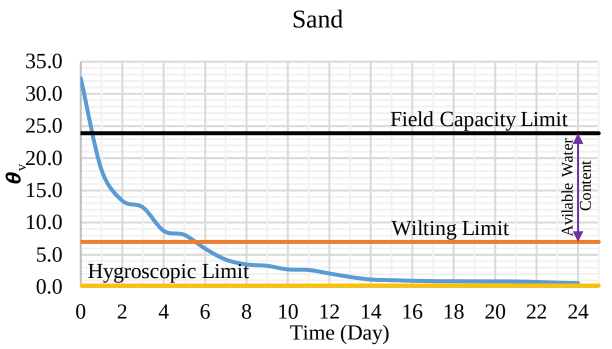

Fig. 2: Sand water limits

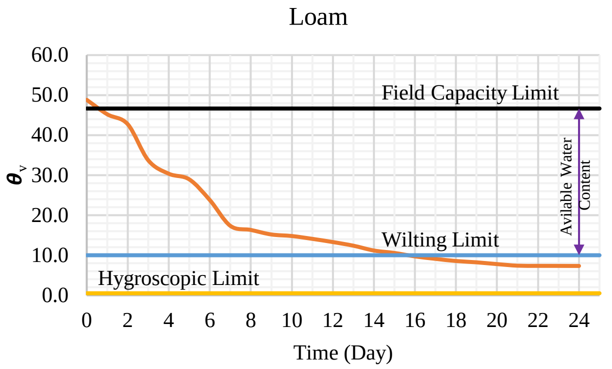

Fig. 3: Loam water limits

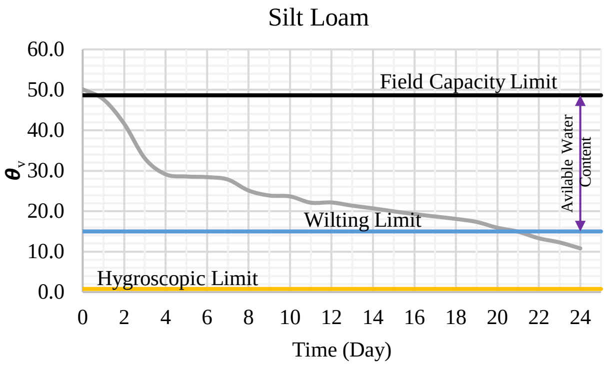

Fig. 4: Silt loam water limits

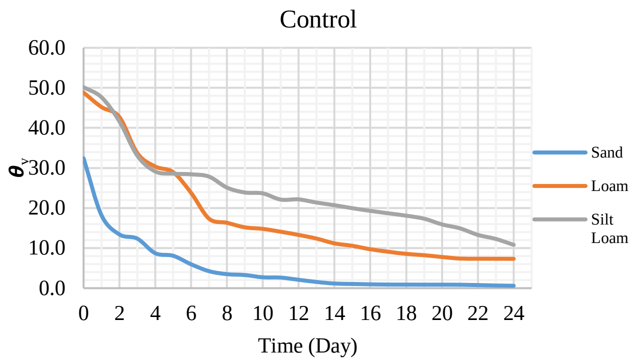

Fig. 5: Control samples

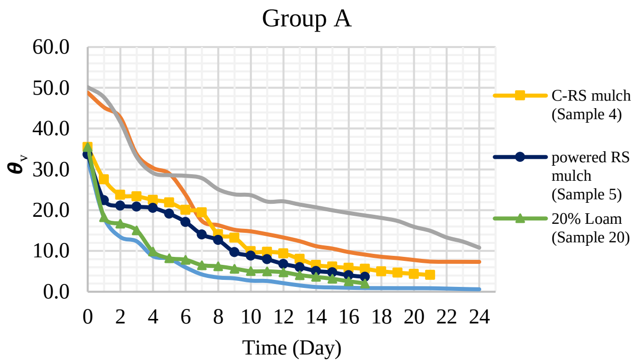

Fig. 6: Mulch

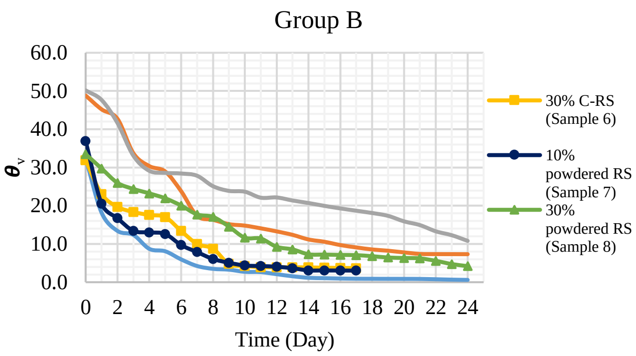

Fig. 7: Rice straw

Control: Fig. 5 shows the three control samples (1, 2 and 3) with the given colors that have been used as a datum to the other samples. As each group of samples used the same technique (with different additive ratio, technique or installation) were presented in the same chart with the three control samples for comparison.

Group A: Fig. 6 shows the effect of mulch on soil water retention in sandy soil, as it's known that sand main problem is the infiltration of water to the deep horizons according to its high porosity and permeability. On the other hand it was expected that evaporation will not be a significant factor in the conservation of water in the soil. Contrary to expectations, mulch showed a significant difference in the water holding as shown that the C-RS mulch gives the optimum water retention even more than the powdered one, as in the case of powdered RS it can absorb larger amount of water from soil surface and the water content measured in the experiment was for the soil under the mulch and does not contain the mulch itself. Beside that C-RS mulch shows great efficiency in reducing the soil erosion**.**

