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Assessing the performance of different cover materials, in mitigation of evaporation from free water surfaces in Sulaimani Governorate / Iraq

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Abstract

In Iraqi Kurdistan region with intensive solar radiation and high vapor pressure deficit, particularly during the summer season, evaporative losses constitute a substantial amount of total stored water. To quantify and estimate evaporation losses besides testing the performance of some selected treatments for mitigating such losses a series of sequential experiments were implemented during some selected rainless months of 2015 and 2016 using evaporation pans. Each experiment was laid in completely randomized design. The treating materials encompassed indigenous and nonindigenous ones. Additionally, meteorological parameters were obtained for the test periods to relate pan evaporation to these parameters on one hand and to estimate pan coefficients from them, on the other hand. In this study the results were; 1) The small plastic balls as a covering materials (D =40 mm) offered the highest percent of evaporation reduction (60.81%) compared to those under large balls and under combination of these two sizes. 2) Comparison of three indigenous plant parts as shading cover, namely, Reed stems, Washingtonian fronds and Date palm mat, showed that the Date palm mat was the most effective material for reducing evaporation. 3) It was noticed that cardboard offered the highest performance compared with two other covering or shading materials (Cork disk and licorice branches) for reducing evaporation. 4) There was not a steady reduction in evaporation rate with an increase in monolayer application rate. The maximum reduction in evaporation rate occurred at an application rate of 0.226 g pan^{-1} Day^{-1} 23.7%. 5) The order of preference of some screened treatment under the same atmospheric evaporation demand was: Small balls > Date palm mat > Monolayer > Control. 6). It was also noticed that the monolayer offered a higher performance during the field tests compared to that obtained during the pan evaporation experiments.

Introduction

In Iraqi Kurdistan region and in many parts of the world, where availability of water resources is scarce, the estimation of evaporation loss is very important for the planning and management of irrigation practices, and these losses should be considered in the design of various water resources and irrigation systems [1].

One of the challenges of water management in arid and semiarid regions is to reduce the huge amount of water loss through evaporation from water surfaces of dam reservoirs and lakes due to extremely high evaporation rates [2]. Among the various techniques for reducing evaporation loss, mechanical devices, such as shed clothes and floating covers, have demonstrated their effectiveness for small storages, but they are not feasible for large areas of water such as reservoirs [3]. For large storage, the use of mono-molecular layers has the potential to be an attractive and cost-effective solution to reduce evaporation.

The present research is mainly focused on the selection of the best available and the most feasible technique considering Iraqi Kurdistan climatic conditions for reduction of evaporation from free water surfaces. In view of the above considerations, this study was conducted with the following objectives:

1) To predict the amount of evaporative losses from water surfaces and from other meteorological data in the area under study.

2) To test the performance of some techniques for reducing evaporation

3) To extrapolate the results obtained from evaporation pan to larger water bodies.

Materials and Methods

1 Description of the Study Area

1.1 Location:

All the experiments with exception of the pond experiment were conducted within the enclosure of the faculty of Agricultural Sciences- University of Sulaymani at Bakrajo with GPS reading of (35° 32′ 41″ N, 45° 21′ 55″ E), which is about 8 km to the southwest of Sulaimani city. The latter is situated to the northeast of Iraq.

1.2 Climate

The climate is of Mediterranean type, giving rise to cold and rainy winters and hot and dry summers. The area as a part of Iraqi Kurdistan region is characterized by large diurnal and annual ranges of temperature. The coldest and the warmest months of the year are January and July respectively. Mean annual temperature amounts is 19 °C with a maximum in July (44 °C) and a minimum in January (-3 °C). The mean annual rainfall (n= 20 years) is 683 mm distributed over rainy months. Based on class A evaporation pan, the region has a high evaporative demand of about 2020 mm [4]. Wind directions are predominantly from southeast and north.

2. Experiments Setup

The selected area was subdivided into three rows. Four pans per each row were installed. The spacing between two pans in the same row was 50 cm. Also the rows were 50 cm spaced. (Figure 1) displays the general view of the experimental design.

Figure 1 General view of the experimental design.

Since it was impossible to evaluate the performance a host of locally and non-locally available materials for evaporation reduction at a time, sequential experiments were conducted. During each test, several materials or a material with different levels were tested.

2.1 Experiment I

The objective of this experiment was to assess the impact of plastic balls of different sizes on evaporation reduction from evaporative pans. Before initiating the experiment, each ball was covered with a thin coat of white paint. The experiment encompassed the following treatments:

1) Control (without cover). 2) Covering with small plastic balls (tennis ball) 4 cm in diameter. 3) Covering with plastic balls 8 cm in diameter (Large balls). 4) Combination of the above two sizes.

The small balls were inserted into the space between the large balls (Mixed).

The water into the evaporation pans was allowed to evaporate over a 20-days period between July 11 to July 30, 2015. Additionally, the recording data included measurement of water temperature with a thermometer at different time intervals at 2:00 pm.

2.2 Experiment II

This experiment was similar to experiment I in all aspects except that the balls were replaced by locally available (indigenous) coverage materials. The materials encompassed: 1) Control (without cover). 2) Sheets of date palm (Date palm mat). 3). Washingtonian fronds. 4). Reed stems.

Before initiating the experiment, circular sheets were made from each of the above materials having the same diameter as the pans and were tied up on wiring. Each material was applied with a thickness of one sheet. The experiment was run over a period of 22 days, from August 20 to September 10, 2015.

2.3 Experiment III

This experiment was similar to experiment I in all aspects except that the balls were replaced by other locally (indigenous) and non-locally available coverage materials. The materials encompassed:

1. Control (without cover). 2. Licorice Branches weed. 3. Disks of cork, 3 cm in diameter and 1 cm in thickness. 4. Cardboard sheet.

