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Polymer Effectiveness at Different Temperature Regimes under the Arid Environmental Conditions of Kuwait

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Abstract: The effects of temperature regimes on polymer performance, growth and internal water status of *Conocarpus lancifolius* Engl. & Diels. were assessed in this study. Five polyacrylamide (PAM) polymers (Broadleaf P_4, Agrihope, Aquasorb, Hydrogel and Hydrosource) were mixed with sandy soil at a concentration of 0.1, 0.2 or 0.4% (w/w basis) and 2.0 kg soil was placed in a 5 liter containers. One *Conocarpus lancifolius* L. plant was planted in each container. Following planting, containers were irrigated with freshwater to attain field capacity and the amount of water applied to each pot was recorded. A set of 75 containers (5 polymers three concentrations and 5 pots per treatment) was maintained under variable ambient temperature (daily maximum and minimum temperatures ranging from 33-49°C and 25-35°C, respectively), environment controlled greenhouse (maximum and minimum temperatures ranging from 27-41°C and 20-35°C, respectively) or indoor temperature regimes (daily maximum and minimum temperature range of 20-24°C and 20-26°C, respectively). Subsequent irrigations were applied when potentiometer reading of four was attained and the amount of water applied to each pot was recorded. Results indicated that soil amended with 0.4% Agrihope utilized least amount of water (33.8, 38.1 and 30.7% less water than the control soil in VAT, GH and LAB conditions, respectively), whereas Hydrogel amended soil utilized the maximum amount of water during the 90 day period. The frequency of irrigation normally decreased with the increase in polymer concentration. After 90 days of planting, the relative height growth rate of *Conocarpus* plants grown under VAT, GRH and LAB temperature regimes ranged from 2.3-9.3, 9.7-34.0 and 3.2-12.1%, respectively. However, neither the polymer type nor the concentrations of individual polymer produced significant differences in height growth rates. Leaves of plant maintained under the LAB conditions contained approximately 47% more chlorophyll than those grown under the VAT regime. Plants grown in Agrihope amended soil showed the highest chlorophyll index. The possible reasons for the differential response of PAM polymers under different temperature regimes are discussed in the paper.

Key words: Cross-linked polymers · Polyacrylamide (PAM) · water holding capacity · plant growth · irrigation water salinity · *Conocarpus lancifolius* Engl. & Diels.

INTRODUCTION

Some of the cross-linked polyacrylamide (PAM) polymers can accumulate moisture as much as 500 times their weight and gradually release it to the plants as per the need. In sandy soils, these substances have also been shown to reduce evaporation, extend irrigation intervals, reduce salinization of land and improve internal water status of plant tissues [1-3]. Therefore, these substances are used in agriculture and horticultural operations to improve the water-holding capacity (WHC) of soils and to reduce crop water requirements.

Studies on the use of polyacrylamide (PAM) polymers in the Arabian Peninsular region are limited. The effect of synthetic polymers (Broadleaf P_4, Agrihope, Aquasorb and Hydrogel) on water holding capacity (WHC), evaporation and water conservation in calcareous sandy and sandy loam soils of Saudi Arabia was studied by Choudhary *et al.* [4]. According to these authors, all four polymers increased WHC, decreased the evaporation

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and as a result increased water conservation in both soils. Broadleaf P_4 was found to be the most efficient polymer. Several factors including salinity of irrigation water and prevailing temperature conditions affect rehydration and release of water from polymer molecules [5].

In soil, PAM degrades at rates of at least 10% per year as a result of physical, chemical, biological and photochemical processes [6]. Intense UV radiation in the open is known to increase the breakdown rates. In view of these facts, studies reported here were conducted to determine the effects of high temperatures on the performance of five PAM polymers (Agrihope, Aquasorb, Hydrogel, Hydrosource and Broadleaf P_4) in enhancing water holding capacity of sandy soils and promoting growth and internal water status of the most widely used ornamental tree (*Conocarpus lancifolius* Engl. & Diels.).