Group B: Fig. 7 shows noticeable increase in soil water holding by increasing the fineness of rice straw and also with the increase of its proportion in the soil, because of it has the ability to absorb water and taking it out gradually and the increase in the specific surface area leads to increased absorption of water and it also increases the efficiency of the soil as a whole to retain water by fill in the spaces between the granules of the soil, which leads to increase the effect of the capillary action and soil water holding.

Group C: Although the results showed in a significant increase in retention of soil water in BS and AS and even exceeded the Loamy soil water content at times as shown in **Fig. 8**, but no plants were planted in the sample mixed with BS and very little at sample with AS, where it was noted that there were many insects that were found in the sample containing BS on the fourth day of the experiment. Whilst the WS and RS achieved a significant increase in water retention values approaching the loam soils in the case of WS and slightly less in the case of RS, the results also showed great productivity of the cultivated plant as they provide the soil with nutrients that benefit the plant to improve its growth.

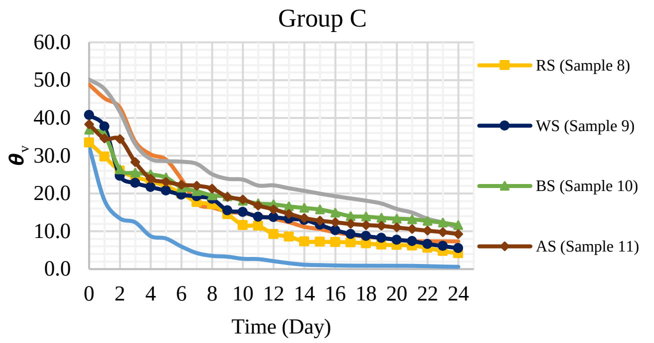

Fig. 8: Agriculture waste

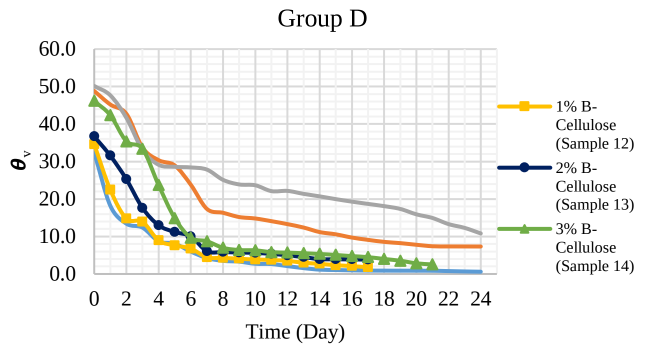

Fig. 9: B-Cellulose

Although their water retention is less than the soil mixed with BS and AS, this provides a clear indication that water retention is not the only factor to choose the most effective additive.

Group D: Fig. 9 shows a clear difference between the water content in the three samples where the water content increases by increasing the B-Cellulose ratio until the eighth day, as the increase in water content is higher in each sample than the sample with a lower in B-Cellulose percentage. The water retention curve of the 1% B-Cellulose sample is very close to the water retention curve of the sand.

