Agroforestry Systems **29**: 61–75, 1995.

An agroforestry practice for the development of salt lands using *Prosopis juliflora* and *Leptochloa fusca*

G. SINGH
Central Soil Salinity Research Institute, Karnal-132 001, India

Key words: fodder crops, nutrient budget, tree-grass mixture, salt land, soil amelioration

Abstract. High salt concentration in the soil is a serious problem in vast areas of otherwise productive agricultural lands in India. Establishment of salt tolerant vegetation could be an effective way of ameliorating this problem. In an 8-year field trial on an alkali soil, growth and biomass production of *Prosopis juliflora* was greater in sole stand than when interplanted with the grass *Leptochloa fusca,* but soil improvement was greater for the mixed tree-grass treatment. *Prosopis* accumulated substantially more biomass nutrients when in sole stand, but total nutrient recycling was similar with and without grass. Less salt tolerant but more palatable fodder crops such as *Trifolium resupinatum, T. alexandrium* and *Melilotus denticulata* were successfully grown with *Prosopis* after removing *L. fusca* in the *Prosopis* plus grass treatment 50 months after commencement. Tentative economic analysis suggests the *Prosopis* plus grass system gives higher returns. The *Prosopis-Leptochloa* system combines production with biological reclamation, and is an appropriate form of reclamation agroforestry for alkali lands.

Introduction

High salt concentrations in the root zone soil limit the productivity of nearly 8.11 million ha of otherwise productive land in India [Singh, 1992]. Many fertile lands in arid and semi arid parts of the country can no longer be cultivated due to the salt problem. There is an urgent need to stop this soil degradation process and to restore the health of already degraded lands. Establishment of a permanent vegetative cover of suitable salt tolerant trees and grasses is one option for rehabilitation of such sites, particularly in view of firewood and fodder shortages, and also from environmental considerations.

Singh et al. [1993] screened a large amount of tree germplasm and found trees of the genus *Prosopis* followed by *Acacia* and *Casuarina* to be highly promising for the rehabilitation of salt lands. Similarly, *L. fusca* followed by *Brichiaria mutica* are reported as promising grasses for growing in salt lands [Hussain and Hussain, 1970; Kumar and Abrol, 1986; Sandhu et al., 1981]. More recently, some systematic research efforts have been made to establish trees and grasses on salt lands [Singh et al., 1989; Tomar and Gupta, 1986], but no attempts to grow trees and grasses together in salt lands have been made. The present study reports results of a long-term field trial where *P. juliflora* was grown 'with' and 'without' *Leptochloa* grass for 8 years on a salt land with an initial pH of 10.4.

Materials and methods

This study was conducted at the Central Soil Salinity Research Institute, Karnal (29°29′ N, 76°56′ E). The site was on a common village land which had previously been used for grazing but was no longer used for cultivation because of severe salt problems. It is typical of the salt soils of the sub-tropical semiarid monsoon regions. The average annual rainfall of the area is about 750 mm, about 80% of which is received during June, July and August. Pan evaporation exceeds precipitation throughout the year except in the monsoon months of July, August and September. The ground water table varied from 5 to 6 m during the summer, to 2 to 3 m during the rainy season.

The soils are characterized by high exchangeable sodium (ESP) levels, high pH throughout the profile, dispersed soil conditions, poor physical properties and a dense impermeable calcic horizon at a depth of about 1 m (Table 1). The type of soil has been classified as an Aquic Natrustalf. *P. juliflora* was planted at 3 m intervals in 5 m wide rows. The performance of *Prosopis* was tested under two situations: with *Leptochloa* grass in the interrow space, and without grass. The two treatments were replicated four times in a RBD design. Each plot accommodated 48 trees and in the whole experiment there were 192 trees with grass and the same number of trees in the without grass treatment. *Leptochloa* grass was transplanted through root cuttings in dry conditions in August 1984. The 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. Good quality water (pH 7.0, EC_2 0.4 dSm^{-1}) from a shallow tube well was used. The same amount of water was applied to *Prosopis* both in the with and without grass treatments. The irrigations were applied only during the first two years (establishment stage) and the total water input (excluding rainfall) for both situations was about 1440 mm. Owing to poor infiltration in alkali soils due to high exchangeable sodium, the salt leaching with water from upper layers to lower layers was negligible. *Leptochloa* grass was planted

Table 1. Initial soil properties of the experimental plot.

Soil depth (cm)	Mechanical analysis (%)			pH	EC (dSm^{-1})	Available nutrients (kg/ha)				
	Sand	Silt	Clay			ESP	% OC	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
120–180	28.4	44.0	27.6	10.0	1.2	84	0.09	29	8	220
180–210	50.8	30.5	17.7	9.8	0.8	76	0.09	12	4	108
210–240	54.2	28.9	16.9	9.6	0.7	70	0.09	6	2	96

at a spacing of 30 × 20 cm. No fertilizer was applied to the grass throughout the study period. In a growth period of 52 months, 15 cuts were taken. The grass was cut at about 5 cm above ground level.

