EVOLVING PLANTING TECHNIQUES FOR AFFORESTATION OF WATERLOGGED SALINE SOILS

O.S. Tomar & Raj K. Gupta

Central Soil Salinity Research Institute, Karnal - 132 001, India

Received August 1996

TOMAR, O.S. & GUPTA, R.K. 1998. Evolving planting techniques for afforestation of waterlogged saline soils. In India, there are large areas affected by the problems of salinity, alkalinity and waterlogging. To rehabilitate these lands, we require proper techniques and suitable salt tolerant species. Three planting techniques, namely sub-surface, ridge-trench and furrow-planting techniques, were compared for afforestation of saline waterlogged soils, and it was found that the furrow-planting technique is the most appropriate and economically sound. Out of several species tried for their survival and growth perfomance, *Prosopis juliflora, Parkinsonia aculeata, Casuarina* spp., *Acacia nilotica, A. tortilis* and *Eucalyptus camaldulensis* are the most suitable for waterlogged saline soils.

Key words: Afforestation - waterlogging - salinity - planting techniques - furrow-planting - ridge-trench method - leaching - physiological drought

TOMAR, O.S. & GUPTA, R.K. 1998. Mengembangkan teknik penanaman untuk penghutanan tanah masin yang menakung air. Di India, terdapat kawasan yang luas yang terlibat dengan masalah kemasinan, kealkalian dan air bertakung. Untuk memulihkan tanah tersebut, kami memerlukan teknik yang betul dan spesies toleran garam yang sesuai. Tiga teknik penanaman iaitu teknik bawah permukaan, teknik penanaman batas-alur dan teknik tanaman alur dibandingkan bagi penghutanan tanah bertakung air masin dan didapati teknik tanaman alur paling sesuai dan paling ekonomi. Daripada beberapa spesies yang dicuba kemandirian dan prestasi pertumbuhannya, *Prosopis juliflora, Parkinsonia aculeata, Casuarina* spp., *Acacia nilotica, A. tortilis* dan *Eucalyptus camaldulensis* adalah paling sesuai untuk tanah masin bertakung air.

Introduction

Salt affected soils are known to occur in arid and semi-arid regions. A combination of factors such as climatic, geological, hydrological and anthropological factors usually contribute to the formation of such soils. In India, about 9 million ha are salt affected out of which 5.50 million ha are saline (including coastal) and 3.58 million ha are alkaline. About 8.53 million ha have been assessed as waterlogged (Government of India 1992). All these lands have deprived the country of its potential for food and fuel production. Due to irrigation, the menace of salinity is encroaching on more and more land every year. This will continue unless measures are taken to control salinity and rehabilitate such lands. In recent years, it has been thought that such lands may be effectively utilised for growing trees which will not only meet the requirement of fuel and fodder for the ever increasing population but also will help in the reclamation of these degraded lands. It is a well known fact that saline soils provide an unfavourable environment for plant growth and, therefore, we need proper technologies of planting and selection of fuel wood tree species to rehabilitate these soils. Keeping this in view, several field experiments were initiated in 1982 to evaluate the proper techniques of afforestation for inland waterlogged saline soils.

Material and methods

Site description

The field experiments in two parts were initiated in 1982 at a representative waterlogged saline site (as also occurring elsewhere in the Gangetic plains) situated at Sampla (28° 46 ' N, 76° 46 'E, 233 m above sea-level) in Haryana State. The area represents a typical semi-arid region with an annual rainfall of 647 mm (average from 1978 to 1993) most of which (82 %) occurs during the monsoon season (June to September). The open pan evaporation, on average, exceeds rainfall except during July and August. The mean daily temperature ranges from 14 °C in January to 36 °C in May. The water-table rises rapidly with the onset of the monsoon and remains very close to the surface during July-August (Figure 1). For the rest of the period it fluctuates between 0.5 and 1.5 m from the surface. This causes poor drainage and aeration, and due to this reason, in the rainy season, most of the rain water is wasted as runoff. During the rainy season, the salinity of the ground water is reduced to about 2 dS m^{-1}, which otherwise is concentrated to about 46 dS m^{-1} during summer (May-June). The stagnation of water during the monsoon causes vulnerability to secondary salinisation and occurs in a low lying basin which has no natural outlet even for surface drainage. The soil has high salinity varying from 20 to 160 dS m^{-1} in 0-15 cm layer during different periods of the year (Figure 2). The major salinisation period extends from January to June. Calcium carbonate concretions and gypsum granules are found in 1-2 m soil depth but are unlikely to cause any hinderance to tree root proliferation. Some of the physico-chemical characteristics of soil and water are included in Table 1. Soil samples were collected and analysed from time to time following normal soil analysis methods (Jackson 1967).

