GREENING SODIC LANDS : BICHHIAN MODEL

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FOREWORD

Iigher concentration of salts in the root zone soil limits the productivity of more than 8 nillion ha lands in India. Nearly one third of salt lands in the country are alkali or sodic ands. After the establishment of Central Soil Salinity Research Institute in 1969 at Karnal nore than one million ha alkali lands have been reclaimed in the states of Punjab, Haryana nd Uttar Pradesh. The reclaimed area is contributing 8-10 million tones of additional ood grains. A sizeable part of alkali lands in the Indo-Gangetic alluvial plain is constituted y village community lands and government lands adjacent to roads, railway lines and long the canals. Owing to common property rights, the reclamation of such lands for rop production is not feasible. Rehabilitation of such areas with forest and fruit trees nd grasses seems promising in view of fuelwood and fodder shortages and environmental onservation. Further, trees and grasses are known to have the potential to reclaim vastelands and provide livelihood security through year round employment generation.

'he Central Soil Salinity Research Institute, Karnal and Forest Department, Haryana ndertook a collaborative research-cum-demonstration project in 1991 to standardize and pgrade technology for afforestation of sodic lands. During the 10 years project period ighly useful information on suitability of forest, fruit and grass species, planting echniques, silvicultural / agrisilvicultural practices and ameliorating effects of trees and rasses on sodic lands has been generated. The project's main investigators Dr. Gurbachan ingh and Dr. J.C. Dagar have compiled this information in the form of a bulletin. The uthors deserve appreciation for conducting a good piece of research in a relatively remote rea 'Bichhian Reserve Forest' Kurukshetra (Haryana) and also its timely compilation for eplication of the generated information for greening sodic lands in the country. I am ure the compilation will be of immense use to researchers, government and non-overnment organizations, policy planners and farmers.

(J.S. SAMRA)

DEPUTY DIRECTOR GENERAL (NRM)

Dated: August 17, 2005

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AUTHORS

EXECUTIVE SUMMARY

The Central Soil Salinity Research Institute, Karnal and the Haryana Forest Department, Panchkula joined hands in 1991 to undertake a collaborative research-cum-demonstration project on afforestation of salt-affected soils. A farm was established at Bichhian Reserve Forest of Saraswati Range in Kurukshetra District (Haryana) on about 30 ha severely sodic land for this purpose. Past efforts to raise any viable forest cover on this piece of land largely failed because of lack of appropriate technologies. The climate of the area is sub-tropical, semi-arid and monsoonic type. The mean annual rainfall is about 52 cm, of which nearby 70% is received between July to September. The pan evaporation exceeds precipitation throughout the year except monsoon months. The soil of the experimental farm was highly sodic having pH more than 10 up to 2 m depth. The electrical conductivity (EC_2) of the surface 15 cm layer varied from 2.2 to 5.4 dS m^{-1}. The most peculiar feature of the soil profile was the presence of precipitated $CaCO_3$ layers at various depths. The $CaCO_3$ content varied from negligible at surface to about 24% upto one meter depth. The soil was very low in organic carbon and nitrogen but sufficient in phosphorus and potash. The groundwater used for irrigation was also sodic with pH 8.3 and Residual Sodium Carbonate (RSC) ranging from 7.2 to 10.8 me l^{-1}. The natural vegetation was open scrub consisting of a few highly salt tolerant trees and shrubs with stunted growth. The prominent species included *Prosopis juliflora, Acacia nilotica, A. leucophloea, Salvadora oleoides* and *Capparis decidua*. The prominent grasses were *Sporobolus marginatus* and *Desmostachya bipinnata*.

The main objectives of the project were to develop location specific silvi-pastoral / agroforstry practices for greening of abandoned sodic lands; to evaluate and identify suitable forest and fruit tree species; to optimize the irrigation requirement to establish forest tree species, and to evaluate the ameliorating effects of trees and grasses. To achieve these objectives, the following long-term and adhoc studies were undertaken:

- Comparative evaluation of silvicultural and silvi-pastoral land use systems
- Evaluation of multipurpose trees using two augerhole depths
- Standardization of site preparation methods and amendment use for growing fruit trees
- Irrigation requirement of selected forest tree species
- Evaluation of indigenous and exotic *Prosopis* germplasm
- Microbial biomass carbon, soil respiration and microrrhizal studies in silvi-pastoral system
- Developing raised and sunken-bed technique to raise forest and fruit trees sensitive to water stagnation and also to conserve rainwater
- Evaluation of selected grasses during establishment stage for sodicity tolerance

Ten years of collaborative research efforts culminated into the development and standardization of package of practices for raising plantations on degraded sodic lands. The significant findings are as under:

- Highly alkali soils with pH > 10 in semi-arid regions receiving about 60 cm annual rainfall can be rehabilitated successfully with suitable salt-tolerant forest tree species such as vilayti babul (*Prosopis juliflora*), frans (*Tamarix articulata*) and desi kikar (*Acacia nilotica*) after making augerholes (20-25 cm diameter and 120-140 cm deep) before commencing of rains during monsoon season. These augerholes are to be refilled with original soil + 8 kg farm yard manure (FYM) + 20 g $ZnSO_4$ + 20 g hydrated benzene hexachloride powder (for protection from termites) before rainy season. Six to nine months old seedlings must be planted after commencement of rains. Three to four spot irrigations with bucket are needed for establishment of saplings. Further irrigation may be given by connecting the augerholes with channels. Irrigation must be provided at least for initial three years after planting the saplings. After that two irrigations during summer and one during winter is mandatory. After the plantation of one year onwards, all the side branches on lower one-third portion of the stem must be removed by periodic pruning to give a proper shape to the trees. Application of dermit or any insecticide to take care of termite attack at regular intervals is must. Periodic weeding of channels helps in establishment of saplings and increases water application efficiency.

- *Tamarix articulata, Acacia nilotica* and *Prosopis juliflora* were found the most successful species producing 97, 70 and 51 t ha^{-1} air-dried aerial biomass, respectively after 7 years of growth when planted in deep augerholes (20-25 cm diameter and 120-140 cm deep). Safeda (*Eucalyptus tereticornis*), jungle-jalebi (*Pithecellobium dulce*), arjun (*Terminalia arjuna*), shisham (*Dalbergia sissoo*), lasura (*Cordia rothii*), balam-khira (*Kigelia pinnata*) and parkinsonia (*Parkinsonia aculeata*) were also found tolerant to high sodicity with more than 70% survival rate but could not produce satisfactory biomass. All the tried species of *Prosopis* proved tolerant to high sodicity except *P. tamarugo*. *P. alba* being thornless appears quite interesting and needs detailed studies particularly about nutritive value of its foliage and strength of wood. Among all *Prosopis* species/strains tried *P. juliflora* was found most superior than others in biomass production. Irrespective of the species, plantation in deep augerholes was always superior than in shallow augerbores.

- Observations on growth parameters such as height and girth at stump height revealed that there was enough variation in height and girth of plants in the same treatment showing the prevalence of spatial variability in sodic profiles. The regression relationship between growth parameters and soil properties indicated that $CaCO_3$ (layer in soil) and EC are the dominant players affecting such variability in plants.

- Sodic soils can be rehabilitated successfully with frost-tolerant fruit trees by following pit-cum-augerhole planting technique. The developed technique involves making augers of 20-25 cm diameter. and 160-180 cm deep bores in 45 cm x 45 cm 45 cm pits dug out manually before monsoon season. These pits– cum– augerbores are refilled with original soil + 8-10 kg gypsum + 10-15 kg FYM + 15-20 kg river silt + 20 g $ZnSO_4$ + antitermite insecticide. Application of 8 kg FYM, 50 g urea and 20 g super phosphate per plant every year proved beneficial. Though the performance of fruit trees in pits of 0.9 x 0.9 x 0.9 m size was superior when compared to pit-cum-augerhole method, but looking into the total cost the pit-cum-augerhole method is recommended for large-scale field plantations. Planting cost was almost half in pit-cum-augerbore method as compared to pit method.

- The promising fruit species identified for planting in sodic soils include: high yielding improved varieties of aonla (*Emblica officinalis*), guava (*Psidium guajava*), ber (*Ziziphus mauritiana*), jamun (*Syzigium cuminii*) and karonda (*Carissa carandus*). Species sensitive to water stagnation such as pomegranate (*Punica granatum*) and Bael (*Aegle marmelos*) may be planted on raised bunds. Sapota (*Achras zapota*) and tamarind (*Tamarindus indica*) are tolerant to sodicity but are sensitive to frost. These are not recommended for the climate where the temperature of winter season is very low occassionaly falling below 0°C.

- Raised and sunken bed technique was developed to raise the forest and fruit trees in sodic lands subjected to prolonged waterlogging during rainy season. In this technique trees are raised on bunds and rice-wheat or kallar grass-berseem crop rotation is taken in sunken beds for high crop production and quick soil reclamation. This not only helps in better establishment of trees but also conserves rain water for higher extended period to boost productivity.

- Among the several silvi-pastoral and agroforestry options tried at Bichhian, the kallar grass (*Leptochloa fusca*) – mesquite (*Prosopis juliflora*) based silvi-pastoral system was the most ideal combination for highly sodic soils in terms of productivity and soil amelioration i.e. reduction in soil pH and increase in organic carbon contents. The soil amelioration was more when the grasses associated with trees as compared to sole trees or sole grasses. *Brachiaria mutica, Panicum laevifolium* and *Chloris gayana* were the other grasses found tolerant to sodicity. In addition to *Leptochloa fusca*, these grasses also have the potential to be an integral part of silvi-pastoral system. Though *Sporobolus marginatus* is highly tolerant to sodicity but this grass is not relished by cattle.

- Net primary productivity, total biomass production and microbial count in *P. juliflora* based silvi-pastoral system was highest followed by *Dalbergia sissoo* based system. The performance of the systems in association with one of the primary colonizers of sodic soils i.e. *Desmostachya bipinnata* grass was superior as compared to other naturally growing colonizer, the *Sporobolus marginatus*.

- These studies further suggested that in addition to sodic soil amelioration the tree-based systems also increased microbial biomass, microbial N and carbon in otherwise dead mass of degraded sodic soil. The soil microbial biomass responded favourably to the increase in organic matter of the soil. It was interesting to find a significant relationship of the soil microbial biomass with the flux of carbon in net primary productivity and plant biomass carbon across various treatments.

INTRODUCTION

Out of 329 million ha geographical land area of the country, about 175 million ha suffer from different limitations expressed to varying degrees and are getting further degraded through natural or man-made processes. Majority of these lands are treated as wastelands because of their low productivity due to soil-based constraints like waterlogging, salinity, sodicity, shallow depth, rocky substratum and sandy soils. The distribution of salt-affected soils is reported to be 8.6 million ha of which about 3 million ha are alkali soils. The alkali soils contain excessive salts capable of producing alkaline hydrolysis products such as Na_2CO_3, $NaHCO_3$ and Na_2SiO_3 and sufficient exchangeable sodium to impart poor physical conditions to soils and, thus, adversely affect the growth of most plants. These soils have high pH (of saturation paste > 8.2 and often approaching 11), exchangeable sodium percentage (ESP) > 15, and varying electrolytic conductivity (EC). The alkali soils are also called as sodic soils when ESP of the soils is invariably very high. The presence of $CaCO_3$ concretions (known as *kankar* pan) at various depths causes physical impedance for root proliferation, therefore, making it difficult for tree establishment. Sometimes many of these layers varying in density and thickness are present in the soil profile.

Most of the alkali or sodic lands do not support a healthy vegetation cover, with the exception of some restricted natural species comprising only a few salt-tolerant trees and bushes such as *Prosopis juliflora, Salvadora oleoides, Acacia nilotica, Capparis decidua, C. sepiaria, Ziziphus nummularia, Clerodendron phlomidis* and *Maytenus emerginatus*. Among herbaceous species *Desmostachya bipinnata, Sporobolus marginatus, Cynodon dactylon, Chloris virgata, Trianthema triquetra, Suaeda fruticosa* and *Kochia indica* are prominent, particularly during rainy season.

During the last three decades, a sizeable area with sodic soils in the Indo-Gangetic plains has been reclaimed by applying gypsum and is now supporting successful crops of rice and wheat. This was possible because gypsum was available locally at 75% subsidized price. With the reduction of subsidy the pace of reclamation has slowed considerably. Moreover, a large portion of the sodic lands does not belong to individual farmers, but is either Government owned or is in the custody of the village Panchayats (an elected judicial body of the village) as community land. At times these lands are leased to farmers by the Panchayats for a short period. Hence, it is not feasible for farmers to apply the costly amendments for reclamation. Therefore, due to the problem of common property rights, the reclamation of such lands for crop production by applying gypsum usually is not feasible.

As most of these marginal lands contribute least to the national output and present a picture of desolation, there is a need to re-vegetate these wastelands and prevent their further degradation. Raising suitable trees (both forest and fruit species) in isolation or in grass or crop-based agroforestry systems is an option of great promise for use of such lands, in view of the growing demand for fuel-wood, timber, fodder, other minor products and also on environmental consideration. This approach will not only help in increasing productivity of these degraded lands through amelioration but in the scenerio of global climate change will meet the environmental obligations through carbon sequestration and will help in protecting the wild-life and general environment.

To develop and upgrade a technology package for greening highly sodic soils using tree based practices, a collaborative research-cum -demonstration project was under taken by CSSRI, Kanal in collaboration with forest department, Haryana at Bichhian village of Saraswati Reserve Forest. Result of the collaborative research conducted for 10 years are reported in this bulletin.

GENERAL FEATURES OF THE STUDY SITE

2.1 Experimental Site

The Central Soil Salinity Research Institute (CSSRI), Karnal and the Haryana Forest Department, Panchkula joined hands in 1990-91 to undertake a collaborative research-cum-demonstration project on Afforestation of Salt-affected Soils. About 30 ha severely sodic land in the Saraswati Reserve Forest was allocated by the Forest Department adjacent to a village Bichhian, near Guhla town of Kurukshetra District (30° 03′ N and 76° 18′ E, at an elevation of 240m) in Haryana State (Fig. 1). The experimental site was long abandoned because of the severe alkalinity problem. Past efforts to produce a viable forest cover by the Forest Department at this site had failed because of lack of appropriate technologies. The area is surrounded by a network of canals and is relatively flat, located in a slight topographic depression.

Original landscape of Bichhian Farm

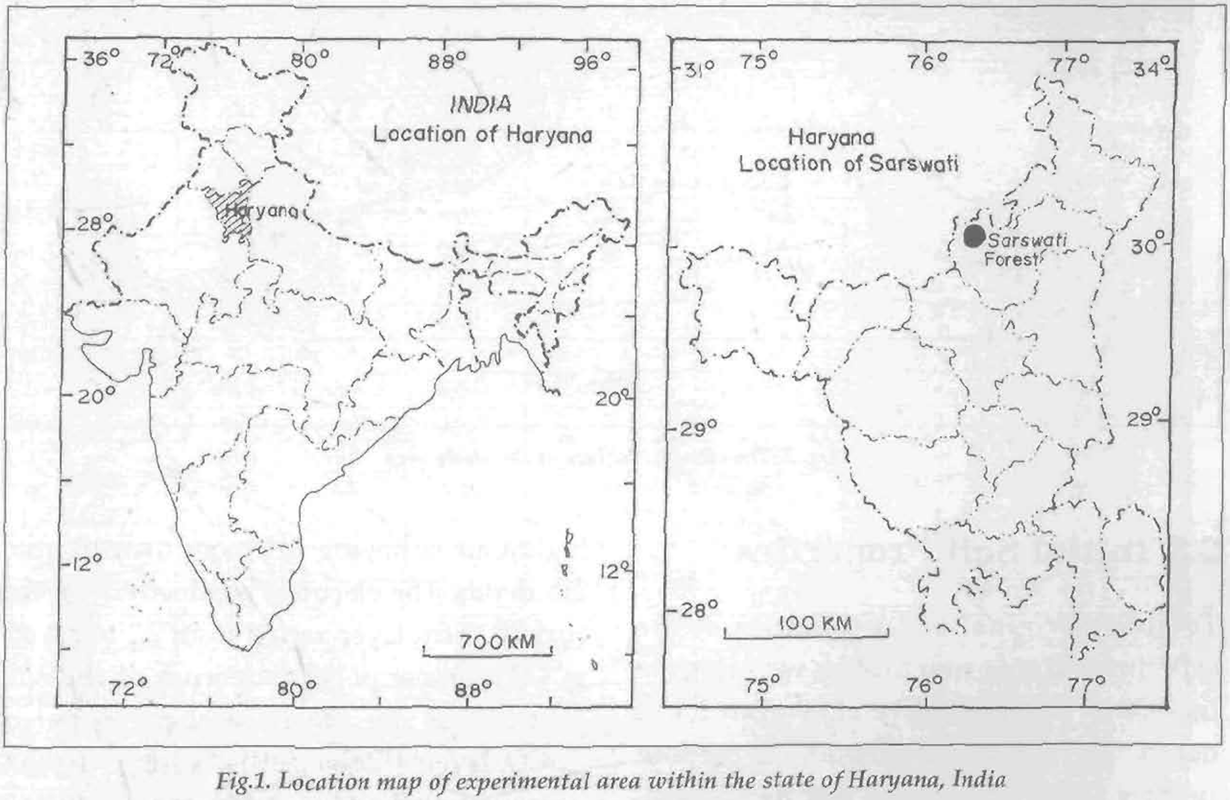


Fig.1. Location map of experimental area within the state of Haryana, India

2.2 Climate

The climate of the area is subtropical, semi-arid monsoonic with little or no water surplus, megathermic with an aridity index of 63.38 and a moisture index of –38.03. Mean annual rainfall of the area is 516 mm and annual potential evapotranspiration is 1407 mm, producing an annual water deficiency of 891 mm. More than 70% of the total rainfall is received between July to September. Months with mean summer temperature >20°C are eight. The mean annual temperature is 24.6°C, the mean summer temperature is 32.4°C, and the mean winter temperature is 15.1°C. The climatic data of the site is shown in Fig. 2. During the experimental period 1991-1999, the actual annual rainfall ranged from 490 mm in 1993 to 1216 mm in 1995.