For chemical analysis, whole-plant grass samples from each plot consisting of edible succulent plant parts were taken at random just before harvest. The samples were washed, oven-dried at 70 °C, ground, and passed through a 16-mesh sieve. The di-acid (HNO_3:$HClO_4$ at a ratio of 3:1) digested plant samples were analysed for Na and K using flame photometer and for Ca, Mg, Fe, Mn, Zn and Cu with a Pye Unicam Atomic Absorption Spectrophotometer. Phosphorus was determined by vanado-molybdo-phosphoric-yellow colour method and sulphur by the turbidity method with a Spectonic 21 spectrophotometer. Total N was determined with a Kjeltic-II automatic nitrogen analyser.

Twelve *Prosopis* trees were harvested from each treatment after 2 and 6 years of plantation and their biomass was separated into stem, branches and foliage biomass. For chemical analysis, samples for stem and branch analysis were prepared by cutting 1-cm long sections along with the bark from both ends of long wood pieces with secateurs. These samples were washed and analysed following standard procedures as explained above for grass analysis.

For collection of litter, wooden traps 90 × 60 × 10 cm were used. The litter was weighed four times during the year. To study nutrient cycling profile the litter was analysed for its nutrient contents. During these years, pod yields were also recorded.

Ninety-six soil samples (48 from sole *Prosopis* stand and the same number in *Prosopis* + grass treatment) were taken 22, 52 and 74 months after planting to investigate any changes in soil properties as a result of tree and grass growth. Infiltration rates were determined using infiltrometer rings.

Results and discussion

Growth performance of Prosopis

The mean plant height and girth growth of *Prosopis* recorded at 2-year intervals from planting up to 6 years was significantly more when *Prosopis* was planted without the grass intercrop (Table 2). Batra and Kumar [1992] also made similar observations in Rhodes grass based agroforestry experiment on an alkali soil. Reduced *Prosopis* growth in 'with grass' treatment was apparently due to smothering effect of grass which grew much more in height during the rainy months than small *Prosopis* saplings during the first two establishment years. Grewal and Abrol [1986] also observed antagonistic effect of *Leptochloa* on trees during establishment period under similar soil and climatic conditions. Many workers [Acharya and Abrol, 1978; Acharya et al., 1979; Ahmed and Quilt, 1980] elsewhere have indicated that adverse effects of high exchangeable sodium on plant growth are accentuated under conditions of

Table 2. Height and girth growth of *Prosopis* recorded at 2-year interval from planting up to 6 years after planting.

Treatment	Years after planting								
	Height (m)			Girth I (cm)			Girth II (cm)		
	2	4	6	2	4	6	2	4	6
Sole *Prosopis*	4.0	4.8	7.1	16.6	22.4	28.1	6.3	12.0	23.3
Prosopis + grass	3.2	3.8	6.5	13.5	18.4	25.3	4.7	9.4	20.3
LSD (0.05)	0.3	0.5	0.5	1.3	2.1	1.8	0.9	2.0	NS

Girth I = girth at stump height (5 cm above ground level).
Girth II = girth at breast height (137 cm above ground level).

high evaporative demands. Because intercropping with grass can affect tree establishment adversely (Fig. 1) when they are planted simultaneously, it is probably better to delay planting grasses until after the establishment of trees. This will avoid competition for soil moisture, nutrients and space between tree and grass during the first two establishment years.

Biomass production by Prosopis

Biomass accumulation of *Prosopis* was recorded twice: 2 and 6 years after planting by harvesting representative trees and dividing this material into parts. The biomass accumulated during the first two years was more than double

Fig. 1. Leptochloa grass when planted simultaneously affected *Prosopis* establishment adversally owing to growth rate differences between the two components.

in the sole *Prosopis* plantations than in the *Prosopis* plus grass treatment (Table 3). However, biomass differences at the 6-year stage were not so marked. At 6 years after planting, the total tree biomass was 37.7 ha^{-1} when *Prosopis* was planted solely and 30.9 Mg ha^{-1} when it was planted in associated with *Leptochloa* grass. Nearly 50% of the total biomass were accumulated in the stem, and leaf biomass constituted between 15 to 20% of the total production. The average biomass production of 6.3 ha^{-1} $year^{-1}$ when planted as sole and 5.2 Mg ha^{-1} $year^{-1}$ when grown in conjunction with grass is less than reported in some other experiments at the same site [Singh et al., 1993]. Low production in the present case is probably due to the low planting density (666 trees ha^{-1}) used as compared to high density (1000 to 2500 trees ha^{-1}) plantations in other studies at the same site [Singh et al., 1993].

