LAND DEGRADATION & DEVELOPMENT

Land Degrad. Develop. **12**: 107–118 (2001)

DOI: 10.1002/ldr.442

RAISED AND SUNKEN BED TECHNIQUE FOR AGROFORESTRY ON ALKALI SOILS OF NORTHWEST INDIA

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Received 31 July 2000; Accepted 8 January 2001

ABSTRACT

Many forest tree and fruit species can be raised on highly alkali soil (pH > 10) but some of them such as pomegranate (*Punica granatum*) are unable to tolerate water stagnation. To avoid water stagnation problems during the monsoon the raised and sunken bed technique has been found suitable for agroforestry practices on highly alkali soil. One fruit-yielding pomegranate and one oil-yielding salvadora (*Salvadora persica*) plantation species were successfully grown on raised bunds to avoid water stagnation and rice–wheat and berseem–kallar grass rotation were grown on sunken-beds constructed for the purpose. The experiment was initiated in 1996 and the above two crop rotations were followed for two consecutive years starting in the summer season. Results of these experiments have also shown that good growth of plantations, on an average 4·3 to 4·9 t ha^{-1} rice (salt tolerant var. CSR-10) and 1·2 to 1·4 t ha^{-1} wheat (KRL 1–4), were obtained in sunken beds. In another rotation 21·3 to 36.8 t ha^{-1} fresh forage of kallar grass (*Leptochloa fusca*) and 44·9 to 47·8 t ha^{-1} fresh forage of berseem (*Trifolium alexandrium*) were obtained. After two years of the experiment, soil amelioration in terms of reduction in soil pH was significant. The effect of plantation in reducing soil pH showed that the pomegranate and salvadora both helped in reduction of soil pH, but the latter due to its well-developed lateral root system was more efficient in lowering the soil pH even at lower depths. The reduction in soil pH by the berseem–kallar grass rotation was better than under rice–wheat rotation.

KEY WORDS: raised and sunken bed technique; rehabilitation; alkali lands; water stagnation; agroforestry practices; crop rotation; salt-tolerant variety; kankar pan; soil amelioration; aridity index; moisture index

INTRODUCTION

Vast tracts of land in arid and semiarid areas lie barren due to sodicity and salinity problems. In India, about 9.38 million ha of land is salt-affected out of which about 3.88 million ha are alkali soils (IAB, 2000). These lands are characterized by high pH, negligible organic carbon, excessive exchangeable sodium, poor fertility, low infiltration and the presence of a hard $CaCO_3$ pan in the profile. Most of these soils do not support any kind of vegetation except some bushes such as mesquite (*Prosopis juliflora*), kair (*Capparis decidua*), caperbush (*C. sepiaria*), salvadora (*Salvadora oleoides*), wild jujube (*Zizyphus nummularia*) and kangkera (*Maytenus emarginatus*) and herbaceous species like seablite (*Suaeda fruticosa*), bui (*Kochia indica*), usar grass (*Sporobolus marginatus*), nonak (*S. diander*), kusha (*Desmostachya bipinnata*), rhodes grass (*Chloris gayana*) and *Trianthema triquetra* (Dagar, 1995) which are found in patches.

During the last three decades until the financial year 1998–99 (India, 2000), a sizeable area (0.53 million ha) that was under sodic soils has been reclaimed by gypsum treatment and is supporting good crops of rice and wheat. This was possible because gypsum was made available to the farmers at a highly subsidized price (almost 75 per cent subsidy). With the reduction in the subsidy on gypsum recently the reclamation process has slowed down considerably. An alternative approach to bringing these soils under vegetative cover is through biological means using agroforestry practices involving salt-tolerant trees and herbaceous forages and crops. The Central Soil

