LONG-TERM EFFECTS OF AMENDMENTS ON *PROSOPIS JULIFLORA* AND SOIL PROPERTIES OF A HIGHLY ALKALI SOIL

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SINGH, G. 1995. Long-term effects of amendments on *Prosopis juliflora* and soil properties of a highly alkali soil. This study was conducted for 8 y at the Gudha experimental farm of the Central Soil Salinity Research Institute, Karnal on a highly alkali soil with an initial pH of 10.3. The effect of four treatments of amendment [no amendments; 3kg gypsum; 3 kg gypsum + rice husk (RH) in 1:2 ratio of rice husk : soil on volume basis; and 3 kg gypsum + 8 kg farm yard manure (FYM) plant $^{-1}$] was evaluated in a field experiment in a randomized block design with four replications. Results indicated that during the initial 4 y, 50% *Prosopis* died without amendments while only 19% died when 3 kg gypsum plant $^{-1}$ was used. *Prosopis* survival after 4 y was 100% when RH and FYM were applied with gypsum. Height and girth of *Prosopis* recorded at 2-y intervals from planting up to 8 y were maximum in plots with gypsum + FYM, followed closely by those receiving gypsum + RH, gypsum and no amendment treatment. Similarly, the biomass accumulated in different parts of *Prosopis* in a growth period of 6 y was 2.5, 29.6, 42.4 and 44.2 Mg ha $^{-1}$ in control, gypsum, gypsum + RH and gypsum + FYM treatments respectively. The mean concentrations of Ca, K and Mg in the leaf, stem and branch of 6-y-old *Prosopis* were less and that of Na was more when no amendment was used compared to the treatments where amendments were used. Uptake of N, P, K, Ca, Mg, S and Na by *Prosopis* in 6 y was higher in plots that received gypsum + FYM (1277.2 kg ha $^{-1}$), followed by gypsum + RH (1198.3 kg ha $^{-1}$), gypsum (689.4 kg ha $^{-1}$) and in the control (58.5 kg ha $^{-1}$). Mean litter and pod yields of *Prosopis* recorded during the study period were markedly higher in amended soil than those without amendments. Total amounts of N, P, K, Ca, Mg, S and Na added to the site through *Prosopis* litter during the study period were 71.8, 937.9, 1557.6 and 1656.7 kg ha $^{-1}$ in no amendment, gypsum, gypsum + RH, and gypsum + FYM treatments respectively. The reduction in pH and EC and improvement in organic carbon and available N status of the soil were maximum in gypsum + FYM (probably due to better tree growth and higher litter fall in this treatment) and least in the no amendment treatment. A rough estimate about the likely effects of amendments on the soil nutrient balance showed a gain of 13, 40, 93, and 121 kg of N, P and K to the site in the control, gypsum, gypsum + RH, and gypsum + FYM treatments respectively.

Key words : Alkali soil - amendments -biomass production -nutrient budget - *Prosopis juliflora* - soil amelioration - soil properties

SINGH, G. 1995. Kesan jangka panjang bagi perubahan ke atas *Prosopis juliflora* dan ciri-ciri tanah bagi tanah beralkali tinggi. Kajian ke atas tanah beralkali tinggi di mana pH permulaannya ialah 10.3 telah dijalankan selama 8 tahun di kebun eksperimen Gudha di Institut Penyelidikan Saliniti Tanah Tengah, Karnal. Kesan empat rawatan perubahan [tanpa perubahan; 3 kg gipsum , 3 kg gipsum + sekam padi (RH) dalam nisbah 1:2 serkam pada : tanah berdasarkan isipadu; dan 3 kg gipsum + 8 kg baja kebun (FYM) tanaman $^{-1}$] telah dikaji didalam lapangan dalam rekabentuk blok rambang dengan empat ulangan. Keputusan menunjukkan dalam empat tahun pertama, 50%