Table 3. Biomas accumulation in different components of *Prosopis* at 2 and 6 years after planting.

Treatment	Biomass accumulation (Mg ha^{-1})									
	2 Years after planting					6 Years after planting				
	Stem	Branch	Leaf	[a]	Total	Stem	Branch	Leaf	[b]	Total
Sole *prosopis*	1.94	1.80	0.63	2.12	6.49	18.2	11.8	3.6	4.1	37.7
Prosopis + grass	0.75	0.70	0.23	0.85	2.53	15.1	10.0	2.9	2.93	30.9
LSD (0.05)	0.10	0.13	0.13	0.15	–	2.4	NS	0.4	0.5	–

[a] and [b]: The biomass through pruning of side branches, 16 and 40 months after planting, respectively.

Nutrient concentration and accumulation in Prosopis

Nutrient concentrations in various parts decreased in the order: leaves, branches, stem both in 'with' and 'without' grass treatments. The nutrient concentrations in parts of *Prosopis* represent medium to high levels reported for many temperate trees and are comparable to multispecies averages obtained in analysis of tropical forest ecosystems and tropical forage legumes. This nutrient concentration trend is commonly encountered in nutrient analysis of tree components. Concentration of almost all the nutrients tested in different parts of the tree was more at the 2-year stage than at 6 years after planting. This may be due to a dilution effect as biomass production at 6 years of age was much more than at 2 years. Further, nutrient composition at both stages in all parts of *Prosopis* was comparatively higher in tree + grass treatment than in the sole Prosopis plantation. Low concentration in the latter may be owing to better growth of trees in this treatment.

At 2 years after planting, the total accumulation of N, P, K, Ca, Mg and S in various parts of Prosopis was almost double (151.6 kg ha^{-1}) when it was planted without grass than in the case of the with-grass treatment (71.8 kg ha^{-1}) (Table 4). However, at 6 years after planting, the difference in nutrient uptake between the two treatments was very small. *Prospis* has the advantage of accumulating more nutrients in the leaves, a tree part which is likely to be left at the site during harvesting. For example, in 6-year old *Prosopis*, although the leaves accounted for less than 11% of the total tree biomass, they contained 37%, 29%, 34%, 27%, 57% and 46% of the total tree N, P, K, Ca, Mg and S, respectively, in sole *Prosopis* plantations and 35%, 31%, 34%, 27%, 68%, and 24% of N, P, K, Ca, Mg and S, respectively, when *Prosopis* was grown along with grass.

Prosopis *pod production*

Pod production in *Prosopis* started in the third year after planting. In the first fruiting year (1986–87), pod production was 126 kg ha^{-1} in sole *Prosopis* plantations and 88 kg ha^{-1} in *Prosopis* plus grass treatment (Fig. 2). Pod production increased in the subsequent years and maximum pod yields were obtained in the 1990–91 season. During all seasons pod yield was higher in sole *Prosopis* plantations than in case of *Prosopis* plus grass, treatment. The average pod production per hectare per year on a high pH soil was calculated to be 852.8 kg when *Prosopis* was grown without grass intercrop and 806 kg in the case of the with-grass treatment. Mean pod yields reported in our study are less as compared to values cited in the literature for many *Prosopis* species. Pod yields up to 140 kg $tree^{-1}$ have been reported [Felker et al., 1980]. However, most of the work on *Prosopis* in the literature deals with pod yields from mature trees [Felker et al., 1980; Sharifi et al., 1982].

Litter production, quality and nutrient additions

There was a progressive annual increase in litter yield as trees aged (Fig. 3). The litter fall was slightly higher under sole *Prosopis* canopies than in the case when *Prosopis* were grown with *Leptochloa* grass. This was apparently due to better tree growth in the sole treatment throughout the study period.

The mean concentration of N, P, K, Ca, Mg, S and Na in the litter of 3- and 6-year-old *Prosopis* plantations was 2.46, 0.26, 1.54, 1.15, 0.51, 0.44 and 0.19 in 'without grass' and 2.56, 0.31, 1.47, 1.22, 0.55, 0.46 and 0.17% in 'with grass' treatment, respectively. The concentration of almost all nutrients was more at the 3-year stage than at 6 years after planting. Less nutrient composition in the litter at the 6-year stage may be due to dilution effect as litter yield in the 6th year was much high than in the 3rd year. Further, the litter obtained from *Prosopis* both at 3 and 6 years after planting had better composition in the tree plus grass treatment than from the sole *Prosopis* plantation.

Total additions of N, P, K, Ca, Mg, S and Na to the soil through litter fall in different years are presented in Fig. 4. Nutrients added to the site through

Table 4. Nutrient accumulations in different parts of 2- and 6-year-old *Prosopis*.

