EXPERIMENTAL ANALYSIS OF EVAPORATION SUPPRESSION TECHNIQUES IN GHOR SAFI-JORDAN.

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ABSTRACT

Evaporation suppression studies are very essential in arid (annual rainfall < 400 mm) and semi-arid (annual rainfall 400~750 mm) regions, like most of the Arab world. Also they are specially important in hot places like the Rift Valley in Jordan where the major irrigation projects are either in operation, or in the process of being implemented. Ghor Safi the hottest region of the Rift Valley, and the lowest was the location of studying experimentally four affordable simple evaporation suppression techniques for three consecutive years (1995-1997). The techniques were as the following floating Styrofoam, floating Rubber foam, Pans filled with sand and stream aggregates, and floating empty plastic canisters. The average evaporation reduction results ranged from 22.26 percent to 49.97 percent. These results are promising, important, and encourage further experimentation and usage in farm ponds.

Keywords: Evaporation suppression, Styrofoam, Rubber Foam, Aggregates, Canisters.

INTRODUCTION

The mean rate of potential evaporation in most of the Arab world is several times the local precipitation. This is specially true in Jordan Rift Valley, where most Irrigation Projects either in operation or under construction. Most farmers of the Jordan Rift Valley use open ponds of variable sizes to store water to be used between their turns of water shares. These ponds are open to a very hot climate, specially in Ghor Safi, which is the lowest place in earth, and the hottest in Jordan (Elevation -350; Lat. N 31° 05': and Long. E 53°28').

These extreme conditions make evaporation suppression studies very important for water resources development. Also the evaporation loss influences pond design, operation and management. Most farmers know the importance of evaporation but they have never tried to quantify that.

Evaporation reduction practices were known in Jordan, most of the Arab world and many hot regions such as India. For more than two thousand years people were used to store water underground or cover pools by wood frames to prevent evaporation of precious water. On the other hand, experimenting on evaporation suppression techniques started with Benjamin Franklin more than 200 years ago in England [1] He covered a pond of water with oil film, which insoluble in water.

Most of the research has been done on chemical films such as hexadeconal (Cetyl alcohol) which form insoluble layers of one molecule thick on water surface [2, 3]. In perfect conditions, evaporation reduction could go as high as 70%, but in practical conditions with wind and waves, the reduction went as low as 20% in ponds in Australia (Fietz, 1976). The chemical film technique required continuos surveillance to ensure unbroken layer. Moreover, it was studied thoroughly in different climates of the world. Therefore, it was excluded in the current experimental study.

The present study concentrated on simple usable, affordable, and durable techniques to suppress evaporation from open water bodies specially, ponds. Since wind correlation with evaporation from Class-A pan was very low, this study excluded experimenting with wind barriers of different heights.

Results showed that techniques of best results were the floating Styrofoam either as balls or as pieces (2.5*2.5 cm) from used boxes. Their white color reflected most of the incoming radiation besides their ability to insulate water surface against outside heat and internal vapor diffusion. The reduction of the evaporation was around 50%. The second best was the pan filled with light color sand with water kept 10 cm below sand surface. The reduction of evaporation was 44.8 percent. The evaporation reduction of the gravel aggregate pans were around 37 percent, which is close to the results of the rubber foam pans. The white painted empty plastic canisters had better results than the transparent canisters due to radiation reflectivity, but both were lower than the other techniques due to the uncovered surface between the canisters.

METHODS

Measurements Versus Modeling

Even though theoretical and empirical modeling of evaporation with climatological factors gave great insight into the evaporation phenomenon [4,5], the popularity of using Pans, specially Pan A for the purpose of evaporation measurements is increasing. Most equations theoretical or empirical based on energy budget, water budget, aerodynamic or combined methods overestimate evaporation [6,7]. They need re-calibration and any error in the parameters of meteorological data rende these equations of limited use.

Therefore, Pan A with some limited variations was used in this study. It is inexpensive, simple to instrument and generally have the annual ratio of lake-to-Pan evaporation reasonably constant from year to year, and from region to region [8].