Group E: Fig. 10 shows that there is an unnoticed difference between the water contents in the samples with 2 and 3% α-Cellulose starting from the sixth day and before that difference is not significant, also the effect on the plant growth in both percentages are the same and far away about the 1%, so the use of 2% α-Cellulose is the optimum percentages.

Group F and G: Fig. 11 and Fig. 12 show a slight difference in water content to that of sand soil with the increase in the content of loam or silt loam soil in the samples. The result of both groups is poor in order to be relied upon to increase the water content as well as they did not show any noticeable increase in plant growth.

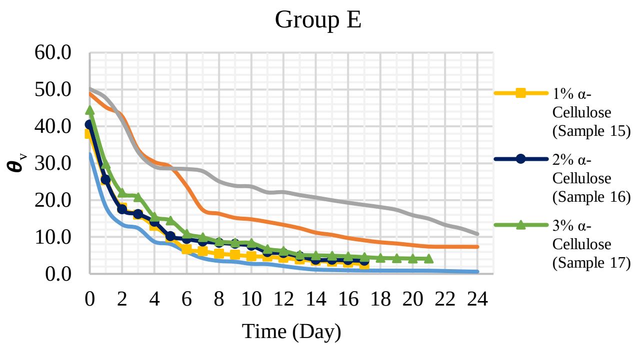

Fig. 10: α-Cellulose

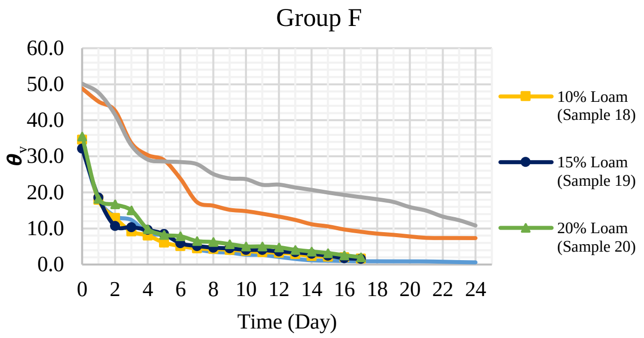

Fig. 11: Loam

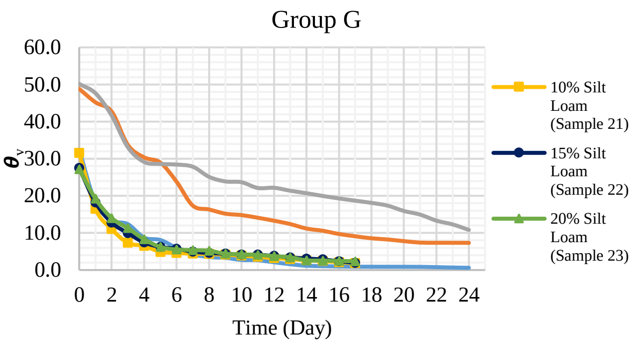

Fig. 12: Silt Loam

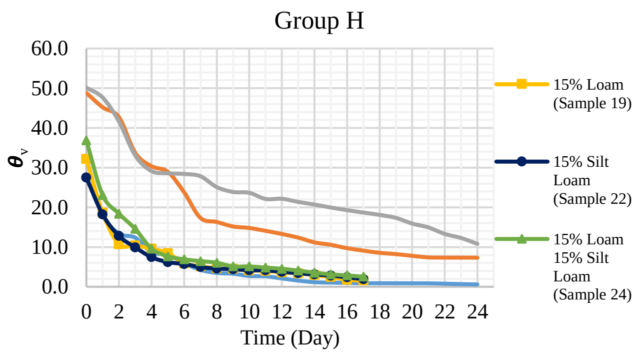

Fig. 13: Sand-Loam-Silt Loam mix

On the contrary, plant growth was negatively affected in the case of silt loam mix compared to that in plain sand. As even if the water content increases with the increase of the percentage of fine soil mixed (loam or silt loam), this is accompanied by an increase in the limit of the water content at which the plant wilt occurs also the soil becomes heterogeneous [29].

