Recycling Rice Straw as an Amendment for Improving Soil Evaporation and Infiltration Rates in Sandy Soils

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ABSTRACT

Laboratory Experiments were conducted on the effects of surface and incorporating different rates of rice straw (RS) on evaporation rate and infiltration rate of two sandy soils, differ in sand fraction less than 250 µm (coarse sand (S1) and,fine sand, S2,) at three levels of RS application: 0.0, 1 and 2% on weight basis. It was observed that there was a significant effect as a result of adding different rates of rice straw (quantity or thickness of the layer), the addition methods of rice straw, percentage of the sand particles with a diameter less than 250 µm and the period between the drying and wetting cycles at p< 0.05 on both evaporation rate and accumulation evaporation of the two sandy soils at subjected to successive drying and wetting cycles (at different periods 4, 7, 11 days). Total cumulative infiltration in control (Z_C), at 90 minutes, was reduced from 68.46 cm in S1 to 40.52 cm in S2(about 1.69 times) as the fraction of sand particles < 250 µm was increased from 47.44% in S1 to 72.08% in S2. The values of total cumulative infiltration, over 90 minutes, were reduced to 51.56 cm (24.7%) and 25.73 cm (62.4%) compared to the control treatment (68.46 cm) in sandy soil (S1) incorporated with1% and 2% of rice straw, respectively. The results showed that the incorporated 1% and 2% of rice straw with soil (S2) reduced total cumulative infiltration by 47.1% and 57.8% compared to control. The results showed that the incorporated 1% and 2% of rice straw with soil (S2) reduced total cumulative infiltration by 47.1% and 57.8% compared to control. The (I_b) value was reached to 5.78 cm/hr (60% reduction compared to control) when S2 mixed with 2% of rice straw.

Key wards: Rice straw, evaporation rate, infiltration rate, sand fraction percentage, wetting and drying cycles.

INTRODUCTION

High infiltration rate leads to increase water losses during irrigation and it is an important constrain in designing efficient irrigation system for sandy soils (Baadelaire, 1975). Another factor that has adverse effects on the agricultural potentialities of sandy soils is the great loss of water through evaporation.

Soil coverage with organic mulches is one of the natural methods and it can be achieved by using plant mulches and mulches from straw left after cereal harvest (Liebman and Davis 2000; Kosterna, 2014; Saad,2017). Rice straw is economical and light weight weed-free organic mulch that is readily available in summer after rice crops have been harvested. This mulch is used as a protective barrier for reducing soil evaporation and enhances hydro-physical properties of soil particularly, coarse - textured soils. Rice straw will break down over time, adding organic matter to the soil.

Zagaroza (2003) showed that the efficient of the mulch was depended on its thickness on the soil surface.

Water-saving using 'Ground Cover Rice Production System' (GCRPS) was evaluated in 2001 and 2002 near Beijing, North China. Compared to Paddy control (lowland rice cultivated under traditional paddy conditions, only 32–54% of irrigation applied in water was in GCRPS treatments (the soil surface was covered with 14 µm thick plastic film or mulched with straw (HongbinTao, et al 2006).

Rice straw mulch lowered total evaporation (Es) from clay loam soil over the crop growth season of wheat by 35 and 40 mm in relatively high and low rainfall years, respectively (Singh et al 2011).

The soil layer contributing to evaporation is fairly shallow and only a few tens of centimeters thick. It is assumed that daily evaporation from a bare soil can be described as isothermal liquid flow of water to the surface driven by pressure gradients with negligible gravity; the flow takes place in a layer of constant thickness, whose lower boundary is a zero-flux plane. The effect of the air-dried layer, as a rate-limiting factor on the transport of water to the soil surface is relatively small, and that most of the control is exerted by the capillary rise layer. For related reasons, thermal gradients resulting from radiation at the surface can also be expected to have relatively little effect on the daily fluxes (Brutsaert, 2014; Fritton et al., 1970; Hanks et al., 1967; Milly, 1984a, 1984b).

El-Hady, et al. 2015 evaluated rice straw (RS)-based hydro-gels, as conditioners for improving the infiltration of sandy calcareous soils. The results showed a decrease in infiltration of the soil due to addition of 2 g hydro-gel kg^{-1} dry soil, reached 17.6%. 2g hydro-gel kg^{-1} soils was recommended dose to get use the RS-hydro-gels as benefit soil conditioner,

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without adverse effects on growth, water and fertilizers efficiency by plants.