Correlation of Pan A with Climatological Factors

Pan A measurements of Ghor Safi station for the years 1995, 1996, and 1997 were taken as basis for comparison, and for evaporation reduction calculations of the used evaporation suppression techniques (Table 1). Pan A measurements were correlated with several climatological factors like monthly mean maximum temperature, monthly mean temperature, monthly mean global solar radiation, monthly mean sunshine hours per day, relative humidity, wind speed, and atmospheric pressure. These correlations were compared with the correlations of measurements of the evaporation suppression pans [9,10]. Since green area width around all evaporation suppression pans was the same in this study, its effect was excludes in this experiment.

Evaporation Suppression Pans

The experimental pans were taken to be identical with Pan A. They were made of unpainted galvanized iron (122 cm) in diameter, 25.4 cm deep [11, 12] except for the Pans which were filled by sand and gravel, the depth was 30.4 cm to allow for 10 cm of sand or gravel above the water level in the Pans. They were mounted on wooden frames to let air to circulate beneath them. They were always filled to a depth of about 20 cm including the capillarity fringe for Pans filled with aggregates. Measurements of all Pans were done daily by a hook gage for continuous monitoring of the evaporation process. The following items are the used evaporation suppression techniques :

Table 1 Correlations of evaporation of Pan A and evaporation suppression techniques with related meteorological factors

Pan	Temp Mean C°	Wind Speed Mean Km/Day	Realtive Humidity %	Sun Shine Mean hrs/Day	Temp Mean Max C°	Mean Global Solar Radiation J/Cm²	Atmospheric Pressure Mean HPa
A	.925	.088	-.893	.965	.954	.938	-.916
A1	.883	.088	-.864	.925	.898	.893	-.848
A2	.928	.073	-.894	.966	.955	.935	-.912
B1	.925	.082	-.896	.963	.952	.939	-.917
B2	.925	.088	-.896	.964	.953	.935	-.917
C1	.924	.083	-.900	.963	.950	.941	-.914
C2	.923	.086	-.890	.959	.952	.931	-.915
C3	.920	.098	-.887	.954	.949	.927	-.914
D1	.915	.109	-.889	.958	.944	.934	-.916
D2	.922	.094	-.888	.958	.949	.930	-.913

Floating Styrofoam

Two different types, physically not chemically, of styrofoam were used as covers over the water surface of the experimented pans.

A1- Polystyrene foam balls (0.4cm) diameter. Two layers were placed to make sure that the exposed water is minimum.

A2- Polystrene foam pieces (2.5*2.5 cm) taken from used boxes. They were put together tightly to minimize uncovered water surface.

Floating Rubber Foam

Two colors of artificial light rubber with internal foam were used to cover water in two Pans.

B1- White floating rubber foam was used to check the effectiveness of white color reflectivity.

B2- *Brown floating rubber foam was used as* a contrast to the white color to check the albido effect of darker colors.

Pans Filled with Aggregates

Three types of common concrete aggregates are used to fill three Pans. They were similar to Pan A in their diameters and metals, but their depth was 30.4 cm instead of 25.4 cm of the typical Pan A. The extra 5 cm was added to allow for deeper aggregate cover above the water levels in the Pans.

These techniques are practised successfully in dry regions in South Africa and India. When the water level goes more than 50 cm below the sand surface level, evaporation ceases in sand reservoirs in both countries.

C1 - Light Colored Sand
It was between yellow and white with nominal diameter of 0.25 mm filling the Pan to 30 cm level. Water was added to maintain 20 cm level.

C2 - Grey Local Stream gravel
It was stream gravel with nominal diameter of 2.5 mm The C2 Pan was filled like C1.

C3 - The Same as C1, but with nominal diameter equal 5 mm for the Grey local stream gravel.

Floating Empty Plastic Canisters-

Plastic canisters colored or transparent *could* be used to suppress evaporation. This technique had been tried in several dry places in the world, specially in Arizona with a small lake covered with 250,000 empty plastic canisters (Brooks et at 1991).