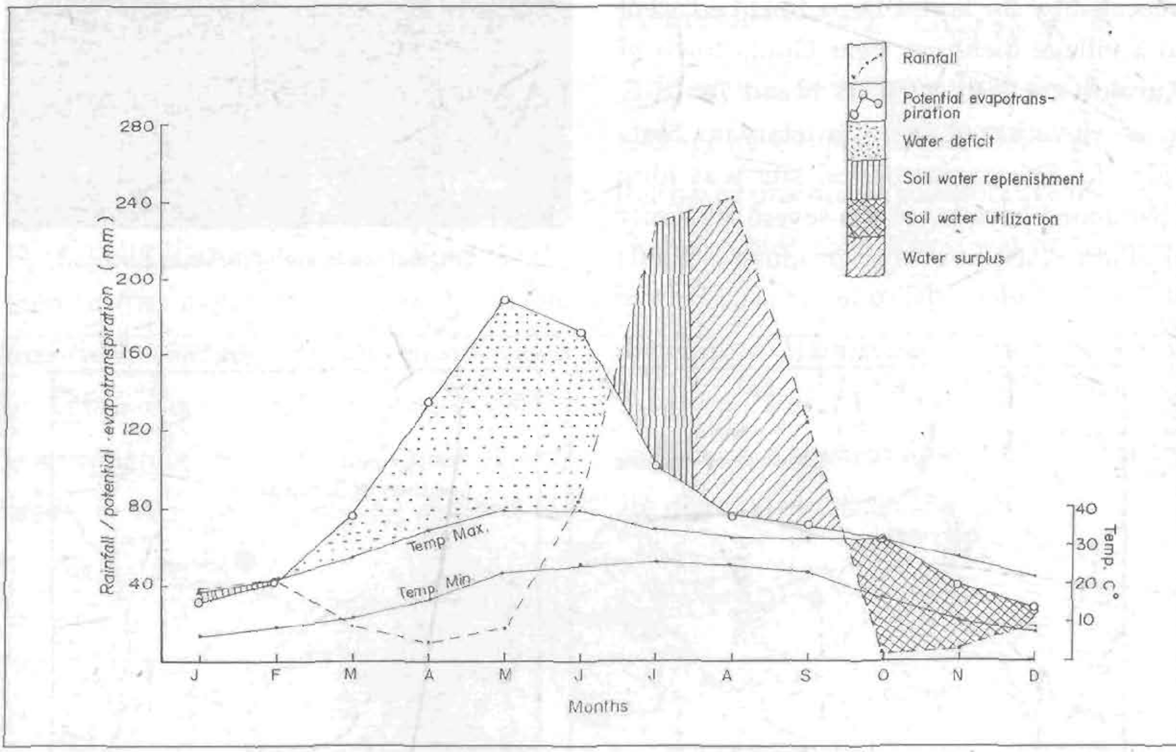


Fig. 2. The climatic feature of the study area

2.3 Initial Soil Properties

To study original soil properties of the experimental area, four profiles were dug out in 1990 at representative sites upto 2.1 m depth. The critical examination of the four profiles (Table 1) revealed that the soil was highly alkali having pH more than 10 upto 2m depth. The electrical conductivity of the surface 15cm layer varied from 2.2 to 5.4 dS m^{-1}. The most peculiar feature of the soil profile was the presence of precipitated $CaCO_3$ layers (*kankar pans*) at various depths, necessitating the need of deeper auger holes/

pits for planting trees. The $CaCO_3$ content varied from negligible amounts at the surface to about 24% nearer to 1m depth. The soil was almost free of organic carbon, but was sufficient in phosphorus and potash. The amount of Ca + Mg,.Na, CO_3, HCO_3 and Cl in the surface layer varied from 3 to 6, 194-369, 72 to 232, 16 to 160 and 22-540 me l^{-1}, respectively. Among micro-nutrients, in surface layer Fe ranged from 19 to 28 ppm, Mn from 2 to 17 ppm, Zn from 1.6 to 2.4 ppm, and Cu from 2.2 to 5.7 ppm, showing the deficiency of zinc.

Soil profile of experimental site showing kankar pans

Table 1. Initial soil properties of four representative profiles of Bichhian farm

Profile depth (cm)	PH_2	EC_2 ($dS\ m^{-1}$)	O.C (%)	Av. P_2O_5 ($kg\ ha^{-1}$)	$CaCO_3$ (%)	Ca+Mg ($me\ l^{-1}$)	Na ($me\ l^{-1}$)
Profile-I							
0-15	10.5	5.4	0.06	65	–	6	368.7
15-30	10.7	5.2	0.05	56	–	4	311.7
30-45	10.7	3.6	0.06	65	3.5	4	217.7
45-60	10.3	7.4	0.05	43	28.3	3	368.7
60-90	10.3	1.6	0.03	24	13.0	2	81.3
90-120	10.2	1.1	0.05	15	20.0	2	32.6
120-150	10.2	0.9	0.05	7	20.9	2	38.0
150-180	10.0	1.0	0.02	13	11.9	3	35.4
Profile-II							
0-15	10.6	3.1	0.04	68	–	4	255.2
15-30	10.5	1.1	0.02	39	–	3	89.5
30-45	10.3	1.0	0.01	30	1.0	4	49.6
45-60	10.2	0.8	0.06	34	36.1	3	54.9
60-90	10.1	0.8	0.05	12	3.9	1	27.2
90-120	10.1	0.7	0.05	24	12.1	2	27.2
120-150	10.1	0.7	0.04	19	16.4	2	23.1
150-180	10.1	0.7	0.04	11	48.1	2	23.1
180-210	10.1	0.7	0.03	12	20.8	2	21.7
Profile-III							
0-15	10.8	2.7	0.05	83	11.4	4	203.9
15-30	10.7	3.3	0.03	57	14.8	4	150.5
30-45	10.3	1.1	0.02	22	23.4	3	60.5

45-60	9.9	0.5	0.02	15	23.0	2	13.0
60-90	9.6	0.4	0.03	15	18.1	2	19.6
90-120	9.4	0.6	0.03	28	2.7	2	17.4
Profile-IV							
0-15	10.4	2.2	0.10	66	–	3	193.7
15-30	10.6	2.7	0.04	80	–	2	210.6
30-45	10.5	2.0	0.04	63	4.4	2	149.6
45-60	10.4	1.0	0.03	40	5.6	3	42.1
60-90	10.3	0.8	0.05	55	33.5	3	29.9
90-120	10.0	0.5	0.04	26	4.0	2	15.2

Profile depth (cm)	**CO_3**	**HCO_3** (me l^{-1})	**Cl**	**Fe**	**Mn** (ppm)	**Zn**	**Cu**
Profile-I							
0-15	212	16	88	20	12	2.4	4.2
15-30	216	12	86	18	5	1.8	6.6
30-45	128	20	48	24	5	1.4	3.9
45-60	200	188	124	22	3	0.8	2.6
60-90	48	20	30	22	5	1.4	1.8
90-120	28	8	16	13	2	1.2	1.9
120-150	20	12	10	12	6	0.7	1.9
150-180	20	48	10	11	7	0.6	1.4
Profile-II							
0-15	172	68	540	23	12	2.2	3.0
15-30	40	48	220	21	10	1.7	5.0
30-45	44	12	16	16	13	1.5	2.2
45-60	28	28	10	15	7	1.0	1.2
60-90	20	8	6	6	4	1.6	1.2
90-120	16	8	4	7	4	0.8	1.1
120-150	20	12	6	8	4	0.5	1.0
150-180	12	12	8	7	5	1.0	1.1
180-210	16	8	4	8	4	0.6	1.5
Profile-III							
0-15	132	160	22	28	17	1.8	5.7
15-30	68	100	14	27	9	1.2	5.4
30-45	28	20	8	15	5	1.5	1.3
45-60	12	8	6	14	4	0.8	1.4
60-90	8	8	20	7	3	1.0	1.4
90-120	16	8	22	5	3	0.7	0.1
Profile-IV							
0-15	72	20	62	19	2	1.6	2.2
15-30	124	28	70	23	24	0.9	2.7
30-45	36	104	74	30	30	0.7	2.9
45-60	20	24	16	8	4	0.4	0.1
60-90	16	8	8	8	9	0.5	1.2
90-120	16	16	4	11	6	0.5	0.8

– denotes absent or negligible.

2.4 Quality of Irrigation Water

The groundwater was more than 13m deep. The source of irrigation was only tubewells water. The water contained high residual sodium carbonate (RSC). The chemical composition of the two tubewell waters used for irrigation is shown in Table 2.

Table 2. Chemical composition of the two tube-well waters used for irrigation

Parameters	Tubewell-I	Tubewell-II
pH	8.3	8.3
EC (dS m^{-1})	0.7	1.8
Ca+Mg (me l^{-1})	0.8	0.8
CO3 (me l^{-1})	0.0	0.7
HCO3(me l^{-1})	8.0	10.9
RSC(me l^{-1})	7.2	10.8

2.5 Natural Vegetation and Successional Trends

Among trees, shrubs and bushes *Capparis decidua, C. sepiaria, Acacia nilotica, A. leucophloea, Salvadora oleoides, Prosopis juliflora, P. cineraria, Maytenus emerginatus, Clerodendron phlomidis, Butea monosperma,*

Natural vegetation showing Capparis decidua *bush*

Ziziphus nummularia, Adhatoda vasica and *Calotropis procera* were prominent. *P. juliflora,* although an exotic, had spread forming gregarious patches almost in the entire area. Among herbaceous species, two grass species *Sporobolus marginatus* and *Desmostachya bipinnata* were predominant communities associated with *Kochia indica, Suaeda fruticosa, Pluchea lanceolata, Trianthema triquetra, T. portulacastrum, Cynodon dactylon, Dactylocteninm aegiptium, Sporobolus diander, Chloris virgata* and *Dichanthium annulatum.* During rainy season, *Croton bonplandianum, Cassia tora, C. occidentalis, Eclipta prostrata, Amaranthus viridis. Echinochloa colonum, Vernonia cinerea* species of *Euphorbia, Corchorus* and *Cyperus* appeared and grew on these soils. Among bushes some climbers such as *Mukia maderaspatana, Ichnocarpus prutescens, Cayratia trifolia, Cocculus pendulus, C. hirsutus, Momordica dioica* and *Asparagus racemosus* were prominent.

A part of the fenced farm area was kept undisturbed to monitor the vegetation succession over the years. During the very first year, grasses like *Chloris barbata, Cynodon dactylon, Cenchrus ciliaris, C. setigerus, Eragrostris* spp., *Dichanthium annulatum, Dactyloctenium aegyptium* and *Echinochloa colonum* appeared as colonizers. *Desmostachya bipinnata* and *Sporobolus marginatus* remained the dominant species. During rainy season, species such as *Cassia occidentalis, C. tora, Achyranthes aspera, Commelina* spp., *Corchorus spp., Abutilon indicum, Sida spp.* and *Cyperus* spp. appeared. In the third year, the number of these species increased whereas density of *Suaeda fruticosa* and *Kochia indica* declined. In the fourth year, the standing fresh biomass of all species ranged from 1.5 to 3.0 kg m^{-2}. Even after four years, *Desmostachya bipinnata* and *Sporobolus marginatus* were the dominant communities, however, the density of many palatable species like *Cynodon dactylon, Dichanthium annulatum, Cenchrus setigerus, Digitaria ciliaris, Eleusine indica, Eragrostis spp., Panicum antidotale, Paspalum spp.* and *Echinochloa colonum* increased considerably.

Protected vegetation showing **Sporobolus marginatus** *grass community*

In the protected vegetation, five grass communities were identified (Table 3), which when harvested at maturity could provide 21.5 to 33.5 t ha^{-1} fresh biomass.

It is obvious that even by simple protection from grazing, the highly alkali soil can produce sizeable forage biomass during rainy season.

Table 3. Harvested fresh biomass of 5 grass communities

Grass community	Harvested fresh biomass (t ha^{-1})
Desmostachya bipinnata	33.5
Dactyloctenium aegyptium – Chloris virgata	22.5
Chloris virgata – Sporobolus marginatus	32.5
Dichanthium annulatum – Cynodon dactylon	22.7
Sporobolus marginatus	21.5

2.6 Specific Constraints

The experimental site being a part of a Reserve Forest was highly prone to wild-life such as blue bulls, deer, rabbits, and stray cattle. To guard against biotic pressure, the area was fenced using *Eucalyptus* poles and barbed wire. During rainy season, the experiments were subjected to prolonged flooding and water stagnation, particularly during August and September. This had adverse effect on the establishment of some of the tree species. Adequate surface drainage is a pre-requisite for success of tree plantation on such areas. The area was also prone to frost during the winter.

Biotic pressure due to stray animals

The farm area subjected to flooding and water stagnation during rainy season

2.7 Objectives

The following objectives were set for developing the abandoned highly alkali soils:

- Standardisation of plantation techniques and evaluation of indigenous and exotic multi-purpose trees in terms of survival, growth performance (height, stump diameter) and biomass production.
- Development of planting technique and identification of promising fruit tree species.
- Developing loation specific silvi-pastoral / agroforestry practices.
- Optimizing cultural practices such as standardization of irrigation schedule for raising trees.
- Natural vegetation and its succession.
- Evaluation of ameliorating effects due to afforestation and silvi-pastoral systems.

EVALUATION OF MULTIPURPOSE TREES

3.1 Establishment

To study the performance of different trees on highly alkali soil (profile-1 in Table 1), a three times replicated field experiment in split block design (Fig. 3) was initiated during August-September, 1992 planting the following 30 multipurpose tree species in shallow (20 cm diameter and 60-75 cm deep) and deep (20 cm diameter and 120-140 cm deep) auger holes made by tractor mounted augers keeping distance of 2 m from plant to plant and 4m between rows:

Making augerholes in highly sodic soil by tractor mounted augers

Replication							← PATHS →						
	SHALLOW							DEEP					
R_1	1	2	3	4	5	6		1	2	3	4	5	6
	12	11	10	9	8	7		12	11	10	9	8	7
	13	14	15	16	17	18		13	14	15	16	17	18
	24	23	22	21	20	19		24	23	22	21	20	19
	25	26	27	28	29	30		25	26	27	28	29	30
	DEEP							SHALLOW					
R_2	27	15	25	4	8	3	↑	27	15	25	4	8	30
	28	1	3	14	21	18		28	1	3	14	21	18
	16	2	26	12	17	19	PATHS	16	2	26	12	17	19
	22	5	24	11	7	29		22	5	24	11	7	29
	9	13	10	23	6	20		9	13	10	23	6	20
	SHALLOW							DEEP					
R_3	16	15	1	2	4	30	↓	16	15	1	2	4	30
	9	24	11	26	8	19		9	24	11	26	8	19
	28	3	25	23	17	18		28	3	25	23	17	18
	6	13	21	7	14	5		6	13	21	7	14	5
	20	29	10	22	27	12		20	29	10	22	27	12

The number 1-30 depict the species as:

1. Dalbergia sissoo
2. Butia monosperma
3. Tectona grandis
4. Kigelia pinnata
5. Albezia lebbeck
6. Thespesia populnea
7. Tamarindus indica
8. Bomax ceiba
9. Ficus virens
10. Acacia auriculaeformis
11. Azadirachta indica
12. Prosopis juliflora
13. Casuarina eqisetifolia
14. Terminalia arjuna
15. Acacia nilotica
16. Cassia siamea
17. Parkinsonia aculeata
18. Cordia rothii
19. Anthocephalus cadamba
20. Acacia leucophloea
21. Leucaena leucocephala
22. Moringa oleifera
23. Pithecellobium dulce
24. Tamarix articulata
25. Eucalyptus tereticornis
26. Pongamia pinnata
27. Melia azedirach
28. Sesbania sesban
29. Bambusa arundinacea
30. Cedrella serrata

Fig. 3. Layout of experiment with 30 forest tree species grown in deep and shallow augerholes

Species	Family	English/trade name	Vernacular name (s)
Acacia auriculaeformis	Mimosaceae	Australian wattle	Australian kikar
A. leucophloea	Mimosaceae	–	Safed kikar, ronjh
A. nilotica	Mimosaceae	Gum arabic	Desi kikar/ babool
Albizia lebbeck	Mimosaceae	East Indian walnut	Siris, kokko
Anthocephalus cadamba	Rubiaceae	–	Kadamb, kadam
Azadirachta indica	Meliaceae	Margosa	Neem
Bambusa arundinacea	Poaceae	Bamboo	Bans
Bombax ceiba	Bombacaceae	Silk cotton tree	Semul
Butea monosperma	Papilionaceae	Flame of the forest	Dhak, palas
Cassia siamea	Caesalpiniaceae	Ironwood tree, Siamese senna	Kasid
Casuarina equisetifolia	Casuarinaceae	Australian pine	Casuarina
Cedrela serrata	Meliaceae	Hill- toon	Kullu neem, drawa
Cordia rothii	Cordiaceae	–	Lasura, gondi
Dalbergia sissoo	Papilionaceae	Sissoo	Shisham
Eucalyptus tereticornis	Myrtaceae	Red gum	Safeda
Ficus rumphii	Moraceae	–	Pilkhan
Kigelia pinnata	Bignoniaceae	Common sausage tree	Balam-khira
Leucaena leucocephala	Mimosaceae	White popinac, lead-tree	Subabul
Melia azedarach	Meliaceae	Bead tree, persian lilak	Drek, bakain
Moringa oleifera	Moringaceae	Drumstick, horse- radish tree	Sainjna, sajina
Parkinsonia aculeata	Caesalpiniaceae	Jerusalem-thorn	Vilayati babul
Pithecellobium dulce	Mimosaceae	Qumachil, madras-thorn, manila tamarind	Jungle-jalebi
Pongamia pinnata	Papilionaceae	Pongam	Papri, karanj
Prosopis juliflora	Mimosaceae	Mesquite	Kabuli/ velayati kikar/babul
Sesbania sesban	Papilionaceae	Sesban, Egiptian rattle-pod	Jainti, ravasan
Tamarindus indica	Caesalpiniaceae	Tamarind	Imli
Tamarix articulata	Tamaricaceae	–	Farash, farans
Tectona grandis	Verbenaceae	Teak	Sagwan
Terminalia arjuna	Combretaceae	–	Arjun
Thespesia populnea	Malvaceae	Indian tulip, portia, umbrella tree	Paras-pipal

Before planting, the augerholes were refilled with a uniform soil mixture (original soil + 3 kg gypsum + 8 kg FYM + 20 g $ZnSO_4$ per augerhole). After planting, 4 irrigations were applied with bucket and later on channel method was followed for irrigation. Each sub-plot accommodated 30 plants. Total area of experiment was about 2.5 ha. Growth parameters such as survival, height and stump diameter were measured at six months interval. Roots of selected species were excavated after 2 and 7 years of planting.

The roots and shoots of 3 representative plants from each sub-plot were separated, cleaned with water-jet, oven-dried and weighed for biomass estimation.

3.2 Growth Performance

After one year of plantation, there was no significant difference in survival of species in two auger depths. Most of the species showed 80-100% survival except *Cassia fistula, Cedrella serrata, Bombax ceiba, Tectona grandis,* and *Thespesia populnea* which were quite sensitive to sodicity. During second year all the plants of *Cedrella serrata* died. The performance of rest of the species was better in deep augerholes but species such as *Tamarix articulata, Prosopis juliflora, Acacia nilotica, Terminalia arjuna, Kigelia pinnata, Casuarina equisetifolia, Cordia rothii, Tamarindus indica, Pithecellobium dulce, Eucalyptus tereticornis, Parkinsonia aculeata, Pongamia pinnata, Dalbergia sissoo, Cassia siamea* and *Anthocephalus cadamba* showed more than 90% survival even in shallow augerholes. *Albizia lebbeck* showed 86% survival in shallow augerholes and 98% in deep augerholes. *Moringa oleifera, Thespesia populnea* and *Tectona grandis* showed less than 50% survival in both augers depths. After three and half years of plantation besides *Cedrella serrata,* many other species such as *Thespesia populnea, Tectona grandis, Acacia auriculaeformis, Bombax ceiba, Sesbania sesban, Melia azedarach* and *Ficus virons* either died or the survival was less than 10% (Table 4). After 5 years of plantation, only 11 species (*P. juliflora, A. nilotica, T. articulata, E. tereticornis, D. sissoo, P. dulce, T. arjuna, K. pinnata, C. rothii, P. aculeata,* and *A. cadamba*) showed more than 70% survival, both in deep and shallow augerholes. *Acacia leucophloea, Butea monosperma* and *Tamarindus indica* showed 59.3, 57.9 and 46.5% survival in deep augerholes and 45.3, 37.0 and 34.1% in shallow augerholes, respectively. Rest of the surviving species showed insignificant survival. After 7 years of plantation, all the plants of *Casuarina equisetifolia, Leucaena leucocephala, Bambax ceiba,* and *Bombusa arundinacea* died. Among tolerant species, the height and stump diameter were significantly high when these were planted in deep augerholes as compared to when planted in shallow (Table 5) because of restriction in their root development in shallow augerholes.