In Egypt, farmers burn around 5 to 6 million tons of rice straw every year, emitting 80,000 tons of carbon dioxide leads to the formation of black clouds in the sky of Egypt and contribute in the global (http://www.ahram.org.eg/3013/9/2013/, and https://www.youm7.com/story/2017/7/31). Legal action has been taken by the Ministry of Environment against farmers who continue to burn rice straw. A number of 16 awareness seminars on measures to address the sources of air pollution and recycling rice straw and benefiting from it has been given to citizens and farmers in villages in Egypt, according to the report by the Ministry of Environment. According to a report by the World Bank, the percentage of pollution from burning rice straw in Egypt annually is estimated at 42% of the total air pollution in Egypt (http://www.albawabhnews.com/2017/9/4).The Egyptian government has adopted measures to encourage gathering rice straw to put into effect an agro-waste system introduced by the ministry instead of burning it. So that, they followed the scientific approach to find the solution by encourage and apply proposed plans to convert rice straw into lucrative materials. But, most of crops are exposed to drought or lack of water needs due to climate changes. In addition the western desert plateau region in Egypt is predominantly sandy as well as two distinct sandy soil areas exist in the cultivated zone of the Nile valley and Delta. Therefore, should encourage and push the using woven mats made from rice husks, organic rice straw mulch bales, spread a layer of rice husks around plants or incorporated rice straw that can be used for all types of mulching, including roses, garden beds, vegetable gardens, pots, trees and shrubs for recycling rice residues instead of its burning to reduce air pollution and saving irrigation water and increase water use efficiency by reducing evaporation rates, improving soil properties, protecting plants and other agronomic aspects. This idea requires intensive academic studies before the announcement and implementation. The main goal of this study was to examine the potential effect of rice straw in reducing evaporation and infiltration of sandy soils.

MATERIALS AND METHODS

1. Soil sampling and analyses

The used soils were collected from Al-Bustan region, Western area of Nile Delta, Egypt. It is classified a *Typictorripsamments* (Labib and Khalil, 1977). Soil samples were collected from different sites of this region, air dried and subjected to dry sieving in order to obtain two different sandy soils. The grain size fractions percentages are depicted in Table1. The sand fraction less than 250 µm in diameter was 72.08% and 47.44% in the first and second soil samples, respectively. The values of bulk density (D_b) and gravimetric saturation percent (SP_w) are shown in Table1.

The average values of pH, ECe, $CaCO_3$ and total organic matter values of the first and second soils are 8.3, 1.2 $dS.m^{-1}$, 2.4% and 0.5%, respectively. The textural classes of the two soils are sand. Dry bulk density was determined by core method (Black and Hartge, 1986). Particle size distribution was determined by the Bouyoucos hydrometer method (Bouyoucos, 1962). Total soluble salts, pH and calcium carbonate content were determined by the procedures outlined in Page *et al.* (1984). Soil organic carbon was determined by 'Walkely-Black 'method and OM percentage was calculated (Nelson and Sommers, 1982).

2. Experiment1: Soil evaporation study

The first Laboratory experiment has been conducted to study the effect of thickness of rice straw mulch (1 and 2 cm thickness 1% and 2% RS on weight basis.), application methods (surface and incorporation) and successive wetting and drying cycles which differ in time intervals (4, 7 and 11days) on reducing evaporation rate from surface layer of the two sandy soils.

Sandy soils were placed in plastic trays (of diameter 15.5 cm and height 3.5cm), closed at the bottom, in two groups. The first group of trays (660.1 cm^3 volumes) was packed of each soil according to its bulk density (D_b) as shown in Table 1. Based on the measured saturation percentage of the soil, 16.5 and 20.8 gram water per 100 gram soil were added to S1 and S2, respectively (Table 1). Thus, the required amount of water was added evenly thereafter. The rice straw was placed in direct contact over the surface of the saturated soil. The second group of trays, having the same dimensions, was packed with air- dried of each soil, and well mixed and incorporated with rates 10g and 20g of small pieces of rice straw (with average length of 17 mm) per 1 kg of soil , then the water was added to attain saturation of the soil.

