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Effect of saline irrigation and its schedules on growth, biomass production and water use by *Acacia nilotica* and *Dalbergia sissoo* in a highly calcareous soil

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Afforestation programmes in arid areas suffer mainly from low rainfall, high evapo-transpirational demands, high salt content of ground-waters and impediment by *kankar* (calcareous) subsoil layers of root proliferation. Two of the most preferred multi-purpose tree (MPT) species, Kikar (*Acacia nilotica* (L.) Del.) and Shisham (*Dalbergia sissoo* Roxb. ex DC) were furrow planted in August 1991 under such an environment in north-western parts of India and the effects of saline irrigation (EC_w 10·5 dS m^{-1}, sodium adsorption ratio 20 mmol l^{-1}) and various irrigation schedules were evaluated for 45 months. Saline irrigation reduced biomass by 16% in *A. nilotica* compared to canal water irrigation, while the reduction was 57% in *D. sissoo*. Irrigation water supplies equalling 10% of the open pan evaporation (OPE) values met water requirements during the initial 2 years after transplanting. However, trees receiving high quantities of water (20% of OPE) during the third year had improved biomass yields by 13% and 21% in *D. sissoo* and *A. nilotica*, respectively. Water-use efficiency (WUE) of *A. nilotica* (10·7 mg.ha.m^{-1}) was much higher compared to *D. sissoo* (1·7 mg.ha.m^{-1}). Most of the salts added through saline irrigation accumulated below channels and were leached both downward and to lateral regions with monsoon rains. Thus furrow planting and irrigation technique, in addition to reducing the applied water quantities, resulted in favourable salt and water regimes for the better establishment of tree saplings with saline water.

Keywords: salinity; irrigation; biomass; trees; India

Introduction

In arid and semi-arid regions of India, irrigation is practised to enhance production from annual crops and perennial fruit trees. The notion of irrigated multi-purpose tree plantations is considered less attractive, especially for situations where fresh water supplies are limited and ground-waters are saline as foresters are reluctant to utilise saline water in the absence of knowledge of appropriate technologies (Yadav, 1991;

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Singh *et al.*, 1993; Gupta *et al.*, 1994). Therefore, afforestation programmes result in poor stands and poor tree growth due to water deficits associated with uneven distribution of rains and long dry spells following monsoons.

The general objectives of saline irrigation for agricultural crops are to use relatively large quantities to leach salts down the root zone, reduce surface evaporation to a minimum and ensure maximum utilisation of water by crops (Bassham, 1979; Ayers & Westcot, 1985; Minhas & Gupta, 1992). For these reasons, and to conserve scarce water, irrigation systems like drip and other micro-irrigation systems are considered to be major advances, but the costs involved prevent their use in afforestation programmes. Moreover, advocation of such strategies for shallow-rooted crop plants is mainly because the added salts are pushed beyond their rooting zones whereas in deep rooted plantations, salts added through saline irrigation may hinder the later growth of trees. Until now, research on using saline waters for silviculture in inland areas has been restricted to initial establishment stages (Boyko, 1968; Tomar & Yadav, 1980; Jain *et al.*, 1983; Chaturvedi, 1984; Singh & Yadav, 1985; Tomar & Gupta, 1985; Gupta *et al.*, 1986; Yadav, 1991; Ahmad & Ismail, 1992; Hussain *et al.*, 1994) but evidence shows that some of the more resistant tree species like *Prosopis, Tamarix* and *Casuarina* could be irrigated with saline waters (10–20 dS m^{-1}) which are otherwise unsuitable for conventional agriculture. However, there is a lack of information on optimal irrigation schedules for the species preferred by foresters. Thus, to evaluate the effects of saline irrigation and its schedules, an experiment with two traditionally preferred tree species for fuel and timber wood, i.e. *Acacia nilotica* and *Dalbergia sissoo*, was initiated in 1991. The results obtained up to January 1995 are reported here.