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Salinity Research Institute has evolved several techniques of afforestation of sodic and saline soils and several salt-tolerant woody and herbaceous species have been identified to rehabilitate salt-affected soils (Singh *et al.*, 1993; Dagar, 1998; Singh and Dagar, 1998; Tomar *et al.*, 1998; Dagar *et al.*, 2001). Trees and grasses once established bring changes in the physical, chemical, biological and hydrological properties of the soil and cause amelioration in it (Prinsely and Swift, 1986; Singh and Dagar, 1998). Usually forest tree species and grasses are considered to have comparatively higher tolerance to soil alkalinity than most of the horticultural species. Singh *et al.* (1997) and Dagar *et al.*, 2001, however, have evaluated 10 species of fruit trees using two site preparation methods (augerhole of 25 cm diameter and 160–180 cm deep made in the centre of 45 × 45 cm pits; and pits of 90 × 90 × 90 cm) and variable amendments. During these studies it was found that though the pomegranate (*Punica granatum*) was sodicity tolerant, it could not withstand water stagnation. Therefore, to avoid water stagnation taking the soil from the beds, 3 m spaced parallel bunds were constructed and plantations of pomegranate and salvadora (*Salvadora persica*) were raised on these bunds and two crop rotations were carried out in the intermediate sunken space. These experiments were conducted to discover a suitable technique for and feasibility of raising woody species of high economic value (in an agroforestry system) which are otherwise salt-tolerant but sensitive to water stagnation during rainy season. These species were grown on raised bunds. Among herbaceous crops the species were selected which usually require adequate water for their optimum growth. The results achieved from this raised and sunken bed technique are discussed here.

MATERIALS AND METHODS

Experimental Site

The studies were conducted at Bichhian experimental farm of the Central Soil Salinity Research Institute (CSSRI) located in semiarid region of Kurukshetra district in Haryana (30° 30′ N, 76° 18′ E, Figure 1). The land was part of the Reserve Forest (the Saraswati Range looked after by the Forest Department of Haryana State) lying abandoned

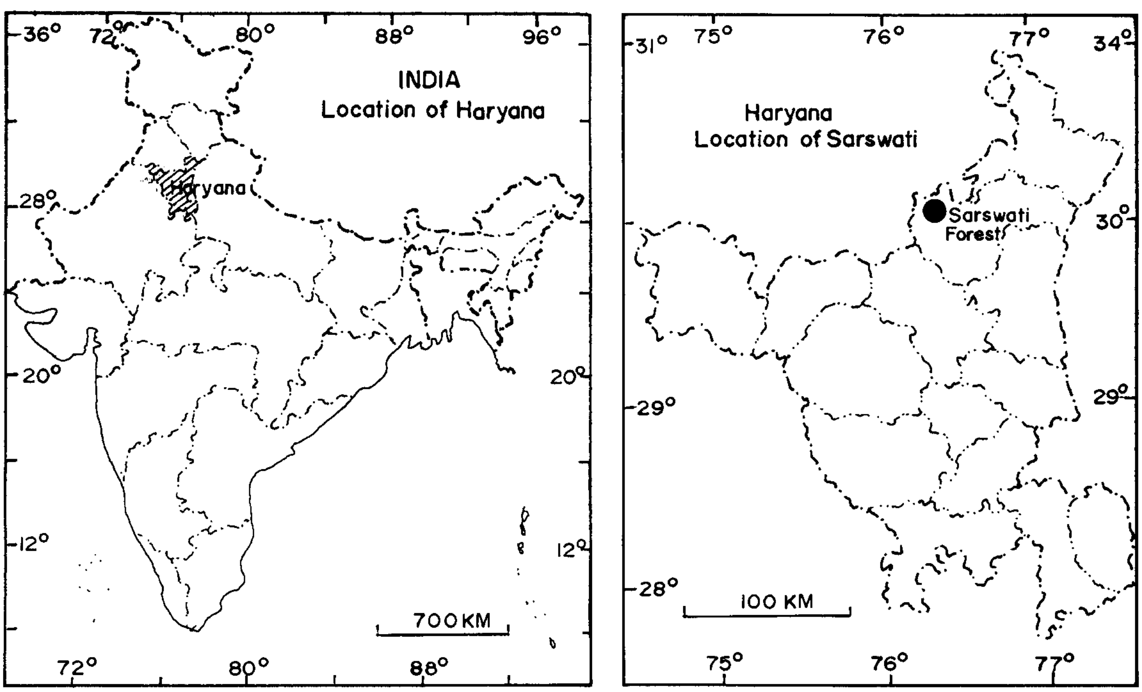

Figure 1. Location map of experimental area within the state of Haryana, India (Saraswati Forest is the study area).

owing to a severe alkali problem. Past efforts by the Forest Department to rehabilitate this area failed largely because of lack of appropriate technologies. A collaborative project was undertaken by CSSRI and Haryana Forest Department to evolve the techniques for rehabilitation of these highly alkali soils and to avoid the problem of water stagnation in some sensitive plantations.