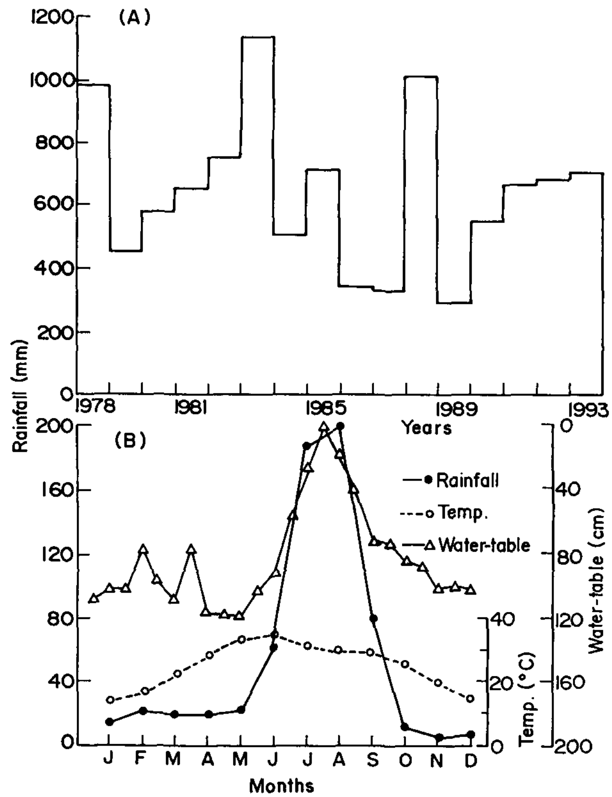

Figure 1. Annual, monthly rainfall, water-table and mean temperature of experimental site

Table 1. General properties of the soil and underground water

Soil depth (cm)	Silt (%)	Clay (%)	Bulk density (g cm^{-2})	pH	ECe (dS m^{-1})	Cation (me l^{-1})			Anion (me l^{-1})		
						Na^+	Ca^+	Mg^+	Cl^-	HCO_3^-	SAR
0-15	16.6	9.2	1.77	7.15	42.5	103	327	163	590	1.3	6.6
15-30	14.4	13.2	1.61	7.20	30.3	70	235	102	400	1.0	5.4
30-45	13.5	16.6	1.55	7.15	24.1	63	184	71	310	1.3	5.5
45-60	13.0	17.9	1.55	7.20	22.8	65	153	82	290	1.1	6.0
60-75	14.0	19.0	1.54	7.15	22.9	60	122	61	240	1.1	6.3
75-90	12.6	20.4	1.53	7.15	21.7	75	102	61	210	1.2	8.3
90-105	12.3	19.4	1.54	7.15	20.6	83	112	71	240	1.3	8.6
Mean	13.8	16.6	1.58	7.16	26.4	74	176	87	326	1.2	6.7
Typical underground water composition				7.4	27	80	109	95	235	1.6	7.9

Note: CO_3^{-2} ions were absent in the soil profile and the ground water contained SO_4^{-2} ions equal to 40 me l^{-1}.

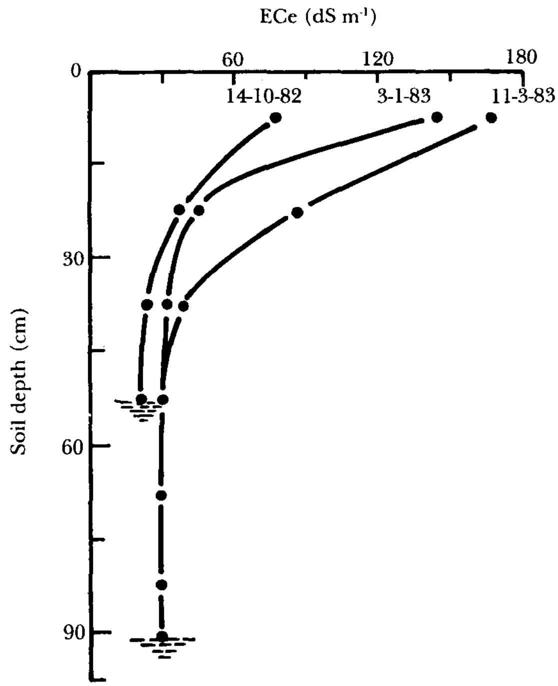

Figure 2. Salt distribution in the soil profile

Planting techniques

For successful tree planting in highly saline waterlogged soils, we need to develop a technique which effects some improvement to the soil conditions such as increasing aeration and reducing salinity in the active root zone of young plants.