Performance of three most successful trees (a)Tamarix articulata, (b)Acacia nilotica *and* (c)Prosopis juliflora *on highly sodic soil*

Table 4. Survival, height and diameter at stump height of forest trees when planted in deep (D) and shallow (S) augerholes on highly alkali soil at different intervals of time

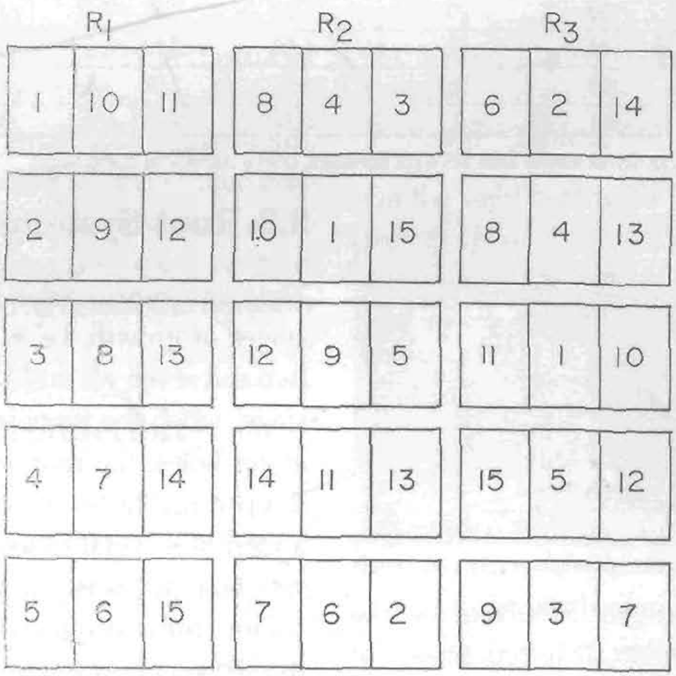
Species	After 2 years						After 3½ years					
	Survival (%)		Height (m)		Diameter (cm)		Survival (%)		Height (m)		Diameter (cm)	
	D	S	D	S	D	S	D	S	D	S	D	S
Prosopis juliflora	100.0	98.7	1.73	1.30	3.5	2.6	98.6	94.3	3.72	2.00	4.5	3.6
Acacia nilotica	100.0	100.0	1.78	1.63	4.1	2.9	98.7	96.3	3.61	2.30	7.4	3.4
Tamarix articulata	100.0	100.0	1.97	1.63	3.0	2.8	94.7	78.0	2.60	2.10	4.6	2.9
Eucalyptus tereticornis	100.0	95.6	2.32	1.98	3.3	2.8	92.3	79.0	3.27	2.15	4.2	3.1
Dalbergia sissco	95.3	97.7	1.17	1.28	2.6	2.5	88.0	89.7	1.97	1.61	3.1	2.6
Pithecellobium dulce	100.0	96.7	1.60	1.38	3.1	2.0	94.7	72.3	1.71	1.59	3.0	2.6
Terminalia arjuna	100.0	100.0	1.11	1.04	3.5	3.1	93.3	92.7	1.53	1.49	3.6	3.5
Kigelia pinnata	100.0	100.0	0.98	0.91	4.3	3.6	95.3	89.3	0.98	0.91	4.5	3.7
Cordia rothii	100.0	98.6	0.79	0.73	2.8	2.7	86.3	78.0	0.90	0.86	3.2	2.9
Parkinsonia aculeata	100.0	95.0	1.83	1.82	2.6	2.1	91.3	83.3	2.27	1.83	2.9	2.3
Anthocephalus cadamba	92.1	90.3	0.65	0.58	2.2	2.1	87.0	78.0	0.69	0.61	2.4	2.3
Acacia leucophloea	64.0	47.3	1.60	1.49	1.9	1.6	61.0	46.0	1.96	1.59	2.0	1.9
Tamarindus indica	100.0	97.3	1.28	1.27	1.9	1.5	76.0	69.3	1.30	1.27	2.5	1.9
Casuarina equisetifolia	100.0	98.9	1.76	1.59	2.8	2.3	29.6	13.3	1.81	1.62	2.9	2.0
Pongamia pinnata	98.6	90.6	0.88	0.84	2.1	1.9	55.0	43.0	1.09	1.04	2.2	2.0
Albizia lebbeck	97.7	86.1	1.23	1.12	2.2	1.9	51.0	38.3	1.83	1.57	2.9	2.1
Cassia siamea	94.8	98.3	1.07	1.05	2.6	2.3	63.3	61.7	1.07	1.05	1.9	1.3
Butea monosperma	70.8	64.0	0.63	0.61	1.7	1.5	59.0	55.7	0.77	0.63	1.8	1.6
Leucaena leucocephala	52.2	57.5	1.63	1.43	2.1	1.9	22.7	16.0	1.73	1.51	2.3	2.0
Bombax ceiba	22.3	24.7	0.88	0.70	2.4	1.9	7.8	5.3	0.97	0.83	2.7	2.2
Bambusa arundinacea	87.8	85.5	0.87	0.82	0.6	0.2	14.0	6.7	0.89	0.83	2.1	1.7
Sesbania sesban	85.8	93.3	0.99	0.97	3.4	3.6	5.6	2.8	1.80	1.71	3.7	3.6
Acacia auriculaeformis	83.9	78.6	1.23	1.26	1.7	1.6	0.9	0.0	1.28	–	1.9	–
Melia azedarach	77.8	51.1	0.96	0.77	2.9	2.4	3.7	0.0	2.43	–	3.1	–
Azadirachta indica	67.2	65.5	1.04	1.00	2.8	2.8	47.7	46.0	1.21	1.11	2.9	2.8
Ficus virens	55.1	53.9	0.63	0.54	1.9	1.7	5.7	3.3	0.67	0.57	2.0	1.8
Moringa oleifera	40.0	33.3	1.53	0.95	3.2	1.8	12.7	5.3	1.56	1.10	3.3	1.9
Tectona grandis	13.3	13.3	0.36	0.43	1.4	1.3	0.9	0.0	0.83	–	1.6	–
Thespesia populnea	52.0	53.1	0.93	0.77	2.4	2.1	–	–	–	–	–	–
Cedrella serrata	2.8	0.0	0.25	–	0.3	–	0.0	0.0	–	–	–	–
LSD (p<0.05)												
Main (Auger depth)	NS		NS		NS		10.80		0.14		0.64	
Sub (Species)	16.3		0.37		0.59		12.48		0.32		0.62	
Main x Sub (Interaction)	NS		NS		NS		17.64		0.45		0.87	

Table 5. Survival, height and diameter at stump height of forest trees when planted in deep (S) and shallow (S) augerholes on highly alkali soil after 5and 7 years of planting

Species	After 5 years						After 7 years					
	Survival (%)		Height (m)		Diameter (cm)		Survival (%)		Height (m)		Diameter (cm)	
	D	S	D	S	D	S	D	S	D	S	D	S
Prosopis juliflora	98.6	88.8	1.42	1.39	6.8	3.9	97.4	86.0	3.98	2.59	8.3	5.3
Acacia nilotica	94.1	93.6	3.68	2.40	8.3	5.6	81.7	76.7	3.66	2.31	8.6	6.4
Tamarix articulata	89.4	74.4	2.99	2.39	5.2	3.4	89.4	74.4	3.24	2.56	7.3	5.4
Eucalyptus tereticornis	89.9	79.9	3.83	3.04	4.5	4.2	89.9	76.0	4.13	3.41	6.0	5.1
Dalbergia sissoo	87.1	86.3	1.98	1.86	3.5	3.2	86.3	83.5	1.99	1.87	6.1	5.3
Pithecellobium dulce	89.4	74.4	1.65	1.41	3.6	2.9	86.7	69.7	1.70	1.62	5.4	4.2
Terminalia arjuna	92.0	86.6	1.42	1.45	3.9	3.7	92.0	86.6	1.51	1.45	5.1	4.8
Kigelia pinnata	93.3	88.8	1.42	1.09	4.5	3.9	93.3	85.7	1.43	1.10	5.2	5.0
Cordia rothii	78.9	76.2	0.93	0.89	3.5	3.0	78.9	76.2	1.04	0.92	4.0	3.2
Parkinsonia aculeata	80.3	76.7	2.31	1.85	3.1	2.7	80.3	76.7	2.36	1.89	4.1	3.3
Anthocephalus cadamba	77.0	71.0	0.71	0.62	3.6	2.7	71.0	68.0	0.72	0.68	4.2	3.7
Acacia leucophloea	59.3	45.3	2.10	1.65	2.5	2.3	59.3	45.3	2.24	1.77	4.8	4.7
Tamarindus indica	46.5	34.1	1.30	1.29	2.7	2.3	26.5	15.3	1.30	1.29	4.1	3.6
Casuarina equisetifolia	18.1	11.6	1.91	1.70	3.1	2.6	0	0	0	0	0	0
Pongamia pinnata	38.0	34.3	1.10	1.01	2.3	2.1	0	0	0	0	0	0
Albizia lebbeck	25.1	22.3	1.85	1.61	2.4	2.3	0	0	0	0	0	0
Cassia siamea	13.1	12.3	0.97	0.95	1.9	1.8	0	0	0	0	0	0
Butea monosperma	57.9	37.0	1.08	0.92	2.2	2.0	0	0	0	0	0	0
Leucaena leucocephala	15.0	11.7	1.81	1.62	2.5	2.1	0	0	0	0	0	0
Bombax ceiba	2.8	0.9	1.21	0.91	2.8	2.0	0	0	0	0	0	0
Bambusa arundinacea	10.0	3.7	0.91	0.85	2.3	1.9	0	0	0	0	0	0
LSD ($p \leq 0.05$)												
Main (Auger depth)	10.99		0.17		1.25		9.43		0.48		0.36	
Sub (Species)	16.51		0.39		20.9		14.22		0.46		1.11	
Main x Sub (Interaction)	23.35		0.55		2.95		20.11		0.65		NS	
NS=Not significant												

In a separate trial, 15 more species were planted in deep auger holes to supplement the list of above tree species. After 2 years of plantation, it was found that 9 species namely, *Acacia senegal, Pterospermum acerifolium, Hardwickia binata, Lagerstroemia speciosa, Populus deltoides, Bauhinia variegata, Cedrella toona, Samanea saman* and *Sterculia* spp. were sensitive to sodicity and could not survive on high pH soil. *Albizia procera* and *Morus alba* were also not found suitable showing only about 20% survival. *Acacia tortilis, Prosopis cineraria, Colospermum mopane* and *Grevillea robusta* showed 80-100% survival.

As *Prosopis juliflora* showed nice performance on highly sodic soils, a separate trial was conducted at the same site by planting 15 strains of 10 species of *Prosopis* (Fig. 4) by raising 8 months old saplings in deep augerholes with the same amendment mixture as described above. These strains except *P. cineraria* and *P. juliflora* were introduced from the Center for Semiarid Forest Resource, Texas, A&M, Kingsville (USA) and Henry Double Day Research Association (UK). Three replications each of 20 plants of each strain were planted. The row-to-row and plant-to-plant distance was



The numbers 1 to 15 depict as :

1. Prosopis velutina 0943
2. P. velutina 0464
3. P. juliflora 197
3. P. chilensis
4. P. juliflora CSR
6. P. velutina 0454
7. P. glandulosa 0933
8. P. alba 0465
9. P. glandulosa 0475
10. P. lavigata
11. P. alba 0751
12. P. alba 0759
13. P. caldenia
14. P. nigra
15. P. cineraria

Table 6. Growth performance of different *Prosopis* strains after 1 & 6 years of plantation in a highly sodic soil

Species/Strains	Survival (%)		Height (m)		DSH (cm)	
	1 year	6 years	1 year	6 years	1 year	6 years
P. velutina 0943	100	96	1.94	3.23	1.84	5.4
P. velutina 0464	100	94	1.76	2.94	1.92	5.0
P. velutina 0454	100	94	1.60	2.90	1.44	5.3
P. juliflora 197	100	100	1.59	3.65	2.02	5.7
P. juliflora CSR	100	100	1.78	3.81	2.08	5.8
P. chilensis	100	98	1.30	2.50	1.78	5.0
P. alba 0465	100	92	1.62	2.84	1.96	5.0
P. alba 0751	100	94	1.83	3.45	2.01	6.0
P. alba 0759	100	96	1.79	3.42	1.98	5.0
P. glandulosa 0475	100	94	1.59	2.93	1.67	5.3
P. glandulosa 0933	100	92	1.57	3.15	2.10	6.0
P. lavigata	100	96	1.68	3.47	2.12	5.3
P. caldenia	100	90	1.52	2.55	1.72	7.2
P. nigra	100	82	1.53	2.13	1.68	5.0
P. cineraria	100	96	0.67	1.85	1.32	5.0
LSD ($p \leq 0.05$)	NS	7	0.24	0.73	0.28	NS

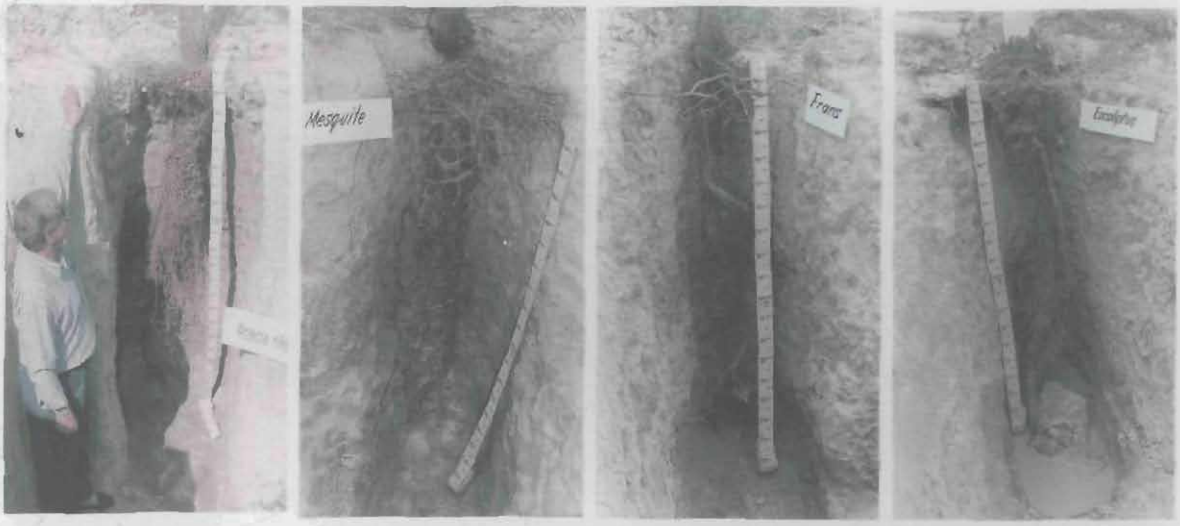
P. tamarugo was also tried but did not survive at all. NS = not significant, DSH = diameter at stump height

Prosopis alba-*a potential thornless species for sodic lands*

4 m and 3 m, respectively. Results of the trial (Table 6) showed that all tested strains of *Prosopis* were tolerant to sodicity. Among these *P. alba* is thorn-less but the growth performance in terms of height and diameter, *P. juliflora* was superior to that of all other species and strains. The differences, however, in trunk diameters were statistically not significant.

3.3 Root Systems

The roots were exposed for evaluation at two stages of growth, i.e. when the plants were two and seven years old. At the two years old stage, when the roots were still confined to auger holes, the root length was greater in deep augerholes than those in shallow augerholes. Total shoot biomass, as well as root biomass, was also higher in deep auger holes indicating an increased plant development. At initial stage the shoot : root ratio was almost one, but with time this ratio increased abruptly indicating that root development in the alkali soil was impeded. When the root development of various species was compared (after 7 years of growth) in terms of root biomass and length the tree species such as *T. articulata, P. juliflora*



Root systems of Acacia nilotica *(restricted in augerholes),* Prosopis juliflora, Tamarix articulata *and* Eucalyptus tereticornis *piercing the kankar pan of sodic soil*

and *A. nilotica* showed a better performance than the others (Table 7). For other species most of the roots remained in augerholes, however, in *T. articulata* roots penetrated even horizontally piercing the hard *kankar* pan. *P. juliflora* and *A. nilotica* also experienced set back due to frost but *T. articulata* did not show any affect of frost.

3.4 Biomass Production

When the total biomass (shoot + root) was compared, it was found that even at 2 years old stage, the maximum biomass was obtained by *T. articulata*, followed by *Eucalyptus tereticornis, P. juliflora, Pithecellobium dulce, Parkinsonia aculeata* and *Kigelia pinnata* in both deep and shallow augerholes. The pruned biomass in these species varied from 2.64 to 73.31 kg ha^{-1} in deep augerholes and 1.47 to 31.75 kg ha^{-1} in shallow augerholes (Table 7). At seven years old plantation total aerial biomass was estimated highest in *Tamarix articulata* followed by *A. nilotica, P. juliflora* and *E. tereticornis* (Table 8, 9).

On the sight having shallow augerholes, the presence of *kankar* pan prohibited the development of root system thereby affecting the growth of plants. Therefore, the biomass was significantly lower.