The quantities of rice straw added in the two groups of trays were 1 and 2% on weight basis which is equivalent to 5.3 and 10.6 tons ha. The trays in the two groups were placed in the laboratory that maintains air temperature varying from 25 to 28^{o}c during the study period. The trays were weighed at the first day of the trial just after the saturation of soils and installation of the rice straw. The soils were subjected to successive six wetting and drying cycles at different interval times. The weight of treatments was measured at 4,7,11 days after the beginning of the experiment at 1pm.

Table .1. Grain - size fractions and some physical properties of the two studied soil samples

Soil Sample No.	% of soil fractions						D_b, Mg. m^{-3}	SP_W %
	1-2 mm	0.5-1.0 mm	0.25-0.50 mm	0.125-0.250 mm	0.053-0.125 mm	< 0.053 mm		
S1	0.0	12.85	39.62	33.23	9.09	5.12	1.68	17.5
S2	0.0	9.0	18.92	38.31	26.14	7.63	1.54	20.8

The statistical design was at random with three replications per treatment.

3. Experiment 2: infiltration study

The second experiment was conducted to study the effect of incorporated of the two rates of rice straw on cumulative infiltration (Z) and infiltration rate (I) of the two sandy soils, which differ in percentage of particles of diameter less than 250 µm. Addition of 1% and 2% of small pieces of rice straw (17mm length) on air-dried weight basis were incorporated with each soil and packed in transparent soil columns (3.25 inches diameter and 20 inches height), plus columns for control treatments (packed with each sandy soil only). The simplest approximation of cumulative infiltration is written as follows (Z) = kt^a **(**Kostiakov, 1923; Lewis, 1937), in which Z= the cumulative infiltration (cm), t= the cumulative time k= a constant representing Z at unit time, dimensionally inconsistent and a= a constant, which represents the slope of an infiltration curve on log-log paper, dimensionless. The basic infiltration rate (I_b) was estimated from the following eqution: (I_b),cm/min = dZ/dt = k. a. t^{a-1}.

4. Statistical analysis:

Analysis of variance by 3Way- CRD (Completely Randomized Design) was used to test the degree of variability among the obtained data. Least significant difference (LSD) test at p = 0.05 was used for the comparison among treatments means, Steel and Torrie (1980). CoHort computer program was used for the statistical analysis, version 6.400.

RERSULTS AND DISCUSSION

1. Soil evaporation study

Average cumulative evaporation (CE) and evaporation rate (ER) in control treatments are shown in Fig.1 A and 1B. The values of CE ranged between 5.33 mm (ER =1.33 mm/d) and 9.61mm (ER= 0.87 mm/d) for S2 (72.08% of particles less than 250 µm) and between 5.52 mm (ER =1.38 mm/d) and 10.67 mm (ER= 0.97 mm/d) for S1 (47.44% of particles less than 250 µm) when both are subjected to 6 wetting and drying cycles with sequence 4 and 11 days intervals, respectively. Moderate values of CE and ER were observed in cycles with 7 days intervals. The evaporation values in S2 were less than its values in S1 by about 3.6, 7.1 and 11% under 4, 7 and 11 days intervals, respectively. The effect of the air-dried layer, as a rate-limiting factor on the transport of water to the soil surface is relatively low, and that most of that of the control is exerted by the capillary rise layer. The thermal gradients resulting from radiation at the surface can also be expected to have relatively little effect on the daily fluxes (Brutsaert, 2014; Fritton et al., 1970; Hanks et al., 1967; Milly, 1984a, 1984b).