To evolve the appropriate technique, saplings of the most common trees of the region, namely *Acacia nilotica, A. tortilis, Eucalyptus camaldulensis, E. tereticornis, Leucaena leucocephala, Prosopis juliflora, Syzygium cuminii, Tamarindus indica* and *Terminalia arjuna,* were planted in March 1984 by sub-surface and ridge-trench planting methods as the first part (Part I) of the experiment. For this, sixteen 6-month-old saplings in each method were planted.

In the case of the ridge-trench planting method, saplings were planted in staggered double-rows on top of the ridges created at 45 cm height from the surface. The ridges were 1.6, 3.0 and 4.5 m wide at the top, middle and bottom respectively. In the sub-surface method, saplings were planted at a depth of 30 cm below the soil surface in auger holes of 45 cm deep. The row-to-row and plant-to-plant spacings were 2.5 and 2.0 m respectively.

Then another part of the experiment (Part II) was planned for further refinements in the sub-surface planting method; 6-month-old saplings of 9 tree species, namely *Acacia auriculiformis, A. nilotica, Casuarina cunninghamiana, C. equisetifolia, C. glauca, Eucalyptus camaldulensis, Parkinsonia aculeata, Tamarindus indica* and *Terminalia arjuna,* were also planted by furrow-planting technique in August 1985 using 20 saplings of each tree species. In this planting technique, a tractor driven furrow maker was used to create 60 cm wide and 20 cm deep furrows at a spacing of 2.5 m and then saplings were planted at plant-to-plant distance of 2 m at the bottom of the furrows. These furrows were subsequently used to irrigate the tree saplings whereas earthen rings were provided to each saplings when the saplings were planted by sub-surface and ridge-trench methods so as to facilitate ponding of irrigation water by buckets/pitchers.

Table 2. Tree height (Ht, cm), girth (cm)* and survival (Sur, %) of different tree species at different ages with two planting methods

Tree species	Planting method	Months after transplanting 18 Ht	18 Girth	18 Sur.	54 Ht.	54 Girth	54 Sur.	108 Ht.	108 Girth	108 Sur.
Acacia nilotica	SS	147	7.26	81	547	na	50	641	44.63	50
	R	211	9.58	100	345	"	31	x	x	0
Acacia tortilis	SS	208	9.55	69	456	"	56	531	34.30	56
	R	121	4.49	94	293	"	25	311	14.2	25
Eucalyptus camaldulensis	SS	176	6.88	50	474	"	31	x	x	0
	R	148	6.53	50	x	"	0	x	x	0
Eucalyptus tereticornis	SS	117	7.54	38	x	"	0	x	x	0
	R	109	6.16	38	x	"	0	x	x	0
Leucaena leucocephala	SS	214	7.60	100	618	"	69	691	36.74	50
	R	127	6.16	100	365	"	13	x	x	0
Prosopis juliflora	SS	262	9.64	100	638	"	100	806	55.91	94
	R	257	9.14	100	472	"	100	640	42.39	100
Syzygium cuminii	SS	x	x	0	x	"	0	x	x	0
	R	x	x	0	x	"	0	x	x	0
Tamarindus indica	SS	61	2.10	19	168	"	19	x	x	0
	R	67	0.62	100	x	"	0	x	x	0
Terminalia arjuna	SS	142	6.82	81	429	"	50	x	x	0
	R	107	3.36	100	x	"	0	x	x	0
CD 5%										
Planting method		ns	1.14	9	60	"	10	50	4.10	8
Tree species		48	2.42	20	127	"	22	100	8.50	16
Planting method × Tree species		67	3.41	28	180	"	31	140	11.90	23

SS and R indicate sub-surface and ridge-trench planting respectively.