D 1- White painted canisters were used in this experiment to explore the effects of reflectivity on evaporation

D 2 - Transparent canisters were used in this experiment to explore the effects of transmissivity and transparency

DISCUSSION

Evaporation Reductions Percentages Using Suppression Techniques

Table 2 presents a summary of the evaporation reduction percentages statistics. The percentage of reduction is calculated monthly by subtracting the evaporation of certain suppression technique pan from Pan A evaporation, and dividing the result by Pan A evaporation. Percentage of reduction varied from about 50.0% for A2 Polystyrene foam pieces to 22,45% for D2 transparent canisters.

Heat insulation and high reflectivity effects of the floating Styrofoam were the causes of that high percentage of reduction. This technique is effective and inexpensive but its light weight renders it limited to small ponds where wind effect is not substantial [3, 13]

The second best is C1 which is the light colored sand, 0.25 mm nominal diameter. The reduction was 44.8%. The evaporation suppression was due to limiting the evaporation opportunity which was the availability of water to be evaporated. A layer of sand was left dry to reduce the evaporation opportunity by limiting the effects of direct radiation, direct convective heating and direct mass transfer of vapor molecules. Even though the dry layer for the light color sand was equal to the two Grey gravel types, the percentage of evaporation reduction was substantially different. This was due to the difference in the pores sizes between the grains where the incoming heat and the outcoming vapor molecules take their routes.

The only problem with sand technique is the limited size of the used water. The sand void ratio was 48%, the 2.5 mm gravel was 50%, and the 5mm gravel was 51%. Around 50%of the water storage should be filled by sand or aggregates. This fact necessitates doubling the size of the water storage facility.

Correlation of Pan A with climatological Factors

Evaporation readings of Pan A were used as reference for the readings of the Pans of evaporation suppression techniques. Therefore, Correlating Pan A readings with the climatological factors of Ghor Safi was the basis for choosing, monitoring, and analyzing the evaporation suppression techniques (Table 1). Also, comparing the used techniques puts the results in perspective as in Table 3.

Table 2 Descriptive statistics of percentage of reduction in evaporation suppression pans

	N	Mean	Std. Deviation		Skewness	
	Statistic	Statistic	Std. Error	Statistic	Statistic	Std. Error
Reduction A1 %	36	48.822	.259	1.553	.691	.393
Reduction A2 %	36	49.969	.276	1.657	.788	.393
Reduction B1 %	36	38.906	.423	2.537	-3.822	.393
Reduction B2 %	36	38.000	.314	1.886	1.886	.393
Reduction C1 %	36	45.275	.498	2.987	-2.455	.393
Reduction C2 %	36	37.725	.372	2.234	.244	.393
Reduction C3 %	36	35.603	.328	1.968	-.065	.393
Reduction D1 %	36	31.100	.368	2.208	.413	.393
Reduction D2 %	36	22.247	.433	2.597	-.443	.393
Valid N (listwise)	36					

Table 4 Correlations of reduction percentage in evaporation suppression techniques

	Reduction A1 %	Reduction A2 %	Reduction B1 %	Reduction B2 %	Reduction C1 %	Reduction C2 %	Reduction C3 %	Reduction D1 %	Reduction D2 %
Reduction A1 %	1.000	.731	.445	.412	.471	.423	.188	.143	.238
Reduction A2 %	.731	1.000	.395	.337	.350	.283	-.018	.101	.259
Reduction B1 %	.445	.395	1.000	.737	.636	.442	.226	.268	.424
Reduction B2 %	.412	.337	.737	1.000	.485	.548	.287	.437	.383
Reduction C1 %	.471	.350	.636	.485	1.000	.204	.206	.027	.049
Reduction C2 %	.423	.283	.442	.548	.204	1.000	.503	.146	.255
Reduction C3 %	.188	-.018	.226	.287	.206	.503	1.000	.511	.498
Reduction D1 %	.143	.101	.268	.437	.027	.146	.511	1.000	.788
Reduction D2 %	.238	.259	.424	.383	.049	.255	.498	.788	1.000

Pan A readings are highly correlated with certain factors (Table 1), such as mean hours per day of sunshine the mean monthly maximum daily temperature, the mean monthly global solar radiation, and the mean monthly temperature. They were negatively correlated with atmospheric pressure and relative humidity. Their correlation with the monthly mean wind speed (km/day) was negligible.