Materials and methods

The experiment was conducted at Bir Forest area, Hisar (latitude 29° 14' N; longitude 76° 12' E) in Haryana state of India. The climate at the site is continental monsoonal type characterized by hot, dry summers and cold winters. The annual rainfall of 300–350 mm occurs mainly during the months of July–September. The soil is a typic *Haplustalf* and highly calcareous (Table 1). The site was lying barren at the time of initiation of experiments in June 1991. The State Forest Department had earlier tried to rehabilitate the site but could not succeed. The experimental area was cleared of whatever natural vegetation was present, levelled and ploughed. Then, furrows (0·6 m wide and 0·15 m deep) were created at 2·5-m intervals with a tractor drawn furrow maker. Auger holes (1·2 m deep, 0·2 m diameter) were dug in the sill of these furrows, 2·0 m apart. These were re-filled with a mixture comprising original soil plus 8 kg of farmyard manure, 30 g super-phosphate, 15 g zinc sulphate and 15 g of iron sulphate. Six-month-old tree saplings were transplanted at auger hole sites during August 1991 at a population of 2000 trees per ha (2·5 m × 2·0 m spacing).

The experimental layout was a split–split plot design containing three replications

Table 1a. *Analysis of 15 soil profiles at the experiment site*

Soil depth (m)	EC_e (dS m^{-1})		pH (1:2 soil:water)		$CaCO_3$ (%)	
	Mean	Range	Mean	Range	Mean	Range
0–0·3	1·1	0·7–1·7	8·4	8·2–8·5	7·5	1·8–17·1
0·3–0·6	1·9	0·7–8·3	8·3	8·0–8·6	8·9	2·4–21·2
0·6–0·9	3·4	0·8–15·8	8·3	7·9–8·7	9·2	1·9–17·6
0·9–1·2	5·8	0·8–20·8	8·2	7·9–8·6	10·3	1·8–18·2

Table 1b. *Dates of irrigation for different schedules with canal and saline water*

	1992–1993				1993–1994			
	Canal water		Saline water		Canal water		Saline water	
Month	I_1/I_3	I_2	I_1/I_3	I_2	I_1/I_3	I_2	I_1/I_3	I_2
October	–	–	–	–	11	11	7	15
November	19	19	21	22	17	9	12	12
December	–	4	–	23	29	9, 29	23	23
January	4	4	6	27	–	10, 19	18	3, 18
February	–	12	11	24	6	6, 26	9	9, 25
March	15	1, 15	15	6, 25	25	6, 25	3, 15	3, 15, 28
April	14	3, 14, 25	15	3, 15, 29	19	7, 17, 28	7	7, 27
May	3, 19	3, 13, 29	4, 21	4, 14, 21, 29	13, 23	6, 16, 28	6, 28	6, 16, 28
June	3, 16, 28	9, 16, 28	7, 29	7, 15, 23	5, 24	5, 12, 24	12, 27	5, 12, 24
July	–	5	–	1	3	3	–	1

with a 2·5 m buffer between each 15 m × 18 m plot. Each experimental plot consisted of 45 trees (five rows and nine plants per row) with a common non-experimental row in between the plots. Twelve treatments consisted of combinations of three variables, i.e. two irrigation water qualities (canal and saline water) in main plots, three irrigation levels based upon climatological approach, i.e. irrigating the channels transplanted with saplings whenever the depth of irrigation water applied (Di_w) to cumulative open pan evaporation (CPE) ratio equalled 0·1 (I_1), 0·2 (I_2), and 0·2 with broader (1·2 m) channels (I_3) in subplots. Thus, the quantity of water applied in I_2 and I_3 was double the quantity in I_1 either by halving the interval or doubling the irrigated area. There were two tree species in sub-sub plots (*Acacia nilotica* (L.) Del. and *Dalbergia sissoo* Roxb. ex. DC). Saline ground-water (electrical conductivity of water, EC_w 10·5 dS m^{-1}, sodium adsorption ration ($SAR = Na/\sqrt{(Ca + Mg)}$ 20 mmol l^{-1}) was applied from a 20-m deep borewell installed at the site while canal water was transported from a nearby canal (5 km from the site) by tractor driven tankers. Common irrigations were applied during initial stages of establishment and the differential irrigation schedules were imposed from May 1992 onwards. No irrigation was applied during the rainy season extending between July–September and the number of irrigations applied during October–June of 1992–93 and 1993–94 were nine and 11 for I_1/I_3, and 17 and 20 for I_2, respectively (Table 1(b)). For both species, gaps were filled during August 1992. Growth measurements were recorded during May 1992, December 1993 and finally during December 1994. The total number of trees in each plot was counted to estimate the percentage of trees which had survived. Measurements of height and diameter at stump height, DSH (0·05 m above ground level), were made on all the surviving plants. Trees were harvested at ground level for biomass yields during January 1995. Fresh weights were recorded at the site and sub-samples of different plant parts were taken for oven-drying.