Group H: Soil water retention was expected to increase significantly as a result of increasing the proportion of soft soils in the sample 24 (15% loam + 15% silt loam) but due to heterogeneity the water content slight increased to that of 15% of loam and also to that of 15% of silt loam as shown in **Fig. 13**. However, given the effect of this increase on plant growth, it was found to give worse results than 15% loam.

Group I: Soil physical barrier (Phys-barrier) showed a negative effect on the soil water content, As a result of application, the soil is not compacted after being placed above the physical barrier from the silt loam so that no openings can take place in the barrier and lead to rapid water leakage, but as a result, the soil porosity increased in the surface layer and water leaks faster from it to the thin barrier layer saturated with a small amount of water and leaks out the rest of the water. For the lower layers of soil (which were not sampled since the study is focused on the root zone of the plant above the barrier) and the result of large spaces between the granules of the soil above the barrier reduced the capillary force between soil and water and thus increased the rate of evaporation, resulting in faster water loss from the soil.

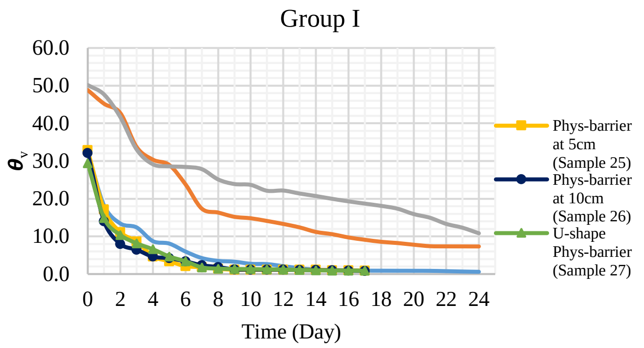

Fig. 14: Physical barriers

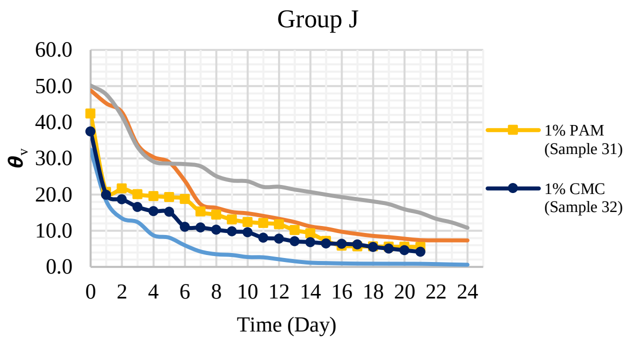

Fig. 15: Commercial additives

Group J: Using the recommended values of the commercial soil showed a high improvement in the water retention in sand soil as shown in **Fig. 15**. However, these commercial material are not environmentally friendly material and also negatively affect the soil in the long run according to the high percentage of sodium. Due to other products such as rice straw, wheat straw or cellulose extracted from rice straw, a high efficiency of soil water retention can be achieved. In addition, it provides nutrients to the plant when decomposed in the soil.

Table- III: Summary of techniques results

Technique	Comments
Mulch	The mulch is a very good alternative that can add value in reclaimed land to water conservation, but it can also cause problems with agricultural machinery.
RS and WS	The use of RS or WS at their powder condition with an appropriate percentage to the soil (30% v/v) can increase the water retention of the sand soil, accordingly decreasing of irrigation water, also they could increase the soil fertility of the soil leading to increased crop productivity and they are a biodegradable materials that has no harm effect on the environment.
BS and AS	Both BS and AS showed a significant increase in sustaining water in soil, but they did not show positive effect in plant cultivation.
Cellulose	Agriculture residuals is a sustainable source of the most natural renewable resource in the earth which is the cellulose [13], that also showed a great results in soil water retention improvement with optimum percentage of 2% w/w for the B-Cellulose and the α-Cellulose, but they are not as good as the raw straws because they were extracted through chemical reactions that produce harmful by-products.
Physical barriers Soil mixing	Neither physical barriers nor mixing of different soil types are useful in increasing soil water retention or even increasing plant productivity.
Acrylamide	Polyacrylamide is considered non-biodegradable material [30], that causes significant environmental pollution, does not degrade easily and results in contamination and harm to the living [31]. Accordingly, even if the efficacy of acrylamide hydrogels is high in increasing the soil water retention, it is not recommended to use it as a result of its environmental impact.