The clear skies most of the year and the persistent high temperature for long hours made the duration of sunshine, the mean maximum temperature, and the mean global solar radiation to have the highest correlation with Pan A readings [4,16] and Tang *et al*, 1993). It was known that these factors are interdependent, but this study treated them separately for deeper exploration for the factors affecting the evaporation process, in order to choose the proper evaporation suppression technique for such hot dry climate.

These three interrelated factors have the major effect on evaporation in this hot dry climate of Ghor Safi. They have a *double-fold effect* on evaporation. Firstly, they provided most of heat energy required for evaporation. Secondly, they lowered the latent heat of evaporation which is generally modelled as the following:

H_L = 597.3-0.564T (from Reference 6)

where T = temperature (C°) and

H_L = required latent heat in cal/gram.

The mean monthly temperature is highly correlated with evaporation, but in the fourth position after maximum temperature sunshine hours and global solar radiation. This shows that in very hot climates the means are not predominant factors, since the maximum temperatures have more effects on evaporation than the mean as found before experimentally [17].

Relative humidity (R_h=e/e_S), the ratio of actual and saturated vapor pressures, has a negative lower correlation than the previous factors. Its negative sign is expected, since the relative humidity gradient is the driving force of evaporation process, whenever relative humidity was low evaporation was regularly high. Also, R_h being lower than the other factors was due to the fact that this region is extremely dry most of the year, and the high temperature lowered the relative humidity by increasing e_S even in fairly humid days, since e_s is a function of temperature.

Atmospheric pressure is negatively correlated with evaporation, since higher atmospheric pressure induces lower evaporation. So, due to the low altitude of Ghor Safi, we expect an atmospheric pressure which suppresses evaporation. But this positive effect due to the negative correlation with evaporation is offset by the temperature rising due to lowering altitude. On the other hand, the variations of the atmospheric pressure from month to month, or from season to season were negligibible This fact rendered the atmospheric pressure in Ghor Safi not directly related to evaporation or evaporation suppression techniques as found in other similar locations [18].

Wind speed correlation with evaporation was negligibly low (Table 1). This could be explained by the fact that Ghor Safi is the lowest point on Earth, which tempered the wind speed specially closer to the ground surface. Also, the vicinity of the experiment area was covered densely by trees. Therefore, experimenting with wind barriers of several heights and directions relative to wind seasonal directions was discarded.

Correlation of Evaporation Suppression Techniques with Climatological Factors

For all evaporation suppression techniques, correlations of the mean sunshine hours per day were still the highest, with A2 even higher than A. All the rest of the techniques were slightly lower than A, with the A1 lowest. Also, the mean maximum monthly temperature was the second highest in the correlations with A. Only A2 higher tha A In the case of the solar radiation, only B1 and C1 were greater than A, while in mean temperature B1 and B2 equal A and A2 greater than A, and the rest are lower. In the case of relative humidity correlations A2, B1, B2, and C1 were greater than A, in the absolute sense of the correlation (Table 1).

Pan A correlations with climatological factors were mostly greater than most of the evaporation suppression techniques correlations, due to the fact that these techniques are intended to limit the effects of these factors on evaporation by being radiation shelters, reflectors, and heat insulators. On the other hand, correlations with the mean monthly temperature and the relative humidity were not affected much due to the storage effects of the body of the evaporation suppression techniques on the escaping water vapor and on the incoming heat.

But in certain cases the vapor storage and heat storage in the suppression techniques offset the sheltering and reflecting effects, and allow prolonged diffusion of vapor even after the relatively cooler evenings (Table 4).

