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Effects of Hydrophilic Polymer on the Survival of Bottonwood (*Conocarpus erectus*) Seedlings Grown under Drought Stress

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Summary

The effect of 0.0 (control), 0.1, 0.2, 0.4, and 0.6 % of the hydrophilic polymer 'Stockosorb K-400 (TM)' hydrogel on survival and growth of buttonwood (*Conocarpus erectus* L.) seedlings grown in sandy soil under drought stress was investigated. Soil water retention increased with increasing hydrogel concentrations. The highest concentration of the polymer prolonged the time of water loss from the soil by about 66 % more than the control soil. During drought stress, the seedlings grown in soil with 0.6 % hydrogel survived for longer time than those grown in the control soil. Hydrogel-amended soil increased significantly the growth of shoots and roots as compared with untreated soil. Plant water potential increased significantly with hydrogel application, thus it may aid in the establishment and growth of *Conocarpus* seedlings under water stress conditions. Effects of 0.4 and 0.6 % of hydrogel on the measured parameters were nearly similar. The study indicates that an amendment of soil with 0.4 to 0.6 % of the hydrophilic polymer 'Stockosorb K-400' can be used in arid and semi-arid areas to provide a better enviroment for *Conocarpus erectus* seedlings to grow.

Zusammenfassung

Wirkung eines hydrophilen Polymers auf das Überleben von 'Bottonwood' (*Conocarpus erectus*) Sämlingen unter Trockenstress-Bedingungen. Es wurde die Wirkung von 0.0 (Kontrolle), 0.1, 0.2, 0.4 und 0.6 % des hydrophilen Polymers 'Stockosorb K-400 (TM)'-Hydrogel auf das Überleben und das Wachstum von *Conocarpus erectus* L.-Sämlingen, die auf sandigem Boden unter Trockenstress kultiviert wurden, untersucht. Die Speicherung von Bodenwasser steigerte sich mit steigender Hydrogel-Konzentration. Die höchste Konzentration des Polymers verlängerte die Dauer bis zum Wasserverlustes im Vergleich zur Kontrolle um über 66 %. Unter Trockenstress-Bedingungen überlebten die Sämlinge mit 0.6 % Hydrogel im Substrat deutlich länger als die Kontrollpflanzen. Substrat mit Hydrogel-Zusatz verbesserte das Wachstum von Trieben und Wurzeln im Vergleich zu Substrat ohne Zusatz signifikant. Das Pflanzenwasserpotenzial erhöhte sich bei Hydrogel-Zugabe signifikant, so dass es bei der Etablierung und der Kultur von *Conocarpus*-Sämlingen unter Trockenstress-Bedingungen hilfreich sein kann. Die Wirkung von 0.4 und 0.6 % Hydrogel auf die untersuchten Parameter war fast identisch. Die Untersuchung zeigt, dass die Zugabe von 0.4 bis 0.6 % des hydrophilen Polymers 'Stockosorb K-400' genutzt werden kann, um in ariden und semi-ariden Gebieten für *Conocarpus erectus*-Sämlinge bessere Wachstumsbedingungen zu schaffen.

Key words. growth – hydrogel – soil amendment – survival – trees – water potential.

Introduction

The proper selection of ornamental and/or reforestation species adapted to arid zone conditions, such as that prevailing in the central region of Saudi Arabia, with lack of water, hot climate, low relative humidity and high evapotranspiration states, is very important. Buttonwood (*Conocarpus erectus* L.), an evergreen tree of family *Combretaceae*, was found to tolerate extreme desert heat where summer temperature may reach 47 °C and grow in soil of very low fertility (NELSON 1996). This tree can grow well and survive under such conditions of high temperature and salinity levels if adequately supplied with water. It is widely used to provide food and cover for wildlife, to protect soils and to fix dunes (POPP et al. 1989). It is also planting as ornamental evergreens for landscaping (GLIMAN and WATSON 1993), producing durable wood (NELSON 1996), and folk medicine (LIOGIER 1990).