Before initiating the experiment, circular sheets were made from each of the above materials having the same diameter as the pans and were tied up on wiring as mentioned earlier. It is worthwhile to mention that each material was applied with a thickness of one sheet. The experiment was run over a period of 27 days, between September 17 and October 13, 2015.

2.4 Experiment IV

For this experiment, fatty alcohol emulsion was selected and sprayed over the water surface. The experiment comprised the following application rates: 0.00, 0.113, 0.226, 0.339 g pan^{-1} day^{-1}. The experiment was run over a period of days between June 14 to July 13, 2016. The experiment was laid out in a completely randomized design with three replicates.

2.5 Experiment V

After testing some selected locally and non-locally available materials for reducing evaporation during the period from July 11, 2015, to July 13, 2016, some effective (screened) materials or levels were selected from the implemented experiment. The screened treatments encompassed: small balls, date palm mat and fatty alcohol with an application rate of 0.226 g pan^{-1} day^{-1} along with the check treatment. The idea behind this experiment was to evaluate the performance of some effective (screened) treatments under the same atmospherically evaporation demand. This is because each of the four experiments had its own atmospheric evaporation demand.

3. The Field (Pond) Experiment

The specific objective of this experiment was to extrapolate the pan evaporation results to a larger water body. To achieve the above objective a pond experiment was conducted at Mergapan site which is about 10 km to the north of Sulaimani city center over a test period August 7 to August 18, 2016. The tested storage was a rectangular parallelepiped basin (cuboid) with dimensions of 6.03 m x 3.0 4 m x 1.11 m. Seepage was also measured because it was impossible to measure evaporation alone. The measured seepage (S) was subtracted from the total water loss (apparent evaporation loss, Ep) to measure the water loss due to evaporation (actual evaporation loss, Ea) or : **EP = S + Ea** [1]

The same pond was used to measure seepage over four days during which the pond surface was covered tightly with sheets of polyethylene. It is also notable to for that the same pond was considered as a control over 5 days during which the pond water was untreated. During the remaining days of the test period, the performance of the fatty alcohol at an application rate of 0.226 g m^{-2} was evaluated.

4 Data Collection

Meteorological parameters, including air temperature, relative humidity, and wind speed, sunshine durations were obtained from the nearby meteorological station at Sulaimani city.

5. Methods of Analysis

Electrical conductivity of the applied water was measured with HANNA Instruments EC 215 Conductivity meter EC-meter Model and adjusted to 25 °C according to [5]. The Water pH was measured with portable pH-meter. The Calculation of Penman-Monteith potential evapotranspiration (ET_o) followed procedures outlined in [6] using CROPWAT software version 8.

6 Statistical Analysis

The data were subjected to analysis of variance (F-test) Stat graphics software release plus 4. Following analysis of variance, least significance difference (LSD) and Dunnett significant difference, were used to compare the means of different treatments. The correlation coefficient among some selected variables were found using Microsoft Excel software. Additionally, the parameters of the two regression models for predicting pan evaporation were determined using IBM SPSS software ver. 22.

Results and Discussion

1. Evaporation suppression as affected by covering the water surface with plastic balls of different sizes during experiment # 1

The experiment lasted for 20 days from July 11 to July 30, 2015. Generally, it can be elucidated from (Fig 2) that the daily water evaporation under treatments exhibited similar trends. A high fluctuation can be observed approximately during the first and the last week of the experiment. This means that the daily pan evaporation cycle repeats itself with considerable changes. A high jump in pan evaporation can be observed during 4 and 18 days from the commencement of the experiment. As indicated in (Fig 2) on a given day, the pan evaporation under the control treatment is superior to those under the covered water surface irrespective of the type of treatment. To go more deeply into the analysis, the cumulative pan evaporation was plotted against elapsed time and the results were displayed in(Fig 3) As can be noticed from (Fig 3), the cumulative evaporation increased linearly with an increase in time irrespective of treatment. Under any treatment, the linear relationship explained about cent percent of the variation in cumulative evaporation on account of variation in time. However, it was observed that the pan evaporation was reduced in the following order: Small balls > Combination balls > large balls > Control

Close examination of Table (1) shows that the predicted average rates of evaporation during the period of the experiment were 15.54, 6.22, 8.49 and 7.85 mm respectively.

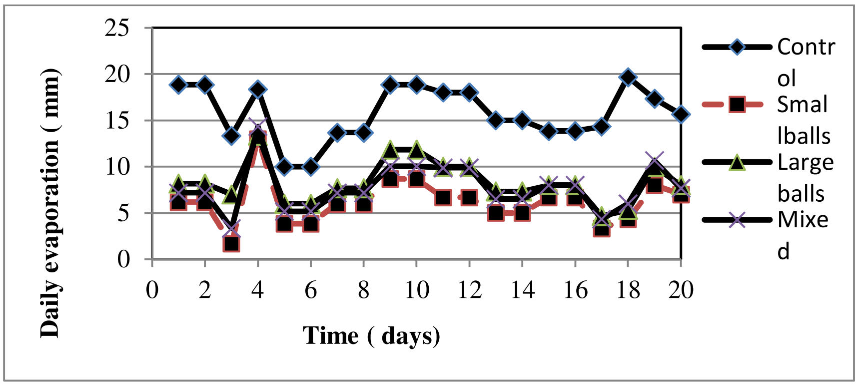

Figure 2 Pan evaporation as affected by covering the water surface with ball of different sizes.