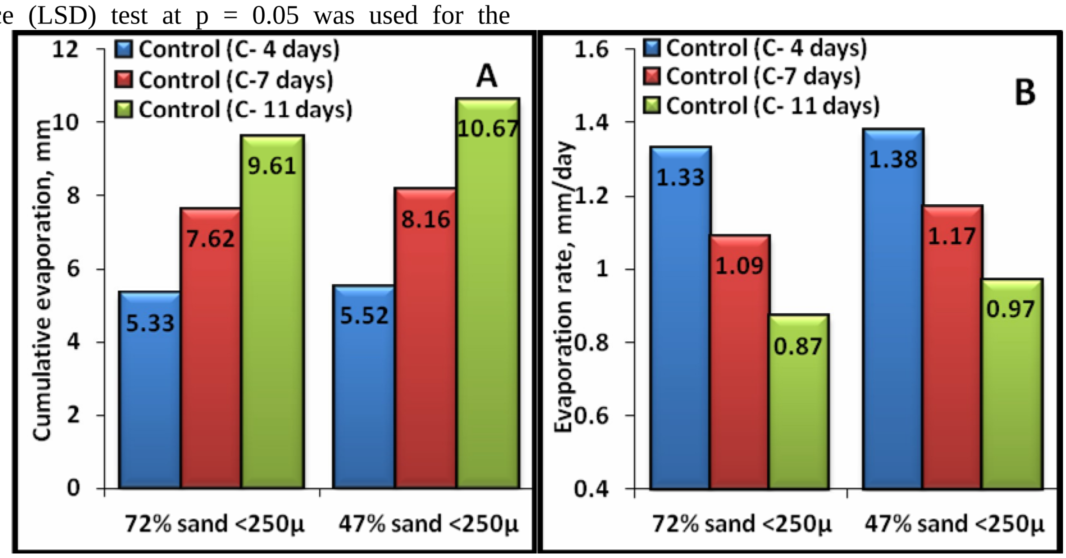

Fig. 1. Cumulative evaporation (A) and evaporation rate (B) from Control treatments (C) of the two sandy soils under three successive wetting and drying cycles varying in time intervals

Effect of surface and incorporation applications of rice straw on evaporation from the two sandy soils, subjected to 6 of wetting and drying cycles (1st run, 4 days interval), (2nd run, 7days interval) and (3rd run, 11 days interval) are shown in Table 2 (a and b) and Figures 2 and 3. It is clear that both application methods of rice straw to sandy soils reduced the amount of water loss by evaporation compared to control. Evaporation rate (ER) and cumulative evaporation (CE) were decreased by increasing the intervals of wetting and drying cycles in all treatments (Table 2a and b). There are significant differences (at $p < 0.05$) as a result of the influence of rice straw mulch (percentage/ thickness) and sand fraction < 250µm on the values of average cumulative evaporation, mm (a) and evaporation rate, mm/day (b) of the two soils under different periods of wetting and drying cycles. Surface applications of rice straw (SARS) is more efficient for decreasing soil evaporation than incorporation of rice straw (IRS) in all treatments. For example, soil evaporation was in the range: 80% to 73% and 94% to 89% of the control treatment in the case of 1% and 2% application of rice straw as surface mulching (SARS) and as incorporation rice straw (IRS) in soil (S2) exposed to 6 runs of wetting and drying cycles with 4 days intervals, respectively. In sandy soil (S1), soil evaporation was in the range 84% to 78% and 96% to 91% of the control when it was mulched with 1% and 2% as SARS and IRS and subjected to 6 runs of wetting and drying cycles with 4 days intervals, respectively.

Table.2. Effect of the quantity of rice straw and sand fraction < 250µs on the average cumulative evaporation, mm (a) and evaporation rate, mm/day (b) of the two sandy soils under different periods of wetting and drying cycles. Values followed by different letters are significantly different ($p < 0.05$).

(a): Mean cumulative evaporation (mm)

Treatments	1st run:4 days intervals			2nd run:7days intervals			3th run:11days intervals			Mean
	C	IRS	SARS	C	IRS	SARS	C	IRS	SARS	
1%RS, S2	5.33	5.02	4.28	7.62	7.20	6.48	9.61	9.29	8.87	7.078c
2%RS, S2	5.33	4.75	3.89	7.62	7.13	6.44	9.61	9.05	8.63	6.939d
1%RS, S1	5.52	5.30	4.63	8.16	7.88	7.41	10.67	10.38	10.05	7.773a
2%RS, S1	5.52	5.00	4.32	8.16	7.74	7.14	10.67	10.22	9.83	7.617b

(b): Daily mean evaporation rate, mm/day

Treatments	1st run:4 days intervals			2nd run:7days intervals			3th run:11days intervals			Mean
	C	IRS	SARS	C	IRS	SARS	C	IRS	SARS	
1%RS, S2	1.33	1.25	1.07	1.09	1.03	0.93	0.87	0.84	0.81	1.024bc
2%RS, S2	1.33	1.19	0.97	1.09	1.02	0.92	0.87	0.82	0.78	0.998c
1%RS, S1	1.38	1.32	1.16	1.17	1.13	1.04	0.97	0.94	0.91	1.113a
2%RS, S1	1.38	1.25	1.08	1.17	1.11	1.02	0.97	0.77	0.72	1.052b

C= Control IRS = Incorporation of rice straw SARS = Surface application of rice straw