Treatment	Plant part	Nutrient accumulations (kg ha^{-1})															
		2 Year after planting								6 Years after planting							
		N	P	K	Ca	Mg	S	Na[a]	Total	N	P	K	Ca	Mg	S	Na	Total
Sole *Prosopis*	Stem	17.0	1.46	15.8	10.5	1.8	2.6	1.7	49.2	54.6	7.3	36.4	54.6	3.6	5.5	3.6	165.6
	Branch	19.0	1.60	18.1	8.2	1.9	2.7	2.3	51.5	94.4	8.3	94.4	70.8	7.1	7.1	4.7	286.8
	Leaf	19.4	1.31	11.3	9.9	4.4	4.6	2.6	50.9	86.4	6.5	68.4	46.8	14.4	18.0	7.2	247.7
	Total	55.4	4.37	45.2	28.6	8.1	9.9	6.6	151.6	235.4	22.1	199.2	172.2	25.1	30.6	15.5	699.6
Prosopis + grass	Stem	8.3	0.50	6.2	4.9	1.0	1.0	1.1	21.9	60.4	6.0	45.3	60.4	4.5	3.0	3.0	182.6
	Branch	9.7	0.64	8.6	4.6	0.9	1.1	1.1	25.5	80.0	7.0	80.0	50.0	7.0	5.0	6.0	235.0
	Leaf	10.0	0.56	5.4	4.5	1.9	2.0	1.3	24.4	75.4	5.8	63.8	40.6	11.6	17.4	2.9	217.5
	Total	28.0	1.70	20.2	14.0	3.8	4.2	3.5	71.8	215.8	18.8	189.1	151.0	23.1	25.4	11.9	635.1

[a] Not included in the total uptake.

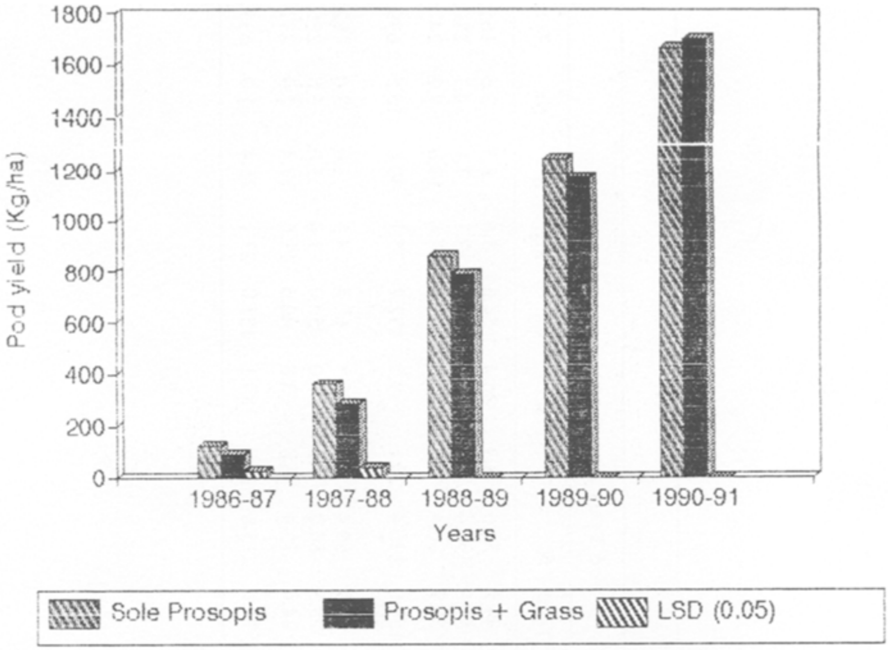

Fig. 2. Pod yields from *Prosopis* during the study period.