Dunnett's t–test revealed that the pan evaporation under any of the applied treatments differed high significantly from that under the control treatment. The percent of reduction ranged between a minimum of 47.14 to 60.81%, Table 2. It is praiseworthy to mention that among above treatments, small ball with a diameter of 4 cm can be considered as an effective candidate as a suppressant for reducing evaporation from free water surfaces.

2. Evaporation suppression as affected by covering the water surface with different local materials during experiment #2

It is evident from (Fig 4) that the daily pan evaporation is characterized by a high fluctuation over the study period. This is particularly true under the control treatment. The high oscillation is due to fluctuation in external evaporatively or fluctuation in the evaporation controlling factors, mainly air temperature and wind speed.

In addition, it can be noted that the drawn curves tended to overlap to a higher extent compared with those of Experiment No.1. To further evaluate the effectiveness of different shading materials, the cumulative evaporation was plotted versus elapsed time under the employed treatments. It can also be observed that there was a marked reduction in pan evaporation under date palm mat shading followed by Washingtonian fronds. However, daily evaporation under the treatments can be arranged in the following descending orders: Control > Reed stems > Washingtonian fronds > date palm mat. Also, it is evident that the linear model attributed about 99% of the variation in cumulative pan evaporation to variation in time (Table 3). Daily pan evaporation under both Ornamental Washingtonian fronds and date palm mat treatments differed high significantly ($P \leq 0.01$) from that under control treatment, whilst the pan evaporation under reed stem differed significantly ($P \leq 0.05$) from that under control treatment (Table 4).

It can also be elucidated from Table 4 that the percent of reduction ranged from a minimum of 34.12% under reed stem to a maximum of 59.48% under the date palm mat. These findings are in concord with findings of [7], who found that the evaporation can be reduced by 47% under shading by a single layer of palm fronds and by 58% by the use of double layer cover.

In the light of the above study, it is concluded that the date palm mat sheet can be a promising shading cover or the likeliest candidate to reduce evaporation from the water surface. The strengths of this approach are date palm is widely distributed across the central and southern parts of the country and the date palm leaves and fronds are considered as disposed of waste after pruning.

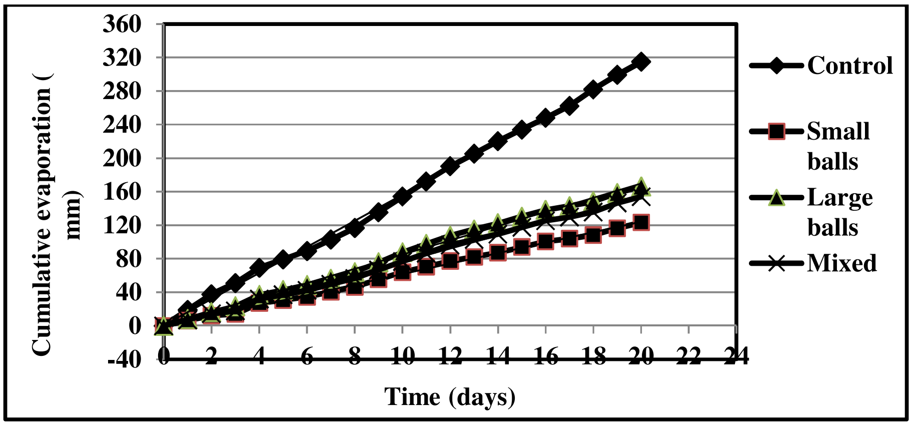

Figure (3) Cumulative pan evaporation as affected by covering the water surface with plastic balls of different sizes during experiment No.1.

Table 1 Regression analysis showing the relationship between cumulative evaporation and elapsed time during experiment No.1

Treatment	Regression equation	R^2	Average rate of evaporation (mm day^{-1})
1. Control	Epan = 0.936 + 15.54 t	0.998	15.54
2.Smal balls	Epan = -0.532+ 6.224 t	0.996	6.22
3. Large balls	Epan = 0.203 + 8.489 t	0.996	8.49
4. Combination of small and large balls	Epan =-2.049+7.847 t	0.997	7.85

Table (2) Summary of Dunnett's t-test and percent of reduction in daily evaporation rate due to different treatments over control in experiment No.1

Treatment(Ti)	Average evaporation rate(mm day^{-1})	Absolute difference |Ti-T1|	Percent of reduction with respect to control = [100 |T1-Ti|] /T1]
Control (T1)	15.73	0.00	0.00
Small balls (T2	6.17	9.57	60.81
Large balls (T3)	8.32	7.42	47.14
Mixed (T4)	7.71	8.03	51.02

$$D(0.05) = t - \text{Dunnett} \quad (3, 8, 0.05) \sqrt{\frac{2\ MSe}{r}} = 2.94. \sqrt{\frac{2 \times 0.542}{3}} = 1.77$$

$$D(0.01) = t - \text{Dunnett} \quad (3, 8, 0.01) \sqrt{\frac{2\ MSe}{r}} = 4.06. \sqrt{\frac{2 \times 0.542}{3}} = 2.44$$