Climate

The climate of the area is subtropical, semiarid, monsoonic with little or no water surplus, megathermic with aridity index 63.38 and moisture index –38.03 as calculated by Sehgal *et al.* (1987) following Thornthwaite and Mather (1957). Mean normal rainfall of the area is 516 mm and annual pan evapotranspiration 1407 mm having water deficiency of 819.8 mm. There are 8 months with a mean temperature >20°C. Mean annual temperature is 24.6°C while mean summer temperature is 32.4°C and mean winter temperature is 15.1°C, but during December and January, sometimes for a couple of days, there is also frost. During the study period (1996–98) the annual rainfall was from 1251 to 1296 mm, most of which occurred from June to September (Figure 2).

Initial Soil Properties

To study the original soil properties of the experimental site a profile was dug out in a representative area up to a depth of 1.2 m. The most peculiar feature of the profile was the presence of precipitated $CaCO_3$ layers (kallar pan)

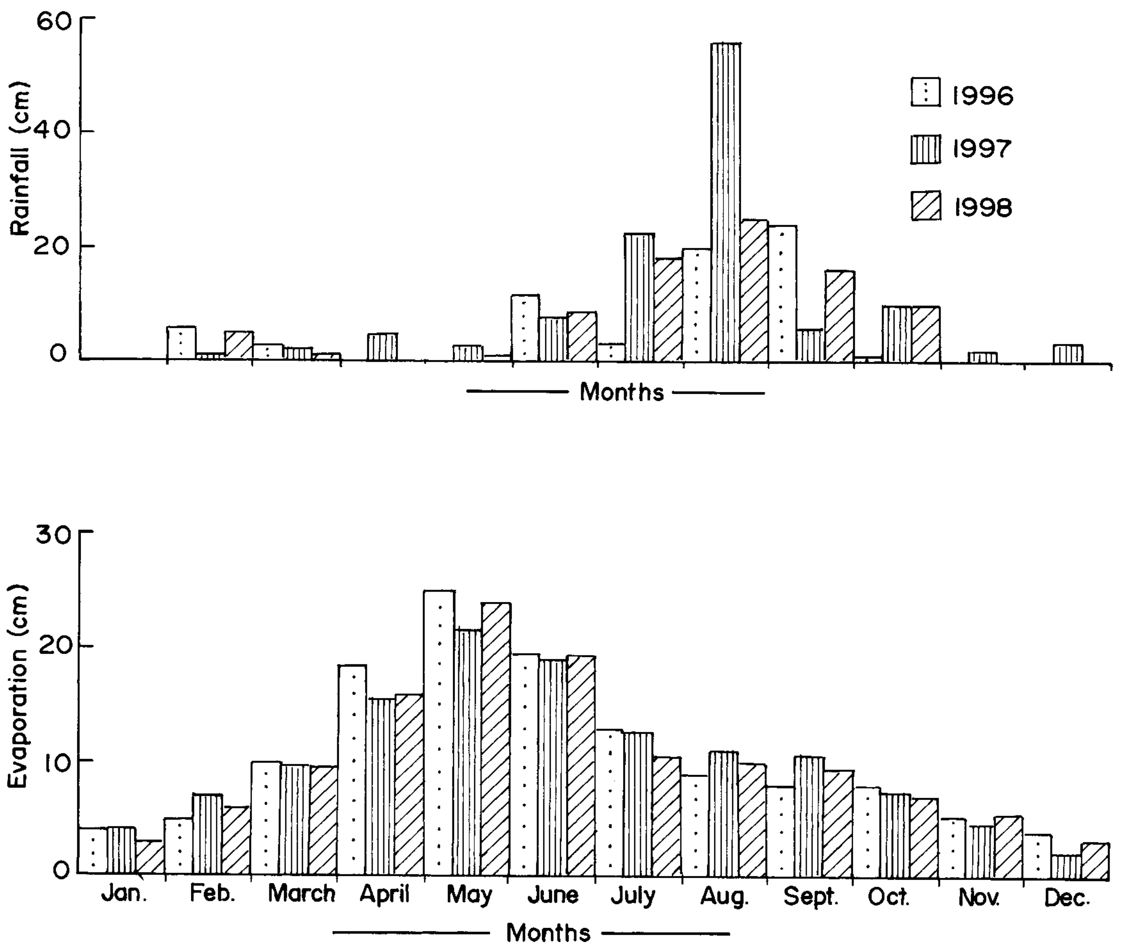

Figure 2. Monthly rainfall and evaporation during experimentation period.