Prosopis mati dalam rawatan tanpa perubahan manakala cuma 19% mati apabila 3 kg gipsum tanaman $^{-1}$ digunakan. Kemandirian *Prosopis* selepas 4 tahun adalah 100% apabila RH dan FYM telah diberikan bersama gipsum. Ketinggian dan ukurlilit *Prosopis* yang direkod pada selang 2 tahun daripada penanaman hingga ke-8 tahun adalah maksimum dalam plot-plot yang mengandung gipsum + FYM, diikuti dengan plot-plot yang menerima gipsum + RH, gipsum dan yang tidak menerima apa-apa perubahan. Biojisim yang terkumpul di bahagian-bahagian berlainan *Prosopis* dalam jangkamasa pertumbuhan selama 6 tahun ialah 2.5, 29.6, 42.4 dan 44.2 mg ha $^{-1}$ di dalam rawatan-rawatan kawalan, gipsum, gipsum + RH dan gipsum + FYM masing-masing. Purata kepekatan Ca, K dan Mg dalam daun, ranting dan dahan *Prosopis* berumur 6 tahun adalah rendah. Kandungan Na adalah lebih tinggi dalam rawatan tanpa perubahan. Pengambilan N, P, K, Ca, Mg, S dan Na oleh *Prosopis* berumur 6 tahun adalah lebih tinggi bagi plot-plot yang menerima gipsum + FYM (1277.2 kg ha $^{-1}$), diikuti dengan gipsum + RH (1198.3 kg ha $^{-1}$), gipsum (689.4 kg ha $^{-1}$) dan kawalan (58.5 kg ha $^{-1}$). Purata sarap dan hasil pod *Prosopis* adalah lebih tinggi dalam tanah yang telah dirawat berbanding dengan kawalan. Jumlah kandungan N, P, K, Ca, Mg, S dan Na yang ditambah kepada tapak kawasan melalui sarap *Prosopis* semasa kajian ialah 71.8, 937.9, 1557.6 dan 1656.7 kg ha $^{-1}$ di dalam kawalan, rawatan-rawatan gipsum, gipsum + RH dan FYM masing-masing. Penurunan dalam pH dan EC serta pembaikan dalam karbon organik dan status N dalam tanah adalah maksimum di gipsum + FYM (mungkin disebabkan tumbesaran pokok dan keguguran sarap yang lebih baik dalam rawatan tersebut) dan minimum dalam kawalan. Anggaran kasar ke atas kesan-kesan perubahan yang mungkin pada keseimbangan nutrien tanah menunjukkan keuntungan sebanyak 13, 40, 93 dan 121 kg N, P dan K kepada tanah dalam kawalan, rawatan-rawatan gipsum, RH + gipsum dan gipsum + FYM masing-masing.

Introduction

Of the 8.5 million ha salt-affected soils in India (Singh 1991), nearly 2.5 million ha alkali soils occur in northern India in the states of Uttar Pradesh, Rajasthan, Haryana and Panjab. Alkali soils of this region have high exchangeable sodium, high pH, varying degrees of calcareousness and excessively low permeability. Most of these soils support no vegetation or allow the growth of only a few wild species such as *Sporobolus marginatus, S. diander, Leptochloa fusca, Desmostachya bipinnata, Suaeda maritima* and *Kochia indica* (Bhumbla *et al.* 1972, Yadav 1980). Many workers (Singh *et al.* 1989a, Abrol *et al.* 1973, Chawla & Abrol 1980, Swarup 1993) have demonstrated the usefulness of amendments in ameliorating alkali soils for crop cultivation. As a result, a sizeable area with alkali soils in India has been producing good crops of rice and wheat. However, little is known about the effect of amendments on establishment of tree crops in alkali soils.

Proprietary rights to a large chunk of land affected by alkalinity in this part of the country mostly lie with village 'Panchayats' (judicial village bodies). Owing to common property rights their reclamation for crop production is neither feasible nor possible. Tree planting is an option of great promise for development of such sites particularly in view of firewood and forage shortages and also with environmental considerations. Research efforts are in progress to develop a technology package for afforestation of alkali soils. As part of these efforts the present investigation was initiated to study (i) the long term effects of amendments on *Prosopis juliflora,* and (ii) the long term changes in soil due to vegetative cover.

Materials and methods

Experimental site

This study (1984 - 1992) was conducted at the Gudha experimental farm of the Central Soil Salinity Research Institute, Karnal. The farm is located at 29° 29' N and 76° 56' E and is about 237 m above mean sea level. The water table fluctuates between 4 and 6 m and the ground water is of good quality. The soils are Aquic Natrustalfs (Bhargava *et al.* 1980), representative of large areas of sodic soils occuring in the Indo-Gangetic plains (Table 1). These soils are lying abandoned and do not contribute to national income. The natural vegetation is very scanty. There are isolated trees of *Acacia nilotica, A. tortilis, Prosopis juliflora, Capparis aphylla, Salvadora* spp. and *Butea monosperma*, with a sparse understory of *Sporobolus marginatus, S. diander, Desmostachya bipinnata, Leptochloa fusca, Suaeda maritima* and *Chloris gayana.*

Table 1. Soil properties of the experimental site

Soil depth (cm)	Mechanical analysis (%)			pH	EC[1] (dSm^{-1})	ESP[2] (%)	OC (%)	Available nutrients ($kg\ ha^{-1}$)		
	Sand	Silt	Clay					N	P	K
0-15	51.4	28.3	20.3	10.3	2.3	94	0.17	82	35	533
15-30	43.5	31.5	25.3	10.3	1.9	93	0.12	73	28	488
30-60	42.8	32.0	25.2	10.1	1.5	90	0.10	60	20	440
60-90	37.0	34.2	28.8	10.2	1.4	91	0.10	42	18	356
90-120	32.4	40.5	27.1	10.2	1.3	92	0.10	34	14	300

1: Measured in 1:2 soil: water suspension.
2: Exchangeable sodium per cent.