The water use of each treatment was estimated using the soil water balance equation:

$$E = P + I - R + G + S$$

where E is evaporation or the total water loss by the processes of transpiration, evaporation from the soil surface and evaporation of the rain water intercepted by tree canopies; P is precipitation; I is irrigation water; R is runoff; G is water movement to or from the ground-water table; and S is change in soil water storage. Precipitation data was taken from an observatory about 3 km from the site. As the water table was quite deep (13 m), flows from and to it were considered negligible. Also the experimental area was surrounded by strong bunds to check any runoff, therefore the values of R were also assumed to be negligible. Changes in soil water storage (0·225 to 3·5 m) were evaluated from moisture measurements at about monthly intervals in four aluminium pipes around the trees (0·3 m laterally and horizontally, mid-way between plants in channels and rows) with a neutron moisture meter (CPN Hydroprobe). Soil moisture in the surface 0–0·3 m at each recording date was simultaneously measured thermo-gravimetrically. Soil samples were also drawn down to 1·2 m depth, air-dried and then evaluated for salinity build up each year before (June) and after (October) the monsoon rains.

Results

Tree growth

The survival percentage during the first year (Fig. 1), when averaged for canal and saline irrigation, was higher in *A. nilotica* (98%) than *D. sissoo* (72%). The higher mortality due to saline irrigations in *D. sissoo* (50%) mainly contributed towards its

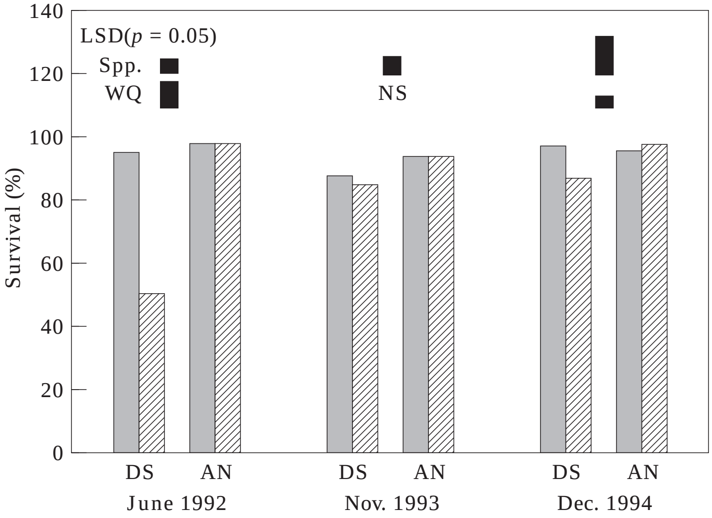

Figure 1. Sapling survival under canal (▢) and saline water (▨) irrigated conditions. DS = *Dalbergia sissoo*; AN = *Acacia nilotica*.

overall low survival. It should be pointed out that the dead saplings were replaced during August 1992. Later observations at 26 and 40 months after transplanting showed that treatment effects on survival remained statistically non-significant (p = 0·05), except for the reduced survival of *D. sissoo* under saline irrigation. The growth of tree saplings measured in terms of plant height and DSH was significantly (p = 0·05) influenced by different treatments (Table 2). *Acacia nilotica* saplings showed better growth at all the recording periods. Within 40 months, *A. nilotica* attained an average height and DSH of 3·8 m and 60 mm, respectively, against the 1·9 m and 31 mm attained by *D. sissoo*. At the 15 month stage, interaction between tree species and water quality was also significant. The growth of *D. sissoo* was reduced with saline irrigation whereas *A. nilotica* trees were taller and had thicker stems with saline irrigation (Table 2). Growth observations made 26 months after transplanting indicate no effect of water quality but its impacts were significant (p = 0·05) on both tree species after 40 months (Table 2). Measured heights were 0·60 and 0·35 m lower in saline water-irrigated *D. sissoo* and *A. nilotica*, respectively, whereas the reductions in DSH were 10 and 6 mm. Relatively less reduction in growth of *A. nilotica* implies its greater salinity resistance. The effects of various irrigation schedules remained non-significant until the observations made 40 months after transplanting. Increasing the quantity of water applied enhanced growth of trees both with canal and saline waters and more so under the conditions when the interval was kept the same (I_3).