Table I. Soil characteristics of the study areas

Soil depth (cm)	pH (1:2)	EC_2 (dS m^{-1})	Org.C (%)	$CaCO_3$ (%)	Ca+Mg (meq l^{-1})	Na (meq l^{-1})	CO_3 (meq l^{-1})	HCO_3 (meq l^{-1})	Cl (meq l^{-1})
0–15	10·4	2·7	0·10	–	4	194	72	20	62
15–30	10·6	3·3	0·04	–	4	211	124	28	70
30–60	10·5	2·0	0·04	4·4	3	150	36	104	74
60–90	10·4	1·2	0·03	5·6	2	42	20	24	16
90–120	10·2	0·8	0·02	33·5	2	30	16	18	8

at various depths. The soil pH and electrical conductivity (EC) were measured by pH meter and EC meter, respectively after mixing ovendried soil in water in a ratio of 1:2. Organic carbon and $CaCO_3$ content were measured using the Walkley–Black method (Walkley and Black, 1934). Ca + Mg, Na, HCO_3 and Cl were determined by the method described by Richards (1954). The $CaCO_3$ content varied from a negligible amount at the surface to about 33·5 per cent at 1 m depth. The organic carbon content was negligible. The soil pH varied from 10.2 to 10.6 and the electrical conductivity varied from 0.8 to 3.3 dS m^{-1}. The anion and cation contents varied at different depths (Table I).

Quality of Irrigation Water

The groundwater was more than 13 m deep. Throughout the study period the water used for irrigation was from the tubewell which had residual sodium carbonate (RSC) as high as 10.8 me l^{-1}. The pH of water was 8.3 and electrical conductivity was 1.18 dS m^{-1}. The CO_3, HCO_3 and Ca + Mg contents were 0.7, 10.9, 0.8 me l^{-1}, respectively. During the rainy season, the rainwater was 591 mm, 934 mm and 689 mm in 1996, 1997 and 1998, respectively in the months of June to September. Due to sunken beds and the low infiltration rate of the soil the rainwater during rainy season flooded in the crops for quite some time, therefore, the requirement of irrigation water from the tubewell was comparatively low and only 12–16 tubewell-water irrigations (each of about 5 cm) were sufficient for kallar grass and rice crops during this season. The number of irrigations given for wheat were 4–5 (each of 3–4 cm) while for berseem 10–12 (each of 3–4 cm) during their growing period.

Experimental Details

In a levelled alkali field augerholes of 20–25 cm diameter and 120–140 cm deep were dug at a distance of 4 m from row to row and 2 m from plant to plant. These were refilled with a mixture of original soil + 10 kg farmyard manure + 10 kg of gypsum + 10 g of zinc sulphate in each augerhole. A small quantity (20 g) of BHC powder (for protection against termites) was applied in each augerhole. The augerholes were marked with a stick. Parallel bunds each of 1 m height and 1 m width were then constructed leaving 3 m space between them. Two rows each of pomegranate (*Punica granatum* Linn.) and salvadora (*Salvadora persica* Linn.) were planted on top of bunds at the marked augerholes keeping a plant to plant distance of 2 m so that in each row 12 plants were accommodated. In the 3 m space remaining in the sunken beds two sets of crops were planted so that during the summer season rice (salt-tolerant var. CSR-10) and forage kallar grass (*Leptochloa fusca* (Linn.) Beauv.) were grown in the month of June on both sides of plantation. During the winter season in rice plots wheat (salt-tolerant var. (KRL-1-4) was grown and in kallar grass plots forage berseem also known as Egyptian clover (*Trifolium alexandrium* Linn.) were grown in November (Figures 3 and 4). Thus the experimental design provided split plots replicated six times. Two rows of each plantation were left uncropped as a control. Six plots of each crop were left unplanted as a control. Kallar grass and berseem gave multiple cuts. For rice and wheat crops 120 kg of N, 50 kg each of potash and phosphate and 25 kg of zinc sulphate were used while sowing the crop. No fertilizer was given to the kallar grass or berseem. After two years of crops three plants of both plantation species from each rotation were excavated for root studies (Figures 5 and 6). The roots were exposed with the help of water jet washing the soil carefully. The fresh and ovendry biomass was taken. The statistical analysis was done on computer using the MSTAT-C method. The plant heights and tillers of crops were measured at flowering stage.