Climate

The study area has a sub-tropical, semi-arid, monsoonic type of climate characterised by a dry and hot spring/early summer, a hot rainy season, a warm autumn and a cool winter. The average annual rainfall is about 700 mm, with 80% received between June and September. Mean temperature starts rising from February onwards until the summer maximum, often exceeding 40 °C, in May or June. Class-A pan evaporation exceeds rainfall in all months except in July and August. Mean meteorological parameters as recorded near the experimental site during the study period are reported in Table 2.

Table 2. Mean monthly climatalogical parameters as recorded near the experimental site during the study period (1984 - 1992)

Month	Temp °C		Rainfall	Pan evap.	Daily sunshine
	Max.	Min.	(mm)	(mm month^{-1})	(h)
January	19.1	6.4	10.2	45.3	7.3
February	22.0	8.1	44.3	65.1	7.6
March	27.2	12.1	21.7	117.2	8.3
April	35.3	15.3	9.1	213.8	9.7
May	38.7	21.6	27.3	296.7	9.4
June	34.7	25.6	68.4	249.4	7.8
July	33.8	26.0	172.7	146.1	6.5
August	32.8	25.4	210.8	117.7	6.1
September	32.8	22.4	100.0	118.1	7.2
October	31.0	16.3	22.2	96.5	8.0
November	27.1	11.1	13.0	59.8	7.7
December	21.8	7.7	30.8	45.0	6.2

Experimental layout

Response of *Prosopis juliflora* to different amendment treatments was studied for eight years in a field experiment organized in a randomised block design with four replicates. The treatments comprised (a) no amendment (only original alkali soil was refilled when planting *Prosopis*), (b) original alkali soil plus 3 kg gypsum plant^{-1}, (c) original alkali soil plus 3 kg gypsum plus rice husk (a rice factory waste material mixed in 1:2 ratio of soil: rice husk on volume basis), and (d) original alkali soil plus 3 kg gypsum plus 8 kg FYM (farm yard/cattle manure). The seedlings were planted in trenches 30 cm deep and 30 cm wide dug across the plots which were refilled back with the dug-out soil blended with amendments in the manner described above before planting trees. Four- to 6-month-old *Prosopis* saplings raised in a good normal soil in polythene bags were transplanted in July 1984 at 3 m intervals in rows 5 m apart. Each treatment accomodated 32 trees. First irrigation was given immediately after planting and subsequent irrigations were applied as and when required at intervals of 15 - 20 days in summer and 25 - 30 days after the July - September monsoon season up to 2 years. Good quality water from a shallow tube-well was used.

Observations recorded

Data on height and girth of *Prosopis* were recorded periodically but the results are discussed on the basis of observations recorded at 2-y intervals from planting up to 8 y. The diameter at stump height (DSH) and at breast height (DBH) were measured at 5 and 137 cm above ground level respectively. The average initial height and DSH of *Prosopis* at planting were 55 cm and 5.5 mm respectively. After 2 and 6 y, representative plants were harvested from each treatment to study the biomass accumulation in different treatments. *Prosopis* leaves, branches and main stem were separated and their fresh and air-dry weight recorded.

For collection of litter, wooden traps 90 cm long, 60 cm wide and 10 cm in height were used. These traps were placed at representative sites (four places in each treatment) in the experimental field. The litter fallen in these traps was weighed at quarterly intervals during the year. *Prosopis* pod yields were also recorded. At four places in each treatment, 5 × 3 m wide areas were marked for this purpose. Pods falling in this area were collected periodically and weighed to determine tentative yearly yields.

Collection, preparation and analysis of soil samples

Soil samples were taken at four places for each plot, before *Prosopis* transplanting. Sampling was repeated in September 1990 to assess any change in soil properties. After collection, samples were air- and then oven-dried, ground with a wooden pestle and mortar, passed through a 2-mm sieve and stored for analysis. Soil pH, electrical conductivity, organic carbon and available N, P, and K were determined by standard procedures (Jackson 1967).