Unfortunately, under conditions described above, *C. erectus*, as many other tree species, raised in nurseries are subjected to water stress soon after planting because of poor root to soil contact and high evaporative demand (GROSSNICKLE et al. 1996; FUCHS et al. 1999). Even in containers, with a limited quantity of media, plants require frequent irrigation to maintain adequate moisture around roots. This problem is exacerbated by the fact that the seedlings typically are nurtured under optimal nutrient and water supply regimes before planting, which can promote poor plant response to more demanding conditions experienced in the field, particularly under conditions of water deficits (LOVEYS 1992).

Thus, improving drought resistance by means of cultural practices and breeding may be an important mean for plant growth in water-limiting environments. However, this procedure requires good knowledge of physiological and biochemical factors involving in plant adaptation and tolerance to drought stress. Antitranspirants may be used to reduce transpiration rate and prevent water stress (ENGLERT et al. 1993; HARRIS and BASSUK 1995). But, the negative effect on stomata opening by most antitranspirants has been shown to curtail photosynthesis and reduce photosynthetic production for extended periods and may hinder the development of new roots (THOMPSON 1992; FUCHS 1999). An alternative way is the use of water-retentive chemicals (hydrophilic polymers) as a possible solution for conserving irrigation and rainwater in such desert regions, where prolonged drought due to insufficient rainfall and irrigation water can be a detrimental factor for plant growth and development.

Hydrogels have the ability to absorb many times their weight of water and store it available for plants relatively long periods, thus they promote the soil water-holding capacity, particularly in sandy soils (ORZOLEK 1993; HAYNES and NAIDU 1998). Hydrogels have been used to establish tree seedlings and transplants in the arid regions and to increase plant survival and overall plant growth particularly for less drought tolerant tree species (SPECHT and JONES 2000), such as *Conocarpus*, while HEISKANEN (1994) reported that hydrogels provided no benefit in the establishment of plant seedlings under field conditions.

The objective of this study was to investigate the effect of a new hydrophilic polymer ('Stockosorb K400'), that is highly cross-linked polyacrylamides with 40 % of amides hydrolysed to carboxylic groups, on soil water content, period of water conservation in the soil, transpiration rate, survival and growth of *C. erectus* seedlings grown under drought stress conditions.

Materials and Methods

Field experiments were conducted at the Research Station of the College of Agriculture and Veterinary Medicine In Al-Qassim, Saudi Arabia during May 2 to July 15, 2003. The weather during the experiment was characterized by sunny, hot, dry days and warm nights. The average daily maximum temperature was 37.6 °C with little variation. The daily minimum temperature during the experiment ranged from 15.6 to 28.5 °C. No rain had fallen during the experimental period.

Six-month old buttonwood (*C. erectus* L.) seedlings were transferred from nursery soil in the greenhouse to 30-L plastic containers filled with 40 kg sandy soil each and previously mixed with 0.0, 0.1, 0.2, 0.4 or 0.6 % (w:w), i.e. 0.0, 40, 80, 160, or 240 g hydrogel 'Stockosorb K400 (TM)' (Chemische Fabrik Stockhausen GmbH und Co. KG, Krefeld, Germany) per pot. Rates of hydrogel were based on previous experience and other reports (EL-SAYED et al. 1991; HUTTERMANN et al. 1999). Each treatment was applied to 10 seedlings. In addition, 10 pots without seedlings were used to monitor evaporative water loss from the soil surface throughout each treatment. The seedlings, averaged 75±4.5 cm tall with a calliper of 2.5±0.3 cm at the soil line, were grown outdoors under natural conditions in a shade-free location. Containers were sunken in the ground such that the surface of the potted soil was at approximately the same level of the surrounding ground surface. Empty containers were used as sleeves to line the holes so that the plant-holding containers could be removed and replaced easily. The tops of the containers were covered with white polyethylene film to minimize evaporation.

