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AMELIORATION OF SODIC SOILS BY TREES FOR WHEAT AND OAT PRODUCTION

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ABSTRACT

Prolonged occupation of sodic soils by trees results in the latters' amelioration in terms of decreased pH and electrical conductivity and improved organic matter and fertility status. To assess whether sodic soils reclaimed by tree plantations can be used for growing agricultural crops, a greenhouse pot trial was conducted during winter of 1994–95 (November–April) at the Central Soil Salinity Research Institute, Karnal, India. Wheat (*Triticum aestivum*, L; cultivar HD 2329) and oat (*Avena sativa*, L. cultivar local) plants were grown in topsoils (30 cm) collected from 24-year-old plantations of *Prosopis juliflora*, *Acacia nilotica*, *Eucalyptus tereticornis*, *Terminalia arjuna* and *Albizia lebbek* that had been established in 1970 on a highly sodic soil (pH_2 10·2–10·5), and a reclaimed sodic soil from a farm field adjacent to the plantations. The organic carbon content and nutrient status of the soil under the 24-year-old plantations was much higher than that of a reference farm soil reclaimed through gypsum in 1974. Soil amelioration was highest under *Prosopis* canopies (pH 7·4 and organic carbon 0·89 per cent) in topsoil and minimum in *Eucalpytus* canopies (pH 8·6 and organic carbon 0·56 per cent). Reduced sodicity and improved fertility resulted in much better growth reference and productivity of the wheat and oat test crops grown on the five plantation soils, than in the reference farm soil. Grain and straw yields of wheat and oats were maximum in *Prosopis* soil (wheat 61·7 g grains and 87·5 g straw and oats 87·9 g grains and 111·1 g straw per pot) and minimum in *Eucalpytus* soil (32·3 and 25·3 g, and 42·7 and 58·5 g per pot). Grain yields of both wheat and oats obtained in the *Prosopis* soil were 4·5 and 3·5 times more, respectively, than obtained in the reference farm soil. The phosphorus concentration in whole plant tissues of wheat and oats was highest in *Prosopis* soils reflecting the prevailing phosphorus status and better restoration processes of the soils. Potassium concentration was little affected due to different soil treatments. The study clearly indicated that prolonged afforestation of sodic soils by tree plantations, particularly by *Prosopis* and *Acacia* trees, may restore the productivity of abandoned soils to much above the present agricultural production levels. The results further suggest that 24 years' occupation of sodic soils by trees, such as *Prosopis*, *Acacia*, *Eucalyptus*, *Terminalia* and *Albizia*, did not result in a build-up or accumulation of toxic allelochemicals which could be injurious to wheat and oats cultivation on such soils. © 1998 John Wiley & Sons, Ltd.

KEY WORDS: Bioamelioration; sodicity; soil restoration; tree plantations; productivity; fertility; wheat; oat

INTRODUCTION

High salt concentration in the root zone soil has degraded nearly 952 million ha (Szabolcs, 1977) of otherwise productive lands in the world. In India, such soils occupy an area of about 8·11 million ha (Singh, 1991). About 30 per cent of the total area under salt-affected soils in India is contaminated by either alkali or sodic compounds. Sodic soils are characterized by high pH, negligible organic carbon, excessive exchangeable sodium, poor fertility, low infiltration and the presence of a hard $CaCO_3$ pan in the profile (Szabolcs, 1989). Most of these soils do not support any kind of vegetation except some highly salt-tolerant herbaceous plants such as *Desmostachya bipinnata*, *Kochia indica*, *Sporobolus marginatus*, *Suaeda maritima* and *Leptochloa fusca* which may grow in patches during the monsoon season.

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During the last two decades, a sizeable area under sodic soils has been reclaimed by gypsum treatment and is supporting good crops of rice and wheat. This was possible because gypsum was available locally at a highly subsidized price (75 per cent subsidy). With the reduction of the subsidy on gypsum in the recent past, the pace of sodic soil reclamation has slowed down considerably. Moreover, a large part of the sodic soils in India is village community land managed by the elected village judicial bodies. Due to whole community rights on such lands their reclamation for crop production is not possible. An alternative approach to reclaiming sodic soils is to use biological means involving growing of salt-tolerant trees and herbaceous plants (Singh, *et al*., 1993; Singh, 1995). Successful efforts have been made to develop and standardize tree plantation techniques in sodic soils (Abrol, 1986; Gill and Abrol, 1991; Singh, *et al*., 1994). By adopting these agroforestry techniques, a sizeable area affected by sodicity has been rehabilitated using *Prosopis juliflora* and *Acacia nilotica* trees.