Collection, preparation and analysis of plant samples

Stem, branch and leaf samples were analysed separately for chemical composition. Samples were washed with tap water, diluted acid (0.1 % HCl), and single-and double-distilled water, then air-dried and oven-dried at 70°C for 48 h, then ground in a Wiley mill, passed through a 16-mesh sieve, and stored in polyethylene bags. Samples of 1 g were digested in a di-acid mixture (HNO_3: $HClO_4$, 3:1). The filtrate was kept in 100 ml plastic bottles. Samples were analysed for Na and K by flame photometry and for Ca, Mg, Fe, Mn, Zn and Cu by Pye Unicam atomic absorption spectrophotometry. Total N was determined by a Kjeltec-II automatic nitrogen analyser. Phosphorus was determined by the vanadomolybdophosphoric yellow colour method (Jackson 1967) and S by a turbidity method (Massoumi & Cornfield 1963), using spectrophotometer model Spectronic 21.

Results and discussion

Tree survival

Mean *Prosopis* survival at 2 y intervals from planting up to 8 y was significantly higher when trees were planted after the application of amendments than without amendment application (Table 3). Within the first 2 y of planting, 37% *Prosopis* died in the control; the mortality rate further increased to 50% during the next two years. Application of rice husk and FYM in conjunction with gypsum was better than when gypsum alone was applied. Gypsum + RH, and gypsum + FYM resulted in 100% survival of *Prosopis* during the initial 4 y. The mean survival of *Prosopis* recorded after 8 y was 44% in the no amendment treatment, 75% in gypsumalone and 85% when the soil was treated with either gypsum + RH or gypsum + FYM. The low survival in non-amended soil may be due to adverse effects of exchangeable sodium in the soil solution on *Prosopis* saplings during the establishment stage. Owing to the very high exchangeable sodium, the plants may have died due to nutritional disorders resulting from excessive sodium uptake. In the case of gypsum ($CaSO_4 . 2H_2O$) treatment, the exchangeable sodium is neutralized by calcium ions and plants escape sodium toxicity hazards. Earlier studies (Singh *et al.* 1989 a, b) also showed that *Prosopis* grows only in alkali soils with pH less than 10.0. In severe alkali soils (pH>10.0) its survival is affected.

Table 3. Effect of amendments on survival, height, girth, litter yield, and pod yield of *Prosopis* recorded during the study period

Amendment	Survival (%)	Height (m)	DSH (cm)	DBH (cm)	Litter yield (kg)		Pod yield (kg)	
					Total	Per year	Total	Per year
		2 y						
None	63	1.5	1.8	0.6	1.24	0.25	480	96
Gypsum	88	3.2	3.9	1.4	14.7	2.95	3580	716
Gypsum + RH	100	3.9	5.5	2.1	22.0	4.40	6000	1200
Gypsum + FYM	100	4.1	5.4	1.9	24.1	4.82	6532	1302
LSD (0.05)	14	0.48	0.7	0.4	2.46	0.84	672	214
		4 y						
None	50	1.7	2.3	1.0				
Gypsum	81	4.3	5.6	3.3				
Gypsum + RH	100	5.2	8.1	4.5				
Gypsum + FYM	100	5.1	8.3	4.4				
LSD (0.05)	16	0.45	1.4	0.9				
		6 y						
None	44	2.5	2.6	1.4				
Gypsum	75	6.9	7.9	6.4				
Gypsum + RH	94	3.3	11.1	9.4				
Gypsum + FYM	91	3.5	11.5	9.3				
LSD (0.05)	15	2.6	1.3	1.2				
		8 y						
None	44	3.0	2.8	1.7				
Gypsum	75	8.2	10.0	7.8				
Gypsum + RH	85	10.2	13.0	11.2				
Gypsum + FYM	85	10.6	13.8	12.0				
LSD (0.05)	17	2.4	1.6	1.4				

Growth performance

Effects of different amendments on height and girth of *Prosopis* recorded at 2- y intervals from planting up to 8 y are reported in Table 3. Mean plant height, diameter at stump height (DSH) and diameter at breast height (DBH) were significantly greater in amended alkali soil than in the control treatment. Application of organic amendments in conjunction with gypsum proved much superior in influencing tree growth than gypsum treatment alone. Beneficial effect of amendments on tree growth in alkali soils is reported in the literature (Abrol & Sandhu 1985).