A completely randomised design with 10 replicates for each treatment was used in this experiment. Seedlings of uniform height (one seedling per pot) were located in lines with spacing of 2 m between lines and 1 m between pots to avoid mutual shading. The ground surface between and surrounding the trees consisted of bare soil. At the time of transplanting, all trees were fertilized with the complete water-soluble fertilizer 'Sangral(TM)' (William Sinclair Horticulture LTD, England) compound fertilizer (20 N-20 P-20 K, plus micronutrients) at the rate of 600 kg ha^{-1}. Each tree received a total of 10 g fertilizer.

For the first 4 weeks, all seedlings were watered to field capacity (FC), supplying an amount of water equal to transpiration losses as pots were weighed every other day, to ensure the establishment of seedlings and to allow adaptation to the field conditions before drought treatments were imposed. By the end of this period, the watering was discontinued and survival and growth variables of the seedlings were determined. The field capacity was determined gravimetrically and found to be 12 %.

Measurements

All measurements were made in randomly chosen plants.

a) Daily water consumption, as the total amount of water absorbed or transpired by plants, was measured gravimetrically.
b) The survival of the seedlings was monitored every other day by their appearance. The tree was considered to be dead when their leaves became yellow dry and dropped. Upon re-watering, dead seedlings cannot grow again.
c) Shoot length, leaf area per plant (measured with a leaf area meter LI-COR Model 3100, Lincoln, NE), and dry weight of plant parts were recorded at harvest. The decision to harvest any particular treatment was based on the need to do so before deaths began to occur, at the beginning of death symptoms. Dry weights were determined after drying at 70 °C till constant weights. Leaves, which dropped during stress-treatment were included.
d) Midday leaf water potential was determined in eight randomly chosen leaves from each treatment, using a pressure chamber (PMS Instrument Co., Corvallis, OR, USA) as described by SCHOLANDER et al. (1965). The sampled leaves were enclosed in a polyethylene bag just before detaching them from the plant and conserved in a thermal isolated box. The measurements were made as soon as possible using a pressure increment of 0.1 MPa per 2 or 3 s.

The experiment was arranged in a completely randomised design and was analysed by analysis of variance. All data were statistically analysed according to SNEDECOR and COCHRAN (1980) with the aid of COSTAT com-

Table 1. Effects of hydrogel amendment on soil-water budget during stress period. (Measurements are based on transpiration only).

Hydrogel concentration (%)	Soil water content (kg/pot)	Time of 50 % water loss (day)	Total loss of water during stress (kg/pot)	% water loss during stress
0.0	4.75 c*	12.2 d	4.27 c	90 a
0.1	5.38 b	14.4 cd	4.30 c	80 b
0.2	7.76 b	18.2 c	5.75 b	75 b
0.4	10.97 a	24.3 b	6.86 ab	64 c
0.6	12.65 a	36.1 a	7.64 a	60 c

* Values represent means of 5 replicates. Means followed by the same letter(s), within a column, are not significantly different at P<0.05.

puter program for statistics. Differences among treatments were tested with LSD at 5 % level of significance.

Results and Discussion

Soil-water status

Soil amended with high concentrations of hydrogel, were able to store much more water than those amended with low concentrations or the control soil (Table 1). At field capacity, pots with 0.6 % hydrogel were found to hold more than 160 % of that recorded for control. There were no significant differences between soils treated with 0.6 % and 0.4 % in their capacity to absorb water. The time needed for losing 50 % of the initial water in the hydrogel-amended soils with 0.4 and 0.6 % was much longer than that recorded for control or low hydrogel concentration treated soils. At harvest, the amount of water remained in control pots was as low as 10 % of the field capacity (approximately 10 % of the initial water content). This amount of water was linearly increased with increasing hydrogel concentration in the amended soils (R2=94 %). An interesting observation was that at 0.4 % and 0.6 % the amount of water remained in the soil by the end of the stress period were as much as 35 % and 40 % of the field capacity. This may indicate that a portion of the irrigation water may be absorbed or bound to the highly concentrated hydrogel material and became in slow release form for the plant use.