3.5 Soil Amelioration

Changes in soil properties (Table 10) showed that *T. articulata* ameliorated the soil by inducing the maximum reduction of ESP and pH values in seven years. It was followed by *P. juliflora* and *A. nilotica*. The organic carbon content in 0-15 cm layer under *T. ariticulata* increased from 0.05 to 0.28%, under *P. juliflora* from 0.04 to 0.30% and under *Acacia nilotica* from 0.02 to 0.14 percent in 7 years. In lower depths, however, the increase was comparatively low. Reduction in ESP was 50,

Table 7. Shoot and root biomass production after 2 years of plantation when grown in deep and shallow augers

Species	Biomass (g/plant) after 2 years of growth						Pruned biomass	
	Shoot		Root		Shoot/Root ratio		(kg ha^{-1})	
	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow
Prosopis juliflora	408	140	454	154	0.90	0.91	36.88	31.75
Acacia nilotica	74	66	96	88	0.77	0.75	70.54	12.46
Tamarix articulata	2485	2100	3025+	2500+	0.82	0.84	73.31	15.74
Eucalyptus tereticornis	815	630	645	595	1.26	1.06	3.76	2.62
Dalbergia sissco	47	45	76	60	0.62	0.75	5.84	5.76
Pithecellobium dulce	358	354	148	144	2.42	2.46	11.39	5.50
Terminalia arjuna	50	46	64	56	0.78	0.82	6.94	5.60
Kigelia pinnata	262	254	234	216	1.12	1.18	2.64	1.47
Cordia rothii	172	136	290	148	0.59	0.92	2.54	0.32
Parkinsonia aculeata	286	130	174	108	1.64	1.20	5.47	4.99
Anthocephalus cadamba	132	56	150	104	0.88	0.54	2.01	0.78
Acacia leucophloea	64	48	59	56	1.08	0.86	2.24	1.50
Casuarina equisetifolia	88	68	148	138	0.59	0.49	11.44	6.40
Tamarindus indica	54	42	70	50	0.77	0.84	3.26	1.57
Pongamia pinnata	52	34	64	50	0.81	0.68	2.16	0.78
Albizia lebbeck	57	54	62	60	0.92	0.90	0.75	0.72
Cassia siamea	56	34	100	84	0.56	0.40	5.31	3.92
Sesbania sesban	232	48	134	58	1.73	0.83	7.58	10.99
Acacia aurieculaeformis	36	34	43	40	0.84	0.85	3.07	2.46
Melia azedarach	18	14	16	12	1.13	1.17	3.82	0.91
Butea monosperma	36	16	166	160	0.22	0.10	0.84	0.78
Azadirachta indica	26	22	25	23	1.04	0.96	2.16	2.26
Ficus virens	17	16	32	30	0.53	0.53	0.83	0.75
Leucaena leucocephala	94	20	80	54	1.18	0.37	1.74	1.01
Thespesia populnea	48	20	56	30	0.86	0.67	1.92	1.36
Moringa oleifera	206	44	208	98	0.99	0.45	0.19	0.03
Tectona grandis	46	34	38	30	1.21	1.13	0.24	0.01
Bombax ceiba	56	36	156	90	0.36	0.40	0.08	0.01
Bambusa arundinacea	38	32	65	58	0.58	0.55	0.40	0.24
Cedrella serrata	0	0	0	0	0	0	0	0
LSD ($p \leq 0.05$)								
Main plot (auger depth)	55.3		15.26		0.03		–	
Sub plot (species)	148.03		52.81		0.23		–	
Interaction (main x sub)	NS		74.68		0.16		–	

+ Complete root could not be excavated.

Table 8. Shoot and root biomass production by forest tree species grown in two augerhole depths on highly alkali soil at seven years of growth

Species	Biomass (kg/plant)						Root length (m)	
	Shoot		Root		Shoot/Root ratio			
	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow
Prosopis juliflora	42.11	20.52	13.17	5.92	3.20	3.47	2.31	1.26
Acacia nilotica	68.33	40.77	14.92	6.69	4.58	6.09	2.54	1.39
Tamarix articulata	107.10	34.10	32.00	11.30	2.72	3.02	7.15+	5.15+
Eucalyptus tereticornis	13.33	5.47	5.81	1.88	2.29	2.91	2.16	1.85
Dalbergia sissoo	1.62	1.35	0.69	0.56	2.35	2.42	1.36	0.65
Pithecellobium dulce	3.65	2.46	3.21	2.08	1.13	1.18	2.66	2.05
Terminalia arjuna	2.33	1.63	1.31	1.06	1.78	1.54	2.71	1.06
Kigelia pinnata	1.00	0.46	1.423	0.69	0.70	0.67	1.46	1.32
Cordia rothii	1.5	0.65	1.81	0.73	0.83	0.89	1.66	0.86
Parkinsonia aculeata	1.15	0.94	0.82	0.52	1.40	1.81	2.08	1.85
LSD ($p \leq 0.05$)								
Main plot (auger depth)	2.48		1.44		NS		0.17	
Sub plot (species)	6.99		2.48		0.66		0.23	
Interaction (main x sub)	9.88		3.51		0.94		0.32	

+ Complete root could not be extracted. NS = not significant

Table 9. Average air-dried aerial biomass of different tree species estimated after 7 years of growth on highly alkali soil

Species	Biomass (t ha^{-1})	
	Deep augerholes	Shallow augerholes
Tamarix articulata	97.33	31.71
Acacia nilotica	69.78	39.09
Prosopis juliflora	51.27	22.06
Eucalyptus tereticornis	14.38	5.20
Pithecellobium dulce	3.96	2.14
Terminalia arjuna	2.68	1.76
Dalbergia sissoo	1.75	1.18
Cordia rothii	1.48	0.62
Kigelia pinnata	1.17	0.49
Parkinsonia aculeata	1.15	0.90

LSD ($p \leq 0.05$) : Between species = 5.94, Between auger depths = 1.17, Auger depth x species = 3.70

Table 10. Change in soil properties under three most successful forest tree species after 7 years of plantation

Species	pH (1:2)				EC_2 (dS m^{-1})				Organic C (%)				ESP			
	A		B		A		B		A		B		A		B	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Prosopis juliflora	10.4	10.5	9.7	10.1	3.15	1.20	0.67	1.02	0.04	0.02	0.30	0.14	87	93	54	69
Acacia nilotica	10.5	10.6	10.1	10.3	3.20	135	0.88	1.23	0.04	0.02	0.14	0.08	91	93	71	79
Tamarix articulata	10.4	10.5	9.2	9.9	3.05	1.13	0.36	0.50	0.05	003	0.28	0.09	85	92	35	62
LSD ($p \leq 0.05$)	NS	NS	0.35	0.13	NS	NS	0.32	0.16	NS	NS	0.14	NS	NS	NS	4.71	NS

A = Initial , B = After 7 Years
ESP = Exchangeable sodium percentage
NS = not significant
1 = soil depth from 0 to 15 cm
2 = soil depth from 15 to 30 cm.

33 and 20 in respective species in 15 cm layer while in lower depths it was 30, 24 and 14, respectively. Due to poor cover, other species did not contribute much in soil amelioration, therefore, these have not been reported.

From these results an inference can be drawn that highly alkali soils (pH >10) may be successfully rehabilitated with *T. articulata*, *P. juliflora* and *A. nilotica* for economic fuelwood production, forage production (from local grasses, at least for initial 3 years) and soil amelioration. Among *Prosopis* species / strains *P. juliflora* is most superior for biomass production, however, the thornless *P. alba*, *P. lavigata*, and *P. velutina* are also among promising tolerant species to sodicity.

GROWING FRUIT TREES

4.1 Standardization of Site Preparation Methods and Amendment Use

One experiment on about 2 ha sodic land was designed to evaluate the response of different fruit tree species to site preparation methods and amendments. The three times replicated experiment in double split design (Fig. 5) was initiated in August, 1992. Initially, saplings of the following ten fruit tree species were planted:

Species	English name	Vernacular name
Achras zapota	Sapota	Cheeku
Aegle marmelos	Bael-tree	Bel-pather
Carissa carandus	Karaunda	Karaunda, karonda
Emblica officinalis	Gooseberry	Amla, Aonla, anwla
Phoenix dactylifera	Date palm	Khajur
Psidium guajava	Guava	Amrud,amrood
Punica granatum	Pomegranate	Anar
Syzygium cuminii	Black/Java-plum	Jamun
Tamarindus indica	Tamarind	Imli
Ziziphus mauritiana	Jujube	Ber
Morus alba	Mulberry	Shatoot

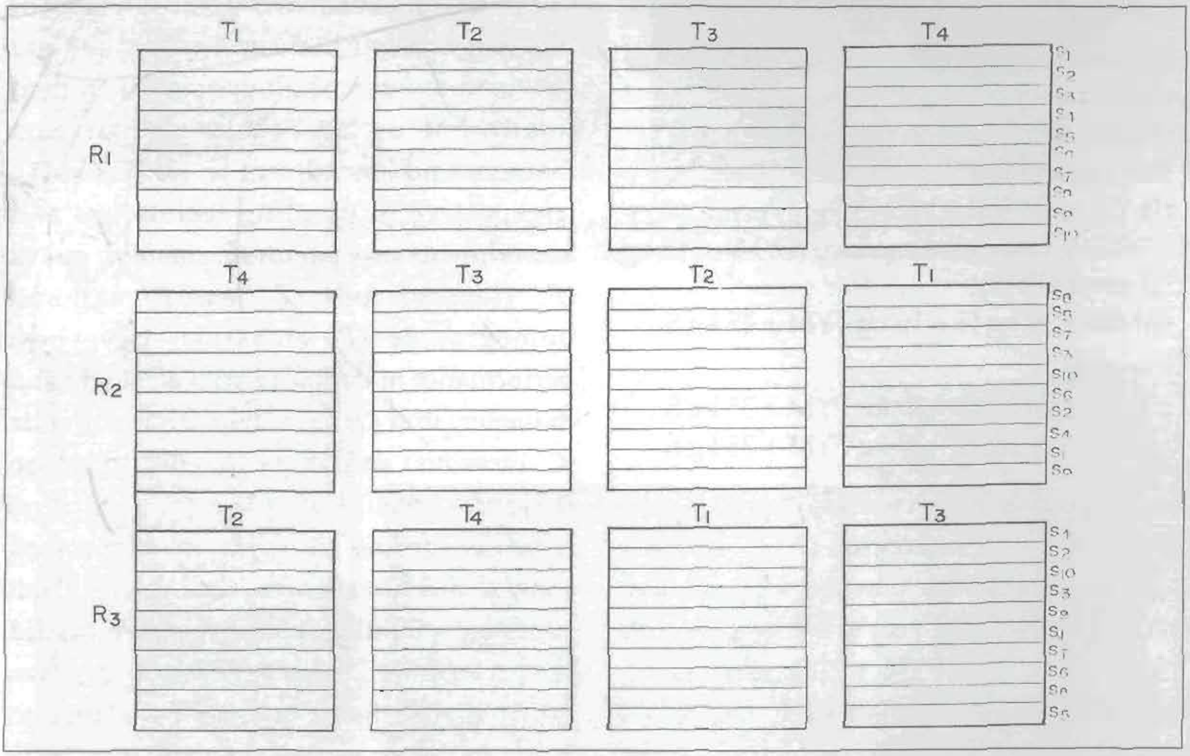


Fig. 4. Layout of experiment with ten fruit tree species planted with two methods of planting using different doses of amendments. T_1 to T_4 depict: T_1 = 5 kg gypsum (G) + 10 kg farm yard manure (FYM) per augerhole, T_2 = 10 kg G + 10 kg FYM per augerhole, T_3 = 20 kg G + 20 kg FYM per pit, T_4 = 20 kg G + 20 kg FYM per pit.

$S_1 - S_{10}$ depict species of fruit trees: **S_1 = Psidium guajava, S_2 = Syzygium cuminii, S_3 = Carissa carandus, S_4 = Emblica officinalis, S_5 = Zizyphus mauritiana, S_6 = Tamarindus indica, S_7 = Phoenix dactylifera, S_8 = Punica granatum, S_9 = Aegle marmelos, S_{10} = Achras zapota/Morus alba.**

After planting, four irrigations were applied with bucket and subsequently rings of 1 m diameter were connected with channels to facilitate channel irrigation. During initial 3 years, 8-12 number of irrigations every year each consisting of 6 cm water depth were applied. Thereafter about 5 irrigations each of 6 cm water depth were applied (usually 3 in summer and 2 in winter).

Site preparation methods – main plot

Pit-cum augerhole method: After making 45 cm x 45 cm x 45 cm pits manually and then piercing 1.6 to 1.8 m deep augerholes of 25 cm diameter with tractor mounted auger were made.

Pit method: Pits of 0.9 m x 0.9 m x 0.9 m were dug manually.

Filling mixture composition – sub plot

For augerholes:

(i) Original soil (OS) + 5 kg gypsum (G) + 10 kg farm yard manure (FYM) + 15 kg river silt (S)

(ii) OS + 10 kg G + 10 kg FYM + 15 kg S

For pits:

(i) OS + 10 kg G + 20 kg FYM + 35 kg S

(ii) OS + 20 kg G + 20 kg FYM + 35 kg S

Each augerhole and pit was also supplied with 20 g $ZnSO_4$ and insecticide (20 g hydrated benzene hexachloride powder) for protection from termites. Every year in February-March, a mixture of 8 kg FYM + 50 g urea + 20 g superphosphate + 20 g insecticide was applied to mitigate the adverse effect of high RSC water and to boost growth.

Sub-subplot: Ten fruit tree species were planted having 12 trees of each species in two rows. Row-to-row and plant-to-plant distance was 4 m and 3 m, respectively. Survival percentage, height and stump diameter were measured at six-months interval. For root studies three soil monoliths one from each treatment were excavated and cleaned with fine water-jet, when the plantations were of 5 years old.

4.2 Growth Performance

There was a perception that most of the fruit trees are sensitive to salt-stress, hence, limited efforts were made in the past to cultivate the fruit species in highly alkali soil. Therefore, to standardize the planting techniques and amendment dose to be used, these experiments were conducted. Growth observations recorded after 2 years of planting showed that survival, height and stump diameter of all species remained unaffected owing to site preparation methods and amendment levels (Table 11). Irrespective of planting techniques and amendments use, jamun (*S. cuminii*), guava (*P. guajava*), ber (*Z. mauritiana*) and pomegranate (*P. granatum*) gave best performance in terms of survival, height and diameter. Imli (*Tamarindus indica*), karonda (*C. carandus*) and aonla (*E. officinalis*) also performed well. Date plam (*P. dactylifera*) which is considered highly tolerant to soil salinity did not perform well under alkali conditions. Similarly, bael (*A. marmelos*) did not perform well. Sapota (*Achrus zapota*) was growing well, but found to be sensitive to frost. Pomegranate was doing exceptionally well, could not withstand prolonged water stagnation (45 days) caused by flood water from adjoining areas. There was mortality in other fruit trees also due to prolonged water stagnation (Table 12).

Performance of five years old fruit trees of (a) guava, (b) ber, and (c) jamun on highly sodic soil. Tamarind (d) recovering from frost damage

Five years old fruit trees of (a) anola, (b) date palm and (c) karaunda showing bearings.

Table 11. Effect of site preparation techniques and amendments on fruit species after 2 years of planting

Fruit species	Site preparation techniques											
	Augerhole						Pit					
	5 kg gypsum			10 kg gypsum			10 kg gypsum			20 kg gypsum		
	Survival (%)	Height (cm)	DSH (cm)	Survival (%)	Height (cm)	DSH (cm)	Survival (%)	Height (cm)	DSH (cm)	Survival (%)	Height (cm)	DSH (cm)
Amla	82	187	4.3	86	182	3.4	86	185	3.6	87	198	4.2
Sapota	98	74	1.7	89	68	1.4	92	82	1.8	87	73	1.9
Imli	100	190	4.6	100	174	4.2	100	167	4.1	100	195	4.0
Ber	96	224	3.4	96	210	3.2	100	230	4.0	100	242	4.2
Datepalm	75	82	—	70	62	—	70	85	—	68	91	—
Karaunda	86	112	2.4	98	157	1.8	100	175	2.1	96	92	2.2
Jamun	100	163	4.7	100	61	4.6	60	60	5.6	100	187	5.4
Bael	56	64	1.1	52	61	1.1	60	60	0.9	58	72	2.1
Pomegranate	92	133	2.7	94	142	3.0	92	134	2.5	100	184	3.0
Guava	100	154	4.0	100	163	4.1	100	177	4.8	100	200	5.5
Mean	88.5	138.3	3.2	88.5	131.1	3.0	89.6	139	3.3	89.6	153.6	3.8

LSD (p ≤ 0.05)	Survival (%)	Height (cm)	DSH (cm)
i) Between plating techniques (A)	NS	3.7	NS
ii) Between amendment doses (B)	NS	NS	NS
iii) Between tree species (C)	8.6	9.8	0.6
iv) A x B	NS	NS	0.8
v) A x C	NS	NS	NS
vi) B x C	NS	NS	NS
vii) A x B x C	NS	NS	NS

This shows that at least half a dozen of fruit species show the tolerance to stagnation of water and may be planted in alkali soils. The frost during early weeks of January also damaged the fruit trees. The most sensitive to frost was sapota showing mortality of all the plants. Some of the fruit trees such as tamarind, pomegranate, karonda and aonla also had the capacity of recovery (Table 13).

After 2 years of plantation, *Aegle marmelos, Achras zapota* and *Punica granatum* met serious set-back. Others recovered the shock at least from frost. The damaged seedlings in these were re-planted. Sapota (*A. zapota*) was replaced by mulberry (*Morus alba*). Jamun (*S. cuminii*) did not experience any mortality due to water stagnation and flooding.

Table 12. Effect of prolonged water stagnation on fruit trees recorded during October of 1994 and 1995

Fruit trees	Plant mortality (%) during	
	1994	1995
P. granatum (Pomegranate)	25	75
A. zapota (Sapota)	10	already died due to frost
T. indica (Imli)	2	0
C. carandus (Karaunda)	12	22
Z. mauritiana (Ber)	6	0
P. dactylifera (Date palm)	12	6
S. cuminii (Jamun)	0	0
P. guajava (Guava)	9	9
A. marmelos (Bael)	50	42
E. officinalis (Aonla)	16	12

Table 13. Relative tolerance of fruit species to frost

Fruit species	Plants damaged (%)	Plants recovered (%)
P. granatum	94	90
A. zapota	100	4
T. indica	92	92
C. carandus	100	88
Z. mauritiana	6	6
P. dactylifera	0	0
S. cuminii	72	72
P. guajava	78	76
A. marmelos	all died due to flood	0
E. officinalis	92	84

Pomegranate had a set-back due to prolonged water stagnation during rainy season. The surviving plants came to bearing in 1997 (above: general view, below: close up view)

General view of fruits evaluation trial after four years of planting (above: just before frost, below: onset of frost)

In some species like *Carissa carandus* the flowering and fruiting were initiated just after 16 months of planting. Pomegranate came to bearing after 20 months of planting and fruits appeared on all the plants. The number varied from 15 to 25 (each weighting between 89-150 grams). Fruits in size and weight were better in those plants which were grown in pits than in augerholes. Due to floods caused by heavy rains, all mature fruits were damaged. Owing to water stagnation stress, no fruit-setting was observed in following winter. During following summer again fruit-setting began but due to subsequent flood during rainy season, almost all the plants died. *Emblica officinalis,* though initiated bearing after 3 years but profuse bearing started only after 5 years of growth. *Ziziphus mauritiana* got set-back in bearing due to floods during initial two years, thereafter, fruits were produced regularly. Every year, the branch tops of *Tamarindus indica* died due to frost in winter and no fruit setting was observed. In guava, plants initiated bearing after 2 years of planting but to promote vegetative growth these were removed. The complete bearing started in fifth year when almost all trees produced fruits. Date palm initiated flowering at the age of three years but all plants initiated flowering only after 5 years of growth. No flowering was observed upto 7 years of growth in *S. cuminii.*

After 7 years of growth, ber, jamun, karonda and guava showed best growth performance in terms of survival, height and girth and all started bearing fruits. Aonla showed 76% survival in augerholes and 84% in pits and started bearing fruits in large numbers. Dateplam initiated flowering. Tamarind had almost complete survival, but every year due to frost, the tips of branches died back upto 0.2 to 0.4 m. The following season these branches recovered, but the plant appeared not suitable for semiarid regions that experience frost. In general, the survival rates and growth performance (height and girth) were better in sites established with the pit method than the augerhole method. When the dose of gypsum amendment was increased, positive plant response increased but statistically the effect of amendment dose was not significant on survival and height of plants. The diameter at stump height was significantly higher in sites established by the pit method in general and particularly when the dose of gypsum was higher (Table 14).