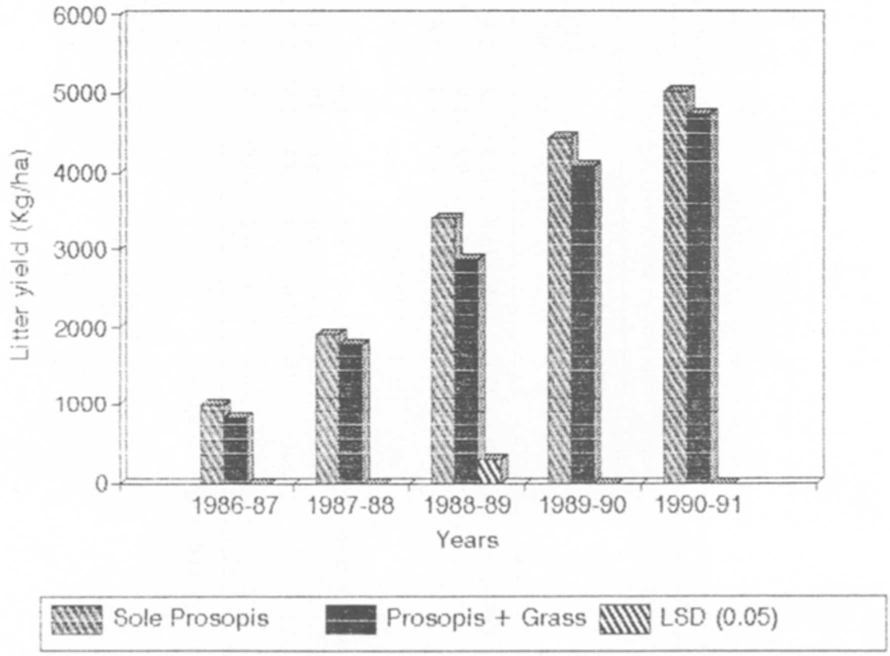

Fig. 3. Annual litter yield of *Prosopis* in 'with' and 'without grass' situations.

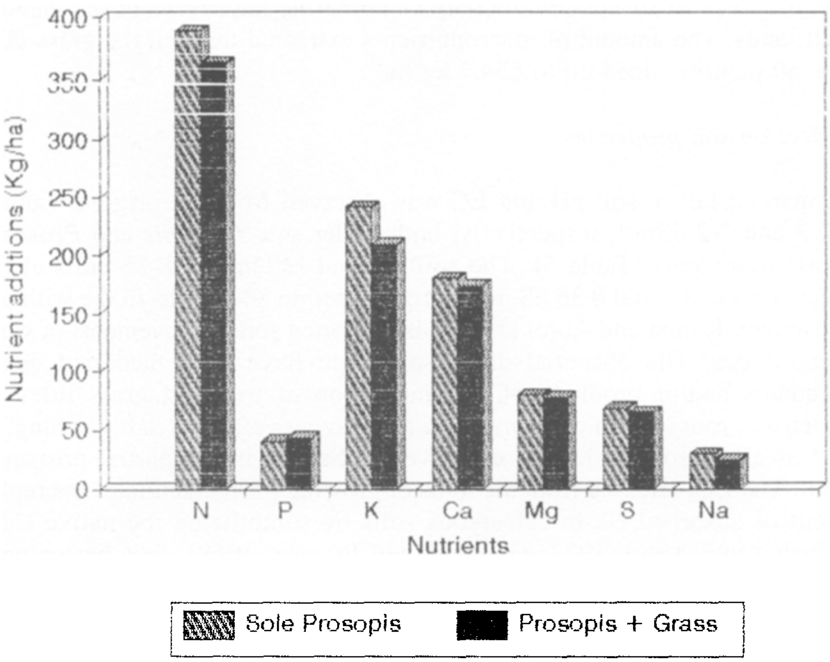

Fig. 4. Nutrient addition through litter fall during the study period.

litter fall during the study period amounted to 1031.9 and 960.5 kg ha^{-1} in sole *Prosopis* and *Prosopis* plus grass plantations, respectively.

Grass production

Leptochloa grass planted in the interspaces yielded 46.5 Mg ha^{-1} green fodder in 15 cuts in a period of about 50 months. Kumar and Abrol [1986] have reported that this grass grows naturally in low-lying alkali soils, where rain-water accumulates. In a pot experiment, they found that its yield improved in response to an increased period of flooding (up to 8 days), indicating its ability to tolerate poor soil aeration caused by temporary waterlogging. The forage yield obtained in the present study was less than reported elsewhere [Kumar and Abrol, 1986] where the grass was grown as a sole-crop and was well-managed, irrigated and fertilized.

Chemical composition of Leptochloa *grass and nutrient uptake*

The mean chemical composition of *Leptochloa* suggests that this could be a useful forage grass for maintaining the mineral element balance in animals raised on salt lands. *Leptochloa* accumulated 173.9 kg sodium ha^{-1} from the soil in 50 months. Comparable results have been reported under similar site conditions indicating that this grass may act as a precursor for the establishment of a plant succession, thereby enabling the improvement of abandoned salt lands. The amount of macronutrients extracted through the grass during the 50 months added up to 654.7 kg ha^{-1}.