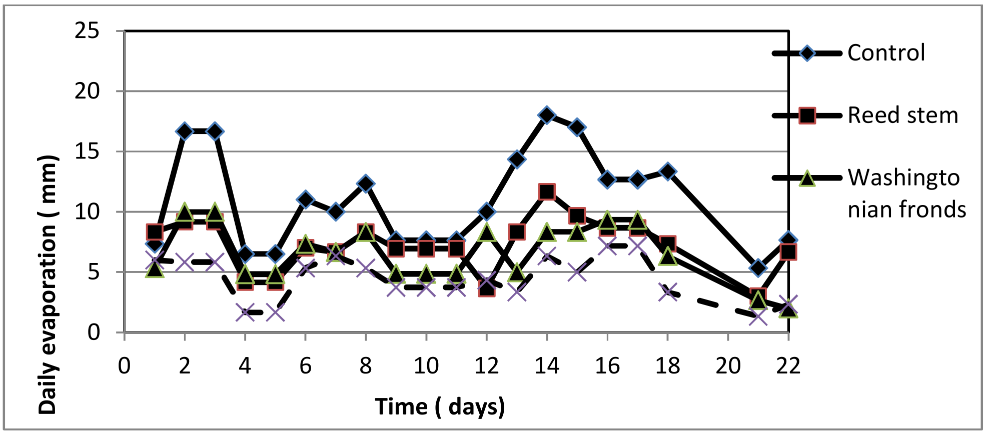

Figure (4) pan evaporation as affected by treatment with different local materials during the period of experiment No.2.

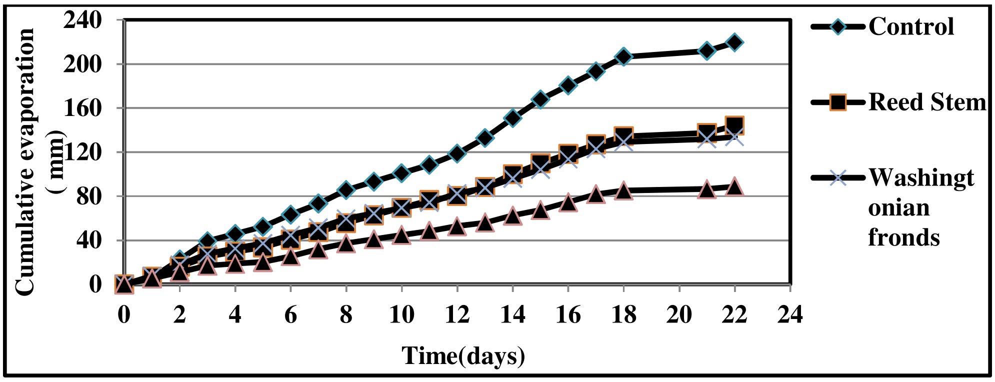

Figure (5) Cumulative pan evaporation as affected by covering the water surface with different indegeneous materials during experiment No.2.

Table 3 Regression analysis showing the relationship between cumulative evaporation and elapsed time during experiment No.2

Treatment	Regression equation	R^2	Average rate of evaporation (mm day^{-1})
1.Control	Epan = 0.476 + 10.57t	0.987	10.57
2. Date palm mat	Epan = 1.85 + 4.295 t	0.986	4.295
3. Washingtonian fronds	Epan = 5.727 + 6.394 t	0.986	6.394
4. Reed stems	Epan = 1.282+ 6.902 t	0.989	6.902

Table 4 Summary of Dunnett's t-test and percent of reduction in daily evaporation rate

Treatment(Ti)	Average evaporation rate (mm day^{-1})	Absolute difference |Ti-T1|	Percent of reduction with respect to control = [100 |T1-Ti|] /T1]
Control (T1)	11.04	0.00	0.00
Date palm mat (T2)	4.47	6.57	59.51
Washingtonian fronds (T3)	6.58	4.46	40.40
Reed stems (T4)	7.27	3.77	34.15

$$D(0.05) = t - \text{Dunnett} \quad (3, 8, 0.05)\sqrt{\frac{2\ MSe}{r}} = 2.94.\sqrt{\frac{2 \times 1.60}{3}} = 3.03$$

$$D(0.01) = t - \text{Dunnett} \quad (3, 8, 0.01)\sqrt{\frac{2\ MSe}{r}} = 4.06.\sqrt{\frac{2 \times 1.60}{3}} = 4.19$$

Further, it is environmentally friendly and capable of withstanding extremely weather conditions of arid regions [7]. In contrast, the weaknesses are the difficulty of implementation and instability under gusty wind conditions.

3. Evaporation suppression as affected by covering the water surface with different local and synthetic materials during experiment No. 3

The plotted data presented in (Fig 6) show the average daily evaporation during Experiment III over a period from Sept 17 to Oct 13, 2016, under covering with different materials. The covering materials (treatments) encompassed: Control (Uncovered), licorice branches 2-cm in thickness, cork disks, and cardboard sheet. It can be observed from (Fig 6) that the drawn curves cannot be represented by smooth curves. These curves exhibited the highest fluctuation compared the plotted curves belonging the other experiment. The fluctuation is very profound under the control treatment. As stated before, the high fluctuation in external. Evaporative may responsible for the profound fluctuation in pan evaporation during the period of the experiment.

Albeit, at a given date the evaporation rate under the control treatment is superior to those under the other treatments, the curves under the remaining treatments are overlapped or interlocked. This is an indication of insignificant differences between the treatments excluding the control treatment.

The obtained data from experiment 3 were re-plotted in term cumulative evaporation versus time and the results were presented in (Fig 7). As can be noticed from (Fig 7) the curves start to diverge with an increase in time. Furthermore, regression analysis showed that the linear relationship attributed more than 92% of the variation in cumulative evaporation to a variation in time under the study treatments.

Additionally, it can be discerned from the above results that the cardboard treatment proved to be the most effective suppressant in this experiment compared with the other treatments. However, over the period of the experiment the order of the treatments effectiveness being: Cardboard sheet > Disks of cork > Licorice branches > Control. The percent of the reduction in pan evaporation ranged from 38.91% under licorice leaves treatment to 54.74% under the cardboard treatment. With no exception, the average daily pan evaporation under all the treatments differed high significantly ($P \leq 0.01$) from that under the control treatment.