Although most of the successful species started bearing fruits no data on fruit production could be taken as the farm was handed over to the forest department as per lease agreement. The results on average biomass production showed that total biomass was higher in pits and increased with application of increased dose of gypsum amendment (Table 15).

The maximum biomass was observed for *Phoenix dacylifera* followed by *E. officinalis* and *S. cuminii* in pits. The root penetration in augerholes was deeper and the percent biomass in deeper layers (1.2 to 2.1 m) was greater than that in pits. In pits, the maximum root biomass occurred between 0.6-0.9 m and 0.9-1.2 m depths (Table 16). In upper layers, the root biomass in pits was higher than in augerholes because in augerholes, generally, the roots were distributed in limited space,

Table 14. Effect of site preparation techniques and amendments on performance of fruit species after 7 years of growth on a highly sodic soil

Species	Site preparation techniques											
	Augerhole						Pit					
	5 kg gypsum			10 kg gypsum			10 kg gypsum			20 kg gypsum		
	Survival (%)	Height (cm)	DSH (cm)	Survival (%)	Height (cm)	DSH (cm)	Survival (%)	Height (cm)	DSH (cm)	Survival (%)	Height (cm)	DSH (cm)
Syzygium cuminii	100	2.76	9.8	100	2.90	10.7	98	3.17	11.7	100	3.98	12.6
Ziziphus mauritiana	96	3.38	5.9	96	3.46	6.2	98	3.52	7.1	100	3.70	7.4
Psidium guajava	100	2.70	8.5	98	2.72	8.7	100	3.20	10.1	98	3.52	10.7
Emblica officinalis	68	3.23	7.7	84	3.51	8.3	86	3.58	8.5	88	3.70	9.3
Carissa carandus	78	1.16	5.6	78	1.58	5.5	86	1.71	5.4	88	1.72	5.6
Tamarindus indica	98	2.73	6.7	98	2.82	6.7	98	2.79	6.9	100	2.90	7.1
Phoenix dactylifera	34	1.77	12.1	34	1.85	12.8	36	2.13	13.4	38	2.51	15.7
*Morus alba**	82	1.86	3.8	82	1.95	4.6	86	2.10	4.7	88	2.4	4.8

LSD ($p \leq 0.05$)	Survival (%)	Height (m)	DSH (cm)
i) Between planting techniques (A)	2.94	0.35	1.05
ii) Between amendment doses (B)	NS	NS	0.56
iii) Between species (C)	5.57	0.28	0.81
iv) Interactions AxB	NS	NS	NS
v) Interactions AxC	NS	NS	1.15
vi) Interactions BxC	NS	NS	1.15
vii) Interactions AxBxC	NS	NS	NS

*Replaced *Achras zapota* after 2 years and observations are for 5 years old plantation. DSH = diameter at stump height, NS = not significant

while in pits these occupied the space extensively in all directions. Moreover, the surface layers of soil have better fertility status than the sub-surface deeper layers.

4.3 Planting Cost

The major expenditure in raising the fruit trees was the site preparation. This involved land development, pit and augerhole digging, preparation of the filling mixture, and refilling the pits and augerholes. Planting cost per hectare using the pit method was almost double that of pit-cum-augerhole method (Table 17). For pit planting method, the major expenditure (about 34.5%of total) was incurred during the pit-digging operation. Due to the presence of thick and cemented $CaCO_3$ layers in the profile, one person could hardly excavate two pits a day, whereas all the augerholes were made within two days by using tractor-mounted mechanical augers. In addition, the volume of soil mixture to be prepared and the time spended refilling the pits was much more than that for augerholes, with the result that labour cost of the pit method was almost four-times higher than that of the augerhole method. The cost of plantation of forest tree species with augerhole method was slightly less as compared to the pit-cum-augerhole method in fruit tree establishment as no pits were dug.

for augerholes in forest tree plantations. Although the number of plants per hectare was greater for the forest species, the cost on inputs and plant material (the seedlings) was lower as compared to fruit tree species.

We may conclude that in highly sodic soils of semiarid regions the forest tree species (as identified earlier) can be raised successfully using the augerhole planting technique that pierces the *kankar* pan in upper 2 m soil layer. For increased economic returns, fruit tree species such as guava, ber, aonla, jamun and karonda may be raised successfully by using pit-cum-augerhole planting technique coupled with higher doses of amendments and fertilizers. The pit method (0.90 m x 0.90 m x 0.90 m) may be better suited in areas where sodic soil profiles have moderate intensities of *kankar* pan. Though the growth performance in pits of 90 cm x 90 cm x 90 cm size was slightly better, the cost of pit-method is almost double compared to the pit-augerhole method. The drainage system in field should be proper so that no water stagnation occurs. The frost sensitive species should be avoided in frost-prone area.

Table 15. Average biomass (kg per tree) of 7 years old fruit trees when grown by augerhole and pit methods using different doses of amendments in sodic soil

Species	Augerhole (5 kg gypsum)				Augerhole (10 kg gypsum)				Pits (10 kg gypsum)				Pits (20 kg gypsum)			
	Stump	Twigs	Roots	Total	Stump	Twigs	Roots	Total	Stump	Twigs	Roots	Total	Stump	Twigs	Roots	Total
Aonla	5.000	5.350	3.500	13.850	8.100	2.650	3.620	14.420	5.610	4.900	4.340	14.850	15.200	5.400	4.500	25.150
Guava	2.350	2.410	2.200	6.960	3.510	2.410	2.350	8.270	4.00	2.350	2.170	8.720	6.500	3.200	2.840	12.540
Jamun	5.400	4.250	2.500	12.150	6.300	4.830	2.800	13.930	7.200	4.900	3.400	15.500	10.750	7.400	4.100	22.250
Ber	4.600	5.200	2.560	12.360	4.750	6.750	3.800	15.300	5.120	7.550	4.150	16.820	5.450	8.800	4.500	18.750
Karaunda	0.875	2.150	0.870	3.895	1.100	2.875	1.430	5.405	1.650	3.475	1.750	6.875	1. 780	4.680	2.400	8.860
Imli	3.650	3.710	3.525	10.885	3.510	3.815	3.670	10.995	3.820	4.050	3.510	11.3 80	4.120	4.650	4.250	13.030
Date palm	3.200	1.250	3.510	18.960	2.815	12.500	3.750	19.065	3.510	15.250	4.800	23.560	3.650	17.875	5.200	26.725
Mulberry	1.500	0.850	2.150	4.500	1. 770	1.525	2.500	5.795	1.850	2.150	2.510	6.510	2.100	2.865	3.120	8.085

LSD ($p \leq 0.05$)

	Stump weight	Twigs weight	Root weight	Total weight
i) Between planting techniques (A)	0.291	0.338	0.257	0.561
ii) Between amendment doses (B)	0.440	0.324	0.179	0.456
iii) Between species (C)	0.223	0.320	0.318	0.719
iv) Interactions A x B	0.063	0.458	NS	0.645
v) Interactions A x C	0.314	0.452	0.450	1.017
vi) Interactions B x C	0.314	0.452	NS	1.017
vii) Interactions A x B x C	0.445	0.639	NS	1.438

Table 16. Percent of total root biomass distributed at different depths in soil in 5 years old fruit species

Species	0-30 cm		30-60 cm		60-90 cm		90-120 cm		120-150 cm		150-180 cm		180-210 cm		210-240 cm	
	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P
Ziziphus mauritiana	0.8	2.8	2.2	9.5	2.3	26.1	4.3	32.9	5.5	20.2	21.7	8.5	30.1	0	33.1	0
Syzygium cuminii	0.7	1.3	2.2	2.6	5.6	34.1	13.4	62.0	24.9	0	53.2	0	0	0	0	0
Phoenix dactylifera	0.8	3.1	1.1	14.3	3.2	60.8	15.8	21.8	79.1	0	0	0	0	0	0	0
Psidium guajava	1.7	2.5	2.6	12.7	2.8	41.0	4.0	31.9	6.0	11.9	36.1	0	49.6	0	0	0
Emblica officinalis	0.5	1.3	1.8	7.1	2.6	31.4	3.5	45.8	4.9	14.4	15.1	0	71.6	0	0	0
Tamarindus indica	0.6	3.9	0.9	13.6	1.1	33.3	2.1	26.4	6.8	15.6	13.4	7.2	22.7	0	52.4	0
Carissa carandus	2.9	1.3	3.3	8.5	4.6	90.2	7.5	0	18.5	0	63.2	0	0	0	0	0

A = augerhole, P = pit

Table 17. Tentative planting cost (Rupees per ha) for raising forest and fruit tree plantations by augerhole and pit methods (based on 1992 prices)

Sr. No.	Item of expenditure	Forest tree plantation by augerholes method (1250 trees ha^{-1})	Fruit trees (833 trees ha^{-1}) Pit method	Fruit trees (833 trees ha^{-1}) Pit-cum-augerhole method
1.	Land development			
	Removing bushes, cultivation/ ploughing, levelling, bunding	2500	2500	2500
2.	Marking pits/augerhole sites	150	100	100
3.	Making pits/auger holes			
	(i) Augers 1.8 m deep @ Rs. 2 per auger	2500		
	(ii) Pit size 0.9 m x 0.9 m x 0.9 m @ 2 pits/person/day		14560	
	(iii) Augers 1.8 m deep after making pits of 0.45m x 0.45m x 0.45m @ Rs.4/augerhole			3332
4.	Preparation of filling mixture and its refilling			
	(i) Pits @ one person/4 pits/day		7280	
	(ii) Augerholes @ one person/15 augerholes	2905		1925
5.	Purchase of inputs			
	(i) Gypsum @ Rs 600 per ton	2250	5000	2500
	(ii) Farmyard manure @ Rs 50 per ton	500	830	415
	(iii) Silt @ Rs. 80 per ton	–	2320	1000
	(iv) Urea, superphosphate, dermicite etc.	500	400	400
6.	Purchase of saplings			
	(i) @ Rs. 2 per saplings	2500		
	(ii) @ Rs. 8 per fruit saplings		6664	6664
7.	Irrigation			
	Four irrigations with buckets @ one person/208 plants/day	840	560	560
8.	Transportation and other miscellaneous charges	1000	2000	1000
	Total expenditure	**15645**	**42214**	**20396**

IRRIGATION REQUIREMENT OF FOREST TREE SPECIES

5.1 Establishment with Different Irrigation Schedules

A three times replicated field experiment was conducted in August-September, 1991 with four tree species in the main plot and 8 schedules of irrigation in the sub-plot (Fig. 6) to observe the response of tree species to irrigation and optimize the irrigation requirements in alkali soil. The total area under this experiment was above 2 ha. Six months old saplings were planted in augerholes of 20-25 cm diameter and 1.2 to 1.4 m deep filled with a mixture of original soil + 3 kg gypsum + 8 kg FYM + 20 kg zinc sulphate + aldrax. The saplings of *Acacia nilotica, Prosopis juliflora, Dalbergia sissoo* and *Casuarina equisetifolia* were planted in main plots at a distance of 4 m and 2 m between rows and plants. Each sub-plot accommodated 24 plants. After planting, 3 spot irrigation and 3 more irrigation in channels were applied for initial establishment of saplings. The damaged seedlings by wild animals were replaced during March, 1992. The following differential irrigation treatments were imposed from April, 1992 :

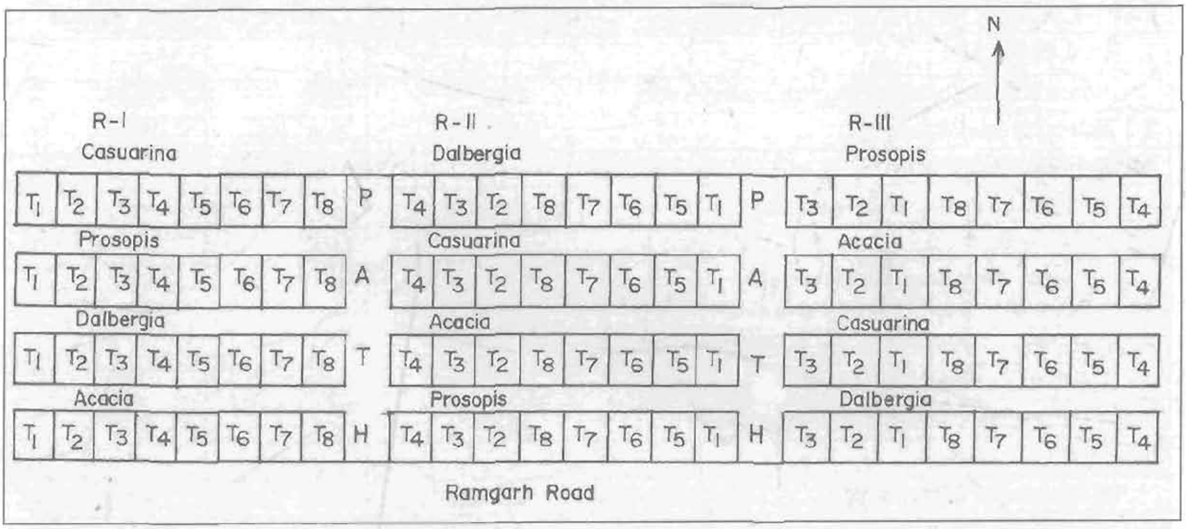


Fig.6. Layout of the experiment to standardize the irrigation requirement for raising forest trees in highly sodic soil. For treatments T_1-T_8 please see text below.

T_1 = Unirrigated after establishment

T_2 = Irrigation upto one year

T_3 = Irrigation upto one year and four irrigation during second year

T_4 = Irrigation upto 2 years

T_5 = Irrigation upto 2 years and 4 irrigations during third year

T_6 = Irrigation upto 3 years and 2 irrigation during fourth year

T_7 = Irrigation upto 4 years

T_8 = Irrigation through out life cycle

Irrigation criteria was:
First year : Diw/CPE = 0.8
Second year Diw/CPE = 0.6
and afterwards 0.4
Where D_{iw} = Depth of irrigation water in mm and CPE = cumulative potential evapotranspiration (mm) of the site

5.2. Survival and Growth Performance

Survival percentage after 16 months of plantation was 90 to 100% in *A. nilotica* and *P. juliflora,* respectively even under unirrigated condition. In *D. sissoo,* it was 80 to 90% under different irrigation treatments and only 60% when the irrigation was stopped. *C. equisetifolia* showed least survival (50-80%) under different irrigations and only 30% when irrigation was stopped. The height and stump diameters were also more under different irrigation treatments as compared to non-irrigated plantations. At 40 months after planting, effect of irrigation schedules was distinct on survival and growth parameters. The survival was highest in *P. juliflora* followed by *A. nilotica, D. sissoo* and least in *C. equisetifolia.* The maximum survival was observed when the plantations were provided with regular irrigation after planting. The growth parameters (height and stump diameter) of all the species also were maximum when regular irrigation was provided (Table 18).

Table 18. Effect of irrigation schedules on survival , height and diameter at stump height after 16 and 40 months of planting of four tree species

Treat-ment	*Acacia nilotica*						*Dalbergia sissoo*						*Prosopis juliflora*						*Casuarina equisetifolia*					
	Plantation age (months)						Plantation age (months)						Plantation age (months)						Plantation age (months)					
	16			40			16			40			16			40			16			40		
	S	H	DSH	S	H	DSH	S	H	DSH	S	H	DSH	S	H	DSH	S	H	DSH	S	H	DSH	S	H	DSH
T_1	90	1.07	1.7	84	1.85	3.2	60	0.86	1.5	44	1.05	2.2	94	1.73	1.9	90	3.33	3.2	30	0.67	1.3	17	1.01	1.9
T_2	100	1.11	1.8	100	2.01	3.0	80	0.93	1.9	72	1.58	2.9	98	1.75	2.0	94	3.74	3.5	50	0.69	1.6	36	1.25	2.5
T_3	96	1.12	2.0	90	2.14	3.5	80	1.03	1.9	74	1.73	3.1	100	1.80	2.1	98	4.03	4.8	52	0.81	1.6	38	1.39	2.6
T_4	98	1.28	2.4	92	2.25	3.9	85	0.95	1.8	80	1.82	3.3	100	2.06	2.4	100	4.07	4.6	60	0.64	1.4	56	1.45	2.2
T_5	100	1.27	2.3	100	2.21	3.8	90	1.07	2.0	80	1.91	3.4	100	2.04	2.3	100	4.09	4.7	80	0.68	1.5	70	1.56	2.5
T_6	98	1.21	2.2	96	2.35	4.0	80	1.06	2.2	74	2.12	3.6	100	1.76	2.0	98	4.15	4.8	75	0.70	1.6	66	1.72	2.3
T_7	100	1.24	2.4	98	2.46	4.6	82	1.07	2.1	82	2.42	3.7	100	1.84	2.3	100	4.35	4.9	70	0.75	1.6	60	1.91	2.6
T_8	100	1.14	2.1	98	2.48	4.8	82	1.00	2.2	79	2.50	4.0	100	1.71	2.2	96	4.40	4.2	80	0.71	1.7	46	1.87	2.3
Mean	98	1.18	2.1	95	2.22	3.85	80	1.00	2.0	73	1.89	3.3	99	1.81	2.2	97	4.02	4.3	62	0.82	1.5	50	1.52	2.4

S = survival (%), H = height (m), DSH = diameter at stump height (cm)

Table 19. Prunned biomass t ha^{-1} of four tree species under different schedule of irrigation

Irrigation Schedule	*Acacia nilotica* Plantation age (months)				*Dalbergia sissoo* Plantation age (months)				*Prosopis juliflora* Plantation age (months)				*Casuarina equisetifolia* Plantation age (months)			
	16	30	40	Total	16	30	40	Total	16	30	40	Total	16	30	40	Total
T_1	0.25	0.19	0.27	0.65	0.08	0.13	0.24	0.45	0.78	1.24	1.01	3.03	0.08	0.12	0.06	0.26
T_2	0.28	0.41	0.37	1.06	0.10	0.35	0.37	0.82	0.79	2.48	1.85	5.12	0.16	0.21	0.13	0.50
T_3	0.29	0.79	0.53	1.61	0.09	0.44	0.51	1.04	0.91	3.03	2.81	6.75	0.10	0.34	0.21	0.65
T_4	0.55	1.48	0.95	2.98	0.08	0.56	0.71	1.35	0.75	3.46	2.56	6.77	0.09	0.41	0.27	0.77
T_5	0.37	1.17	0.86	2.90	0.10	0.53	0.48	1.11	0.88	3.29	1.87	6.04	0.13	0.48	0.51	1.12
T_6	0.37	1.24	1.32	2.93	0.10	0.44	0.52	1.06	0.87	3.61	2.81	7.29	0.09	0.37	0.41	0.87
T_7	0.25	1.08	1.21	2.54	0.09	0.56	0.43	1.08	0.88	3.39	2.91	7.18	0.10	0.43	0.37	0.90
T_8	0.44	1.49	1.29	3.22	0.19	0.61	0.47	1.21	0.98	3.50	3.26	7.74	0.12	0.49	0.48	1.09
Mean	0.34	0.97	0.85	2.24	0.09	0.45	0.47	1.93	0.85	3.00	2.39	6.24	0.11	0.35	0.31	0.77

To give a proper shape to the plants, these were pruned at 16, 30 and 40 months old stages. The total pruned biomass was maximum in *P. juliflora* followed by *A. nilotica, D. sissoo* and *C. equisetifolia* (Table 19). The biomass was least in un-irrigated treatments. These studies clearly show that plantations need regular irrigation after plantation at least for initial threeto four years.