Effect on soil properties

A marked fall in soil pH and EC was observed from the original values of 10.3 and 2.2 dSm^{-1}, respectively, both under sole *Prosopis* and *Prosopis* + grass treatments (Table 5). The soil pH and EC in the 0–15 cm soil layer decreased to 8.9 and 0.36 dS, respectively, within 74 months in the with-grass treatment. Kumar and Abrol [1986] also reported soil improvements of similar magnitudes. The observed decreases might have been mediated by root exudates and/or products of decomposition of tree and grass litter. The extensive root system of *Leptochloa* also favours efficient salt leaching. The pH of alkali soils is 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 absorbed Na in calcareous soils by solubilizing the native $CaCO_3$ [Chabra and Abrol, 1977; Goertzen and Bowers, 1958], thus hastening the process of soil reclamation. *Prosopis* plus *Leptochloa* during their 74-month growth increased organic C and available N in the 0–15 cm layer of the profile from 0.19% and 73kg ha^{-1} to 0.58% and 165 kg ha^{-1} (Table 5). Similar increase was also observed in the 15–30 cm layer. The increase was much more in the with-grass than in without-grass treatment. This was due to increased bio-

Table 5. Effect of *Prosopis juliflora – Leptochloa fusca* agroforestry system on some properties of a salt land.

Soil property	Depth (cm)	Months after planting							
		Prosopis				*Prosopis* + grass			
		0	22	52	74	0	22	52	74
pH	0–15	10.3	10.0	9.7	9.3	10.3	9.7	9.4	8.9
	15–30	10.3	10.0	9.9	9.7	10.4	10.0	9.8	9.4
EC (dSm^{-1})	0–15	2.2	0.83	0.66	0.46	2.2	0.70	0.42	0.36
	15–30	1.5	0.84	0.78	0.68	2.0	0.94	0.63	0.60
Organic carbon (%)	0–15	0.18	0.20	0.30	0.43	0.19	0.28	0.43	0.58
	15–30	0.13	0.12	0.19	0.29	0.12	0.16	0.21	0.36
Available N (kg ha^{-1})	0–15	79	83	100	133	82	96	136	165
	15–30	73	72	84	98	73	82	104	134
Available P (kg ha^{-1})	0–15	35	33	30	36	35	29	22	30
	15–30	31	30	32	34	31	24	19	26
Available K (kg ha^{-1})	0–15	543	519	528	555	573	471	402	486
	15–30	490	480	478	500	490	430	412	478

logical activity through grass roots, litter fall and N fixation by the grass. *Leptochloa* has a heavy fraction of lignin content, which would act as a good substrate for the synthesis of humus. Since alkali soils are deficient in organic matter, cultivation of this grass may therefore raise the stable organic-matter level of alkali soils due to its rapid turnover. One among the N-fixing bacteria associated with the roots of *Leptochloa* has been identified as *Klebsiella pneumoniae*. It has now been established that nitrogen so fixed is absorbed by the grass to make up for more than 50% of its N content [Malik and Zafar, 1985].

The mean P and K contents in the soil measured 22, 52 and 74 months after planting were less when *Leptochloa* was grown in association with *Prosopis* (Table 5). However, very little change in available P and K status in the soil was observed when no grass was grown in the interspace. The decrease in P and K is obviously due to their removal through grass harvests.

Prosopis and *Leptochloa* improved the permeability of the deflocculated alkali soils and helped in their amelioration. The cumulative infiltration of water in the soil where *Prosopis* and grass were grown for more than four years was 54 mm in 48 h while it was only 24 mm in plots without grass (Fig. 5). The increase in downward movement of water in grassed soil is due to the improved physical condition of the soil, as the root penetration opens up the soil, and the addition of organic matter also favours soil improvement.

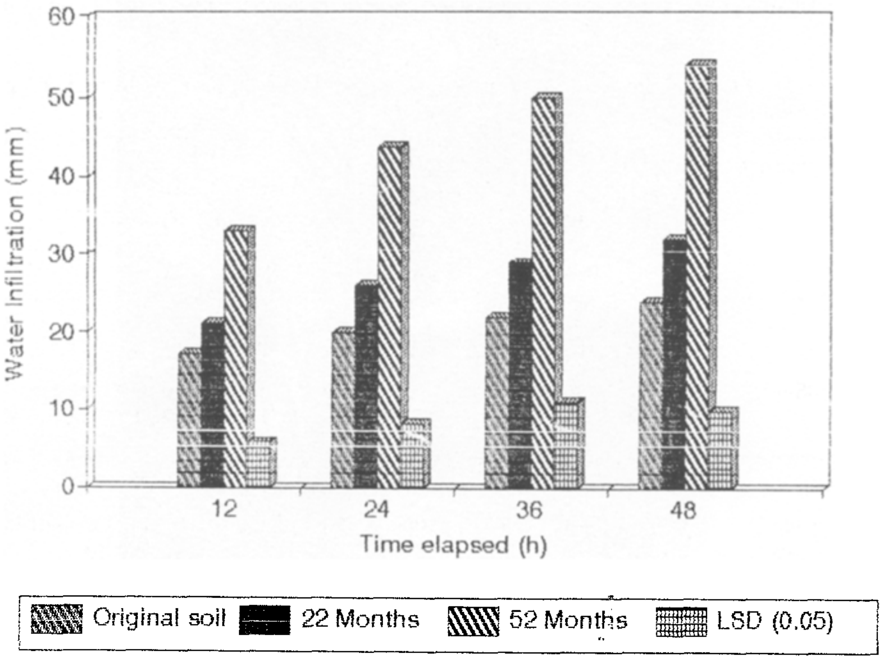

Fig. 5. Effect of *Prosopis-Leptochloa* agroforestry system on water infiltration.