S_1= 72.08% of sand particles < 250µ S_2= 47.44% of sand particles < 250µ

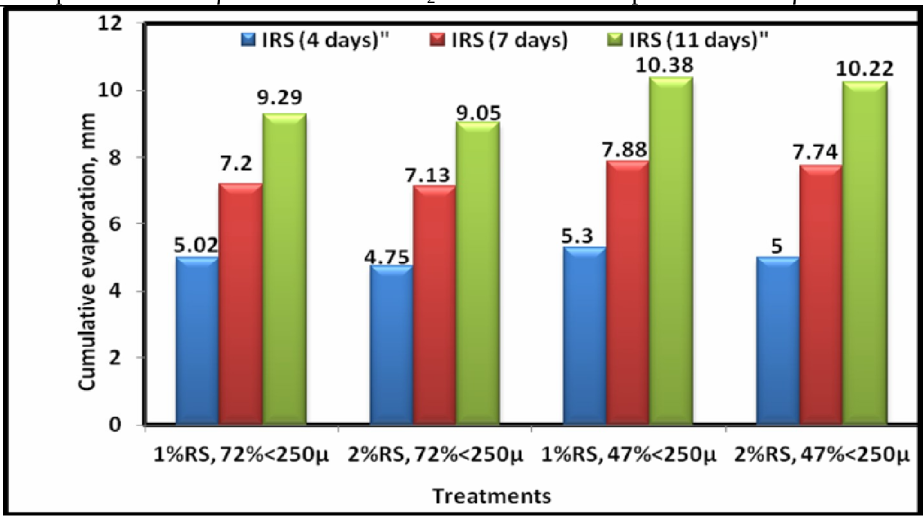

Fig. 2 Average cumulative evaporation as a result of incorporated rice straw, IRS of two sandy soils exposed to three successive wetting and drying cycles were varying in time intervals

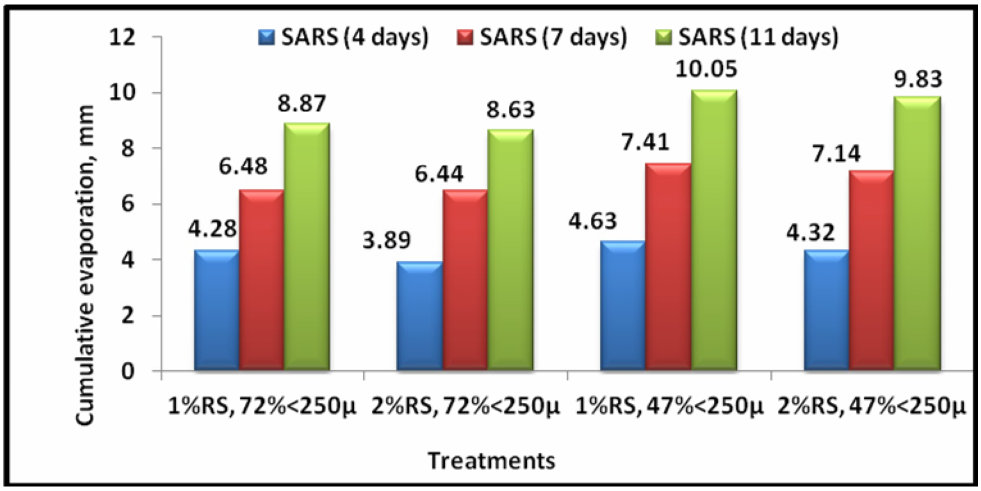

Fig. 3. Average cumulative evaporation as a result of surface application of rice straw, SARS of the two sandy soils exposed to three successive wetting and drying cycles were varying in time intervals

The reduction percentages in soil evaporation in the 3rd run (11 days intervals) for all treatments were the least (4 to 8% in IRS and SARS, respectively) compared to the other runs as shown in Table 2 and Figures 2 and 3.

There are significant differences at $p < 0.05$ in soil evaporation due to the application methods of mulching sandy soils by rice straw in all treatments (Table 3). Rice straw checked 12.6% and 5.1% of mean accumulation soil evaporation under SARS and IRS treatments, respectively.

There are significant differences in mean cumulative soil evaporation at ($p< 0.05$) due to the different in time intervals between wetting and drying cycle in all treatments (Table 4). The average value of evaporation rate decreased from 1.23 to 0.85 mm/day for 4 and 11 days due to the dryness of soil (Table 4).