Table 4 Descriptive Statistics of Pan A and Evaporation Suppression Pans

Evaporation	Range	Minimum	Maximum	Sum	Mean	Std. Deviation	Variance	Skewness
Pan	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic
A mm	284.6	59.5	344.1	6989.7	194.158	96.640	9339.302	.039
A1 mm	144.7	30.3	175.0	3473.9	96.497	48.314	2334.252	.134
A2 mm	141.7	28.3	170.0	3499.9	97.219	48.509	2353.143	.032
B1 mm	171.9	36.1	208.0	4347.9	120.776	60.062	3607.442	-.081
B2 mm	180.9	37.1	218.0	4428.9	123.025	61.090	3732.014	-.068
C1 mm	155.9	32.1	188.0	3792.9	105.358	51.929	2696.575	.025
C2 mm	170.9	38.1	209.0	4339.9	120.553	60.785	3694.832	.008
C3 mm	189.9	38.1	228.0	4486.9	124.636	61.811	3820.593	.053
D1 mm	205.9	42.1	248.0	4817.9	133.831	66.968	4484.757	.065
D2 mm	236.9	46.1	283.0	5434.9	150.969	75.729	5734.814	.090

Trends of reduction Percentages

As apparent in the trend of Figures 1 to 9, most evaporation suppression techniques had some kind of increasing trends, except for A2 which had essentially constant reduction percentages through out the 36 months, and C2 which was slightly decreasing.

The floating Styrofoam pieces (A2) were completely packed and did not need clogging or cementing by wet dust like the floating Styrofoam balls (A1). However, the edges of the Styrofoam pieces deteriorated throughout time which offset any cementing effects. Therefore, it was understandable to have A1 with increasing trend and A2 with slightly horizontal trend. On the other hand, (C2) the (2.5) mm grey gravel had a slightly decreasing trend because cementing and clogging effects were offset by the albido effect of the color becoming darker. Since the poreholes of C3 gravel were larger than C2, the cementing effects offset the albido effects.

The mostly increasing trend indicated some kind of an increasing effectiveness of the reduction techniques. Actually throughout time, the dust and moisture produced some kind of clogging glue which enhanced the ability of the technique to prevent convective heat from entering and to prevent vapor from escaping. But in the case of D1 and D2 the evaporation reduction increasing trends were clearly high due to the fact that the empty plastic canisters gained more flexibility with time through the direct solar heating. This flexibility allowed for more compact packing by minimizing the uncovered water surface. When the solar heating reduced the covered water surface by reducing the size of the empty plastic canisters, more canisters were added to insure compact packing.

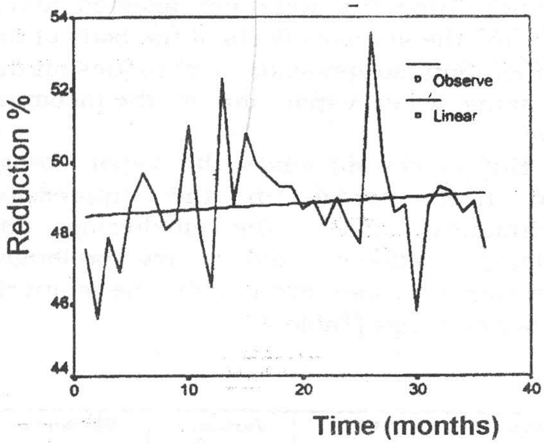

Figure 1 Trends in percentage of reduction for evaporation suppresion Techniques (Technique A1)

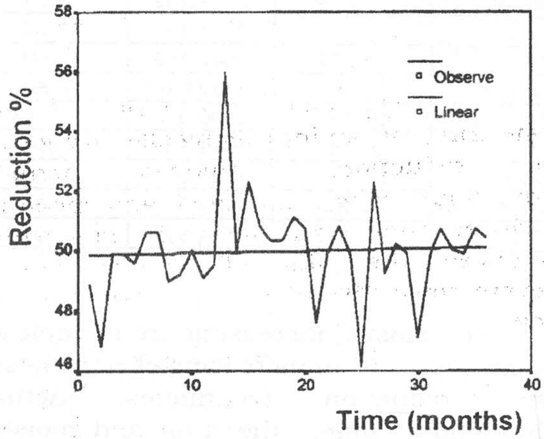

Figure 2 Trends in percentage of reduction for evaporation suppresion Techniques (Technique A2)