MATERIALS AND METHODS

Polymers and experimental conditions: Five cross-linked PAM polymers, Aquasorb (AS), Agrihope (AH), Broadleaf P_4 (BL), Hydrogel (HG) and Hydrosource (HS) were used in the study reported here. The experiment was conducted during July to October 2005 under three temperature regimes: variable ambient (VAT), evaporatively cooled greenhouse (GRH) and uniform (comfort) indoor temperature regimes (LAB). The variable ambient weather during the study was extreme with daily maximum and minimum temperatures ranging from 33-49°C and 25-35°C, respectively. The greenhouse environment was more moderate than the ambient weather with maximum and minimum temperatures ranging from 27-41°C and 20-35°C, respectively. In contrast, the laboratory environment was uniform with daily maximum and minimum temperature range of 20-24°C and 20-26°C, respectively. The relative humidity fluctuations inside the greenhouse and in the open were higher than that in the laboratory.

Experimental procedure: Measured quantities of the polymer (0, 0.1, 0.2, or 0.4% by weight) were thoroughly mixed with soil and uniform quantities (2 kg) of this soil were placed in 5 liter plastic containers. One plant of *Conocarpus lancifolius* (a widely used ornamental plant with high water needs) was planted in the center of each pot. The soil was irrigated with fresh water (1.6 dS m^{-1}) and the volume of water required to saturate the soil was recorded. Subsequent irrigations were applied when moisture meter (Westminster light and moisture meter) showed a reading of 4 or less (equivalent moisture percentage was 2.18%). At each irrigation event, enough water was allowed to be absorbed by the soil in each pot and the amount of water applied was recorded. The daily maximum and minimum temperature, relative humidity and light intensity during the course of the investigation were recorded. Soil samples were analyzed for various chemical and physical parameters using recommended procedures [7, 8].

Experimental design and data analysis: The experiment consisted of five polymers with three concentrations each and three temperature regimes. With five containers per treatments, a set of 75 containers were maintained under each of the three temperature regimes. Using the data on height and plant canopy, the relative growth rate was calculated as follows:

$$\text{Relative growth rate} = \frac{\text{Final reading - Initial reading}}{\text{Initial reading}} \text{ X } 100$$

Chlorophyll index of upper and lower leaves was measured using a chlorophyll meter (model COM-200, Opti- Sciences, USA). Evapotranspiration rate was recorded using the gravimetric method. The total amount of water used for irrigation was commuted on completion of the study. ANOVA procedure along with Duncan's Multiple Range Test was used to analyze the data and separate significant means [9].

RESULTS

Amount of water used for irrigation: The amount of water applied to the experimental plants under the variable ambient temperature (VAT), greenhouse (GRH) and laboratory (LAB) conditions ranged from 3.98 (0.4% Agrihope)−6.51 l (0.2% Hydrogel), 3.03 (0.4% Agrihope)−4.9 l (0.1% Aquasorb), 1.18 (0.4% Agrihope)−2.04 l (0.2% Hydrogel), respectively (Table 1). It was clearly demonstrated that plants grown in 0.4 Agrihope required 33.8, 38.1 and 30.7% less water than control in VAT, GH and LAB conditions, respectively. As expected, water consumption under the laboratory conditions were nearly 70% lower compared to that under variable ambient temperature regimes.

Plant Height: *Conocarpus* plants maintained under greenhouse conditions grew faster than those under variable ambient temperature and laboratory temperature regimes. After 90 days of planting, the relative growth rates in height in VAT, GRH and LAB temperature regimes

Table 1: Total amount of water applied to *Conocarpus lancifolius* plants grown in polymer amended soils under three temperature regimes

	Amount of water applied to each container (L) **		
Polymers*	VAT	GRH	LAB
AS 0.1	6.01	4.90	1.71
AS 0.2	5.85	4.54	1.62
AS 0.4	5.38	4.35	1.68
AH 0.1	5.48	4.31	1.76
AH 0.2	5.50	4.13	1.68
AH 0.4	3.98	3.03	1.18
BL 0.1	6.09	4.03	1.70
BL 0.2	5.95	3.86	1.67
BL 0.4	5.52	3.52	1.38
HG 0.1	6.34	4.28	1.95
HG 0.2	6.51	4.34	2.04
HG 0.4	5.82	4.37	1.97
HS 0.1	6.32	4.15	1.95
HS 0.2	5.72	4.35	1.94
HS 0.4	4.59	4.66	1.97
SEM - Polymers***		0.08	
Temperature regimes		0.06	
Polymer concentrations		0.06	