Reduction percentage in soil evaporation increased when sandy soil mulched with 2% rice straw on weight basis in both soils and under varying application methods and all wetting and drying cycles (Table 5).

Table. 3. The average cumulative evaporation, mm (a) and evaporation rate, mm/day (b) of the two sandy soils exposed to 6 wetting and drying cycles differed in periods as affected by the application methods of rice straw (RS) . Values followed by different letters are significantly different ($p < 0.05$)

Treatments	4 days		7 days		11 days		Mean
	S2	S1	S2	S1	S2	S1	
(a): Mean cumulative evaporation (mm)							
C	5.33	5.52	7.62	8.16	9.61	10.63	7.812a
IRS	4.885	5.15	7.165	7.81	9.17	10.3	7.413b
SARS	4.085	4.475	6.46	7.275	8.75	9.94	6.831c
(b): Daily mean evaporation rate, mm/day							
C	1.33	1.38	1.09	1. 17	0.87	0.97	1.135a
IRS	1.22	1.28	1.02	1.12	0.83	0.86	1.055b
SARS	1.02	1.12	0.93	1.03	0.79	0.82	0.951c

C= Control IRS = Incorporation of rice straw SARS = Surface application of rice straw
S2= 72.08% of sand particles < 250µm S1= 47.44% of sand particles < 250µm

Table. 4. Effect time interval of wetting and drying cycles on mean cumulative evaporation and daily mean evaporation rate (b) of sandy soils. Values followed by different letters are significantly different at ($p < 0.05$)

	(a): Mean cumulative evaporation(mm)			(b): Daily mean evaporation rate (mm/day)		
Treatments	4 days	7 days	11 days	4 days	7 days	11 days
C	5.425	7.890	10.120	1.36	1.13	0.92
IRS	5.017	7.487	9.735	1.25	1.07	0.84
SARS	4.280	6.867	9.345	1.07	0.98	0.81
Mean	4.907c	7.415b	9.733a	1.226a	1.06b	0.856c

C= Control, IRS = Incorporation of rice straw , SARS = Surface application of rice straw

Table.5. Relative evaporation reduction % of the mulching treatments in relation to the control

	Reduction percent					
	1st run:4days intervals		2nd run:7days intervals		3th run:11days intervals	
Treatments	IRS	SARS	IRS	SARS	IRS	SARS
1%RS, S1	5.82	19.7	5.51	14.68	3.33	7.70
2%RS, S1	10.88	27.01	6.43	15.48	5.83	10.20
1%RS, S2	3.98	16.30	3.54	10.42	2.35	5.46
2%RS, S2	9.42	21.74	5.15	12.50	3.86	7.53

S_1= 47.44% of sand particles < 250µ S_2= 72.08% of sand particles < 250µ

2. Experiment 2: Soil infiltration study

2.1. Cumulative infiltration and infiltration rate of the control treatments

Effect of the percentage of sand fraction (< 250µs in diameter) in the two soils on cumulative infiltration (cm) is shown in Fig.4. Total cumulative infiltration (Z_C) value, at 90 minutes, was reduced from 68.46 cm to 40.52 cm (about 1.69 times) as fine fraction of sand particles < 250 µm was increased from 47.44% in S1 to 72.08% in S2. Power relations with high R^2 between Zc (cm) and time (t, min) in the control treatments are shown in Fig. 4. The basic infiltration rate (**I_b)** values are 27.98 and 14.53 cm/hr in S1 and S2, respectively (Table 6).

2.2. Cumulative infiltration and infiltration rate of mulched sandy soils

Effects of rice straw on cumulative infiltration (Zr) are given in Fig.ures 5 and 6. Power relations with high R^2 between Zr (cm) and time (t, min) are shown in Fig. 5 and 6.