* : Girth was measured at stump height (5 cm) for 18 months while later it was measured at breast height (137 cm).

x : Observations not recorded due to complete mortality.

na : not available.

ns : not significant.

The irrigation was applied on the basis of irrigation water (IW) and cumulative pan evaporation (CPE) ratio, which was 0.1. Soil samples at monthly intervals were collected from each planting method and analysed for electrical conductivity. On the basis of 3-y soil data, salinity contours in different planting methods were drawn (Figure 3). Plant survival, height and girth were recorded at regular intervals up to 108 and 90 months of transplanting of seedlings in Parts I and II of the experiment respectively, but the data of only three ages are reported here for the sake of brevity (Tables 2 and 3).

Table 3. Tree height (Ht, cm), girth at breast height (cm) and survival (Sur, %) of different tree species at different ages with furrow planting method

Tree species	Months after transplanting								
	39			78			90		
	Ht.	Girth	Sur.	Ht.	Girth	Sur.	Ht.	Girth	Sur.
Acacia auriculiformis	203	1.73	40	242	5.81	5	250	5.97	5
Acacia nilotica	500	24.70	90	587	30.67	90	604	36.96	90
Casuarina cunninghamiana	335	10.35	95	408	12.38	65	461	14.67	45
Casuarina equisetifolia	333	7.41	95	388	10.05	85	452	14.36	85
Casuarina glauca	245	6.06	70	372	10.56	55	443	14.20	55
Eucalyptus camaldulensis	640	25.14	80	884	34.22	30	1034	44.31	20
Parkinsonia aculeata	280	6.88	80	390	21.52	75	403	24.48	75
Tamarindus indica	x	x	0	x	x	0	x	x	0
Terminalia arjuna	252	8.89	90	283	12.32	10	x	x	0
CD 5%	73	5.86	21	138	7.22	28	136	7.78	28

x : Not recorded due to complete mortality.

Results and discussion

Planting techniques

During the monsoon (July-August), the ground water-table remained very close to the soil surface (Figure 1) and the temperature was low in winter and high during summer. Figure 2 indicates that salinisation occurred from January to June and the major salt accumulation zone remained in the upper (0-30 cm) layer. The lower layer was observed to be less hostile and be in equilibrium with the salinity of the ground water-table. Such situations prevailing at the experimental site are not very conducive/favourable for raising tree plantations as the twin problems of high salinity and high water-table generally do not allow for easy plant establishment. For successful afforestation of highly saline soils, generally we need improved soil conditions at the time of planting the saplings, because a plant is more sensitive to salinity exposure at an early stage than at a later stage (Ayers & Hayward 1948, Kapp 1947). Therefore, to avoid excessive salinisation and to provide better aeration an approved technique is essential. As reported earlier (Tomar & Gupta 1985, Ritson & Pettit 1992), for better aeration, usually the creation of ridges is considered better, but when we compared the two methods, i.e. planting on high ridges and by the sub-surface method, more salinity was developed on the ridges and the survival percentage and growth (height and girth) were better when we planted the seedlings by the sub-surface method (Table 2). The survival of all the tree species in the ridge-trench planting method had an edge over the sub-surface method at the initial stage of establishment, because as long as the irrigation was being applied, the salinity at the root zone could not increase much through leaching of the ridges (Shah 1957), and the plants showed better survival. After two years when irrigation was completely stopped, the salt accumulation increased rapidly (Figure 3) and 100% mortality was observed on ridges except in *Proposis juliflora* and *Acacia tortilis*. *Acacia nilotica* also survived and showed better growth at the initial stage, but after stopping irrigation this species could not survive at all.

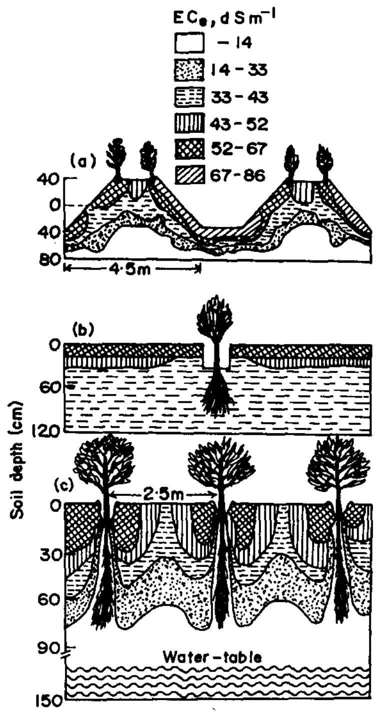

Figure 3. Typical salt distribution patterns under (a) ridge-trench, b) sub-surface, and (c) furrow-planting methods in water-logged saline soils