SILVICULTURAL AND SILVI-PASTORAL LAND USE SYSTEMS

6.1 Establishment of Silvicultural and Silvi-pastoral Systems

A three times replicated field experiment with four tree species in the main plot and six inter-crop treatments in the sub-plots (Fig. 7) was initiated in August-September, 1991 to compare the productivity of different silvicultural and silvi-pastoral systems and their ameliorating effects. Total area under this experiment was about 3 ha. The four species were planted with augerhole technique accommodating 36 plants in each sub-plot in a 4 m x 2 m planting geometry. The tree species included *Acacia nilotica, Prosopis juliflora, Dalbergia sissoo* and *Casuarina equisetifolia*. The inter-crop treatments in sub-plots were as follows:

T_1 = Only trees (unweeded)
T_2 = Only trees (weeded)
T_3= Kallar grass (*L. fusca*) for 4 years
T_4 = Kallar grass in the second year for 3 years
T_5 = Kallar grass in second year for two years
T_6 = *S.marginatus* in the first year for 4 years

Kallar grass *(Leptochloa fusca)* was planted in inter-spaces from root-stocks/stem cuttings at 50 cm (row-to-row-distance) x 20 cm (plant to plant) spacings in August, 1992. The root-stocks of *Sporobolus marginatus* were uprooted from experimental area and planted at the same spacing as mentioned for kallar grass. No amendment was used for raising grasses except 100 kg and 20 kg ha^{-1} of nitrogen and zinc sulphate, respectively were applied after planting. The irrigation was applied on need basis.

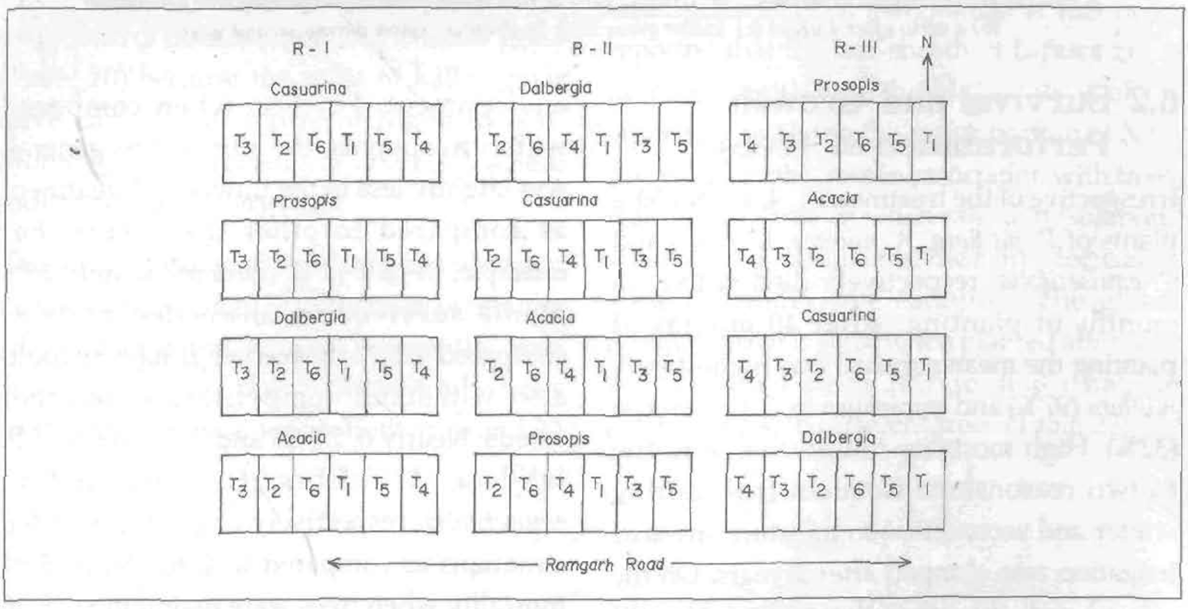


Fig. 7. Layout for the experiment to develop silvi-pastoral practices for abandoned sodic lands. For treatments T_1-T_6 please see text

A view of silvi-pastoral experiment. (a) Grasses raised from cuttings after one year of tree plantation (b) a view after 4 years (c) kallar grass with Dalbergia sissoo *during second year*

6.2 Survival and Growth Performance of Trees

Irrespective of the treatment, 1, 4, 11 and 30% plants of *P. juliflora, A. nilotica, D. sissoo* and *C. equisetifolia,* respectively died within 16 months of planting. After 40 months of planting the mean survival was highest in *P. juliflora* (97%) and minimum in *C. equisetifolia* (32%). High mortality in *Casuarina* was due to two reasons-one frequent frost during winter and second due to moisture stress as irrigation was stopped after 2 years. On the other hand, the other three species could withstand the stress and adapted to arid environment. Further, when compared within treatments, the survival in general, was slightly less in the unweeded treatment as compared to other treatments. For example, in case of *C. equisetifolia,* only 29% plants survived in unweeded plots as compared to 50% in weeded. *P. juliflora* could also withstand competition with other weeds. Nearly 6, 23, 26 and 71% plants of *P. juliflora, A. nilotica, D. sissoo* and *C. equisetifolia,* respectively died in unweeded situations as compared to 1, 6, 15 and 50% mortality when trees were maintained clean weeded (Table 20).

The measurement of height and girth showed that *P. juliflora* and *A. nilotica* had advantage as compared to other species probably due to their better tolerance and adaptation to soil sodicity. *Casuarina* is considered highly tolerant to salinity under tropical situation, performed very poorly when planted on alkali soils of Bichhian. Irrespective of spacings, the height and diameter were inferior when the trees were left unweeded as compared to other treatments. As compared to weeded, the growth was also affected adversely in those treatments where grasses were planted with trees. During monsoon, the grasses had luxuriant growth and could compete with the young seedlings having adverse effect on their growth. This adverse effect may be mitigated by planting the grasses when the trees are at least one year old. Our experience shows that it is better to plant grasses when the trees are well established, say after two years. The *Sporobolus marginatus* had more adverse effect on growth of trees as compared to kallar grass (Table 20) because the roots of kallar grass have capacity of fixing nitrogen in soil. Moreover, *S. marginatus* is luxuriant where sodicity in soil is very high.

Trees were pruned of side branches upto one third of the total stem length first at 16 months after planting and again at 30 months after planting to give a proper shape to the trees and to get some fuel wood. Both at 16 and 30 months stages, the pruned biomass was highest in *P. juliflora* and minimum in *D. sissoo* (Table 21). In almost all the species, the pruned biomass recorded at 30 months after planting was nearly 3 times more than at 16 months stage and it was significantly more when trees were maintained as clean weeded as compared to unweeded and when grasses were planted with trees particularly during the first establishment year.

6.3 Grass Production

The forage yield of *Leptochloa fusca* was nearly 3 times more than *Sporobolus marginatus*. These could produce highest biomass in association with *Casuarina* and lowest in association with *Prosopis* (Table 22). This difference was due to the difference in canopy of the trees. More cuts and the biomass were obtained during rainy season.

L. fusca proved more productive under alkali conditions than *S. marginatus*. It has been reported that the leaf-sheath of *L. fusca* grass helps in regulating the Na^+ content of its lamina by retaining the major portion of Na^+. The yield of this grass in association with trees was almost same as when raised in isolation, whereas in *S. marginatus*, the same decreased abruptly under tree canopies. The green forage yield of *L. fusca* when planted after two years ranged from 26.7 to 40.0 t ha^{-1} in association with different trees (Table 23).

Table 20. Effect of different treatments on survival, height and stump diameter of four species after 40 months of plantation

Treatment	*Acacia nilotica*			*Prosopis juliflora*			*Dalbergia sissoo*			*Casuarina equisetifolia*		
	Survival (%)	Height (m)	DSH (cm)	Survival (%)	Height (m)	DSH (cm)	Survival (%)	Height (m)	DSH (cm)	Survival (%)	Height (m)	D S H (cm)
T_1 = Sole trees (unweeded)	77	2.0	3.0	94	3.5	4.6	74	1.6	2.0	29	1.2	2.0
T_2 = Sole trees (weeded)	94	2.5	4.4	99	4.3	4.9	85	2.7	5.0	50	2.1	3.3
T_3 = Trees+kallar grass for 4 years	90	2.3	4.1	99	3.6	4.8	94	1.9	3.8	33	1.4	3.1
T_4 = Trees+kallar grass after 1 years (for 3 years)	95	2.4	4.2	100	3.7	4.7	79	2.0	4.3	31	1.5	2.9
T_5 = Trees+kallar grass after 2 years (for 2 years)	88	1.6	3.3	97	4.1	4.8	73	1.6	3.2	28	1.1	1.7
T_6 = Trees+ *Sporobolus marginatus* for 4 years	90	2.0	3.1	95	4.0	4.8	71	1.5	2.8	24	1.4	2.1
Mean	89	2.1	3.7	97	3.9	4.8	79	1.9	3.7	32	1.4	2.5

Table 21. Air-dried pruned biomass (kg ha^{-1}) of different tree species as affected by different treatments after 16 and 30 months of plantation

Treatment	A. nilotica Months after planting		P. juliflora Months after planting		D. sissoo Months after planting		C. equisetifolia	
Months after planting	16	30	16	30	16	30	16	30
T_1	252	672	545	2475	131	471	122	562
T_2	356	1766	977	4687	294	1254	364	1254
T_3	430	1770	1219	3599	182	804	476	1136
T_4	230	1270	734	3694	122	942	117	807
T_5	445	1875	924	3564	96	556	109	869
T_6	426	1246	1134	3574	252	1032	450	990
Mean	356	1433	922	3999	179	843	273	936

Treatments $T_1 - T_6$ as in table 20.

Table 22. Green forage yield (t ha^{-1}) of *Leptochloa fusca* (Lf) and *Sporobolus marginatus* (Sm) grasses when grown with different tree species during different years

Associate trees	1992		1993		1994		1995		Mean	
	Lf	Sm	Lf	Sm	Lf	Sm	Lf	Sm	Lf	Sm
A. nilotica	7.5	2.6	18.6	6.67	22.8	7.0	16.0	4.8	16.2	5.3
P. juliflora	6.8	3.0	20.0	6.4	20.8	5.4	14.8	3.8	15.6	4.7
D. sissoo	8.2	2.5	23.4	8.2	22.0	6.4	14.4	4.2	17.0	5.3
C. equisetifolia	8.2	2.8	20.4	7.6	24.2	7.8	16.8	4.5	17.4	5.7
Without trees	8.3	2.6	22.0	9.4	23.4	8.2	19.8	5.4	18.1	6.4
Mean	7.8	2.7	20.6	7.7	22.6	7.0	16.2	4.5	16.9	5.5

Table 23. Green forage yield (t ha^{-1}) of *L. fusca* grass when grown with four trees after two years

Associate trees	1994	1995	Total	Mean
Acacia nilotica	18.8	12.0	30.8	15.4
Prosopis juliflora	17.2	10.0	27.2	13.6
Dalbergia sissoo	16.5	10.3	26.8	13.4
Casuarina equisetifolia	20.4	13.7	34.1	17.0
Without trees	23.4	16.6	40.0	20.0
Mean	19.3	12.5	31.8	15.9

6.4 Effect on Soil Properties

When soil properties in terms of pH and organic carbon contents were compared under different treatments of cultivation of grasses in interspaces, it was found that irrespective of grass–treatments the maximum reduction in soil pH and increase in organic carbon contents was found in *P. juliflora* plots because of its better root and shoot growth in alkali soil, more litter fall, and improved microbial status in soil. The soil amelioration was more when the grasses associated with trees as compared to sole trees or sole grasses. *L. fusca* was more effective than *S. marginatus* (Table 24) because of more shoot biomass and root spread of *L. fusca* in sodic environment as compared to *S. marginatus*. The extensive root system helps in leaching of salts from the top layer. It is reported that pH of alkaline soils is highly sensitive to changes in the partial pressure of CO_2. The release of CO_2 from roots facilitates the replacement of absorbed sodium in calcareous soils by solubilizing the native $CaCO_3$ and thus enhances the process of soil reclamation. Marked increase in organic carbon content in tree + *L. fusca* grass treatments may be attributed to an increase in biological activity in the previously barren soil as a result of grass root development, litterfall, fine root decomposition and nitrogen fixation by trees and grasses. One of the nitrogen fixing organisms that has been reported with *L. fusca* roots is *Klebsiella pneumoniea*. It is reported that this grass has the capacity to fix nitrogen as per its requirement. Moreover, the grass has quite high lignin content which may serve as a good substrate for the synthesis of humus. Thus, by growing this grass we may raise the stable orgnic matter in alkali soils, which have very low level of humus. Magnitude of reduction in soil pH and increase in organic carbon status of the soil was least in those plots where the sole trees were grown and the vegetation was weeded out as compared to other treatments where other vegetation played a role. Therefore, in-situ recycling of residues of miscellaneous vegetation is recommended to improve soil health.

6.5 Carbon Storage, Nitrogen Cycling and Bioamelioration

In the previous experiment, the unweeded treatment of the trees was predominated by natural vegetation consisting of *Desmostachya bipinnata* as dominant grass with three tree species viz. *A. nilotica*, *P. juliflora* and *D. sissoo*. Other associate species included *Cynodon dactylon*, *Cyperus rotundus*, *Dichanthium annulatum*, *Erigeron linifolius*, *Leptochloa panacea*, and *Sporobolus marginatus*. For this study the stand dominated by *Desmostachya*

Table 24. Effect of different tree and grass species on soil pH and organic carbon status (in 15 cm layer) after 4 years of planting

Treatments	*A. nilotica*				*P. juliflora*				*D. sissoo*				*C. equisetifolia*			
	pH_2		OC (%)		pH_2		OC (%)		pH_2		OC (%)		pH_2		OC (%)	
	I	F	I	F	I	F	I	F	I	F	I	F	I	F	I	F
T_1	10.2	9.8	0.10	0.18	10.0	9.7	0.12	0.21	10.0	9.8	0.16	0.22	9.9	9.7	0.18	0.24
T_2	10.1	9.9	0.14	0.20	10.2	9.9.	0.12	0.20	9.7	9.7	0.20	0.26	10.2	10.0	0.20	0.26
T_3	10.2	9.5	0.10	0.26	10.3	9.4	0.14	0.30	9.9	9.4	0.12	0.24	10.1	9.5	0.14	0.26
T_4	10.2	9.7	0.12	0.20	10.4	9.7	0.12	0.28	10.1	9.7	0.17	0.25	9.7	9.4	0.14	0.20
T_5	10.0	9.7	0.08	0.16	9.8	9.5	0.17	0.26	10.3	10.1	0.12	0.20	10.3	10.1	0.12	0.17
T_6	10.2	10.0	0.12	0.22	10.0	9.7	0.11	0.18	10.0	9.7	0.16	0.19	10.2	9.8	0.20	0.24

I-initial value F= Final value (after 4 years of plantation). Treatment $T_1 - T_6$ as in Table 20.

bipinnata was compared with *Sporobolus marginatus* system in association with above mentioned three tree species. Thus, the sub-plot treatments were comprised of *D. bipinnata* and *S. marginatus* plots. These studies were conducted when trees were seven years old. The results were published by B. Kaur, S.R. Gupta and G. Singh (*Agroforestry System* 45 : 13-20, 21-29, 2002). The litterfall was colleted at monthly intervals from March, 1997 to March 1998 using the litter traps. The soil core method was used for excavating fine roots to a depth of 0 to 15 cm. These were soaked in water for 24 hours and washed under a fine jet of water using a sieve shaker filter with 2 mm to 0.5 mm mess screens successively. Biomass and productivity of trees were estimated by dimension analysis of sample trees using allometric regression equations between the circumferences at breast height (cbh) and biomass of various tree components. All trees within the treatment plots were marked and their circumferences measured at 1.35 m height from the ground during March, 1997 to March, 1998. The regression equations showing the relationship between growth and biomass of trees were computed to determine the biomass of tree components (Table 25). Total biomass of trees was estimated on the basis of total stand density of 1250 trees ha^{-1}. Aboveground net primary productivity (ANP) of trees was calculated on the basis of sum of increment in the biomass of non-photosynthetic parts over a time of one year and litter production during the same period of time.

Seasonal variations in the biomass of grasses in different treatments were studied by the harvest method using 50 cm x 50 cm harvest plots at an interval of 2 to 3 months for one year. Root biomass (upto 15 cm depth) was determined by excavating soil cores from the harvested plots and separated from soil by soaking in water and washing under a fine jet of water. The ANP of grasses was computed using the trough peak analysis of data on live and dead shoots. It is based on summation of all positive changes in live biomass and concurrent positive changes in the standing dead biomass. Below ground net production (BNP) was calculated by

Table 25. Regression of long dry weight of different tree components (Y) and log cbh (X) for Acacia nilotica, Dalbergia sissoo and Prosopis juliflora in silvi-pastoral system

tree species /Plant component		Corr. Coeff. (r)	Intercept a	slope b	SE of intercept	SE of b
A. nilotica (N = 8)	Bole	0.74	-1.149	1.277	0.043	0.123
	Branch	0.74	-0.850	0.999	0.124	0.357
	Root	0.94	-0.420	0.615	0.029	0.084
	Total	0.96	-0.173	0.007	0.038	0.110
D. sissoo (N = 8)	Bole	0.89	-1.037	1.226	0.117	0.225
	Branch	0.72	-0.037	0.508	0.096	0.183
	Root	0.98	-0.583	0.857	0.032	0.061
	Total	0.92	-0.023	0.852	0.070	0.134
P. juliflora (N = 9)	Bole	0.86	-0.239	0.709	0.051	0.156
	Branch	0.88	-1.886	1.945	0.122	0.369
	Root	0.95	-0.142	0.569	0.020	0.060
	Total	0.92	-0.728	1.388	0.072	0.218

summing all positive changes in belowground biomass as recorded during different seasons. Organic carbon in plant samples was determined using powdered ground samples by dichromate oxidation method and total nitrogen concentration was estimated using semi-microkjeldahl method. The microbial biomass carbon (MBC) was determined by the fumigation extraction method using the formula : MBC = 2.64 x EC, where EC (extractable carbon) is the difference between carbon extracted from fumigated and unfumigated soil samples.