Table 3 shows the pruned and total biomass of the two tree species for the harvest of October 1993 (28 months) and January 1995 (42 months), respectively. *Acacia nilotica* produced almost 6 times higher biomass than *D. sissoo*. The reduction in biomass of *A. nilotica* due to saline irrigation equalled 16%, whereas it was 57% in *D. sissoo*. Again the lower productivity could be minimised by giving larger quantities of saline irrigation in *A. nilotica* but this treatment had little impact on *D. sissoo* productivity. The average improvements in biomass with application of double the quantities of water (I_2 and I_3) amounted to 13 and 21% in *D. sissoo* and *A. nilotica*, respectively.

Table 2. *Effect of irrigation schedules with saline (SW) and canal (CW) water on the growth parameters of* D. sissoo *and* A. nilotica

Irrigation at Di_w/CPE*	December 1992				February 1994				December 1994			
	D. sissoo		*A. nilotica*		*D. sissoo*		*A. nilotica*		*D. sissoo*		*A. nilotica*	
	CW	SW	CW	SW	CW	SW	CW	SW	CW	SW	CW	SW
Tree height (m)												
0·1	0·70	0·60	1·78	1·90	1·32	1·20	2·88	2·80	2·17	1·52	3·95	3·38
0·2	0·72	0·60	1·65	1·92	1·27	1·25	3·10	3·04	2·21	1·64	3·91	3·76
0·2 (BC)**	0·70	0·68	1·84	2·05	1·28	1·25	3·10	2·94	2·22	1·67	4·11	3·77
Mean	0·71	0·63	1·75	1·96	1·29	1·23	3·03	2·93	2·20	1·61	3·99	3·64
LSD (*p*=0·05)												
Irrigation levels	NS				0·11				0·13			
Tree species	0·11				0·12				0·20			
Water quality (W.Q.)	NS				NS				0·35			
Species×W.Q.	0·15				NS				NS			
DSH (mm)												
0·1	9	7	24	27	24	22	45	43	35	24	61	53
0·2	9	7	22	26	23	21	46	45	36	26	63	58
0.2 (BC)	9	9	26	30	24	22	47	46	37	28	66	59
Mean	9	8	24	28	24	21	46	44	36	26	63	57
LSD (*p*=0·05)												
Irrigation levels	NS				NS				9			
Tree species	2				16				12			
Water quality	NS				NS				7			
Species×W.Q.	3				NS				NS			

*Di_w and CPE denote depth of irrigation water applied and cumulative U.S. open pan evaporation, respectively.

**Broad channels.

Table 3. *Effect of various irrigation schedules with canal and saline water on biomass (dry weight, Mg ha^{-1}) production by* D. sissoo *and* A. nilotica

Tree species/ water quality	Irrigation applied at Di_w/CPE* ratio of							
	0·1	0·2	0·2**	Mean	0·1	0·2	0·2**	Mean
	Pruned biomass (Dec 1993)				Cut biomass (January 1995)			
Acacia nilotica								
Canal water	0·48	0·44	0·52	0·48	17·68	21·98	22·91	20·85
Saline water	0·42	0·47	0·47	0·45	15·92	18·74	17·84	17·50
Mean	0·45	0·45	0·49	0·46	16·81	20·35	20·38	19·18
Dalbergia sissoo								
Canal water	0·08	0·09	0·08	0·08	3·91	4·35	4·52	4·28
Saline water	0·08	0·08	0·11	0·09	1·67	1·84	2·05	1·85
Mean	0·08	0·08	0·09	0·09	2·79	3·10	3·28	3·06
LSD ($p = 0{\cdot}05$)								
Tree species	0·05				0·77			
Water quality (W.Q.)	NS				0·48			
Irrigation levels	NS				0·43			
Species×W.Q.	NS				1·09			

*Di_w and CPE denote depth of irrigation water applied and cumulative U.S. open pan evaporation.