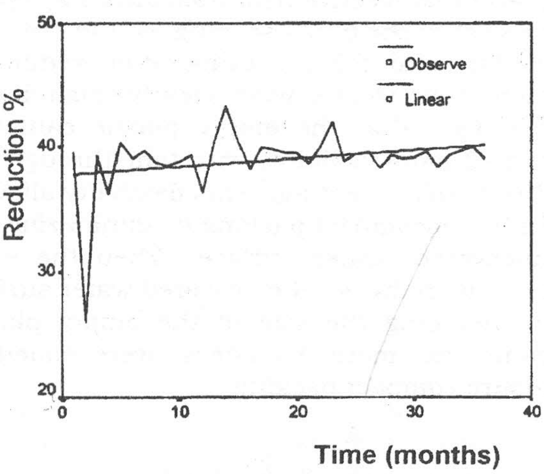

Figure 3 Trends in percentage of reduction for evaporation suppresion Techniques (Technique B1)

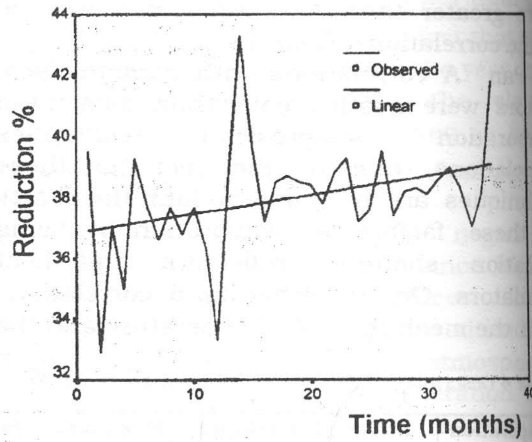

Figure 4 Trends in percentage of reduction for evaporation suppresion Techniques (Technique B2)

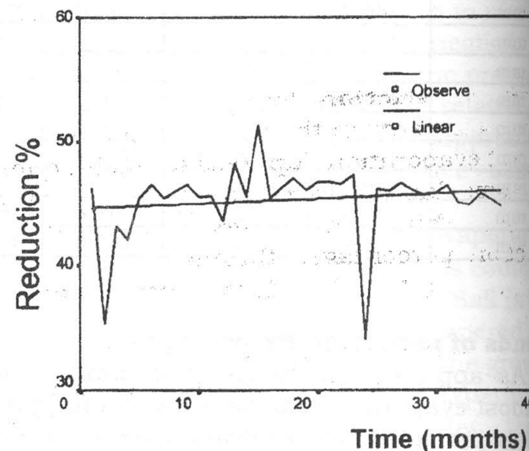

Figure 5 Trends in percentage of reduction for evaporation suppresion Techniques (Technique C1)

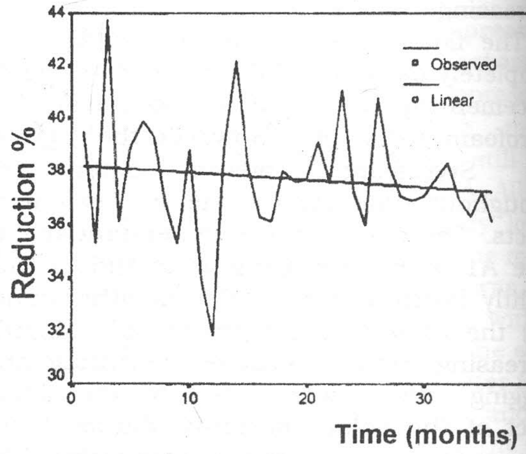

Figure 6 Trends in percentage of reduction for evaporation suppresion Techniques (Technique C2)

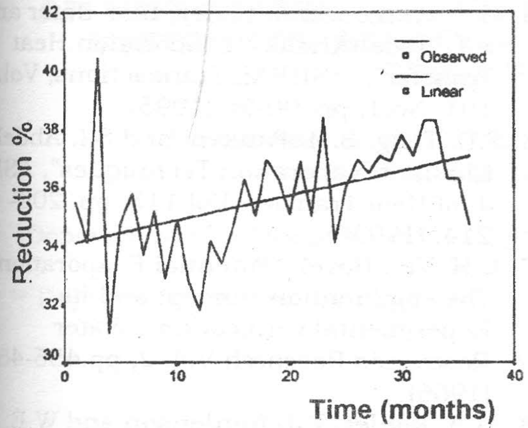

Figure 7 Trends in percentage of reduction for evaporation suppresion Techniques (Technique C3)