6.6 Plant Biomass and Net Primary Productivity

The monsoon rains triggered an active growth of herbaceous vegetation and biomass attained a peak value during rainy season. The plant biomass was greater in *Desmostachya bipinnata* dominated vegetation as compared to *Sporobolus marginatus* dominated vegetation (Table 26). The root: shoot ratio varied from 0.88 to 1.25. The development of high belowground biomass is considered an adaptive strategy for the plants to survive under stress conditions. Net primary productivity of herbaceous vegetation on *D. bipinnata* stand (t ha^{-1} yr^{-1}) was : ANP = 6.50, BNP = 3.87, TNP = 10.37, and on *S. marginatus* stand was : ANP = 1.87, BNP = 1.33, TNP = 3.20. The difference in productivity of the two systems could be attributed to the marked differences in soil conditions and phenology of dominant plant species.

The carbon content ratios in different primary producer compartments of grasses were : 33.6 to 35.4% live shoots, 36.9 to 37.5% dead shoots, 37.5 to 38.0% litter, and 35.1 to 36.2% roots. Nitrogen concentration in plant components was : live shoots 1.19 to 1.12%, dead shoots 0.89 to 0.95%, litter 0.81 to 0.68% and roots 0.98 to 1.01%. Of the total carbon input into the system, 38 to 42% was associated with belowground and 62 to 58% with aboveground production.

Table 26. Average plant biomass, productivity, carbon and nitrogen content and uptake in shoots and roots of *Desmostachya bipinnata* and *Sporobolus marginatus* in 'grass only' treatment

Plant component		Average biomass/C&N contents (t ha^{-1})		Productivity/C&N uptake (t ha^{-1} yr^{-1})	
		D. bipinnata	*S. marginatus*	*D. bipinnata*	*S. marginatus*
Shoots	Dry matter	6.50	3.05	6.50	1.87
	Carbon	2.23	1.13	2.18	0.66
	Nitrogen	0.165	0.031	0.077	0.021
Roots	Dry matter	2.91	1.21	3.87	1.33
	Carbon	1.02	0.35	1.36	0.48
	Nitrogen	0.028	0.010	0.038	0.013

Tree biomass in *D. binnata* based silvi-pastoral system was greater than *S. marginatus* based system. On the average, 63 to 87% of tree biomass was accumulated in perennial structures (20 to 33% bole, 22 to 46% branches, 16 to 22% coarse roots). Biomass of grasses growing along with trees varied from 0.42 to 3.92 t ha^{-1}. It decreased due to integration of trees in silvi-pastoral system. For example, grass biomass under *P. juliflora* was significantly lower than under *A. nilotica* and *D. sissoo* because of difference in canopy formation. The relative contribution of litterfall varied due to survival of tree species and climatic seasonality. The total litterfall form trees ranged from 0.34 to 5.21 t ha^{-1} yr^{-1}, the value being maximum (t ha^{-1} yr^{-1} 5.21) in the case of *P. juliflora* + *D. bipinnata* silvi-pastoral system. The litter accumulation on the ground floor was higher in *P. juliflora* followed by *D. sissoo* and lowest in *A. nilotica* (Table 27). Addition of organic matter in the form of litterfall and fine roots had a direct effect on the status of soil organic matter in the slivi-pastoral systems. The fine root biomass varied significantly in different

Table 27. Biomass (t ha^{-1}) of different plant components in silvi-pastoral systems of *A. nilotica* (An), *Dalbergia sissoo* (Ds) and *P. juliflora* (Pj) along with *D. bipinnata (Db)* and *S. marginatus* (Sm) grasses

Plant components	An+Db	An+Sm	Ds+Db	Ds+Sm	Pj+Db	Pj+Sm	LSD ($p \leq 0.05$)
Trees							
Foliage*	2.18	-	3.95	0.34	5.21	2.76	0.88
Branch	4.16	-	6.29	0.25	20.82	11.55	2.21
Bole	5.04	-	4.62	0.23	9.78	7.90	0.56
Coarse roots	3.33	-	4.32	0.23	7.30	6.15	0.37
Fine roots	0.72	-	1.29	0.08	2.32	1.18	0.26
Ground floor litter	1.81	-	2.05	0.29	3.40	2.13	2.10
Total	17.24	-	22.52	1.42	48.83	31.63	-
Grasses	1.41	3.35	3.92	2.94	0.42	0.72	0.28

* Calculated from litterfall. '–' denotes no biomass as *Acacia nilotica* trees died.

systems. The organic matter content in fine roots was 33 to 44% to that of litterfall in the trees + *D. bipinnata* systems and the same was comparatively lower in *S. marginatus* based systems, which could be attributed to poor performance of trees at high pH on the *Sporbolus*-site. A greater account of fine root biomass in the trees + *D. bipinnata* system could improve nutrient and water absorption as fine roots remained in constant flux over the time and their turnover rate was high.

Total net production in trees + *D. bipinnata* systems was greater than the trees + *S. marginatus* systems. Among trees *P. juliflora* based system was most superior followed by *D. sissoo* and *A. nilotica*. Similar was trend in aboveground net production, which attained appreciably high values (3.69 to 12.74 t ha^{-1} yr^{-1}) in the case of trees + *D. bipinnata* systems, while it was only 0.49 to 6.08 t ha^{-1} yr^{-1} in the trees + *S. marginatus* systems due to poor growth of trees. Total net production of grasses ranged from 0.79 to 6.91 t ha^{-1} yr^{-1} in case of trees + *Desmostachya* based systems, while in case of *Sporbolus* based systems it varied from 0.64 to 3.10 t ha^{-1} yr^{-1} (Table 28).

Table 28. Net primary productivity (t ha^{-1} yr^{-1}) of different tree-based silvi-pastoral systems

Plant components	Tree + *D. bipinnata* systems				Tree + *S. marginatus* systems			
	A. nilotica	*D. sissoo*	*P. juliflora*	LSD ($p \leq 0.05$)	*A. nilotica*	*D. sissoo*	*P. juliflora*	LSD ($p \leq 0.05$)
Trees foliage	2.18	3.95	5.21	1.28	-	0.34	2.76	0.63
Branch	0.59	0.62	6.51	1.31	-	0.05	2.70	1.06
Bole	0.92	1.17	1.02	0.46	-	0.10	0.62	0.17
Coarse roots	0.28	0.74	0.61	0.18	-	0.05	0.39	0.11
Fine roots	0.72	1.29	2.32	0.32	-	0.08	1.18	0.25
Aboveground	3.69	5.74	12.74	1.92	-	0.49	6.08	1.08
Belowground	1.00	2.03	2.93	0.35	-	0.13	1.57	0.31
Grasses	2.75	6.91	0.79	0.31	3.10	2.17	0.64	0.24
Total	7.26	14.68	16.46	1.38	3.10	2.79	8.29	1.21

Fertility of soil, water availability and vegetation structure determined to a large extent the fraction of net primary productivity being allocated belowground. This study showed that the belowground allocation of net productivity was more in grass only systems (1.33 to 3.87 t ha^{-1} yr^{-1}) than in the trees + grass systems (1.00 to 2.93 t ha^{-1} yr^{-1}).

6.7 Carbon and Nitrogen Contents in Plant Biomass

In tree-based silvi-pastoral systems, aboveground carbon pool was greater in branches and boles as compared to foliage. The extent of storage of carbon in aboveground parts of the trees + *D. bipinnata* systems were 4.95, 6.03 and 14.80 t ha^{-1}, respectively in *A. nilotica, D. sissoo* and *P. juliflora* systems accounting for 66 to 80% of total carbon content of the vegetation (Table 29). Carbon content of total plant biomass was 1.44 t C ha^{-1} and 12.32 t C ha^{-1} in case of Ds + Sm and Pj + Sm treatments, respectively. The amount of total carbon input through net primary production in the trees + *Desmostachya* systems (t ha^{-1} yr^{-1}) was : 2.81 An + Db, 5.37 Ds + Db and 6.50 Pj + Db. The wood (bole + branches) and coarse roots accounted for 33 to 54% of total carbon input in the tree layer, the remaining being channelised for the formation of foliage (31 to 51%) and fine roots (14 to 16%). Organic carbon input in the form of foliage and fine roots into the soil varied from 1.17 to 2.84 t C ha^{-1} yr^{-1} in the trees + *D. bipinnata* systems. The carbon input through net primary productivity in the case of Ds + Sm and Pj + Sm treatments was 0.98 and 3.24 t C ha^{-1} yr^{-1}, respectively. The coarse and fine roots formed about 20% of total net production in the trees + *S. marginatus* systems.

Table 29. Carbon and nitrogen contents (t ha^{-1}) in plant biomass of *A. nilotica* (An), *D. sissoo* (Ds) and *P. juliflora* (Pj) along with *D. bipinnata* (Db) and *S. marginatus* (Sm) grasses in silvi-pastoral systems

Plant Components	An+Db	An+Sm	Ds+Db	Ds+Sm	Pj+Db	Pj+Sm
Trees (Foliage + branch + bole)						
Carbon	4.95	-	6.03	0.33	14.80	9.28
Nitrogen	0.115	-	0.184	0.013	0.313	0.184
Coarse + fine roots						
Carbon	1.48	-	2.06	0.11	3.66	2.80
Nitrogen	0.060	-	0.065	0.004	0.125	0.097
Grasses						
Carbon	0.37	1.18	1.01	1.00	0.09	0.24
Nitrogen	0.24	0.038	0.070	0.035	0.012	0.017

The addition of carbon into the soil through fine roots and aboveground litter amounted to 0.16 to 1.49 t C ha^{-1} yr^{-1} in the tree + *Sporobolus* systems. The carbon fixed by the plants is the primary source of organic matter input into the soil, which provides substrate for microbial processes and accumulation of soil organic matter.

Total uptake of nitrogen for the tree + *D. bipinnata* systems (t N ha^{-1} yr^{-1}) was in order : 0.231 (Pj + Db) > 0.156 (Ds + Db) > 0.083 (An + Db), which it amounted to only 0.038 to 0.135 t N ha^{-1} in the case of trees + *S. marginatus* treatments. Nitrogen uptake by grasses growing in association with the trees, varied from 0.027 to 0.082 t N ha^{-1} yr^{-1}. About 87% (An + Db), 89% (Ds + Db) and 77% (Pj + Db) of the net annual N uptake by the vegetation was returned to the soil through litterfall and turnover of fine roots. Trees retained 4 to 21% of the total N uptake in bole, branches and coarse roots in *Dalbergia* and *Prosopis* based systems. On the basis of storage of carbon and nitrogen in the perennial tree components as well as improvement of soil organic status, the silvi-pastoral systems were found to be accumulating systems that could effectively increase biological production and productivity of sodic soils.

6.8 Microbial Biomass Carbon

The microbial biomass carbon (MBC) in soils of only grass systems was found low (65 to 46 μg C g^{-1} soil in 0 to 7.5 cm soil depth, 30 to 21 μg C g^{-1} soil in7.5 to 15 cm depth). In the trees + *D. bipinnata* silvi-pastoral systems, soil microbial biomass carbon varied from 88 to 127 μ g C g^{-1} soil (0 to 7.5 cm soil depth) and from 35 to 51 μg C g^{-1} soil (in 7.5-15 cm soil depth). On the other hand, in the case of trees + *S. marginatus* silvi-pastoral systems, the soil carbon content varied from 0.26 to 0.36% in different treatments. It varied from 51 to 76 μg C g^{-1} soil in 0 to 7.5 cm depth and from 23 to 32 μg C g^{-1} soil in 7.5 to 12 cm depth (Table 30). It was probably due to poor tree performance in highly alkali soil having *Sporobolus* grass.

There was steep decline in soil organic matter and microbial biomass carbon in sub-surface layers of soils across the treatments. This study suggests that in silvi-pastoral systems, the microbial biomass increased due to the faster ameliorative effects of trees and grasses on the soil conditions and the increase in organic carbon content of the soil-plant system. The soil microbial biomass responded favourably to the increase in organic matter of the soil. It was interesting to find a significant relationship of the soil microbial biomass with the flux of carbon in net primary productivity ($r = 0.92$, $p < 0.05$) and plant biomass carbon across various treatments ($r = 0.83$, $p < 0.05$).

The levels of soil inorganic nitrogen varies significantly with respect to tree and grass species. In trees + *D. bipinnata* silvi-pastoral systems, soil inorganic N varied from 10-13 μg g^{-1} soil in 0-7.5 cm depth and from 7 to 8 μg g^{-1} soil in 7.5 to 15.0 cm depth. In only grass system it was 6 μg g^{-1} soil at both depths.

Table 30. Soil microbial biomass carbon (MBC) in different grass and silvi-pastoral systems

Treatments	MBC (μg C g^{-1} soil) in soil depth		MBC/Organic C (%) in soil depth	
	(0-7.5 cm)	(7.5 to 15.0 cm)	(0-7.5 cm)	(7.5 to 15.0 cm)
D. bipinnata alone	65	30	2.24	1.88
S. marginatus alone	46	21	1.90	1.58
A. nilotica + D. bipinnata	88	35	2.43	1.96
D. sissoo + D. bipinnata	121	48	2.61	2.01
P. juliflora + D. bipinnata	127	51	2.70	2.02
A. nilotica + S. marginatus	51	23	1.96	1.62
D. sissoo + S. marginatus	64	28	1.99	1.66
P. juliflora + S. marginatus	76	32	2.11	1.68
LSD ($p \leq 0.05$)	5.21	3.88	0.15	0.15

The increase in respective depths was 25 to 62% and 16 to 33% as compared to only grass system. For the trees + *S. marginatus* system inorganic N level at these depths varied from 9 to 10 μg g^{-1} soil at 0 to 7.5 cm depth and it was 6 μ g g^{-1} soil at 7.5-15.0 cm depth.

Soil nitrogen availability was significantly greater in trees + *D. bipinnata* systems as compared to trees + *S. marginatus* systems. It was interesting to note that soil carbon was linearly related to microbial C and soil N ($r = 0.97$ to 0.95, $p = 0.05$). These relationships are well expected as plants add organic matter and nitrogenous compounds into the soil (particularly when trees are leguminous), which are processed through the decomposition pathways and soil food webs. In this study, it is clear that the native microflora in sodic soils are quite efficient in the decomposition of organic matter. It is evident that soil microbial biomass and nitrogen mineralization rates increased due to increase in soil organic matter in different silvi-pastoral systems. An enlarged soil microbial biomass pool and greater soil nitrogen availability may serve silvi-pastoral systems to flourish well and to convert almost a dead mass of sodic land to productive normal soil.

6.9 Soil Respiration and Microrrhizal Studies

Soil respiration in the form of dehydrogenase activity and CO_2 evolution was quantified (CSSRI Annual Report, 1993-94) under kallar grass (*Leptochloa fusca*) based silvi-pastoral system at different growth stages for two depths of highly alkali soils (pH 10.1 to 10.3 in 0-15 cm depth and 10.0 to 10.5 in 15-30 cm soil depth). The dehydrogenase activity decreased with the increase in depth. The decrease in lower depth varied from 49 to 74% as compared to surface layer. The overall increase in dehydrogenase activity was 11 times higher in tree alone treatment, 13 times in trees + grass treatment and 7 times in 'grass alone' treatment as compared to without any vegetation (Table 31).

CO_2 evolution decreased by 13% in lower depth compared to upper layer (0-15 cm) at initial stage. At later stages of growth, CO_2 evolution increased by 30 to 44% with the increase in depth (Table 31). This indicates that in contrast to dehydrogenase activity, CO_2 evolution is not a good index of soil microbial activity for highly alkaline calcareous soil. Interference of $CaCO_3$ in CO_2 determination may lead to variable results.

Results of a survey conducted to study the build-up of microrrhizal spore population under different silvi-pastoral systems showed that in highly alkali soil the population was initially very low. The native grasses such as *Desmostachya bipinnata* and *Sporopolus marginatus* showed better colonization of their roots by microrrhiza as compared to Kallar grass introduced in the system . This is evident from N-mineralization studies, discussed in previous section.

Table 31. Dehydrogenase activity (µg TPF g⁻¹ soil) and CO_2 evolution (mg CO_2 100 g⁻¹ soil) under *Leptochloa fusca* silvi-pastoral systems at different periods of time in two soil depths at Bichhian farm

Treatment	Soil depth	19-1-93		11-10-93		18-3-94		Mean	
	(cm)	DHA	CO_2	DHA	CO_2	DHA	CO_2	DHA	CO_2
A. nilotica	0-15 15-30	17.1 5.4	35.8 28.7	56.3 49.8	17.7 41.7	46.2 15.4	20.9 40.4	39.9 23.5	24.7 36.9
A. nilotica + *L. fusca*	0-15 15-30	27.0 19.2	32.8 37.3	80.2 83.3	28.9 41.9	44.7 28.0	23.9 39.5	50.6 43.5	28.5 39.6
D. sissoo	0-15 15-30	22.8 4.3	21.3 29.7	79.8 53.6	27.7 36.0	40.6 25.4	29.4 20.0	47.7 27.8	26.1 28.6
D. sissoo + *L. fusca*	0-15 15-30	32.4 9.6	34.7 24.8	197.4 26.1	14.5 55.7	43.0 18.2	8.4 19.8	90.9 18.0	19.2 33.4
P. juliflora	0-15 15-30	41.0 4.4	35.8 28.1	157.0 56.0	52.1 25.8	50.3 36.8	36.6 28.2	82.8 32.4	41.5 27.4
P. juliflora + *L. fusca*	0-15 15-30	57.3 8.1	37.9 24.5	161.5 48.0	23.8 44.0	87.7 28.8	15.2 27.5	102.2 28.3	25.6 32.0
C. equisetifolia	0-15 15-30	33.4 6.8	36.3 24.0	34.0 18.5	31.3 25.7	50.0 24.6	21.0 33.3	39.1 16.6	29.5 27.7
C. equisetifolia + *L. fusca*	0-15 15-30	9.5 0.6	18.2 15.9	29.8 27.9	15.7 41.1	29.2 23.3	24.4 16.3	22.8 17.3	19.4 24.4
L. fusca	0-15 15-30	17.5 7.6	25.5 27.0	14.3 6.6	21.1 27.3	11.0 5.5	16.7 27.5	14.3 6.7	21.1 24.1
Bare soil	0-15 15-30	1.8 1.2	21.9 22.2	5.5 2.9	22.4 25.6	6.8 2.5	16.7 23.2	4.7 2.2	20.3 23.7
Mean	0-15 15-30	26.0 6.7	30.0 26.2	89.1 40.7	26.0 37.5	41.0 20.9	21.3 27.6	52.0 22.8	25.6 29.8

DHA = dehydrogenase activity.