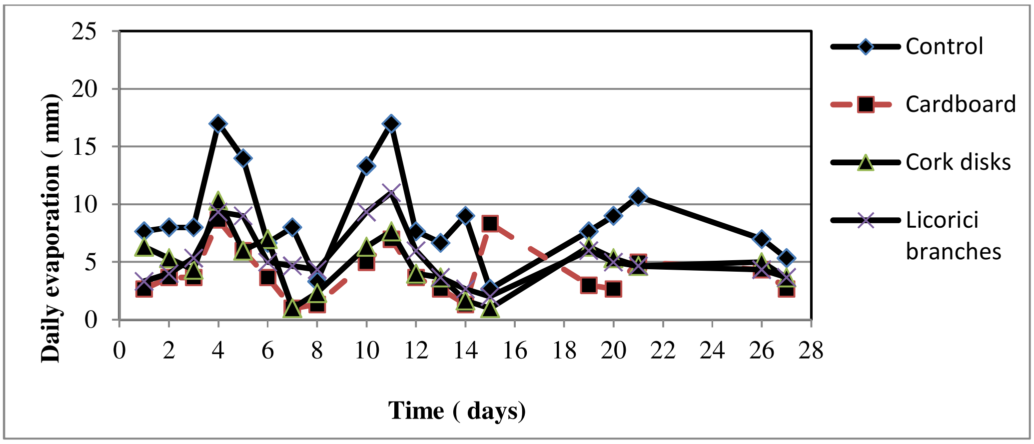

Figure 6 Pan evaporation as affected by treatment with different local materials during the period of experiment No. 3.

Table (5) Regression analysis showing the relationship between cumulative evaporation and elapsed time during experiment No.3.

Treatment	Regression equation	R^2	Average rate of evaporation (mm day^{-1})
1. Control	Epan = 17.35 + 6.435 t	0.938	6.435
2. Licorice branches	Epan = 9.507 + 4.044 t	0.928	4.044
3. Disks of cork	Epan = 12.55+ 3.318t	0.936	3.318
4. Cardboard sheet	Epan = 0.404+ 2.893 t	0.995	2.893

4. Evaporation suppression as affected by different rates of monolayer application during experiment No. 4

Fig 8 illustrates the comparison of pan evaporation under different application rates of fatty alcohol during the period from June 14 to July 13, 2016. The daily application rate ranged from 0 g $pan^{-1}day^{-1}$ under control treatment to 0.339 g $pan^{-1}day^{-1}$ under the fourth treatment with a concentration interval of 0.113 g $pan^{-1}day^{-1}$ As (C3) indicated, all the treatments responded similarly to atmospheric evaporation demand. Furthermore, the results indicated that the daily evaporation under the treated waters did not differ appreciably from that under the control treatment at the early stage of evaporation, while the difference became more significant after 8 days from evaporation commencement. This implies that the lower the atmospheric evaporation demand; the lower would be the treatment performance. In other words, the treatments that appeared quite promising in the middle of the summer season became much less effective early in summer season.

By contrast, Gallego - Elvira et al., (2013) [8] showed that high temperatures and high incoming radiation negatively affected the persistence of the condensed monolayer and decreased product performance. The declivity in evaporation reduction percentage as the water temperature increase may be attributed to factors. At high water temperature, more water molecules have higher kinetic energy and have a better chance to penetrate the films and then escape to the air.

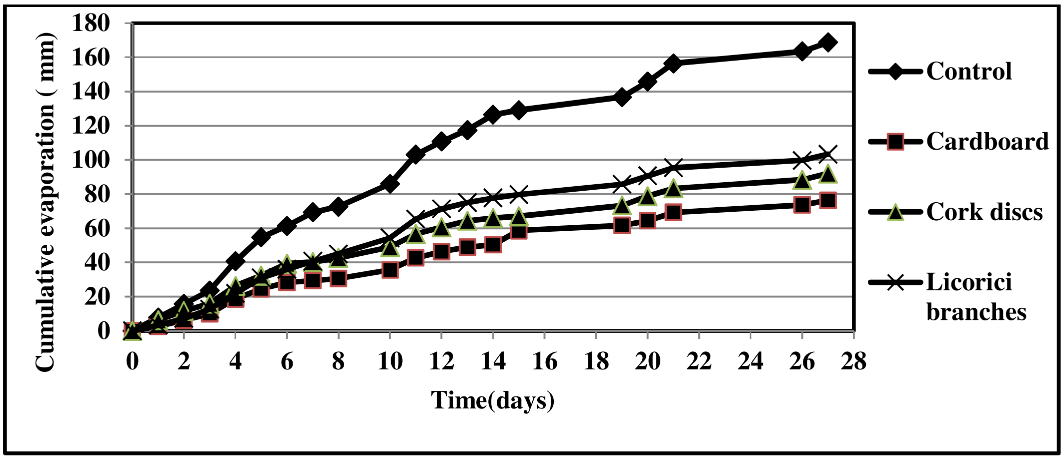

Figure 7 Cumulative pan evaporation as affected by different treatments during experiment No.3.

Furthermore, at high water temperature, the evaporation rate of the film becomes significant and deteriorates the film quality [9].To go in depth analysis, the data of experiment 4 was re-plotted as cumulative evaporation versus time and the results were illustrated in (Fig 9).