Crops after Leptochloa *grass*

In the same experiment, *Leptochloa* was ploughed under in October 1988 and other profuse forage crop species, *viz.* Egyptian clover (*Trifolium alexandrium*), Persian clover (*T. resupinatum*), lucerne (*Medicago sativa*), sweet clover (*Melilotus denticulata*) and oats (*Avena sativa*) sown. Over a six-month growth period, four cuts of Egyptian clover, Persian clover and lucerne were taken on 15 February, 30 March, 18 April and 17 May, 1989. However, only one cut each of sweet clover and oats, was taken on 19 February and 21 April, respectively. The forage yields were in the order: Persian clover > Egyptian clover > lucerne > sweet clover > oats. After four years of *Leptochloa*, good to satisfactory harvests of the other forage crops can be obtained in this soil type (Fig. 6).

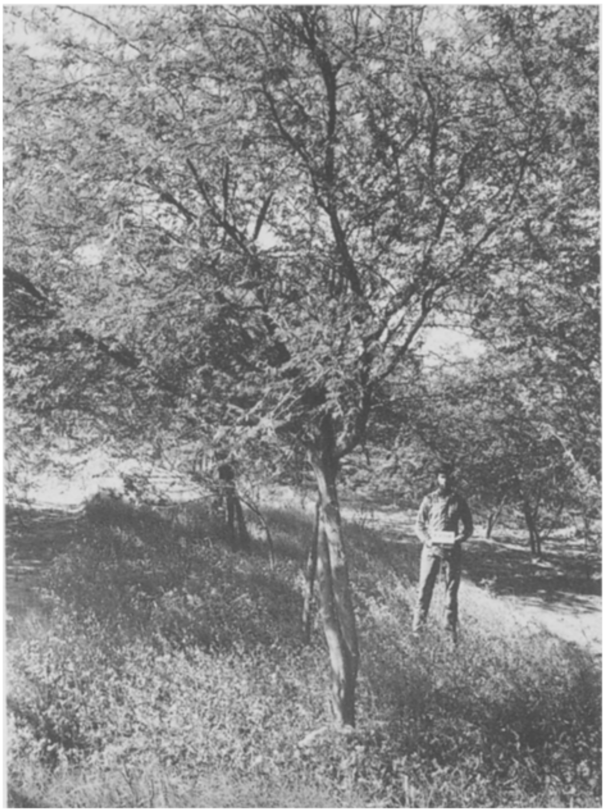

Fig. 6. A good crop of Egyptian clover growing under the canopies of 56-month-old *Prosopis* trees. Egyptian clover intercrop was grown after removing *Leptochloa* grass.

Table 6. Nutrient (kg ha^{-1}) budget of a salt land after 6 years under soile *Prosopis* and *Prosopis* plus grass plantations.

	Sole *Prosopis*				*Prosopis* + grass				
	Original status (avaliable)	Additions through litter	Uptake by trees	Soil status after 6 years	Original status (available)	Addition through litter	Uptake by trees	Uptake by grass	Soil status after 6 years
Nitrogen	79	389	235	133	82	364	216	209	165
Phosphorus	35	41	22	36	35	44	19	43	30
Potassium	543	242	199	555	573	210	189	162	486

Nutrient budget

In the sole *Prosopis* plantation, 389, 41 and 242 kg ha^{-1} of N, P and K, respectively, was added to the soil through litter, and 235, 22 and 199 kg of N, P and K, respectively, was taken by trees (Table 6). After 6 years there was a build up of 54 kg of N, 1 kg of P and 10 kg of K ha^{-1}. In the *Prosopis* + grass treatment the soil contained yet more nitrogen after 6 years compared to the original status, even though the uptake was much more than the addition through litter fall. Slight depletion in available P and K status in this treatment is probably due to their removal through grass harvests. Such a high removal of nutrients through tree and grass components did not result in site depletion problems, thereby suggesting long-term sustainability of this land management system.