* AS = Aquasorb; AH = Agrihope; BL = Broad leaf P_4; HG = Hydrogel; HS = Hydrosource. 0.1 = 0.1%, 0.2 = 0.2% and 0.4 = 0.4% on w/w basis

** VAT = Variable ambient temperature regime; GH = Greenhouse conditions; LAB = Laboratory temperature regime. Average of three replications; Significant at P = 0.5 (*) or P = 0.01 (**); NS= Non-significant

*** Data on amount of water used were statistically analyzed using Analysis of variance (ANOVA) procedures. Polymers, temperature regime and concentrations were statistically significant at $P \le 0.5$

ranged from 2.3−9.3, 9.7−34.0 and 3.2−12.1%, respectively (Table 2). Neither the polymer type nor the concentrations of individual polymer differed in promoting height growth.

Plant canopy: Neither the polymer nor the concentration effects were evident in plant canopy (Table 2). However, the percent increase in plant canopy of *Conocarpus* plants after 90 days of planting under VAT, GRH and LAB conditions were -4.3−17.6, -0.2−31.8 and -2.5−19.6%, respectively.

Chlorophyll index: Plant maintained under laboratory conditions, in general, had higher chlorophyll index values than those under VAT and GRH temperature regimes (Table 2).

Evapotranspiration rates: On day 30, the amount water lost due to evapotranspiration per day ranged from 0.168−0.332, 0.062−0.108 and 0.060−0.068 ml d^{-1} under VAT, GRH and LAB conditions, respectively (data not reported). With the onset of more favorable weather during the second half of duration of the experiment (at 60 day stage), the evaporation rate under VAT, GRH and LAB conditions was reduced to 0.100−0.138, 0.054−0.134 and 0.044−0.074 ml d^{-1} respectively (Table 2). Differences in evaporation rates were not statistically significant.

Chemical and physical properties of growing media: The addition of Agrihope, Aquasorb and Hydrogel at all concentrations and Hydrosource at 0.2 and 0.4% increased electrical conductivity, cation exchange capacity and HCO_3 levels in the substrate. The addition of Agrihope also increased the levels of Mg, K, CO_3 and SO_4 in the substrate (Table 3). Similarly, the addition of Hydrogel increased the levels of Ca, Mg, CO_3 and SO_4. Aquasorb addition increased the levels of Na, HCO_3, CO_3 and exchangeable sodium percentage in the medium.

Hydrogel, Hydrosource and Broadleaf P_4 amended soils had lower bulk density than the control soil (Table 4). In contrast, addition Aquasorb and Agrihope at rate of 0.1 and 0.2% increased the bulk density slightly, whereas at the highest concentrations (0.4%) they had no

Table 2: Height and canopy growth, chlorophyll index and evapotranspiration rates of *Conocarpus lancifolius* plants grown at different temperature regimes in polymer-amended soils