Figure 3. *Salvadora persica* on raised bunds and rice crop in sunken beds.

Figure 4. Pomegranate (*Punica granatum*) on raised bunds and wheat and berseem crops in sunken beds.

Figure 5. Root system of *Salvadora persica*.

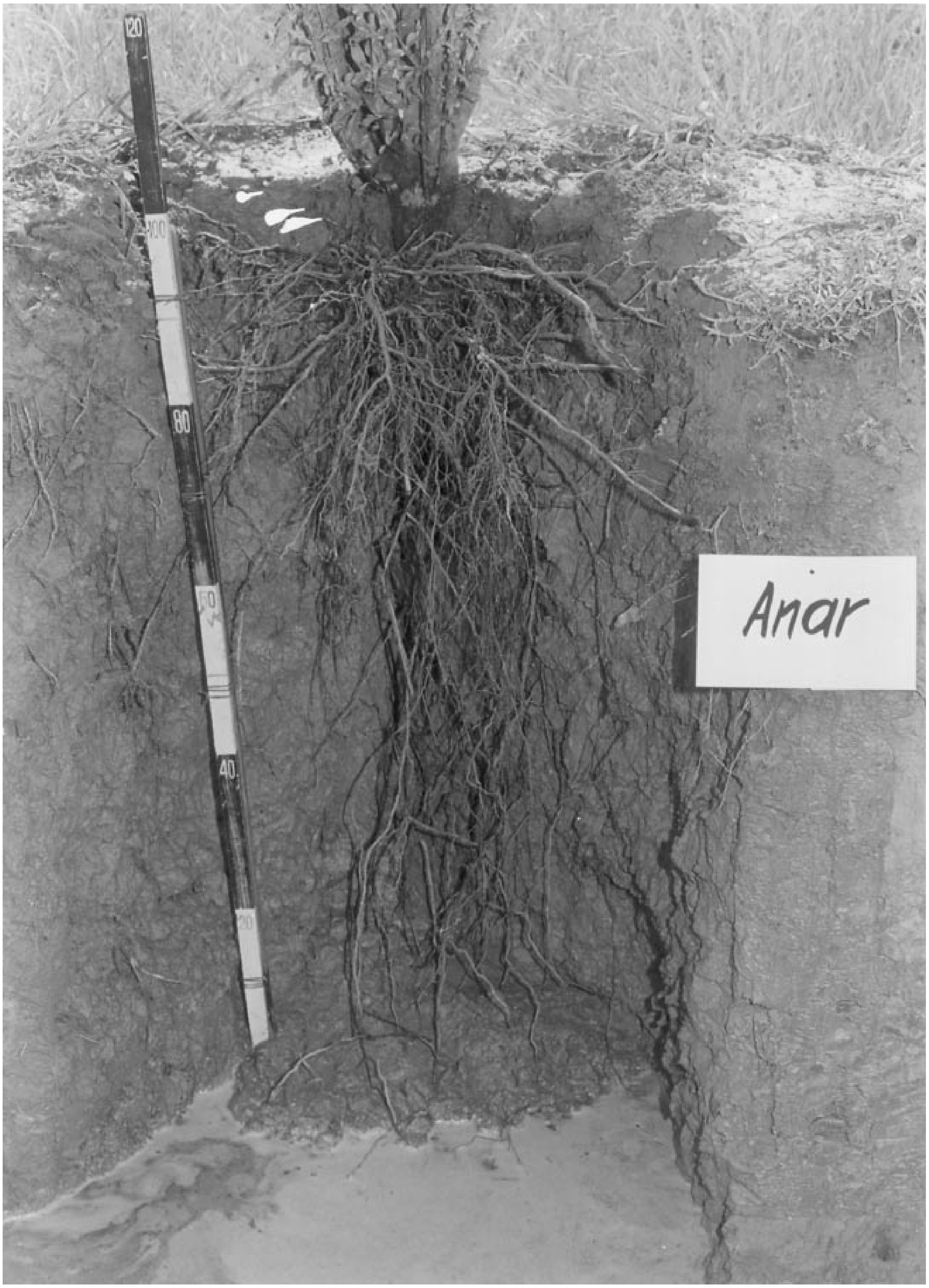

Figure 6. Root system of pomegranate, Anar (*Punica granatum*).