When we compared the sub-surface planting method with the furrow method, we found that the furrow-planting method was superior as it gave lower salinity in the root zone (Figure 3) and consequently better survival percentage, height and girth (Table 3), while the original salinity of the field before any land configuration was the same. In the furrow-planting method, the furrows were subsequently used for irrigation of tree saplings. Besides reducing the water application costs, this helped in providing uniformity in water application and subsequently reduced the salinity in the root zone at 0-120 cm depth. The downward and lateral fluxes of water and salts from these furrows helped to create a zone of favourable low salinity below (Figure 3). A comparative model of these techniques is shown in this figure. Creation of such niches favours the establishment of young tree seedlings. When we compared the salt contents in the root zones in the three planting methods, the salinity was observed the lowest in the furrow technique because of more adequate leaching. Thus, with the furrow-planting technique, it was possible to keep salt concentrations lower in the root zones of trees to the extent that the trees were able to escape the adverse effects of salinity. Moreover, this method is more economical and viable than other conventional methods for undertaking large scale plantations of forest trees. On comparing survival and growth observations of common tree species, viz. *Acacia nilotica, Eucalyptus camaldulensis, Tamarindus indica* and *Terminalia arjuna*, by the three planting methods (Tables 2 and 3), it could be seen that the survival and growth of these species (except *Tamarindus indica*) markedly improved with the furrow-planting technique at the initial stage of growth. These results are also in line with the earlier report of Krepkii (1981) who observed that irrigation by furrows or in circles around the stems improved the performance of trees. Similarly, McKell (1986) reported plant establishment on processed oil shales. It was observed that native salt tolerant seedlings, propagated in containers, could be grown directly in shale at ECe levels as high as 25 dS m^{-1}. The top-soil trenches installed in the processed oil shale disposal pile appeared to provide the most favourable growing situation for the adopted species.

Promising tree species

Afforestation programmes for saline waterlogged soils also require the proper selection of tree species for a particular agro-climatic zone. As the main problems of these soils are high water-table, high salinity of soil and underground water, impeded drainage and low soil aeration for tree growth, tree species should be those which can tolerate these multiple stresses. Only such species should normally be preferred which are inherently capable of tolerating high salt content and can thrive well under high water-table conditions. The high salt content in soil solution also causes physiological drought and thus the chosen species should also be drought resistant. The selection of the species is, therefore, naturally governed amongst many other factors by the nature and amount of salt. In situations of single stress of soil salinity or waterlogging, the species can be grown only under that particular stress and not for other situations for which the tree species is sensitive. For the present study located in a semi-arid waterlogged saline zone, a number of species were evaluated. Based upon their performance after 108 and 90 months of transplantation in Parts I and II of the experiment (Tables 2 and 3), *Prosopis juliflora* could be rated the most tolerant species as it could be grown satisfactorily on soils with salinity levels of up to 30-40 dS m^{-1} in their active root zone. This tree species also performed well under the ridge-trench planting method where the salt accumulation was very high, even when the irrigation was stopped. This confirms the earlier reports of many workers. Felker *et al.* (1981) observed that *Prosopis* is the first legume known to grow in salinity equivalent to that of sea water.