Biomass production

The mean biomass accumulated in *Prosopis* parts (stem, branch and leaf) at 2 and 6 y after planting was nearly 10 times greater in gypsum-treated soil than in no amendment treatment (Table 4). Similarly, in another study on a similar soil, Singh *et al.* (1989a) obtained 6- and 9-fold increases in biomass yield of *Prosopis* by surface application of gypsum at 7.5 and 15.0 Mg ha^{-1} respectively as compared to no amendment treatment. The total biomass accumulations by *Prosopis* in 2 y were 0.17, 1.63, 3.74 and 5.36 t ha^{-1} in no amendment, gypsum, gypsum + RH, and gypsum + FYM treatments respectively. At 6 y after planting total biomass production was about one and half times more in gypsum + RH/gypsum + FYM treated soil compared to the treatment where gypsum alone was used for planting the trees. Nearly 50% of the total biomass was accumulated in the stem, and leaves constituted about 10 - 15% of the total biomass. Higher pruned and harvested biomass values in gypsum + RH, and gypsum + FYM treated plots were apparently due to improved nutrient status of alkali soils which are otherwise severely deficient in organic matter, nitrogen, calcium and zinc. Addition of organic amendments not only reduces the nutrient deficiencies but also enhances biological activity in otherwise dead mass of soil. Owing to increased soil biological activity microbial transformations are also triggered.

Table 4. Effect of amendments on biomass accumulation in different parts of 2- and 6-y-old *Prosopis*

Amendment	Biomass accumulation (t ha^{-1})							
	2 y after planting				6 y after planting			
	Stem	Branch	Leaf	Total	Stem	Branch	Leaf	Total
None	0.08	0.07	0.02	0.17	1.2	1.0	0.3	2.5
Gypsum	0.70	0.72	0.21	1.63	16.8	9.8	3.0	29.6
Gypsum + RH	1.68	1.55	0.51	3.74	21.4	15.8	5.2	42.4
Gypsum +FYM	2.03	2.42	0.91	5.36	21.9	16.6	5.7	44.2
LSD (0.05)	0.15	0.20	0.04	0.41	2.8	2.4	0.7	4.3

Nutrient composition and total accumulations

Effects of amendments on mean nutrient concentrations in different plant parts of 6-y-old *Prosopis* are given in Table 5. The nutrient concentrations in *Prosopis* decreased in the order: leaf, branch and stem. The nutrient concentrations in various parts of *Prosopis* represent medium to high levels reported for many temperate trees (Leaf 1973) and are comparable to multi-species averages obtained in analysis of tropical forest ecosystems (Golley *et al.* 1975, Lundgren 1978, Singh 1982, Steward *et al.* 1981). This nutrient concentration trend is commonly encountered in nutrient analysis of tree components (Lundgren 1978, Steward *et al.* 1981, Singh 1982). Effect of different amendment treatments on mean N, P, Mg and S concentrations in various *Prosopis* parts was neglegible. Calcium and potassium concentrations were markedly less in the control as compared to treated plots. Highest uptake of Na in the control treatment was probably due to high exchangeable sodium status of the alkali soil. The decrease in Na concentration in plant parts in gypsum, gypsum + RH, and gypsum + FYM treatments was mainly due to a decrease in the exchangeable sodium percentage in the soil. Decreases in K uptake with an increase in exchangeable sodium percentage are also reported in the literature (Bains & Fireman 1964, Mehrotra & Das 1973, Singh & Abrol, 1985, Singh 1988). Similarly (Bernstein & Pearson 1956, Singh *et al.* 1969, Poonia *et al.* 1972, Singh & Abrol 1985) also reported a decrease in the uptake of Ca in different field crops with an increase in the exchangeable sodium percentage.

Nutrient accumulations were calculated by multiplying nutrient concentrations with the respective weights of *Prosopis* parts. The highest accumulations in gypsum+ RH, and gypsum + FYM treatments were probably due to higher biomass yields in these treatments (Table 5). Irrespective of the treatments, the nutrients accumulated were highest in branches and minimum in stem parts of *Prosopis.* These observations show that *Prosopis* has the advantage of tying a greater quantity of the nutrients in the leaves, a tree part which is likely to be left at the site during harvesting. Recycling of nutrients through leaf litter fall helps in mitigating site depletion problems owing to such high nutrient removals through *Prosopis* plantations.

Litter production, its quality and nutrient additions to the site

Effect of amendments on litter yields of *Prosopis* was recorded yearly starting from 1986 - 87 and total yields are reported in Table 3. Total litter yields obtained in five years (1986 - 87 to 1990 - 91) were nearly 7, 13 and 14 times higher in gypsum, gypsum+RH and gypsum + FYM treatments respectively than in the control treatment. The mean (average of 5 y) litter yields ha^{-1} y^{-1} were 0.25, 2.95, 4.4 and 4.82 kg when *Prosopis* was planted without amendments, with 3 kg gypsum $plant^{-1}$, with 3 kg gypsum + RH $plant^{-1}$ and with gypsum 3 kg + FYM 8 kg $plant^{-1}$ respectively. The higher litter yields from *Prosopis* in amedment treated alkali soil were probably due to better growth of trees in these treatments compared to no amendment treatment. Irrespective of the amendment treatments, the litter production by *Prosopis* also increased regularly from year to year and maximum yields were obtained during 1990 - 91. There were seasonal changes in litter fall. Winter months accounted for a major fraction of annual litter in *Prosopis.* This is unlike deciduous plantations which yield maximum litter during summer months (Kikujava *et al.* 1984). Gill *et al.* (1987) also observed similar bimodal trend in litter production in the case of *Acacia nilotica* and *Eucalyptus tereticornis* plantations.