Table (6) Summary of Dunnett's t-test and percent of reduction in daily evaporation rate due to different treatments over control in Experiment No.3

Treatment(Ti)	Average evaporation rate (mm day^{-1})	Absolute difference |Ti-T1|	Percent of reduction with respect to control = [100 |T1-Ti|] /T1]
Control (T1)	8.87	0.00	0.00
Licorice branches, (T2)	5.42	3.45	38.90
Disks of cork (T3)	4.82	4.05	45.66
Cardboard sheets (T4)	4.01	4.86	54.79

$$D(0.05) = t - \text{Dunnett}\ (3, 8, 0.05)\sqrt{\frac{2\ MSe}{r}} = 2.94.\sqrt{\frac{2 \times 0.585}{3}} = 1.84$$

$$D(0.01) = t - \text{Dunnett}\ (3, 8, 0.01)\sqrt{\frac{2\ MSe}{r}} = 4.06.\sqrt{\frac{2 \times 0.585}{3}} = 2.54$$

As indicated by the data of (Fig 9), the divergence between evaporation curves under each of the monolayer treatments and that under control treatment tended to become wider with an increase in time, particularly, after about 10 days from evaporation commencement as stated before. Further, at a given date, the increase in monolayer concentration from 0.113 to 0.339 did not lead to an appreciable reduction in evaporation rate. Regression analysis showed that the average rate of evaporation represented by the slope of the regression line were 13.18, 10.52, 10.49 and 10.20 under the application rates of 0, 0.113, 0.226 and 0.339 g pan^{-1} day^{-1} respectively. Additionally, the results presented in Table 7 revealed that there was not a steady reduction in evaporation rate with an increase in monolayer application rate. The maximum reduction in evaporation rate occurred at an application rate of 0.226 g pan^{-1} day^{-1} (23.57%). The percent of reduction increased from 20.57 to 23.57% as the monolayer concentration was doubled. In a similar study, Al-Saud (2010) observed that the evaporation rate from surface water was reduced overall up to 47.2% to 50.5% when fatty alcohol was added at concentrations of 100 and 200 /1000 $m^{-2}day^{-1}$ respectively.

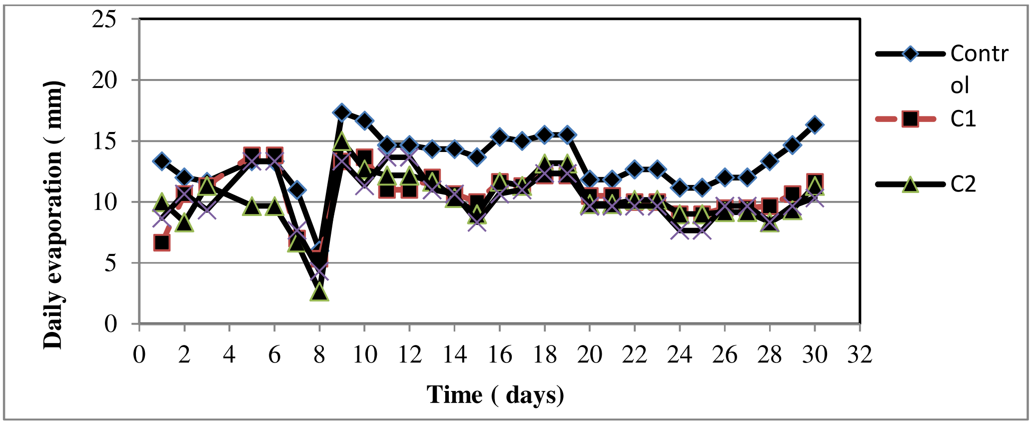

Figure (8) Pan evaporation as affected by different concentration of fatty alcohol during the period of experiment No.4.

It was also noticed from Table 4.10, that the evaporation rate under the entire application rate differed high significantly from that under the check treatment. As unexpected, a slight drop in percent of the reduction in evaporation rate occurred when the application rate increased from 0.226 to 0.339.
On the opposite, Kahalekar and Kumawat (2013)[10] observed that as the concentration of cetyl alcohol increased from 50 mg $m^{-}2$ day^{-1} to 150 mg m^{-2} day^{-1} the percent of the reduction in daily evaporation rate increased from 22.09% to 33.85%. However, existing evidence suggested that monolayer application rates may need to be up to three times those recommended by manufacturers to achieve satisfactory results [11].This signals that monolayer application rate should be increased to reduce the cuts in the monolayer film due to the wind effect, which creates voids in the surface of water allowing the surface to be without protection. Hobbs (1961)[12] revealed that in order to compensate for the higher water temperatures occurring during midsummer, heavier and more frequent treatment applications would be required to maintain evaporation control at a practical level. Albeit the evaporation reduction of around 24% due to monolayer application is much less than evaporation reduction under the treatments of the previous experiments, it still represents a significant saving for a water supply from a practical point of view. However, the treatments can be ranked as follows according to effectiveness: 0.226 g pan^{-1} day^{-1}> 0.339 g pan^{-1} day^{-1} > 0.113 g pan^{-1} day^{-1} > control. However chemical methods are not as effective as physical methods [13].

5. Comparison of some screened treatments which offered the best performance during the experiments 1 through No.4.

Since each of the four experiments had its own atmospheric evaporation demand, it was impossible to select the best evaporation retardants. Therefore, this experiment was conducted during the test period July 21 to August 3, 2016 representing 14 days of evaporation. Following the termination of experiment 4, the above test period was devoted to evaluating the performance of the following screened treatments: small plastic balls, date palm mat sheet and fatty alcohol with an application rate of 0.229 mg pan-1 day-1 along with check treatment under the same atmospheric external evaportivity. Approximately, the linear relationship attributed % of variation in daily pan evaporation to variation in time under each treatment. Furthermore, the results illustrated that the plotted curves tended to diverge with an increase in time,

particularly at the end of the experiment period (Fig 10). It is also evident from (Fig 10) that the order of preference of the treatments for evaporation suppression is as follows:
Small balls > Date palm mat > Monolayer > Control.