Economic gains

Rough estimates were made about the likely benefits of growing *Prosopis* as sole plantations or in combination with the salt tolerant *Leptochloa* grass on an abandoned high pH site. The total expenditure per hectare including planting costs and after care in 6 years was Rs. 9500 for raising sole plantations and Rs. 13000 for raising trees and grass simultaneously. The net income per hectare per year was calculated based upon average sale rates of commodities (wood, fodder, etc.) prevalent in the local market. The net income per hectare per year was much higher (Rs. 4866) when *Prosopis* and grass were grown together in a unified agroforestry system compared to sole Prosopis plantations. The indirect benefits such as improvement in soil health as a result of tree and grass growth are not included in these calculations.

Conclusion

This study shows that *P. juliflora* and *L. fusca* are appropriate plants for salt lands. The study also shows the potential for fuel wood and forage production when the two species are planted together in a unified agroforestry system under irrigated conditions. However, further work is needed to find the best time to plant the grass. This agroforestry practice appears to be promising for exploiting those salt lands which cannot be readily reclaimed through conventional techniques.

Acknowledgements

The author is grateful to Dr I. P. Abrol, Deputy Director General (Soils, Agronomy and Agroforestry), ICAR, New Delhi and Dr S. S. Cheema, FACU, JOS C/o ADPLA, 27 Dover Street, London for their guidance and support during the planning and establishment years of this study. The author also wishes to thank Dr N. T. Singh, Former Director, CSSRI, Karnal for his interest and support to agroforestry programmes in the institute.

References

Acharya CL and Abrol IP (1978) Exchangeable sodium and soil water behaviour under field conditons. Soil Sci 125: 310–319

Acharya CL, Sandhu SS and Abrol IP (1979) Effect of exchangeable sodium on the field drying pattern of soil at two evaporative demands. Soil Sci 127: 56–62

Ahmed B and Quilt P (1980) Effect of soil moisture stress on yield, nodulation and nitrogenase activity of *Macroptilium atropurpureum* CV. Siratto and *Desmodium intrortum* CV. Green Leaf. Plant and Soil 57: 187–1940

Batra Lalita and Kumar Ashok (1992) Nitrogen fixation by trees in an alkali soil under Rhodes grass based agroforestry system. Annual Report, pp 102–106. CSSRi, Karnal

Chhabra R and Abrol IP (1977) Reclaiming effect of rice grown in sodic soil. Soil Sci 124: 41–45

Felker P, Clark PR, Osborn JF and Cannell GH (1980) Utilization of mesquite (*Prosopis* sp.) pods for ethanol production. In: Tree Crops for Energy Production on Farms, Proc Workshop Solar energy Research Institute, 14 Nove 1980, pp 65–78 National Technical Information Service, Springfield, VA

Grewal SS and Abrol IP (1986) Agroforestry on alkali soils. Effect of some management practices on initial growth, biomass accumulation and chemical composition of selected tree species. Agroforestry systems 4: 271–289

Goertzen J and Bowers CA (1985) Carbon dioxide from plant roots as a factor in the replacement of absorbed sodium in a calcareous soil. Soil Sci Soc Am Proc 22: 36–37

Hussain M and Hussain MA (1970) Tolerance of *Diplachne fusca* Beauv (Australian grass) to salt and alkali. Research Publication, Vol 25

Kumar A and Abrol IP (1986) Grasses in alkali soils. Bull No 11. CSSRI, Karnal, 95 pp

Malik KA and Zafar Y (1985) Quantification of root associated nitrogen fixation in Kallar grass estimated by ^{15}N Isotope dilution. In: Malik KA, Muztaba Naqvi SH and Aleem MIH (eds) Nitrogen and the Environment. NIAB, Faisalabad, Pakistan

Sandhu GR, Aslam Z, Salim M, Satter A, Qureshi RH, Ahmed N and Wyn Jones (1981) The effect of salinity on the yield and composition of *Diplachne fusca* (Kallar grass). Plant Cell Environ 4: 177–181

Sharifi MR, Nilsen ET and Rundel PW (1982) Biomass and net primary production of *Prosopis glandulosa* (Fabaceae) in the Sonoran desert of California. Am J Bot 69: 760–767

Singh Gurbachan, Abrol IP and Cheema SS (1989) Effect of irrigation on *Prosopis Juliflora* and soil properties of an alkali soil. Int Tree Crops J 6: 81–99

Singh Gurbachan, Singh NT and Dagar JC (1993) Agroforestry in salt-affected soils. Technical Bulletin No 17. CSSRI, Karnal, India, 65 pp

Singh NT (1992) Dry land salinity in the Indo-Pakistan sub continent. Paper Presented in the International Conferrence on Degradation and Restoration of Arid Lands, held at Texas Technical University, Lubbock, TX, USA, Sept 24–25, 1991

Tomar OS and Gupta RK (1986) Performance of some forest tree species in saline soils under shallow and saline water table conditons. Plant and Soil 87: 329–335