Table 5. Nutrient concentrations and total accumulations in different parts of 6-y-old *Prosopis* as influenced by amendment treatments

Amendment	Plant part	N	P	K	Ca	Mg	S	Na	Mean
		Nutrient concentration (%)							
None	Leaf	2.7	0.3	1.1	0.9	0.4	0.5	0.3	0.89
	Branch	0.9	0.1	0.7	0.5	0.1	0.1	0.1	0.36
	Stem	0.5	0.07	0.1	0.4	0.4	0.4	0.07	0.17
	Mean	1.4	0.16	0.63	0.60	0.18	0.21	0.16	0.47
Gypsum	Leaf	2.6	0.2	1.7	1.6	0.4	0.6	0.2	1.04
	Branch	0.8	0.1	1.0	0.7	0.1	0.1	0.08	0.41
	Stem	0.4	0.05	0.2	0.4	0.02	0.03	0.02	0.16
	Mean	1.3	0.12	1.0	0.90	0.17	0.24	0.10	0.54
Gypsum + RH	Leaf	2.8	0.3	1.7	1.4	0.5	0.4	0.16	1.04
	Branch	1.0	0.1	1.2	0.8	0.1	0.08	0.06	0.48
	Stem	0.6	0.06	0.3	0.3	0.05	0.05	0.04	0.20
	Mean	1.5	0.15	1.1	0.83	0.22	0.18	0.09	0.57
Gypsum + FYM	Leaf	2.6	0.2	1.5	1.6	0.5	0.4	0.17	1.00
	Branch	1.2	0.1	1.0	0.7	0.2	0.1	0.06	0.48
	Stem	0.6	0.04	0.3	0.4	0.05	0.05	0.03	0.27
	Mean	1.5	0.12	0.93	0.90	0.25	0.18	0.09	0.56
		Nutrient accumulations (kg ha^{-1})							
None	Leaf	8.1	1.0	3.3	2.7	1.2	1.5	0.9	18.7
	Branch	9.0	1.0	7.0	5.0	1.0	1.0	1.0	25.0
	Stem	6.0	1.0	1.2	4.8	0.5	0.5	0.8	14.8
	Total	23.1	3.0	11.5	12.5	2.7	2.7	2.7	58.5
Gypsum	Leaf	78.0	6.0	51.0	48.0	12.0	18.0	6.0	219.0
	Branch	78.4	9.8	98.0	68.6	9.8	9.8	7.8	282.2
	Stem	67.2	8.4	33.6	67.2	3.4	5.0	3.4	188.2
	Total	223.6	24.2	182.6	183.8	25.2	32.8	17.2	689.4
Gypsum + RH	Leaf	145.6	15.6	88.4	72.8	26.0	20.8	8.3	377.5
	Branch	158.0	15.8	189.6	126.4	15.8	12.6	9.5	527.7
	Stem	128.4	12.8	64.2	64.2	10.7	10.7	2.1	293.1
	Total	432.0	44.2	342.2	263.4	52.5	44.1	19.9	1198.3
Gypsum + FYM	Leaf	148.2	11.4	85.5	91.2	28.5	22.8	9.7	397.3
	Branch	199.2	16.6	166.0	116.2	33.2	16.6	10.0	557.8
	Stem	131.4	8.8	65.7	87.6	11.0	11.0	6.6	332.1
	Mean	478.8	36.8	317.2	295.0	72.7	50.4	26.3	1277.2

The mean concentrations of K, Ca, Mg, and S in *Prosopis* litter were markedly higher when trees were planted after applying amendment than in the control (Table 6). However, N and P concentrations were little affected owing to differential treatments. The mean concentrations of N, P, K, Ca, Mg, S and Na were 0.83% in the control, 0.91% in gypsum, 1.01% in gypsum + RH, and 1.0 % in gypsum +FYM treatments. Nutrient additions to the site through *Prosopis* litter were calculated by multiplying nutrient concentrations with the respective litter weight in each treatment.