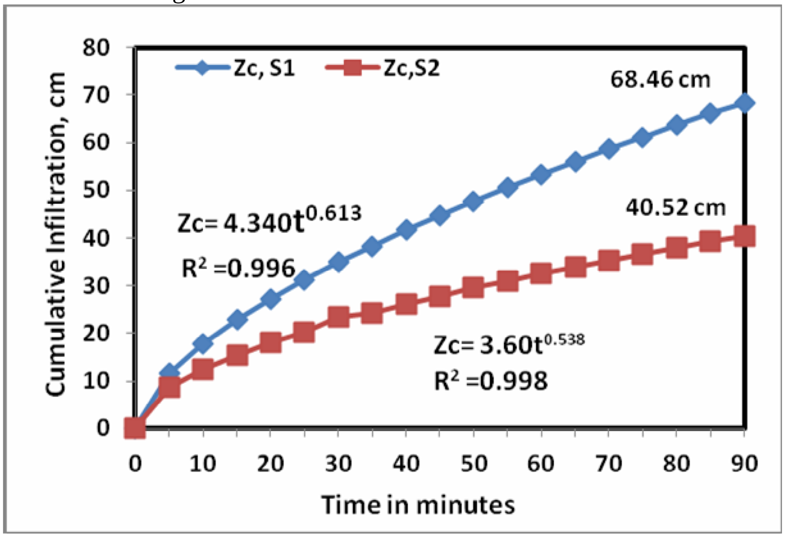

Fig.4. Cumulative infiltration (Z_c) of the control treatments (unmulched S1and S2)

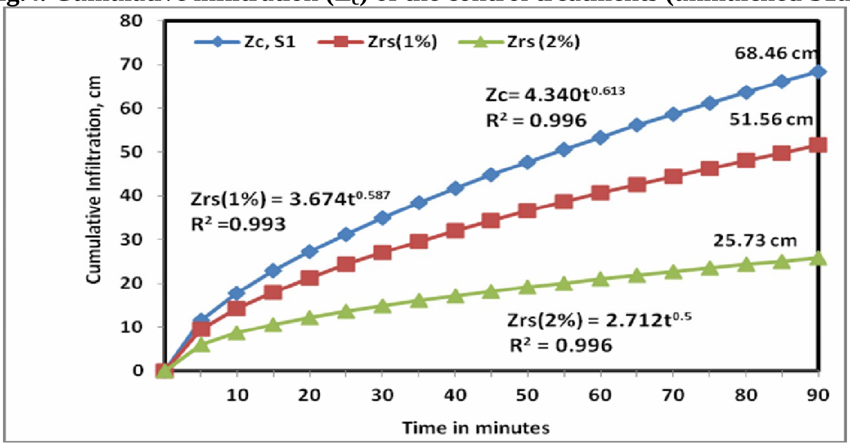

Fig.5. Cumulative infiltration curves of mulched soil (S1) Incorporated with 1% and 2% of rice straw on weight basis compared to control

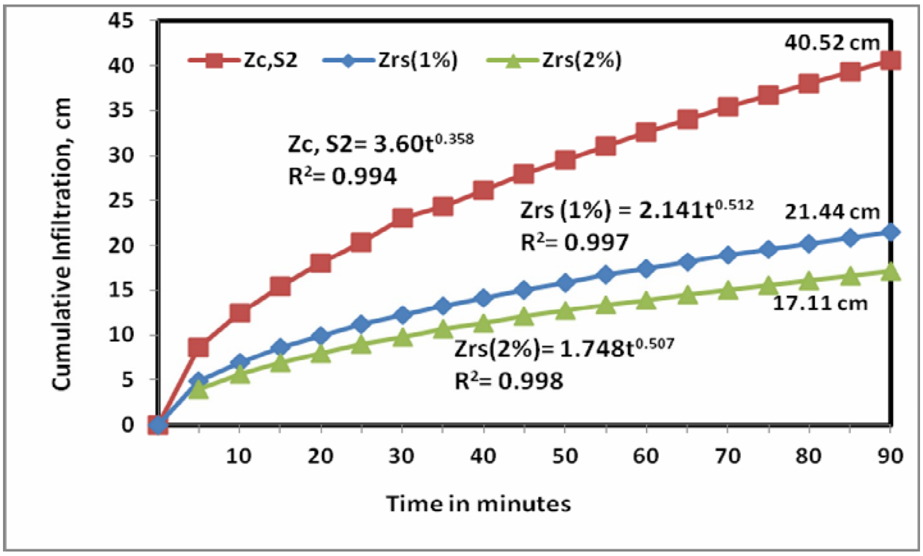

Fig.6. Cumulative infiltration curves of mulched soil (S2) Incorporated with 1% and 2% of rice straw on weight basis compared to control.