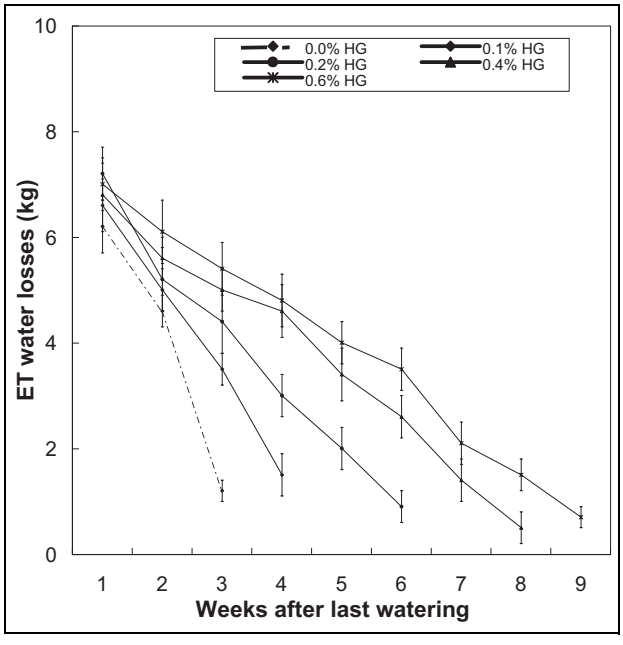


Fig. 1. Effects of hydrogel amendment on weekly evapotranspiration after the last rewatering of *Conocarpus* seedlings. Vertical bars indicate standard error of the mean (n= 8 seedlings).

Confirming other studies, the present one has shown that this new type of hydrogels can be used successfully for ornamental trees both in the greenhouse and in parks (DEHGAN 1995). This type of hydrogels greatly improves the water retention capacity of the soil, providing a better environment for plants to grow well. In this regard, containers with 0.4 % and 0.6 % hydrogel absorbed more than twice of that water absorbed by control soil (nearly 11 and 13 kg, respectively, instead of 5 kg). With 0.1 and 0.2 % of hydrogel applications, only about 5.5 and 8 kg water were absorbed, respectively. This dramatic effect of the hydrogel is in agreement with AL-DARBY (1996), who found an exponential increase in the water content of a sandy soil with increasing hydrophilic soil conditioners. This high ability of the soil to held great amount of water and increase its retention capacity as hydrogel concentration increases may also explain the very low amount of water percolating from hydrogel amended soils (MUKHOPADHYAY et al. 1994).

At all times of measurements, the kinetics of the weekly loss of water shows that soils with higher hydrogel concentrations and consequently, longer plant life, released more water during the stress period (after the last watering) than the control or low hydrogel treated soils (Fig. 1). Therefore, the ratio of soil water content at the beginning of stress treatment and at harvest time was significantly higher at 0.4 and 0.6 % hydrogel than at lower concentrations or the control (Fig. 2). As a result, cumulative water loss for hydrogel-treated seedlings, particularly high concentrations, was higher than that for the control seedlings (Fig. 3). It seems that overall transpiration of plants was affected by the use of hydrogel in the media since hydrogel potentially increased water availability. SPECHT and JONES (2000) observed an increase in overall water uptake and stomata activity in-