RESULTS AND DISCUSSION

Normally the raised and sunken-bed technique is used in rainfed vertisol regions of India where, on the ridges, plantations such as neem or pomegranate and crops such as cotton can be raised in a conservative moisture regime and during the rainy season rice can be raised in sunken beds where the clay soil presents water penetrating into the deep layers. As in alkali soils the infiltration rate is very poor, therefore, with some additional irrigations, the salt-tolerant variety of rice could be grown with success. Initially the water was kept standing in sunken beds then the salt-tolerant variety of rice (CSR-10) was planted using seedlings from nursery in half the plots and in the other half the forage kallar grass (as it can withstand both high salt content and water stagnation) was planted through its culms. Kallar grass can tolerate soil salinity of as high as EC 30 dS m^{-1} and a pH up to 10.5. In other studies it was found that it could extract 114.3 kg sodium ha^{-1} from the soil in two years and during its six years of growth the contents of organic C and available nitrogen in the upper 15 cm soil layer were found to have increased from 0.2 per cent and 73 kg ha^{-1} to 0.6 per cent and 158 kg ha^{-1}, respectively (Singh *et al*., 1993; Singh and Dagar, 1998). This was due to increased biological activity through grass roots, litterfall and nitrogen fixation. One of the nitrogen-fixing organisms that was associated with its roots was identified as *Klebsiella pneumoniea* (Malik *et al*., 1986). The traditional crop rotations of the area (rice–wheat) and the kallar grass–berseem (another popular leguminous forage) were used.

As pomegranate was found salt-tolerant in pot-house studies but could not withstand water stagnation, in the field it has been used as the plantation species along with another salt-tolerant and oil-yielding plantation of salvadora on raised bunds. In high pH soils gypsum is usually added as an amendment to allow for a rice crop followed by wheat. But here the salt-tolerant rice variety (CSR-10) developed by CSSRI gave 3.6–3.9 t ha^{-1} during the first year and 4.4–4.9 t ha^{-1} during the second year without applying any amendment. Though there was a slight yield reduction of rice in association with the plantation as compared to the control (without plantation), the difference was not statistically significant. During the first year, the wheat crop benefited from the plantation but during the second year when the root system might have interfered with the crops, the yield of wheat was reduced by 10.3 per cent with the salvadora and 5.5 per cent with the pomegranate. The reduction in yield with the salvadora was greater because its root systems developed more laterally as compared to pomegranate where the roots penetrated more deeply into the soil. Similarly the yields of kallar grass and berseem were greater with plantations during the first year, while during second year these started declining as compared to the control (Table II). The wheat and rice straw is used for fodder, therefore the yield data of airdried straw is also given; the trend is similar to that of grains.

The height and the number of tillers per rice plant were less in the first year in association with the plantations while they were greater during the second year, except that height with salvadora was greater during the first year (Table III). The height and number of grains per spike of wheat plant varied along both plantations and control (Table IV). During the first year in pomegranate and salvadora most of the plants remained between 5–15 cm height as compared to the control where about 66.7 per cent plants were between 16–20 cm height. During the second year also these were taller in the control plots. The number of grains per spike is also affected by the presence of plantations (Table IV), but these parameters were not found to be correlated with yield.

Performance of Plantations with Crops

During the first year, pomegranate benefited under both crop rotations, especially with the rice-wheat, while during the second year the growth was better with the kallar grass–berseem rotation, probably because of the availability of nitrogen fixed by the leguminous berseem. Salvadora, also benefited from the crop rotations especially with the rice–wheat during the second year. In all cases, the height of plantation was greater with crops, but this was not statistically significant. Similarly, the diameter at stump height was greater with crops than without crops, and it was significantly higher in the salvadora, particularly with the rice-wheat association (Table V).

Biomass Production in Plantation

After two rotations of crops the root and shoot biomass of both plants showed that biomass of the latter was greater than that of the roots, and the crops helped in increasing biomass of both plantations as compared to the controls. In

Table II. Yield (t ha^{-1}) of rice–wheat and kallar grass–berseem in sunken beds when grown with pomegranate (*Punica granatum*) and salvadora (*Salvadora persica*) plantations on raised bunds on alkali soil