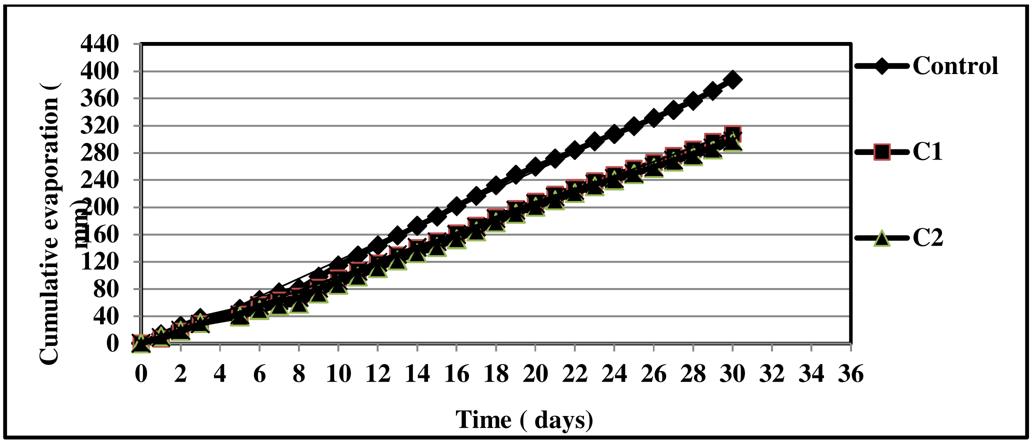

Figure (9) Cumulative pan evaporation as affected by different concentration of fatty alcohol during experiment No.4.

Table (7) Summary of Dunnett's t-test and percent of reduction in daily evaporation rate due to different treatments over control in Experiment No. 4

Treatment(Ti)	**Average evaporation rate(mm day^{-1})**	**Absolute difference |Ti-T1|**	**Percent of reduction with respect to control =[100|T1-Ti|] /T1]**
Control (T1)	13.35	0.00	0.00
C1 (T2)	10.60	2.75	20.60
C2 (T3)	10.20	3.15	23.60
C3 (T4)	10.24	3.11	23.30

$$D(0.05) = t - \text{Dunnett} \quad (3, 8, 0.05)\sqrt{\frac{2\ MSe}{r}} = 2.94.\sqrt{\frac{2 \times 0.342}{3}} = 1.40$$

$$D\ (0.01) = t - \text{Dunnett} \quad (3, 8, 0.01)\sqrt{\frac{2\ MSe}{r}} = 4.06.\sqrt{\frac{2 \times 0.342}{3}} = 1.94$$

Additionally, the findings of Table 8 revealed that the percent of reduction under these treatments varied between as low as 32.68% under the monolayer treatment to as high as 71.8. % under covering the pans with small plastic balls. It is also evident from Table 8 that the pan evaporation under each of the screened treatments differed high significantly ($P \leq 0.01$) from that under the check treatment. It is apparent from the above results that a considerable amount of water can be saved through applying one of this treatment to control evaporation from water surfaces of the existing ponds and dams in the region. Saved water may lead to an increase in the cultivated area [14].

6. The Field Experiment

Fig 11 depicts the water losses from the field tests as affected by an application rate of 0.20 g m^{-2} day^{-1} of fatty alcohol at Mergapan during a time interval from 7 August to 18 August 2016. Seepage was measured because it was impossible to measure evaporation alone. The measured seepage was subtracted from the total water loss to measure the water loss due to evaporation. On average the evaporation losses under the untreated and treated water were 15 and 4.68 mm day $^{-1}$ respectively.

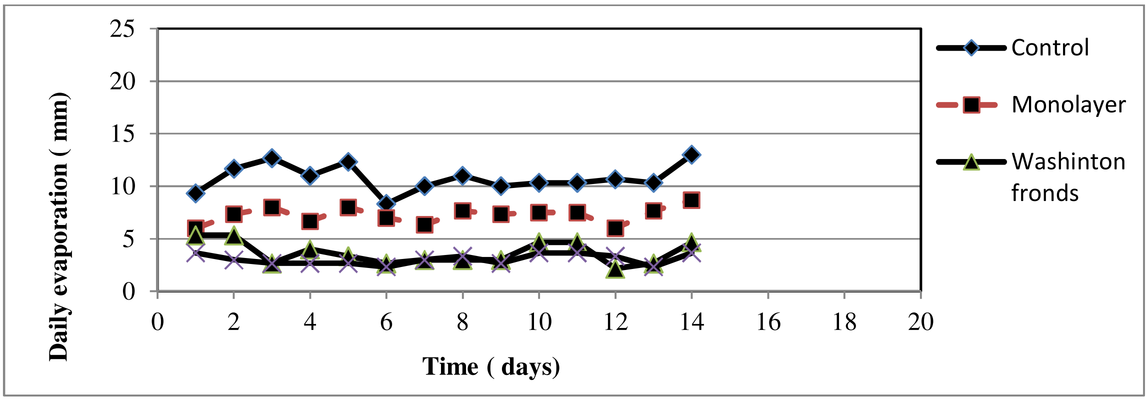

Figure 10 pan evaporation as affected by different treatments during the period of experiment No.5.