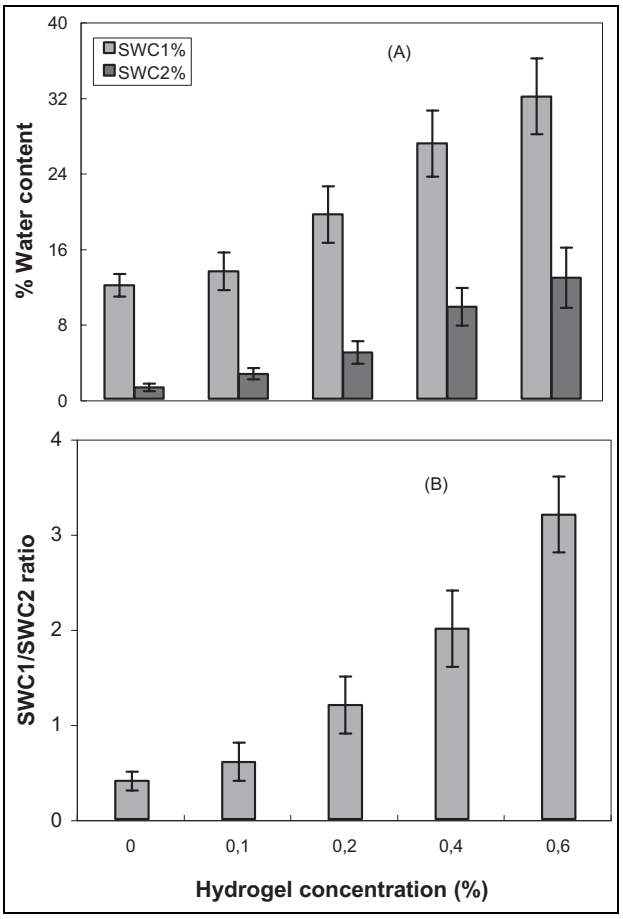


Fig. 2. Effects of hydrogel amendment on: (A) percentage of soil water content at beginning of stress (SWC1) and at harvest time (SWC2) and (B) SWC1/SWC2 ratio. Vertical bars indicate standard error of the mean (n= 4 measurements)

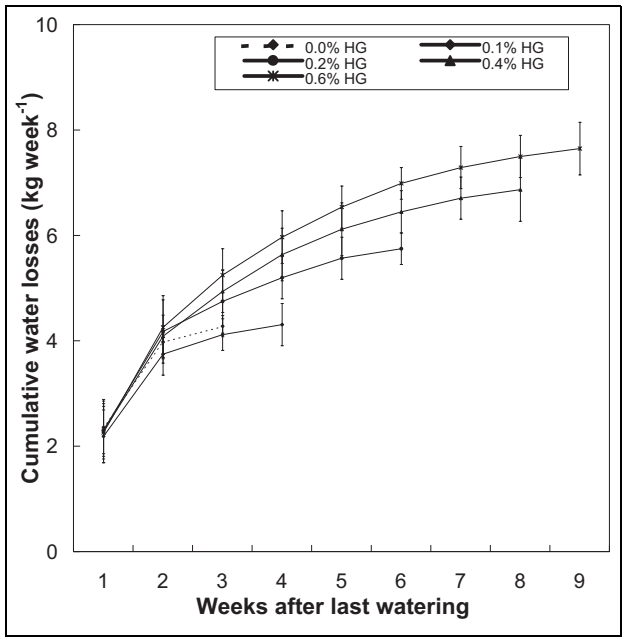


Fig. 3. Effects of hydrogel amendment on cumulative water loss (kg/week). Vertical bars indicate standard error of the mean (n= 8 seedlings).

crease in many tree seedlings including Queensland maple (*Flindersia brayleana*), gum trees (*Eukalyptus grandis*), and oak (*Quercus rubra*) when hydrogels were incorporated into the media. They found also the overall increase in plant mass, by hydrogels, was associated with the increase in transpiration and carbon dioxide intake.

The water harvested by the hydrogel was readily transferred both to the seedlings and the atmosphere. This confirms the findings of SPECHT and JONES (2000) who showed that soil amendment prolonged the time until 50 % of the soil water was evaporated. In this connection, hydrogels were found to potentially influence soil structure, compaction, soil texture, and evaporation rates (HELALIA and LETEY 1988). Since soils amended with the higher concentrations of hydrogel retained much more water during the irrigation period than the control soils, they could afford to lose more water and still retain more soil moisture than the other treatments.