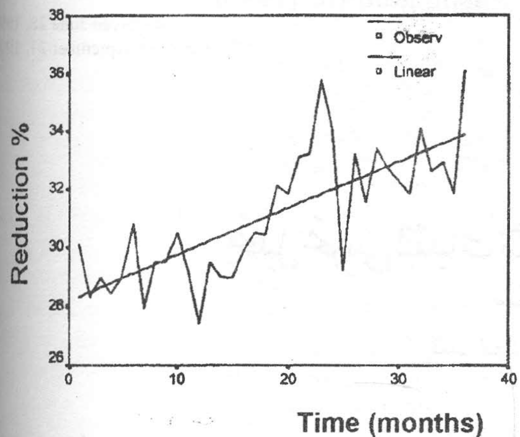

Figure 8 Trends in percentage of reduction for evaporation suppresion Techniques (Technique D1)

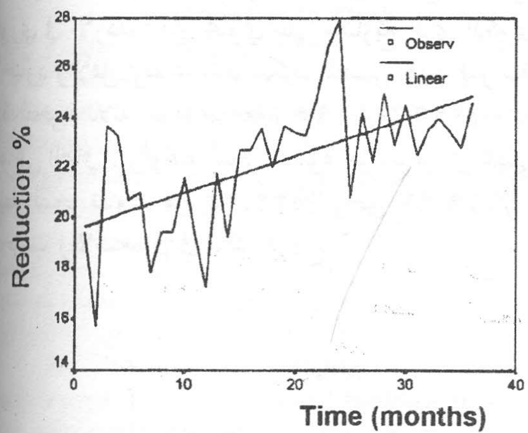

Figure 9 Trends in percentage of reduction for evaporation suppresion Techniques (Technique D2)

CONCLUSIONS AND RECOMMENDATIONS

Reducing evaporation in Jordan worth extensive research and field trials. Evaporation suppression practices provides us with important inexpensive water resource. This experiment of four groups of evaporation suppression techniques in Ghor Safi, Jordan, indicated that evaporation can be reduce by inexpensive techniques for ponds and irrigation pools. The best technique was the floating styrofoam of foam balls, with 49.97% evaporation reduction, then foam pieces, with 48.82% evaporation reduction. The third was the sand pans, with 45.285% evaporation reduction. The other two evaporation suppression groups were less effective. This experiment could be done again in other climates, with different pan sizes, and in variates of these techniques.

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تحليل تجريبى لتقنيات تشيط التبخر فى غور الصافي - الاردن

سليمان الطراونة
قسم الهندسة المدنية - جامعة مؤته

ملخص البحث

دراسات تنشيط التبخر مهمة جداً في المناطق الجافة وشبه الجافة مثل معظم الوطن العربي ، خاصة في المناطق الحارة كـالأخدود الغوري في الأردن الذي يحتوي على مشاريع الري الكبرى ، سواء العاملة الآن او التي تحت التنفيذ. وغور الصافي الأشد حرارة في الأخدود والأقل ارتفاعاً اتخذ المكان المناسب لهذه الدراسة التجريبية لأربعة تقنيات غير مكلفة وبسيطة لتنشيط التبخر ، وقد كانت مدة التجربة ثلاثة أعوام متتابعة (١٩٩٥-١٩٩٧). والتقنيات المستعملة كانت كالتالي : البلوسترين الفقاعي الطافي ، والمطـاط الفقاعي الطافي ، وأوعية البخر المملوءة إما بالرمل أو بحصى السيول ، وعلب البلاستيك الفارغة. وقد وجدت التجارب أن معـدل تنشيط التبخر تفاوت من ٢٢,٢٥% وحتى ٤٩,٩٧% حسب تقنية التنشيط وهذه نتائج واعدة ومهمة ، وتشجع على المزيد مـن التجريب والاستعمال في برك المزارع.