On average, the percent of the reduction in evaporation due to monolayer application was estimated as 69%. Lower percent of reduction would be expected when the experiment lasts for a longer period because the weather was calm during the study period. The wind speed ranged from 1.5 to 2.5 m s^{-1} Apart from this result, Saggai et al. (2013) [15] observed that the best evaporation reduction rate was registered in case of a mixture of hexadecanol (cytel alcohol) and octadecane (stearyl alcohol) (24%). Further, they concluded that in suitable conditions evaporation losses were reduced by up to 60%.

It seems from the above results the performance of monolayers to reduce evaporation depends on the substance used to form the monolayer and the prevailing conditions. For instance, Fitzgerald and Vines (1963) [16] noticed that evaporation savings of 10 -20% were found with winds up to 16 km h^{-1} to 0% at 24 km h^{-1}. It was also noticed that the monolayer offered a higher performance during the field tests compared to that obtained during the pan evaporation experiments. The higher performance of the monolayer application during the field experiment can be ascribed to its lower water temperature compared to those of the pan evaporation experiments.

The water temperature was in neighborhood of about 20 ^{o}C during the storage tests. On the other hand, the water temperatures were 23 and 25 ^{o}C during the experiments IV and V, where fatty alcohol was used. The percent of evaporation reduction due to the application of fatty alcohol at an application rate of 0.339 g pan^{-1} during experiment IV and V were 23 and 33% respectively. Previous studies revealed that there was a fall in the reduction of evaporation with the rise of water temperature, from about 60% at 20 ^{o}C through about 35% at 30 **^{o}C** to about 15 % at 60 ^{o}C [17]. Albeit, the chemical treatment did not offer the highest performance during the previous pan evaporation experiments, it was used to extrapolate the pan tests to the storage tests. One justification is the ease of implementation on a larger scale. It is also noteworthy to mention that the use of fatty alcohol as an evaporation suppressant has limited impact on aesthetics but are less efficient than physical structures. Further, the chemical treatment is less permanent, but it can be implemented easily. Based on a rate reduction of 10.32 mm day^{-1}, the depth of saved water during the summer months from June 1 to August 31 will be 950 mm. However, any savings gained by reducing evaporation losses could significantly improve overall the agricultural use efficiency of the region. Accordingly, it is believed that it is highly feasible and cost effective to apply the fatty alcohol on a large scale to the existing earthen ponds and reservoirs of Iraqi Kurdistan region to reduce water loss through evaporation from water surfaces.

Table (8) Summary of Dunnett's t-test and percent of reduction in daily evaporation rate due to different treatments over control in experiment No.5

Treatment(Ti)	**Average evaporation rate (mm day^{-1})**	**Absolute difference |Ti-T1|**	**Percent of reduction with respect to control = [100 |T1-Ti|] /T1]**
Control (T1)	10.78	0.00	0.00
Small balls (T2)	3.04	7.74	71.80
Date palm mat(T3)	3.66	7.12	66.08
C3(T4)	7.26	3.52	32.68

$$D(0.05) = t - \text{Dunnett}\ (3, 8, 0.05)\sqrt{\frac{2\ MSe}{r}} = 2.94.\sqrt{\frac{2 \times 0.072}{3}} = 0.64$$

$$D(0.01) = t - \text{Dunnett}\ (3, 8, 0.01)\sqrt{\frac{2\ MSe}{r}} = 4.06.\sqrt{\frac{2 \times 0.0.072}{3}} = 0.89$$

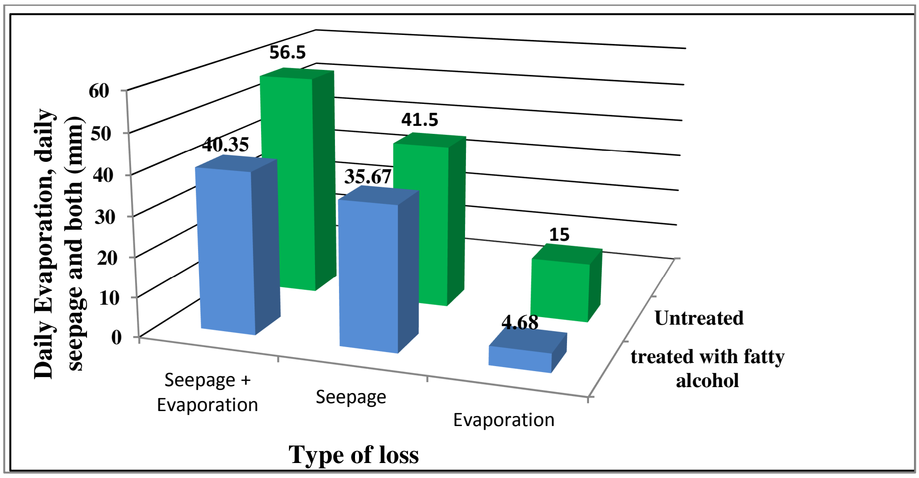

Figure (11) Evaporation suppression from a stationary water pool as affected by treatment with fatty alcohol during August, 2016

Conclusion

1. Evaporative losses constitute a substantial amount of total stored water leading to low water storage efficiency in the region under study.
2. The performance of plastic ball as evaporation retardant increases with decrease in its size.
3. There was no a steady increase in evaporation reduction over the range of monolayer concentration from 0.00 g pan^{-1} day^{-1} to 0.339 g pan^{-1} day^{-1}
4. Among the tested synthetic materials, small balls (D= 40 mm) offered the highest performance.
5. Among a host of indigenous materials as evaporation retardants, the date palm mat can be considered as the most effective materials.
6. When both effectiveness and ease of implementation are taken into consideration, the fatty alcohol at a concentration of about 0.226 g pan^{-1} day^{-1} can be considered as the best treatment for reducing evaporation from free water surfaces on a large scale.

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