	Height growth (%)			Canopy growth (%)			Chlorophyll index			Evapotranspiration		
Polymers[a]	VAT[b]	GRH	LAB	VAT	GRH	LAB	VAT	GRH	LAB	VAT	GRH	LAB
AS 0.1	8.2	19.0	8.0	17.6	22.5	4.4	48.55	40.13	53.51	0.114	0.098	0.054
AS 0.2	6.3	25.3	12.1	6.3	22.4	5.1	43.84	37.07	63.73	0.122	0.112	0.052
AS 0.4	7.1	34.0	11.6	4.3	21.0	1.7	48.82	35.49	57.00	0.130	0.134	0.052
AH 0.1	3.9	22.9	3.2	5.7	21.2	4.3	40.60	36.87	51.59	0.122	0.064	0.044
AH 0.2	6.0	19.8	5.7	4.0	21.4	1.3	35.94	26.29	50.34	0.126	0.054	0.050
AH 0.4	6.6	17.6	5.2	8.5	10.1	0.9	37.80	30.39	57.49	0.108	0.072	0.048
BL 0.1	5.8	13.7	4.5	3.4	9.1	19.6	34.57	31.39	44.96	0.116	0.094	0.050
BL 0.2	6.9	6.9	5.7	11.4	0.2	4.5	34.56	29.31	46.40	0.128	0.098	0.054
BL 0.4	8.8	15.7	5.5	4.5	8.8	6.9	36.43	33.90	52.93	0.142	0.092	0.064
HG 0.1	9.3	9.7	5.9	4.8	3.1	2.5	23.61	28.23	55.09	0.100	0.098	0.070
HG 0.2	6.7	16.3	6.4	12.9	16.9	1.8	28.96	29.48	56.37	0.112	0.088	0.072
HG 0.4	2.3	20.2	11.2	1.6	31.8	0.5	25.97	36.30	66.11	0.138	0.108	0.064
HS 0.1	7.9	20.4	5.9	9.6	17.7	3.5	24.69	33.62	46.83	0.116	0.074	0.074
HS 0.2	3.4	28.7	3.9	10.2	21.5	0.9	36.84	40.10	46.08	0.114	0.076	0.072
HS 0.4	3.6	36.2	7.4	10.0	25.1	1.7	45.99	52.41	59.27	0.106	0.070	0.068
Significance - Polymer[c]			NS			NS			* (3.9)			NS
Conc. ©			NS			NS			NS			NS
Temp (T).			** (3.4)			* (2.9)			** (5.9)			NS
P X C			NS			NS			** (1.8)			NS
P X T			NS			NS			* (2.7)			NS
P X C X T			NS			NS			NS			NS

Table 3: Chemical analysis of the growing medium at time 0

			Cations (meq l^{-1})				Anions (meq l^{-1})					
Polymers[a]	pHs	EC (3:1) (dS m^{-1})	Ca^{+2}	Mg^{+2}	K^{+}	Na^{+}	CO_3^{-2}	HCO_3^{-1}	Cl^{-1}	SO_4^{-2}	CEC meq/100 g	ESP (%)
NP	8.10	1.67	9.13	1.88	0.53	7.91	<0.01	0.20	3.86	15.58	2.34	4.81
AS 0.1	7.70	2.12	12.88	2.50	4.05	8.72	1.00	0.50	4.69	21.96	2.87	4.51
AS 0.2	7.80	2.26	11.38	3.63	6.65	5.39	1.00	0.50	6.07	19.48	3.28	2.87
AS 0.4	8.10	2.10	7.75	2.63	11.61	5.22	1.00	2.50	3.09	20.62	3.42	3.32
AH 0.1	7.60	2.41	5.75	1.00	0.55	17.82	2.00	3.50	3.77	15.85	3.22	12.70
AH 0.2	8.20	2.56	4.25	1.50	0.44	19.98	2.00	5.50	1.03	17.65	3.64	15.02
AH 0.4	8.10	2.65	5.62	1.38	0.41	21.12	3.00	4.00	3.76	17.77	3.15	14.48
BL 0.1	8.30	1.29	7.25	1.25	0.35	7.64	1.00	1.50	2.69	11.31	3.86	5.27
BL 0.2	8.20	1.83	4.50	1.75	0.69	12.87	2.00	3.00	3.31	11.51	2.63	9.85
BL 0.4	8.30	1.65	6.75	1.00	0.42	10.55	<0.01	5.50	2.22	11.01	6.35	7.44
HG 0.1	7.10	4.31	29.75	8.50	9.75	8.82	1.00	4.00	2.70	49.12	2.72	2.94
HG 0.2	7.00	3.50	24.25	5.88	5.22	8.75	1.00	3.00	5.52	34.58	3.33	3.27
HG 0.4	7.30	4.56	28.75	7.00	14.64	12.25	1.00	1.00	5.45	55.18	3.64	4.17
HS 0.1	7.80	1.38	7.25	1.25	1.24	2.53	<0.01	1.50	5.65	5.12	2.55	1.81
HS 0.2	7.80	1.94	10.38	4.38	0.89	8.99	<0.01	1.00	3.99	19.65	2.61	4.73
HS 0.4	7.90	2.45	13.50	3.50	6.16	8.21	1.00	0.50	4.90	24.97	5.65	4.05
Polymer (P)[b]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Conc. (C)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	* (1.0)	NS
P X C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a] NP = No. polymer (control); AS = Aquasorb; AH = Agrihope; BL = Broadleaf P_4; HG = Hydrogel; HS = Hydrosource. 0.1 = 0.1%, 0.2 = 0.2% and 0.4 = 0.4% on w/w basis