It was also observed that species like *Acacia nilotica, A. tortilis, Casuarina* spp., *Parkinsonia aculeata, Eucalyptus camaldulensis* and *Leucaena leucocephala* could be grown on sites with ECe of 10-25 dS m^{-1}. Species such as *Eucalyptus tereticonis, Terminalia arjuna, Syzygium cuminii, Tamarindus indica* and *Acacia auriculiformis* were found sensitive and could be grown satisfactorily only at sites with ECe <10 dS m^{-1} (Tables 2 and 3). Among the common tree species planted in Parts I and II of the experiment, it was observed (Tables 2 and 3) that at a later stage after stopping the irrigation, the ground water salinity played a major role in increasing soil salinity. *Tamarindus indica* and *Terminalia arjuna* died completely even by the furrow-planting technique, while *Eucalyptus camaldulensis* survived by only up to 20 %. *Acacia nilotica* proved to be hardy and more tolerant as the survival percentage of this tree species remained up to 50 and 90 % by the sub-surface and furrow planting techniques until the period of 108 and 90 months of transplanting respectively, but it could not survive on ridges due to a higher salt content in the root zone. Earlier, Tomar and Gupta (1985), in a pot house study, had compared the performance of selected tree species of arid and semi-arid areas and reported that trees differ in their ability to withstand salinity and aeration stresses individually and simultaneously. *Prosopis juliflora* and *Casuarina equisetifolia* tolerated successfully both stresses simultaneously for up to 40 days while *Acacia nilotica* was considered comparatively less tolerant under similar artificially created saline waterlogged conditions. Similar observations were also made by Le Houeron (1986) who tried many native and exotic tree species in the Mediterranean region and reported their salt tolerance. Species of *Casuarina, Acacia, Tamarix, Salvadora* and some provenances of *Eucalyptus* were found salt tolerant. Arar (1975) established 700 ha of forest plantations using a drip method of irrigation on permeable sandy soils with water of poor quality having ECe of up to 17 dS m^{-1}. Species of *Tamarix, Prosopis, Casuarina, Eucalyptus, Acacia* and *Zizyphus* were doing well when excessive salinity was used for irrigation.

It can be concluded that of the three plantating methods, the furrow-planting technique provided the least hostile saline environment to the roots in the high salinity / waterlogging conditions and therefore, could ensure better survival and plant growth. This planting technique seems to be quite practical and economically feasible and may be advocated for growing large scale plantations in saline waterlogged conditions. Plants on the ridge-trench method suffered due to excessive salt accumulation, poor leaching and instability of ridges. In those situations where salinity of the root zone (0-120 cm depth) remains higher than 30 dS m^{-1}, salt tolerant tree species like *Prosopis juliflora* can be raised even by the sub-surface and ridge-trench planting methods, whereas *Acacia nilotica, A. tortilis, Parkinsonia aculeata, Casuarina* spp. and *Eucalyptus camaldulensis* may be grown in furrows. The remaining tree species were observed sensitive to saline waterlogged conditions and no planting technique was found useful in raising these species under such stresses.

Acknowledgements

The authors are grateful to N.K. Tyagi, the Director, Central Soil Salinity Research Institute, Karnal, for his encouragement and valuable suggestions. We are also thankful to J.C. Dagar for critically examining this manuscript.

References

ARAR, A. 1975. Quality of water in relation to irrigating sandy soils. *Food and Agriculture Organisation Soils Bulletin* 25 : 73 - 83.

AYERS, A.D. & HAYWARD, H.E. 1948. A method for measuring the effects of soil salinity on seed germination with observations on several crop plants. *Proceedings of the Soil Science Society of America* 13: 224 - 26.

FELKER, P., CANNEL, G.H., CLARK, P.R., OSBORN, J.F. & NASH, P. 1981. *Screening Prosopis (Mesquite) Species for Biofuel Production on Semi-arid Lands.* Final report, United States Department of Energy, Washington D.C. 226 pp.

GOVERNMENT OF INDIA. 1992. *Indian Agriculture in Brief.* Directorate, Economics of Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi. 460 pp.

KAPP, L.C. 1947. The effect of common salt on rice production. *Arkansas Agriculture Experiment Station Bulletin* : 465 - 67.

JACKSON, M.L. 1967. *Soil Chemical Analysis.* Asia Publishing House, New Delhi. 498 pp.

KREPKII, I.S. 1981. Growing trees on saline chestnut soils of Northern Kazakhstan Lesnoe. *Khozyaistvo* 1: 27 - 29.

LE HOUERON, H.N. 1986. Salt tolerant plants of economic value of the Mediterranean basin. *Reclamation and Revegetation Research* 5: 319 - 41.

MCKELL, C.M. 1986. Propagation and establishment of plants on arid saline land. *Reclamation and Revegetation Research* 5 : 363 - 375.

RITSON, P. & PETTIT, N.E. 1992. Double-ridge mounds improve tree establishment in saline seeps. *Forest Ecology and Management* 48 : 89 - 98.

SHAH, S.A. 1957. *Prosopis juliflora.* (Letter). *Indian Forester* 83 : 472.

TOMAR, O.S. & GUPTA, R.K. 1985. Performance of some forest tree species in saline soils under shallow and saline water table conditions. *Plant and Soil* 87: 329 - 335.