Seedling survival and growth

Hydrogel treatments increased the survival time of the *Conocarpus* seedlings after the last watering treatment, as compared with the control (Table 2). Seedlings were able to grow for about 2 months without watering when soil was amended with 0.4 or 0.6 % hydrogel.

In spite of water stress conditions, some growth increment of the stressed shoots was noticed. As hydrogel concentration increased, shoot growth and root and shoot dry weights increased to reach their maximum values at 0.6 % hydrogel. There were no significant differences between shoot growth and dry weights of 0.6 % and 0.4 % hydrogel-treated plants. Roots grown in hydrogel-amended soils showed more adventitious roots and were more branched as compared with those grown in the control soils. However, the length of the main root did not differ significantly in all five treatments (data not shown).

With reduced irrigation rates for some tree seedlings, CALLAGHAN et al. (1989) reported that hydrogel amendment increased the survival rate by 1.5 times than seedlings without hydrogel treatments. When irrigation was withheld for six days, CALLAGHAN et al. (1989) found that all of the control tree seedlings died compared to the 57 and 71 % survival rate of the hydrogel-amended soil. Moreover, HUTTERMANN et al. (1999) found that 0.4 % hydrogel amendments doubled the survival rate and prolonged water availability for *Pinus* halepensis use when irrigation was stopped. They found also that, hydrogel media allowed for several weeks to pass before seedlings started to die whereas in the control with no hydrogel plants started to die after some days of drought. In sandy soils, it was found that incorporation of hydrogels for *Lycopersicon esculentum* (HENDERSON and HENSLEY 1986), *Lactuca sativa*, *Rhaphanus sativa*, and *Triticum aestivum* (JOHNSON and LEAH 1990) increased both the dry weight and the time from irrigation stop to wilting.

Comparable to the present study, the increased soil water storage with increased hydrogel concentration in pot experiments with the seedlings, in principle, is also found in the measurements of the suction potential in pressure plate tests in other study (HUTTERMANN et al. 1999). This suggests that the total amount of water

Table 2. Effects of hydrophilic polymer amendment on survival (days of trees after last watering treatment), shoot growth increment, root and shoot dry weights of *Conocarpus erectus* seedlings at harvest time.

Hydrogel concentration (%)	Survival (days)	Shoot growth increment (cm)	Root dry weight (g)	Shoot dry weight (g)
0.0	21.2 c*	3.2 c	3.54 c	8.42 c
0.1	28.4 c	5.3 bc	4.46 b	12.54 b
0.2	38.5 b	7.5 b	5.02 b	15.23 b
0.4	52.4 a	10.5 a	6.25 a	24.13 a
0.6	60.7 a	12.4 a	6.83 a	25.44 a

*Values represent means of 6 replicates. Means followed by the same letter(s), within a column, are not significantly different at P<0.05.

stored in the hydrogel should be available for the plants growing on this substrate (SCHACHTSCHABEL et al. 1989; KRAMER and BOYER 1995). The results of the present experiment with *Conocarpus* seedling indicate that the plants do not have full access to this water reservoir. Whereas the plants in the control soils died only after the water content was reduced to 1.2 %, the tree in the soils amended with 0.4 and 0.6 % hydrogel died even at a water content of about 9.7 and 12.8 %. A significant part of the water stored by hydrogel was apparently not available for the plants. Early studies showed that hydropholic polymers reduced nutrient losses from soil, reduced soil salinity, and therefore enhanced plant growth by allowing nutrients, incorporated in the hydrogel matrix, to release to the plant as needed (LENTZ and SOJKA 1994; SHAKESBY et al. 2000).