Table 6. Steady infiltration and cumulative infiltration of the two sandy soils mulched with 1 and 2 % of rice straw

	Z, cm (after 90 min)		I_b, cm/hr	
Treatments	**S1***	**S2****	**S1***	**S2****
Control (no- mulch): C	68.46	40.52	27.98	14.53
1% rice straw	51.65	21.44	20.17	7.32
2% rice straw	25.73	17.11	8.58	5.78
S1* (47.44% of particles < 250µm)				
S2 * *(72.08% of particles < 250µm)				

The results in Table 6 are shown that the basic infiltration rate (I_b) was decreased as a result of addition of rice straw. For example, the incorporated 2% of rice straw with S1 reduced (I_b) to 8.58cm/ hr (69.3) compared to control (27.98 cm/hr). The (I_b) value was reached to 5.78 cm/hr (60% reduction compared to control) when S2 mixed with 2% of rice straw as shown in Tale 6. The values of both infiltration rate and cumulative infiltration were decreased upon the application of rice straw to the sandy soils. This is might be due to the change of pore morphology, pore size distribution and non-connectively of pores. (Fei, et al. 2008, Yang et al 2013).

CONCLUSION

Surface applications of rice straw (SARS) are more efficient for decreasing soil evaporation than incorporation of rice straw (IRS) in the sandy soils. Rice straw reduced 12.6% and 5.1% of mean accumulation soil evaporation under SARS and IRS treatments, respectively. The evaporation values in fine sandy soil (S1) are less than its values in (S2) about 3.6, 7.1 and 11% under 4, 7 and 11 days intervals, respectively. The results are showed that the incorporated 1% and 2% of rice straw with soil (S2) reduced total cumulative infiltration by 47.1% and 57.8% compared to control. The (I_b) value was reached to 5.78 cm/hr (60% reduction compared to control) when S2 mixed with 2% of rice straw.

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الملخص العربي

اعادة تدوير قش الأرز لتحسين معدلات البخر والتسرب في الأراضى الرملية

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أجريت تجارب معملية على تأثير إضافات سطحية ودمج معدلات مختلفة من قش الأرز على معدلات البخر والتسرب لنوعين من التربة الرمليةوالتي تختلف في نسبة جزء الرمل الأقل من ٢٥٠ ميكرون، حيث استخدمت ثلاثة مستويات مختلفة من قش الارز، وهي: صفر، ١ و ٢ %على أساس الوزن. لوحظ أن هناك تاثير معنوى لكل من المعدلات المضافة من قش الأرز وكذلك طرق الاضافة ونسبة جزء الرمل ذات قطر أقل من ٢٥٠ ميكرون عند p < 0.05 على كل من معدلات البخر والبخر التجميعى للاراضى الرملية عند تعرضها لدورات متعاقبة وعلى فترات زمنية مختلفة من الجفاف والابتلال. إنخفض إجمالي قيمة التسرب التراكمي (ZC) ، في ٩٠ دقيقة ، من ٦٨,٤٦ سم في S1 إلى ٤٠,٥٢ سم في S2 (حوالي ١,٦٩ مرة) نتيجة زيادة الجزء الناعم من حبيبات الرمل الاقل من ٢٥٠ ميكرون من ٤٧،٤٤ ٪ في S1 إلى ٧٢،٠٨ ٪ في S2. أظهرت النتائج انخفاض قيم التسرب التراكمي الكلي ، بعد ٩٠ دقيقة بنسب ٢٤،٧ ٪ و٦٢،٤ ٪ عند خلط التربة الرملية (S1) بنسب ١ ٪ و ٢ ٪ من قش الارز على أساس الوزن على التوالي مقارنة بالكنترول . كما أوضحت النتائج أيضآ أن خلط ١٪ و ٢٪ من قش الأرز مع التربة الرملية (S2) أدت إلى انخفاض التسرب التراكمي الإجمالي بنسب ٤٧،١٪ و ٥٧،٨٪ على التوالى مقارنة بالكنترول.

وأظهرت النتائج أن خلط ١ ٪ و ٢ ٪ من قش الأرز مع التربة (S2) على أساس الوزن خفضت معدل التسرب بنسبة ٤٧،١ ٪ و ٥٧،٨ ٪ مقارنة بالكنترول بينما وصلت قيمة (Ib) إلى ٥،٧٨ سم / ساعة (انخفاض بنسبة ٦٠٪ مقارنة بالكنترول) عندما تم خلط التربة S2 مع ٢٪ من قش الأرز.