[b] Data were analyzed using ANOVA procedure; NS = Nonsignificant at P≤0.05, * = significant at P≤0.05, ** significant at P≤0.01. Figures in the parenthesis are Standard Error of Mean

Table 4: Physical properties of growing medium at time zero

Polymers[a]	Concentrations (%)[a]	Bulk density (g cm^{-3})	Porosity (%)	AWC (% by weight)[b]
No Polymer	0.0	1.33	72.37	7.29
Agrihope	0.1	1.46	67.68	13.16
	0.2	1.49	48.05	13.36
	0.4	1.33	59.86	18.79
Aquasorb	0.1	1.64	87.09	12.86
	0.2	1.69	88.75	15.04
	0.4	1.31	90.93	12.38
Broadleaf P_4	0.1	0.92	82.47	9.29
	0.2	0.91	90.76	17.99
	0.4	1.21	83.74	14.09
Hydrogel	0.1	1.05	64.36	10.75
	0.2	1.09	66.57	8.68
	0.4	0.93	77.59	11.32
Hydrosource	0.1	1.30	28.03	16.85
	0.2	1.03	78.30	17.01
	0.4	1.04	74.42	21.68
Significance[c]		**	**	**
SEM [d]		0.06	4.2	0.99

[a] Polymers were mixed with sandy soil at 0.1, 0.2 and 0.4% on w/w basis, [b] AWC= Available water capacity % by weight (Field capacity - wilting point)
[c] The data were analyzed using "t" test at $P \le 0.05$; * = significant at $P \le 0.05$, ** significant at $P \le 0.01$, [d] SEM = Standard Error of Mean

effect. While the addition of Aquasorb and Broadleaf P_4 increased the porosity, addition of Agrihope lowered it slightly. Polymer amended soil had the higher available water capacity than the control soils.

DISCUSSION

All polymers tested in the present study were least effective under variable ambient temperature (VAT) regime whereas they were most effective under greenhouse (GH) conditions. The reduced effectiveness of polymers in the VAT regime, to a large extent, may be related their degradation due to high temperature and light intensity [6]. Higher rates of evaporation in the VAT regime contributed to increased salt build up in the soil, which in turn, may have adversely affected polymer effectiveness [5].

Plant growth was the best under greenhouse conditions, whereas, it was the poorest under VAT regime. The plant growth under the uniform indoor conditions was intermediate. This might be related to degradation of polymers under high temperature breakdown of the higher relative humidity that prevailed in the greenhouse. Similarly, because of lower and uniform temperatures, plants under LAB conditions lost least amount of water by evapotranspiration (the differences were evident in absolute terms) and consequently, required less frequent irrigations. On the other hand, plants under VAT in the open were exposed to extremely high temperatures and low humidity conditions. The high evapotranspiration rates in absolute terms under these conditions might have masked all other effects. However, Johnson and Leah [3] found evapotranspiration rates in polymer-treated plants to be 21 to 56% lower than in control plants.

Among the five polymers tested, addition of Agrihope at 0.4% on weight basis was most effective in reducing water requirement. Higher available water capacity in polymer amended soils suggest that they allowed the soil to hold more water possibly by minimizing percolation and surface evaporation losses. Consequently, polymer amended soils required less frequent irrigations. Similar results have been reported by Johnson [1] and Choudhary *et al.* [4].

The results reported here conclusively show that a significant amount of irrigation water can be saved by the addition of Agrihope at 0.4% to the sandy soil.

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