Plant-water status

The effect of hydrogel on the water potential (Ψ_w) of the *Conocarpus* seedlings is shown in Fig. 4. It is obvious that Ψ_w of water-stressed control plants dropped rather fast after about 15 days of stress treatment, with death occurring one week later. Seedlings grown at 0.1 and 0.2 % hydrogel showed the same pattern of decline in their Ψ_w, starting 7 and 15 days later, respectively. Plants grown in 0.4 and 0.6 % hydrogel amended-soil, however, exhibited a different pattern. The decline in their Ψ_w started on day 40 and 45, respectively, and they took 15 and 30 days until the same minimum value of about –4.2 MPa was reached just before plant death. This change in water retention and plant water potential pattern is similar to the one described for the differences between sandy and loamy soils (SCHACHTSCHABEL et al. 1989). This view is strongly supported by the water budget of the 30 L container during the stress experiment containing 0.4 to 0.6 % hydrogel. Soil amended with 0.4 % hydrogel, for example, had a substantial percentage (27 %) of water content at the beginning of the desiccation experiment, which was reduced to 9.7 % when the seedlings finally died. According to the figures given by KRAMER and BOYER (1995), the soil was thus converted by hydrogel amendment from a typical sandy soil to a loam or even silt clay soil with re-

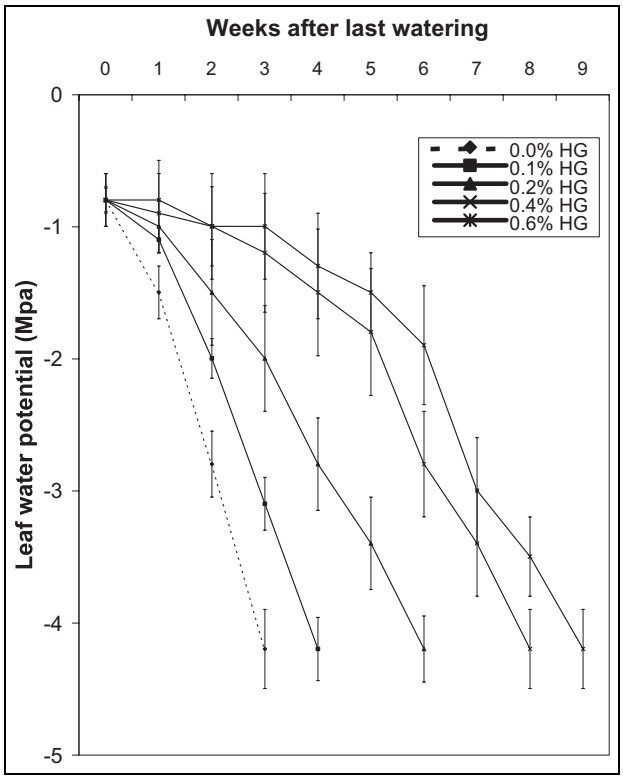


Fig. 4. Effects of hydrogel amendment on leaf water potential (MPa) of *Conocarpus* seedlings. Vertical bars indicate standard error of the mean (n= 8 seedlings).

gard to its hydraulic properties. Addition of hydrogels to a sandy soil changed the water holding capacity to be comparable to silty clay or loamy type and increased overall water holding capacity (LENTZ and SOJKA 1994; ZHANG and MILLER 1996; HUTTERMANN et al. 1999).

It is evident, from the present study, that using of HG may be a useful tool playing a significant role in the early establishment and growth of landscape tree species under arid and semi-arid conditions. Hydrogels have the potential to improve the growth of *Conocarpus* seedlings in the critical days after planting out. Increasing dry weights of seedling shoots and roots were achieved by the treatmants. Enhanced leaf retention and some evidence of accelerated roots extension, are important factors. The longer survival of *Conocarpus* seedlings under water stress together with the growth of shoot and root systems will considerably increase the fitness of the seedlings and enable the plants to grow fairly well under drought conditions. If maximum growth rates are to be sustained, a healthy canopy to trap sunlight and carbon dioxide, and a root system extending to tap into soil reserves of moisture and nutrient are essential. This can be achieved, to some extent, by the application of hydrophilic polymer soil amendments.

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