Table 6. Effect of amendment on mean concentrations of nutrients in *Prosopis* litter and nutrient additions to the site through litter fall

Nutrient	Concentration (%)				Nutrient additions (kg ha^{-1})			
	No amendment	Gypsum (G)	G+ RH	G+ FYM	No amendment	G	G+ RH	G+ FYM
N	2.6	2.4	2.5	2.5	32.2	352.8	550.0	602.5
P	0.26	0.24	0.29	0.30	3.2	35.3	63.8	72.3
K	1.0	1.4	1.7	1.6	12.4	205.8	374.0	385.6
Ca	0.82	1.2	1.4	1.4	10.2	176.4	308.0	337.4
Mg	0.48	0.53	0.53	0.58	6.0	77.9	116.6	139.8
S	0.39	0.44	0.50	0.48	4.8	64.7	110.0	115.7
Na	0.24	0.17	0.16	0.14	3.0	25.0	35.2	33.7
Mean/ Total	0.83	0.91	1.01	1.0	71.8	937.9	1557.6	1656.7

Pod production

Effects of amendments on *Prosopis* pod yields are reported in Table 3. In the case of treatments, *Prosopis* started podding in the third year and continued thereafter throughout the study period. However, in the untreated soil podding started in the fourth year after planting, and only on a few plants . Further, seed setting in the pods was also not proper and most of the pods were without seeds on ripening in the control plot. The average pod yields were 96, 716, 1200 and 1302 kg ha^{1} y^{1} when *Prosopis* was planted without amendment, with 3 kg gypsum $plant^{1}$, with 3 kg gypsum + RH $plant^{-1}$ and with 3 kg gypsum + 8 kg FYM $plant^{-1}$ respectively. These values were less compared to values reported for many *Prosopis* species. Pod yields up to 140 kg $tree^{-1}$ are reported on non-saline lands (Felker *et al.* 1980). However, most of the work on *Prosopis* deals with pod yields from mature stands (Felker 1979, Sharifi *et al.* 1982), whereas the yields in this study were from young *Prosopis* trees in non-fertile high pH soil.

Effect on soil properties

There was a marked fall in soil pH and EC during the experimental period, from their original values of 10.3 and 2.2 respectively (Table 7). After a growth period of 6 y the soil pH and EC in the 0 - 15 cm soil layer fell to 9.7 and 0.68 dSm^{1} with no amendment, 9.2 and 0.55 dSm^{-1} in gypsum, 8.8 and 0.22 dSm^{-1} in gypsum + RH, and 8.7 and 0.23 dSm^{-1} in gypsum + FYM treatment. The decrease in soil pH and EC might be due to the root exudates and/or products of decomposition of tree litter. Reductions in these soil properties in plots treated with gypsum + RH, and gypsum + FYM compared to either control and/or gypsum treatment were observed probably due to higher tree litter yields. Further, the extensive and sturdy root system of *Prosopis* helped leaching of salts from the top layer. Ponnamperuma (1972) reported that pH of alkaline soils was highly sensitive to changes in the partial pressure of CO_2. The CO_2 released from the roots of growing plants facilitates the replacement of adsorbed Na in calcareous soils by solubilizing the native $CaCO_3$ (Goertzen & Bowers 1958, Chhabra & Abrol 1977) and thus enhances the process of soil reclamation. Other studies on afforestation of alkali soils reported by Grewal (1984), Gill (1985), Singh *et al.* (1989a), Singh and Gill (1992), Singh *et al.* (1993), and Gill and Abrol (1991) also showed that leguminous trees ameliorate high pH soils at a much faster rate than non-leguminous ones.

Table 7. Effect of *Prosopis* canopies achieved through differential treatments on soil properties 6 y after planting

Soil property	Soil depth (cm)	Initial status	6 y after planting			
			No amendment	Gypsum	Gypsum + RH	Gypsum + FYM
pH	0-15	10.3	9.7	9.2	8.8	8.7
	15-30	10.3	10.0	9.7	9.3	9.4
EC (dSm^{-1})	0-15	2.2	0.68	0.55	0.22	0.23
	15-30	1.5	1.02	0.64	0.48	0.42
Organic carbon (%)	0-15	0.18	0.28	0.40	0.60	0.66
	15-30	0.13	0.15	0.20	0.45	0.51
Available N (kg ha^{-1})	0-15	79	92	128	180	196
	15-30	73	80	112	132	140
Available P (kg ha^{-1})	0-15	35	36	34	32	30
	15-30	31	30	33	28	29
Available K (kg ha^{-1})	0-15	543	556	535	538	552
	15-30	490	485	505	470	496