**Broad channels.

Water balance

Field measurements for soil water contents were started in June 1992 just before the onset of monsoonal rains. The initial soil water storage was very low, i.e. 233 mm down to 3·0 m and the layers below 0·6 m contained water almost as low as air-dry moisture contents (5–7% v/v). As only the furrow area was irrigated, better moisture regimes were maintained below the sill of furrows than the inter-row area. Overall water storage in the soil profile increased during the monsoons but due to high evaporative demands in the area, a major portion of the rain water was evaporated back to the atmosphere. The increases in soil water storage recorded after the cessation of the monsoon season (October) over that before it (June) were only 52, 114 and 56 mm during 1992, 1993 and 1994, respectively, which were just 15%, 31% and 11% of the total rainfall received during the intervening periods. The soil water data were used to estimate evaporation (E as defined earlier) in each treatment (Table 4). If it is assumed that soil water evaporation was similar under all the treatments, these data indicate that even though the growth of *D. sissoo* was initially poor when compared with *A. nilotica*, it was extracting more water. However, from the second year onwards, water losses under *A. nilotica* increased markedly. With the maintenance of better moisture regimes, increased supplies of water resulted in greater water losses whereas these were reduced with saline irrigation. The calculated values of water-use efficiency (Table 4) indicate that *A. nilotica* had much higher WUE (10·7 mg.ha.m^{-1}) than *D. sissoo* (1·7 mg.ha.m^{-1}) and WUE was also reduced with saline irrigation.

Salinity build up

Soil salinity for the main root zone (0–1·2 m soil) was monitored each year during June (when salt accumulation with saline irrigations was maximal) and October (marking the recession of the monsoon rains). Salt build up did not vary with tree species but increasing the quantity of irrigation water increased the salt loads and thus resulted in higher salinity. The average values for 3-year measurements were 5·7 dS m^{-1}, 7·7 dS m^{-1} and 6·4 dS m^{-1} for I_1, I_2 and I_3, respectively. The patterns of salt accumulation and leaching are illustrated through salinity contours (Fig. 2). As the irrigations were applied only to fill the furrows planted with trees, most of the salts accumulated in the zone below the sill of furrows and only a few moved laterally towards inter-row spaces. However, during the monsoon rains, a major portion of the accumulated salts below the sill of furrows was again pushed down and laterally towards the inter-row areas. On average, about 40% of the salts accumulated with irrigations between October to June was pushed below main rooting zone (1·2 m) by monsoon rains of 1992 and 1993, but salt leaching was reduced considerably (14%) during 1994.

Discussion

Vast tracts of arid land lie barren because of no irrigation source except ground-water which is often very deep and saline. Also, aquifers are usually low yielding and the arid soils store insufficient water to carry plantations. Rehabilitation of such areas is limited to two possibilities; either through the exploitation of plants native to arid environments by devising systems which use limited waters efficiently by preventing its loss to the dry environment or into the ground (Boyko, 1968; Benemann, 1979; Armitage, 1984; Gupta *et al.*, 1994). The results from our experiment show that both species could be established satisfactory by applying saline water in reduced amounts to limited area of furrows. *Acacia nilotica* is known to be quite tolerant of salts (Tomar & Yadav, 1980; Jain *et al.*, 1983) and adapted to arid climates, however *D. sissoo* is

Table 4. *Calculated values of evaporation, E (mm*), for various treatments during the period of monsoon rains (July–September) and post-rainy period (October–June) when plantations received irrigations*

	1992	1992–93		1993–94		1994–95		
Treatment	July–Sept	Oct–June	July–Sept	Oct–June	July–Sept	Oct–Feb	Evaporation* (mm)	WUE (mg.ha.m^{-1})
Rainfall (mm)	355	49	366	62	492	41		
Tree species								
D. sissoo	290	308	267	348	453	144	1808	1·7
A. nilotica	315	251	238	414	440	128	1786	10·7
Water quality								
Canal water	302	280	273	395	445	156	1851	6·8
Saline water	303	292	231	367	444	106	1743	5·0
Irrigation level (Di_w/CPE)								
0·1	307	203	216	361	448	127	1662	5·9
0·2	292	330	270	391	443	149	1875	6·3
0·2 (BC)	304	323	269	392	440	132	1860	6·4

*On the basis of changes in soil water storage in 3·0 m soil profile.
BC = broad channels.

considered to be sensitive to salinity (Tomar & Yadav, 1980; Singh *et al.*, 1993). Our data showed that better water regimes are maintained in soil below the sill of furrows, where there are most roots, during the irrigation periods between October to June. Most of the rain water during the monsoon season (July–September) came as runoff from inter-row areas into the furrows. The soil, being relatively light-textured, allowed for quick leaching (≈40%) of accumulated salts, with the result that average salinity in the soil below furrows remained quite low (4·5–10·1 dS m^{-1} in soil down to 1·2 m). Thus, the furrow planting and irrigation technique helped in the creation of 'niches' that provided favorable soil water and salinity regimes for the better establishment and growth of tree seedlings. Similar effects of furrow planting and irrigation technique have earlier been reported in a saline and water-logged soil when irrigated with canal water (Tomar *et al.*, 1994). In the absence of data on water requirements of trees during the establishment phase, the amounts of water supplied were based on assumed values of crop coefficients. But no difference in the growth of trees up to 28 months for