IV. CONCLUSIONS

The experiment results indicated that mixing rice straw or wheat straw with soil by 30% v/v increases water retention in sandy soil in addition to crop productivity. Also, the use of cellulose extracted from agricultural residues showed an improvement in soil water retention properties by adding an optimal cellulose ratio of 2% w/w. Beside that, the mulch can be used to significantly increase the efficiency of water retention in land that does not rely on machinery for seeding and harvesting. On the other hand, physical barrier techniques and mixing of different types of soil offer low efficiency. And regarding the commercial additives, although they offer good efficiency, they expose land and the environment to long-term deterioration.

V. RECOMENDATIONS

The soil moisture content of each pot was determined as a single unit by taking the sample at full depth with different moisture content at different depths of the soil surface. Since plant absorption of water varies with depth (decreases with increasing depth) and moisture content varies with depth (increases with increasing depth). So to achieve a more accurate results, advanced equipment and techniques can be used to measure soil moisture along the root depth of the plant.

Bean straw and alfalfa straw have a very large capacity to increase soil water retention but have a negative effect on plant growth, so scientists should look for a way to overcome this defect and take advantage of their water conservation ability.

The experiment was performed on a small scale, to apply this in practice (large scale fields) it must be tested on a pilot scale model.

Acrylamide hydrogels not preferred to be used until studies are carried out on the possibility of eliminating toxic residues from polymerization or finding ways to prevent this degradation. Especially since there is not much research to study the impact of these substances in the soil in the long term, where more attention is focused on the manufacture of new products with high efficiency in the short term without considering the effects of these materials later.

APPENDIX

Appendix- I: Summary of the samples

Sample no.	Type	Additive type	(v/v) %	(w/w) %
1	Control	N/A	–	–
2	Control	N/A	–	–
3	Control	N/A	–	–
4	Mulch	Loam	20	16.75
5	Mulch	Loam	20	16.75
6	Additives	C-RS	30	2.2
7	Additives	powdered RS	10	0.85
8	Additives	powdered RS	30	3.65
9	Additives	powdered WS	30	6.1
10	Additives	powdered BS	30	8.15
11	Additives	powdered AS	30	5.19
12	Additives	B-Cellulose	7	1
13	Additives	B-Cellulose	14	2
14	Additives	B-Cellulose	21	3
15	Additives	α-Cellulose	7	1
16	Additives	α-Cellulose	14	2
17	Additives	α-Cellulose	21	3
18	Additives	Loam	10	8.21
19	Additives	Loam	15	12.44
20	Additives	Loam	20	16.75
21	Additives	Silt Loam	10	7.88
22	Additives	Silt Loam	15	11.96
23	Additives	Silt Loam	20	16.14
24	Additives	Loam & Silt Loam	15 & 15	12.89 &12.3
25	Physical barrier	N/A	–	–
26	Physical barrier	N/A	–	–
27	Physical barrier	N/A	–	–
28	Additives	PAM	–	0.1
29	Additives	CMC	–	0.1

Appendix- II: Samples water limits

Sample	Hygroscopic Limit	Wilting Limit	Available Water Content	Field Capacity
1	0.225	7	16.886	23.89
2	0.505	10	36.654	46.65
3	0.785	15	33.657	48.66
4	0.369	8	22.716	30.72
5	0.369	8	18.904	26.90
6	0.196	7	19.584	26.58
7	0.183	7	20.115	27.12
8	0.185	8	23.238	31.24
9	0.177	8	30.916	38.92
10	0.217	-	36.001	36.00
11	0.202	-	36.045	36.05
12	0.213	7	20.303	27.30
13	0.198	7	26.610	33.61
14	0.237	7	36.870	43.87
15	0.242	7	23.412	30.41
16	0.211	7	24.518	31.52
17	0.242	7	28.684	35.68
18	0.267	8	16.632	24.63
19	0.319	8	16.023	24.02
20	0.327	8	17.163	25.16
21	0.333	10	12.542	22.54
22	0.330	11	10.921	21.92
23	0.369	12	10.393	22.39
24	0.364	9	19.574	28.57
25	0.215	7	16.460	23.46
26	0.209	7	14.264	21.26
27	0.202	7	13.646	20.65
28	0.189	7	22.406	29.41
29	0.252	7	19.926	26.93

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