Growing of *Prosopis* resulted in marked increase in organic carbon and available N build-up of a barren alkali soil. The maximum build-up was observed in gypsum + RH, and gypsum + FYM treatments and minimum in the control treatment. In a growth period of 6 y, the organic carbon and available N in the 0 - 15 cm layer of the profile increased from 0.18% and 79 kg ha^{-1} to 0.28% and 92 kg ha^{-1} in control, to 0.40% and 128 kg ha^{-1} in gypsum, to 0.60% and 180 kg ha^{-1} in gypsum + RH, and 0.66% and 196 kg ha^{-1} in gypsum + FYM treatments respectively (Table 7). Increases in organic carbon and available N were also observed in the 15 - 30 cm layer. However, the magnitudes of improvement were less. This may be due to an increase in biological activity in the previously barren soil as a result of tree root growth, litter fall and N fixation by the *Prosopis* trees. Field studies elsewhere (Tiedemann & Klemmedson 1973, 1986, Rundel *et al.* 1982) also showed that soil under *Prosopis* canopies contains 2 - 3 times as much organic matter and N as soils away from the canopy. Similarly, studies in a Californian desert showed that *Prosopis* produced 30 kg N ha^{-1} y^{-1} when their crown covered 34% of the land surface area. Rundel *et al.* (1982) suggested that up to 100 kg N ha^{-1} y^{-1} might be fixed by *Prosopis*, given greater ground cover and better management practices. Earlier studies at Karnal (Singh & Gill 1992, Singh *et al.* 1993) also showed higher organic carbon and available N status under tree canopies than in the adjacent sites without trees.

There was little effect of differential amendment treatments on available P and K contents of the soil (Table 7). Probably, P and K uptakes by the *Prosopis* trees were the same as those added to the soil through litterfall; therefore P and K balance in the soil remained almost the same. Moreover, the experimental soil was already high in available P and K status. The available P and K status of the 0 - 15 cm layer recorded 6 y after planting changed from 35 and 543 kg ha^{-1} to 36 and 556 kg ha^{-1} in the control, to 34 and 535 kg ha^{-1} in gypsum, to 32 and 538 kg ha^{-1} in gypsum + RH, and to 30 and 552 kg ha^{-1} in gypsum + FYM treatments respectively.

Nutrient balance

A rough estimate was made about the likely nutrient additions to the site through litter fall and nutrient removals from the site by *Prosopis* during the study period under different treatments and its effect on available N, P and K status of the experimental soil (Table 8). Available N status of the soil was doubled in 6 y in gypsum + RH, and gypsum + FYM treatments compared to the original soil status. Even in the control treatment there was a gain of 13 kg N to the soil. Total N, P and K gains to the site in 6 y were 27 kg ha^{-1} in the control, 40 kg ha^{-1} in gypsum, 93 kg ha^{-1} in gypsum + RH, and 121 kg ha^{-1} in gypsum + FYM treatments. This showed that a high removal of nutrients through tree parts did not result in site depletion.

Table 8. Nutrient budget of the experimental site (0 - 15 cm) as affected by varying *Prosopis* canopies achieved through differential application of amendments

Amendment	Nutrients	Inital soil status	Addition through litter	Uptake by trees	Soil status after 6 y	Gain/ deficit
		(------------	------------	kg ha^{-1}	------------	------------)
None	N	79	32	23	92	+13
	P	35	3	3	36	+ 1
	K	543	12	12	556	+13
	Total	657	47	38	654	+27
Gypsum	N	79	353	224	128	+49
	P	35	35	24	34	- 1
	K	543	206	183	535	- 8
	Total	657	594	431	697	+40
Gypsum + RH	N	79	550	432	180	+101
	P	35	64	44	32	- 3
	K	543	374	342	538	- 5
	Total	657	988	818	750	+93
Gypsum + FYM	N	79	603	479	196	+117
	P	35	72	37	30	- 5
	K	543	386	317	552	+ 9
	Total	657	1061	833	778	+121

Conclusion

The present field study revealed that 50% *Prosopis* seedlings died within four years of planting when no amendment was applied at the time of planting. Addition of 3 kg gypsum plant $^{-1}$ improved the survival rate to 81%. Further, addition of organic amendments in conjunction with gypsum resulted in 100% *Prosopis* survival in the highly degraded alkali soil, the type which covers nearly 2.5 million ha in northern India. The overall effect of amendments on *Prosopis* growth, biomass production, pod yield, litter production was in the order: gypsum + FYM > gypsum + RH > gypsum > no amendment. Owing to the better growth of *Prosopis* in gypsum + RH, and gypsum + FYM treated soils, reduction in pH and EC and improvement in fertility status of the site in terms of increase in soil organic matter and available N were markedly higher than in the control and only gypsum amended alkali soil. These observations clearly show that nutrient extraction from the site through *Prosopis* was replenished by additions of large amounts of litter in the above two treatments. Since alkali soils are poor in calcium, organic matter, nitrogen and zinc nutrition, application of organic amendments such as rice husk and farm yard manure in addition to only chemical amendments (gypsum) is therefore very beneficial in raising successful *Prosopis* plantations on highly degraded alkali soils.

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