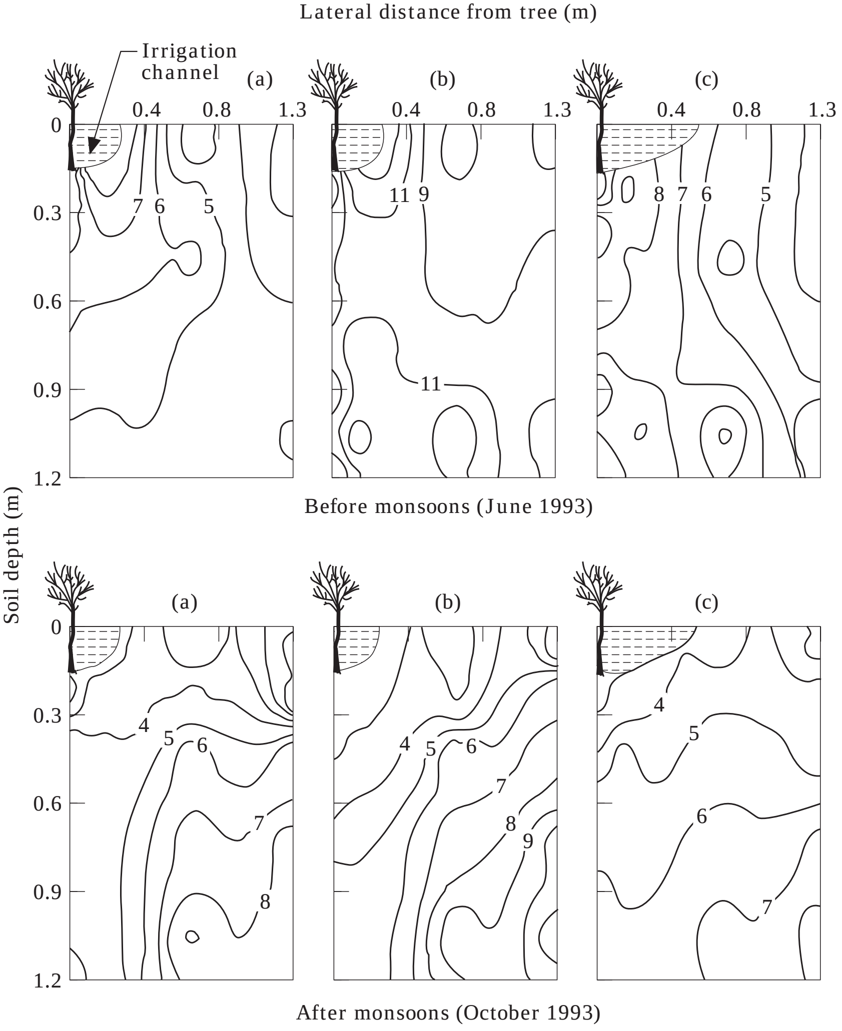

Figure 2. Contours of salinity under different irrigation schedules measured before and after the monsoon of 1993. (a), (b) and (c) denote irrigation at Di_w/CPE of 0·1, 0·2, 0·2 (broader channels), respectively, while the numbers on contour lines denote soil salinity (EC_e dS m^{-1}).

irrigation quantities between 0·1 to 0·2 times the open pan evaporation values show that the crop coefficient value of 0·1 as under I_1 was sufficient to carry plantations for 2 years. The growth rates slowed down during the third year under this treatment because with the progressive growth and depletions of soil water, soil water availability became limiting. It can be concluded that *A. nilotica* had higher productivity per unit water (WUE = 10·7 $mg.ha.m^{-1}$) and lower yield reductions with saline irrigations. This species holds promise for afforestation of arid lands with a scarcity of water. Irrigation support was stopped after 3 years and the experiment is now being continued to assess the fate of applied salts in the soil, and whether plants are able to draw their water requirements from the soils and continue to grow.

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