Plantation	Grain yield						Straw yield						Fresh yeild of kallar grass			Fresh yield of berseem		
	Rice			Wheat			Rice			Wheat								
	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean
Pomegranate	3·6	4·2	3·9	1·3	1·4	1·3	4·4	6·0	5·2	1·9	1·9	1·9	21·6	30·5	36·0	50·9	44·6	47·8
Salvadora	3·8	4·1	3·9	1·6	1·3	1·4	4·6	5·9	5·2	2·3	1·7	2·2	21·0	32·1	26·5	51·9	39·5	45·7
Control (without plantation)	3·9	4·7	4·3	1·0	1·4	1·2	4·9	6·1	5·5	1·5	2·0	1·7	19·3	21·3	21·3	35·9	53·8	44·8
LSD ($P<0\cdot05$)	NS	NS	NS	0·39	0·11	0·25	NS	NS	NS	0·48	0·11	0·29	1·81	3·19	2·50	5·38	4·45	4·91

NS, not significant.

Table III. Mean height and number of tillers/plant of rice during the first and second years with pomegrante (*Punica granatum*) and salvadora (*Salvadora persica*) plantations

Plantations	Height of rice plant (cm)		No. of tillers/plant	
	First year	Second year	First year	Second year
Pomegranate	76·0	77·5	16·8	19·53
Salvadora	78·4	76·2	17·2	18·8
Control (without plantation)	70·5	79·0	13·1	21·5
LSD ($P \leq 0 \cdot 05$)	5·46	4·40	3·18	2·33

Table IV. Percent range in height and number of grains per spike in wheat plants with pomegranate (*Punica granatum*) and salvadora (*Salvadora persica*) plantations

Range	With pomegranate		With salvadora		Control (without plantation)	
	First year	Second year	First year	Second year	First year	Second year
Plant height (cm)						
5–10	45·0	41·9	63·3	57·6	18·3	15·3
11–15	55·0	55·6	35·0	37·4	15·0	21·7
16–20	–	2·5	1·7	3·5	46·7	41·5
More than 20	–	–	–	1·5	20·0	21·5
No. of grains/spike						
Up to 10	51·7	47·1	68·3	56·8	46·7	34·9
11–15	37·7	32·5	29·0	31·7	45·0	48·8
16–20	11·7	13·2	2·7	6·4	5·0	9·8
More than 20	4·9	7·2	–	5·1	3·3	6·5

Table V. Performance of plantations with different crop rotations

Crop rotation	Pomegranate (*Punica granatum*)				Salvadora (*Salvadora persica*)			
	Height (cm)		Diameter (mm) at stump height		Height (cm)		Diameter (mm) at stump height	
	One year old	2 years old	After one year	After 2 years	After one year	After 2 years	After one year	After 2 years
Rice–wheat	194·7	227·2	4·3	7·3	175·7	397·5	8·0	14·0
Kallar grass–berseem	183·3	231·5	4·4	7·4	178·2	375·5	6·9	13·3
Control (without crop)	180·3	219·3	4·1	7·1	177·7	369·3	6·7	12·5
LSD ($p \leq 0 \cdot 05$)	NS	NS	NS	NS	NS	NS	0·70	0·73

NS, not significant.

pomegranate, the biomass was more in kallar grass–berseem rotation while in salvadora, it was more in the rice-wheat rotation (Table VI). When the root biomass was separated into 30 cm intervals, in pomegranate, it was 66.4 per cent in 0–20 cm, 17.7 per cent in 30–60 cm, 7.1 per cent in 60–90 cm and 8.8 per cent in below 90 cm depth, while in salvaodra the same was 52.9 per cent, 22.9 per cent, 9.1 per cent and 15.1 per cent, respectively. The lateral roots competing with crops for nutrition were more in salvadora as compared to pomegranate. In both plantations when there was no competition with the crop, the roots were longer in deeper layers. In respective depths the percentage in pomegranate was 53.6, 21.3, 13.6 and 11.5 per cent while in salvadora it was 50.7, 18.9, 11.6 and 18.8 per cent, respectively.

Table VI. Average shoot height, root and shoot length and root biomass of pomegranate (*Punica granatum*) and salvadora (*Salvadora persica*) with different crop rotations after two rotations of crops

Crop rotation	Pomegranate: Height of shoot (m)	Pomegranate: Length of root (m)	Pomegranate: Over dry biomass per plant: Shoot (kg)	Pomegranate: Over dry biomass per plant: Root (kg)	Salvadora: Height of shoot (m)	Salvadora: Length of root (m)	Salvadora: Over dry biomass per plant: Shoot (kg)	Salvadora: Over dry biomass per plant: Root (kg)
Rice–wheat	2·0	1·7	4·0	0·6	4·0	2·4	9·4	2·6
Kallar grass–berseem	2·3	1·8	4·3	0·7	3·8	2·3	8·6	2·4
Control (without crop)	1·9	1·7	3·9	0·6	3·5	2·1	8·3	2·1

LSD ($p \leq 0·05$)	Shoot height	Root length	Shoot biomass	Root biomass
Between main-crop rotation (A)	NS	NS	NS	NS
Between sub-plantations (B)	0·38	0·46	0·44	0·43
Between interactions (A × B)	NS	NS	NS	NS

NS, not significant.