6.10 Spatial Variability Analysis

A variation in growth of trees was observed despite of the fact that uniform soil working method was employed for planting various tree species. To find out reasons for such a variation in trees growth, extensive soil sampling was done at different depths (0-20, 20-60 and 60-110 cm) at a grid of 4 x 4 m along transects in East-West and North-South directions in silvi-pastoral experiment. The data was analysed for pH, EC (1:2), organic carbon (OC), available P (extracted by Olsen's method) and $CaCO_3$ content (Collin's calcimeter method). Means, standard deviations (SDs) and coefficient of variations (CVs) for soil properties were calculated (Tables 32 and 33). Data on pH of surface 0-20 cm soil showed least SD (CV = 7%), whereas $CaCO_3$ content of surface soil showed highest variation (CV = 81%).

Table 32. Summary statistical analysis of data (mean lateral surface variability)

Soil property	Mean	SD	Range	CV (%)
pH (1:2)	9.5	0.70	8.0-10.5	7
EC_2 (dS m^{-1})	1.2	0.59	0.2-2.7	48
OC (g kg^{-1})	0.2	0.16	0-0.8	62
$CaCO_3$ (g kg^{-1})	1.8	1.44	0-6.6	81
Available P (mg kg^{-1})	11.3	8.15	9.7-12.8	72

Lateral variability in respect of soil pH under all tree species was minimum and $CaCO_3$ content showed largest variation (CV = 76%) under *P. juliflora*, 104 percent for *D. sissoo* and 67% for *C. equisetifolia* in upper 20 cm soil layer. *A. nilotica* showed maximum coefficient of variation (91%) for OC content in the same depth (Table 33). In general, maximum variability was recorded in the deepest soil depth (60-110 cm) for all the characteristics and under all the four species. Fractile diagrams based on the cumulative frequency distribution functions showed that all soil parameters were normally distributed.

The number of observations needed to obtain a mean value of a given parameter with a given precision and confidence was calculated using the formula : $N = (St_L / d^2)$, where 'S' is the standard deviation (SD), 'd' is the allowable error (precision required within the given limits of the true mean), and 't_L' is the value of two tailed student's test with infinite degrees of freedom at the desired confidence level L. The number of samples required for obtaining a mean value with in a given precision varied largely for different parameters (Table 34).

Growth parameters such as height and girth at stump height revealed that there was enough variation in height and girth of plants. The regression relationship between growth parameters and soil properties indicated that $CaCO_3$ and EC significantly affected both the height and girth of the plants. Soil pH was found to relate with girth, but organic carbon and available phosphorus did not show any correlation with plant height and girth (Table 35).

Multiple variate analysis showed R^2 of 0.20 ($p = 0.05$) between girth and soil properties. Tree girth probably is a better index of growth than height.

This study showed that pH, EC, OC, available P and $CaCO_3$ content were normally distributed. However, soil pH showed least variation and $CaCO_3$ the highest, which will determine the number of samples to be drawn for a realistic analysis.

Table 33. Summary statistical analysis of the vertical data under different tree plantations at Bichhian Farm

Soil property	Depth (cm)	*Acacia nilotica*				*Prosopis juliflora*				*Dalbergia sissoo*				*Casuarina equisetifolia*			
		Mean	SD	Range	CV	Mean	SD	Range	CV	Mean	SD	Range	CV	Mean	SD	Range	CV
pH_2	0-20	10.0	0.6	8.4-10.5	6	9.4	0.7	8.1-10.2	7	9.4	0.9	8.0-10.5	9	9.3	0.7	8.2-10.3	7
	20-60	10.2	0.4	9.2-10.5	4	9.9	0.7	8.3-105	7	9.9	0.5	8.9-10.7	5	9.6	0.7	8.3-10.5	7
	60-110	10.2	0.3	9.4-10.6	3	9.9	0.7	8.8-10.8	7	10.2	0.2	9.7-10.6	2	10.0	0.5	9.2-10.6	4
EC_2 (dS m^{-1})	0-20	1.6	0.5	0.4-2.3	32	1.1	0.7	0.2-2.7	61	1.1	0.5	8.0-10.5	9	1.0	0.5	0.4-2.2	47
	20-60	2.7	1.0	0.9-4.3	38	2.4	1.7	0.3-4.9	68	2.0	1.3	8.9-10.7	5	1.7	1.8	0.2-5.1	88
	60-110	3.3	1.2	1.6-6.4	36	2.9	1.9	0.4-6.2	67	2.6	1.5	9.7-10.6	2	2.7	0.1	0.4-5.5	67
Org. C (g kg^{-1})	0-20	0.2	0.2	0.0-0.78	91	0.3	0.2	0.1-0.8	61	0.2	0.1	0.1-0.5	44	0.3	0.1	0.1-0.5	34
	20-60	0.2	0.2	0.0-0.6	85	0.3	0.2	0.1-0.7	76	0.2	0.1	0.0-0.3	45	0.2	0.1	0.1-0.4	44
	60-110	0.2	0.2	0.5-4.0	105	0.2	0.2	0.0-0.6	96	0.1	0.1	0.0-0.2	69	0.1	0.0	0.0-0.2	44
$CaCO_3$ (g kg^{-1})	0-20	1.9	1.2	0.5-4.0	64	1.9	1.5	0.0-5.6	76	1.8	1.9	0.2-6.6	104	1.5	1.0	0.0-3.9	67
	20-60	2.0	0.7	0.6-3.2	35	2.3	1.2	0.6-4.8	50	2.4	1.9	0.5-8.5	81	1.7	1.2	0.2-3.7	69
	60-110	2.9	3.2	0.8-13.5	110	2.9	2.6	0.4-9.7	92	2.8	2.6	0.7-9.6	93	2.0	1.9	0.6-7.4	93
Available P (mg kg^{-1})	0-20	11.7	8.2	1.6-31.6	69	11.0	7.1	0.8-24.2	65	9.7	7.7	0.9-22.5	78	12.8	9.6	0.9-34.7	75
	20-60	14.0	7.8	0.7-28.9	56	11.6	10.5	0.5-37.0	91	15.0	8.3	1.0-32.6	55	10.4	9.0	0.9-27.8	87
	60-110	11.3	9.2	0.2-37.7	81	11.4	9.5	0.7-33.8	83	13.2	8.0	0.4-24.3	60	12.7	9.2	0.9-30.2	72

Table 34. Number of observations required for a given accuracy of determination of different soil properties

Soil property	No. of observations required at precision			
	± 10 %		± 20 %	
	Probability		*Probability*	
	90%	95%	90%	95%
pH	1	2	1	1
EC	64	90	16	22
OC	111	157	28	39
$CaCO_3$	178	251	44	63
Av. P	142	200	35	50

Table 35. Relationship between growth parameters of plant and soil properties

Properties	Regression equations *for height (cm)*	Correlation *coefficient*	Regression equations *for girth (cm)*	Correlation *coefficient*
$CaCO_3$	$Y = 246.60 - 24.30 X$	0.32*	$Y = 16.89 - 1.71 X$	0.33*
OC	$Y = 190.70 + 50.32 X$	0.10	$Y = 11.69 + 8.56 X$	0.17
pH	$Y = 541.59 - 35.60 X$	0.24	$Y = 45.06 - 3.29 X$	0.34*
EC	$Y = 277.92 - 61.11 X$	0.33*	$Y = 19.98 - 5.03 X$	0.40*
Av. P	$Y = 223.75 - 1.75 X$	0.14	$Y = 15.80 - 0.17 X$	0.20

* Significant at LSD ($p \leq 0.05$).

EVALUATION OF GRASSES

7.1 Survival & Biomass Production

Performance of 20 grasses was evaluated in a three-time replicated experiment on alkali soil of original pH 10.4, applying three treatments of gypsum, viz. 0, 25 and 50% of gypsum requirement (GR). Observations recorded four months after planting showed that grasses such as munj (*Saccharum bengalensis*), palmarosa (*Cymbopogon martinii*), lemon grass (*C. flexuosus*), citronella (*C. nardus*), bhabbar (*Eulaliopsis binata*), baru (*Sorghum halepense*), hybrid napier (*Pennisetum purpureum*), anjan (*Cenchrus ciliaris*), *C. setigerus* and *Setaria glauca* could not survive even in gypsum treated plots. Those which could survive successfully in unamended plots included : kallar grass (*Leptochloa fusca*), para grass (*Brachiaria mutica*), *Sporobolus marginatus*, *Panicum virgatum* (exotic), klein (*P. laevifolium*), vetiver (*Vetiveria zizanioides*), blue panic (*P. antidotale*), guinea grass (*P. maximum*), Rhodes grass (*Chloris gayana*) and kans (*Saccharum spontaneum*) showing 33 to 99% survival, producing 0.6 to 17.4 t ha^{-1} fresh forage biomass without application of gypsum. There was 1.4 to 20.5 t ha^{-1} biomass at 25% GR and 1.8 to 19.5 t ha^{-1} biomass at 50 % GR (Table 36).

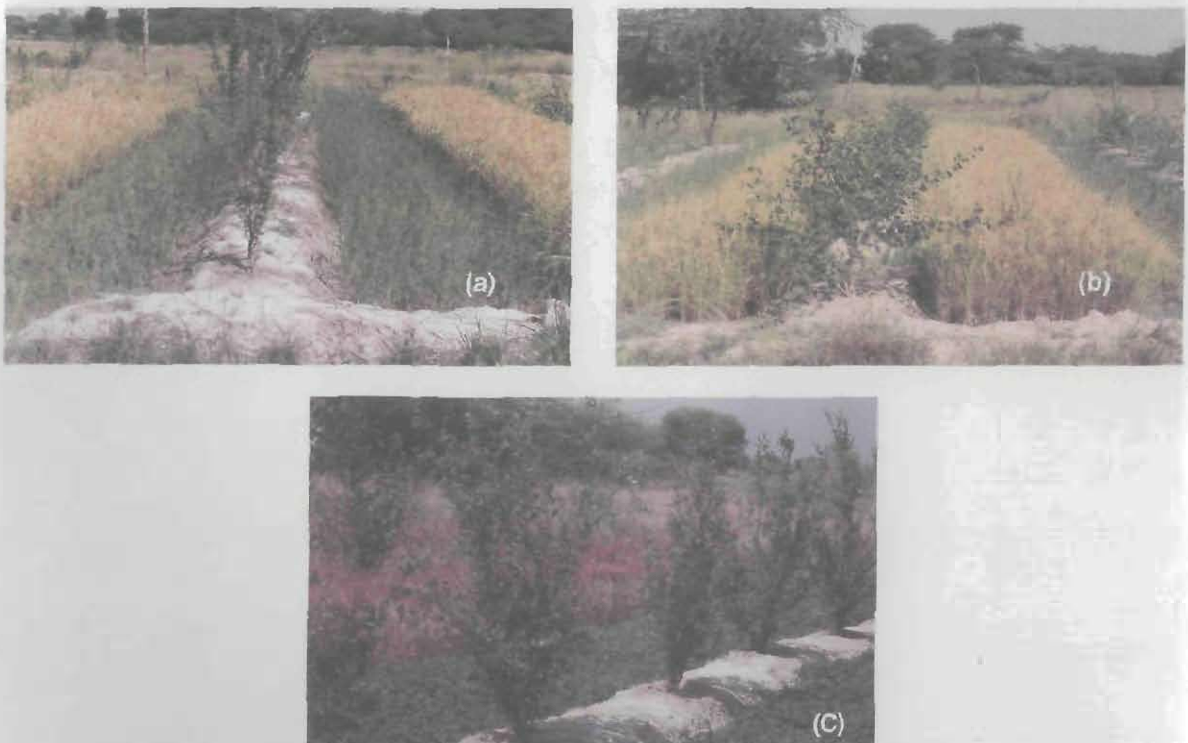
Table 36. Performance of some grass species in bare and gypsum amended alkali soil

Species	Survival (%)			Fresh biomass (t ha^{-1})		
	GR (0%)	GR (25%)	GR (50%)	GR (0%)	GR (25%)	GR (50%)
Leptochloa fusca	99	98	99	17.4	20.5	18.7
Brachiaria mutica	95	98	99	11.4	15.6	19.5
Sporobolus marginatus	83	88	86	7.8	8.4	9.2
Panicum virgatum	82	90	92	4.2	5.8	6.7
Vetiveria zizanioides	63	93	93	5.2	14.4	17.5
P. laevifolium	57	86	87	3.4	6.7	7.9
Panicum antidotale	49	73	72	2.8	4.9	5.4
P. maximum	48	52	54	1.2	1.7	2.8
Chloris gayana	37	46	48	0.8	1.4	1.8
Saccharum spontaneum	33	52	69	0.6	2.5	3.8
LSD ($p \leq 0.05$)	5.6	14.2	6.5	-	-	-

RAISED AND SUNKEN BED TECHNIQUE

8.1 Plantation Technique

To find out suitable technique to avoid water stagnation for waterlogged sensitive species and to conserve rain water, a raised and sunken bed planting technique was tried, so that tree species (both fruit and forest trees) may be planted on raised bund and excess rain water is stored in trench. The augerholes (20-25 cm diameter and 120-140 cm deep) at a distance of 4 m from row to row and 2 m from plant to plant were dug. These were refilled with usual standard soil mixture as described earlier. The augerholes were marked with sticks. 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*) and *Salvadora persica* 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 grown so that during the rainy season, rice (salt-tolerant variety CSR-10) and forage kallar grass (*Leptochloa fusca*) were grown in the month of June on both sides of plantation. No irrigation was provided to grass during rainy season while only a few irrigations were given to rice crop. During the winter season



Raised and sunken bed technique: (a) Pomegranate on bunds and kallar grass/rice in sunken beds (b) salvadora on bunds and rice/kallar grass in beds; (c) pomegranate on bunds and wheat/berseem in beds in rice plots, wheat (salt-tolerant variety KRL-1-4) was grown and in kallar-grass plots forage Egyptian clover/*berseem* (*Trifolium alexandrium*) were grown in November. Thus, the experimental design provided split plots replicated six times. Two rows of each plantation were left uncropped 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 per ha were applied while sowing the crops. No fertilizer was applied to kallar grass and *berseem*. After two years of crops three plants of each plantation species were excavated for root studies. The fresh and oven-dry biomass was taken.

8.2 Yield & Soil Amelioration

Rice grown in trenches gave 3.6-3.9 t ha^{-1} during first year and 4.1 to 4.7 t ha^{-1} grain yield during second year without applying any amendment. Effect of tree plantations on paddy yield was negligible. The wheat yield was 1.0-1.6 t ha^{-1} during first year and 1.3-1.4 t ha^{-1} during second year showing no impact of plantation. Similarly, 19.3 to 21.6 t ha^{-1} fresh forage was obtained from kallar grass during first year and 21.3 to 32.1 t ha^{-1} during second year. Fresh yield of *berseem* was 35.9 to 51.9 t ha^{-1} during first year and 39.5 to 53.8 t ha^{-1} during second year (Table 37).

The performance of both the plantations showed that height and stump diameter were not affected due to crop cultivation at least for first two years. The biomass was slightly more in association with crops showing the advantage of crop-cultivation (Table 38).

The reduction in soil pH was greater under crops than it was in the sole plantations. After one complete sequence of crops the *kallar* grass – *berseem* rotation played a more significant role in reducing pH in upper layer, however, they had no significant role in lower depths. During the second year, both plantations and crops

Table 37. Crop yield (t ha^{-1}) when grown with pomegranate and salvadora

Crop/yield parameters			Plantations		Control	LSD
			Pomegranate	Salvadora	(without plantation)	($p \leq 0.05$)
Paddy	Grain	1st year	3.6	3.8	3.9	NS
		2nd year	4.2	4.1	4.7	NS
		Mean	3.9	3.95	4.3	NS
	Straw	1st year	4.4	4.6	4.9	NS
		2nd year	6.0	5.9	6.1	NS
		Mean	5.2	5.25	5.5	NS
Wheat	Grain	1st year	1.3	1.6	1.	0.39
		2nd year	1.4	1.3	1.4	0.11
		Mean	1.35	1.45	1.2	0.25
	Straw	1st year	1.9	2.3	1.5	0.48
		2nd year	1.9	1.7	2.0	0.11
		Mean	1.9	2.0	1.75	0.29
Kallar grass	Fresh forage	1st year	21.6	21.0	19.3	1.81
		2nd year	30.5	32.1	21.3	3.19
		Mean	26.05	26.5	20.3	2.50
Berseem	Fresh forage	1st year	50.9	51.9	35.9	5.38
		2nd year	44.6	39.5	53.8	4.45
		Mean	47.75	45.7	44.85	4.91

played a role in reducing soil pH at the surface as well as lower layers. Of the two plantations *Salvadora* was more effective while among crops *kallar* grass-*berseem* rotation played more beneficial effect than rice-wheat rotation (Table 39). In *Salvadora,* both bark and leaves act as sink for salt accumulation. Similarly, kallar grass also has a tremendous capacity for extracting sodium from the soil.

Raised and sunken bed technique proved quite successful in raising plantations which otherwise suffer set backs due to stagnation of water during monsoon. In sunken beds salt-tolerant and high water requiring crops can be cultivated with great success. This not only gives satisfactory crop yield but also helps in ameliorating the soil at faster pace without application of any amendments. The stored rain water also helps in ground water recharge and moderating irrigation requirement particularly during *kharif.*

Table 38. Performance of plantations with different crop-rotations (after two years of growth)

Crop rotation	Pomegranate					Salvadora				
	Height (m)	Stump diam (cm)	Root length (m)	Oven Dry biomass (kg/plant)		Height (m)	Stump diam (cm)	Root length (m)	Oven Dry biomass (kg/plant)	
				Shoot	Root				Shoot	Root
Rice- wheat	2.27	1.5	1.7	4.0	0.6	3.98	2.8	2.4	9.4	2.6
Kallar grass-berseem	2.32	1.6	1.8	4.3	0.7	3.76	2.7	2.3	8.6	2.4
Control (without crop)	2.19	1.4	1.7	3.9	0.6	3.69	2.5	2.1	8.3	2.1
LSD (p ≤ 0.05)	Height	Stump diam.	Root length	Shoot biomass	Root biomass					
Crop rotation	NS	NS	NS	NS	NS					
Plantations	0.38	NS	0.46	0.44	0.43					
Crop rotation x plantations	NS	NS	NS	NS	NS					

Table 39. Effect of plantations and different crop rotations on soil pH when grown for 2 years

Plantation		Soil pH (1:2) after harvesting the respective crops							
		0-15 cm soil depth				15-30 cm soil depth			
		Rice	Kallar grass	Wheat	Berseem	Rice grass	Kallar	Wheat	Berseem
First year	Pomegranate	9.72	9.67	9.78	9.48	10.12	10.05	10.00	9.91
	Salvadora	9.65	9.55	9.58	9.26	10.05	10.05	9.95	9.92
	Control (without plantation)	9.80	9.80	9.82	9.65	10.34	10.16	10.20	10.05
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	9.65	9.69	9.47	9.54	10.09	9.93	9.86	9.81
LSD (p ≤ 0.05)		0-15 cm				15-20 cm			
		1st year		2nd year		1st year		2nd year	
Between plantations		0.19		0.17		NS		0.11	
Between crops		0.10		0.10		NS		0.09	
Interaction (plantations x crops)		NS		NS		NS		NS	