Table VII. Effect of pomegranate (*Punica granatum*) and salvadora (*Salvadora persica*) plantations and different crop rotations on soil pH when grown for two years (starting from summer season)

Plantation	Soil pH (1:2) during first year after harvesting the respective crops							
	0–15 cm soil depth				15–30 cm soil depth			
	Rice	Kallar grass	Wheat	Berseem	Rice	Kallar grass	Wheat	Berseem
First year								
Pomegranate	9·7	9·6	9·7	9·4	10·1	10·0	10·0	9·9
Salvadora	9·6	9·5	9·5	9·2	10·0	10·0	9·9	9·9
Control (without plantation)	9·9	9·8	9·8	9·6	10·3	10·1	10·2	10·0
LSD ($p \leq 0·05$)								
Between plantations (A)		0·19		0·21		NS		NS
Between crop combination (B)		NS		0·10		NS		NS
Between interactions (A × B)		NS		NS		NS		NS
CV (%)		1·71		1·42		1·64		16·21
Second year								
Pomegranate	9·56	9·21	9·40	9·09	9·86	9·79	9·68	9·67
Salvadora	9·36	9·09	9·19	8·96	9·87	9·77	9·72	9·66
Control without plantation	9·65	9·69	9·47	9·54	10·09	9·93	9·86	9·81
LSD ($p \leq 0·05$)								
Between plantations (A)		0·17		0·17		0·11		0·09
Between crop combination (B)		0·10		0·10		0·09		NS
Between interactions (A × B)		NS		0·17		NS		NS
CV (%)		1·46		1·51		1·34		1·44

Crop rotations: rice–wheat, kallar grass–berseem.
Initial average pH_2 was 10·3 at 0–15 cm and 10·5 at 15–30 cm depth.
NS, not significant.

Effect on Soil pH

After preparing the field for sowing the pH of all plots was taken at two depths, i.e. 0–15 cm and 15–30 cm depths. The soil pH was also observed after harvesting each crop and it was found that there was a gradual reduction in pH in all the treatments. The pH reduction was greater under crops than it was in the sole plantations. However, after the first cropping season the role of the plantation was significant in the upper surface only. After one complete sequence of crops the kallar grass–berseem rotation played a more significant role in reducing pH in the upper layer, however, they had no significant role in the lower layer (Table VII).

During the second year, both plantations and crops played a significant role in reducing pH at the surface as well as in the lower layers. Among plantations salvadora played a more positive role compared with pomegranate, and among crop rotations kallar grass and berseem crops reduced soil pH more efficiently than rice–wheat rotation. Rao *et al*. (1999) observed well-defined salt compartmentation in salvadora. The bark and senescent leaves acted as a potential sink for sodium and chloride ions and these together accumulated over 90 per cent of salt taken up by the plant accumulating up to 13.25 mg g^{-1} and 13.84 mg g^{-1} sodium and 13.92 mg g^{-1} and 14.04 mg g^{-1} chloride, respectively when grown on a saline black soil having salinity of 60–70 dS m^{-1} in upper 30 cm soil layer. As discussed earlier, kallar grass also has a tremendous capacity for extracting sodium from the soil. The role of berseem in reclamation of alkali soil is well established (Singh and Dagar, 1993); hence the kallar grass and berseem could play an important role in reducing soil pH in alkali soil.

CONCLUSION

The raised and sunken bed technique appears to be quite successful in raising plantations such as pomegranate and salvadora which otherwise suffer set backs due to stagnation of water. In sunken beds rice–wheat (salt-tolerant varieties) as well as kallar grass–berseem rotation of crops can be obtained with great success. This not only gives satisfactory crop yield but also helps in ameliorating the soil at faster pace without applying any costly amendment. The final recommendations regarding performance of fruit trees and other plantations needs further experimentation for a longer duration.

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