Trees ameliorate the surroundings in which they grow. Once established, they bring moderating changes in the physical, chemical, biological and hydrological properties of the soil (Prinsely and Swift, 1986). Many workers (Gill, *et al*., 1987; Evans, 1992; Singh and Gill, 1992; Garg and Jain, 1992; Singh, 1996) have clearly demonstrated the ameliorating effect of tree plantations on sodic soils. However, very little is known about whether agricultural crops can be grown successfully on the sodic soils reclaimed through tree plantations. The present pot study was conducted to assess the growth and production potential of the two most commonly grown agricultural crops (wheat and oats) planted on top-soils collected from 24-year-old plantations of *Prosopis juliflora*, *Acacia nilotica*, *Eucalpytus tereticornis*, *Terminalia arjuna* and *Albizia lebbek*. The objectives were:

1. To assess the productivity of wheat and oat crops grown in sodic soils reclaimed through tree plantations in comparison to their productivity in the soils reclaimed through gypsum at the same farm.
2. To assess whether prolonged occupation of sodic soils by selected trees results in accumulation of certain allelochemicals which may affect wheat and oat cultivation in such soils.

MATERIALS AND METHODS

Experimental Site

Five closely planted *Prosopis juliflora*, *Acacia nilotica*, *Eucalpytus tereticornis*, *Terminalia arjuna* and *Albizia lebbek* plantations planted at the experimental farm of the Central Soil Salinity Research Institute, Karnal, Haryana in northwestern India were selected for this study. The study area represents a typical subtropical, semiarid monsoonic type of climate characterized by a dry, hot spring, early summer that is hot and rainy, a warm autumn and a cool winter. The average annual rainfall is about 700 mm, of which 80 per cent is received between June and September. The temperature starts rising from February onwards until the summer maximum, often exceeding 40 °C, is reached in May or June. The mean monthly minimum temperature is recorded in January. There is ample sunshine throughout the year. Class A pan evaporation exceeds the rainfall except in July and August.

Plantation History

The plantations were established in 1970 (Yadav, *et al*., 1971) on a highly alkali soil. The trees were planted in 90 cm deep pits prior to the onset of the monsoon season. The dug-out soil was amended with gypsum and farmyard manure or replaced with normal farm soil before planting. The saplings were irrigated regularly during the first two years of establishment. The initial properties of the soil profile adjacent to the experimental site are given in Table I.

Experimental Details

For the present study, bulk topsoil taken from 30 cm was collected from a mid-row location in each of five plantations. The soil was transported to the greenhouse. The samples were mixed, ground and composted for

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Table I. Some physico-chemical characteristics of the soil profile recorded in 1970–71 near the plantation site

Depth (cm)	pH_s	ECe (mm hos cm^{-1})	Na (me l^{-1})	Ca (me l^{-1})	CO_3 (me l^{-1})	HCO_3 (me l^{-1})	ESP (%)	$CaCO_3$ (%)	Clay (%)	Silt (%)	Sand (%)
0–10	9·3	14·9	156	0·8	106	37	95·2	11·2	11·2	15·5	71·1
10–35	9·6	10·7	119	1·2	77	27	95·7	20·2	20·2	24·2	51·7
35–70	9·4	4·4	40	2·1	29	13	88·8	25·0	25·0	21·1	47·4
70–112	8·7	2·1	27	0·6	18	8	68·7	25·0	25·0	22·5	48·5
112–190	8·6	2·1	26	0·4	13	6	29·1	10·2	10·2	17·8	56·6

ESP = Exchangeable sodium per cent.
Source: Bhumbla, *et al*., 1972.

each treatment. A control (reference) farm soil reclaimed by gypsum (as per gypsum requirement) nearly 20 years back mostly under a rice–wheat system was also included to represent a productive agricultural land. The soils collected from the six treatments (comprising of *Prosopis, Acacia, Eucalyptus, Terminalia* and *Albizia* and the reclaimed control soil) were used to fill in ceramic pots. The pots, each containing 20 kg of soil, were arranged in a completely randomized design using three replications for a total of 36 pots. These pots were divided into two sets of experiments for growing wheat and oat, which are common winter crops grown in the region. Ten seeds each of wheat and oat per pot were sown on 21 November 1994. The soils were not fertilized during the study period (November–April), but irrigation was applied when required.

Collection, Preparation and Analysis of Soil Samples

Soil samples at 15 cm intervals up to 120 cm depth were collected from four places under the canopies of the five plantations to assess improvement in soil properties. After collection, samples were air- and then ovendried, ground in a wooden pestle and mortar, passed through a 2-mm sieve and stored for analysis. The soil pH, electrical conductivity (EC), organic carbon and available P and K were determined by standard procedures (Jackson, 1967).

Collection, Preparation and Analysis of Plant Samples

Leaf, stem and root samples of wheat and oat were analysed separately for chemical composition. Samples were washed with ordinary water, dilute acid (0·1 per cent HCL), and single and double-distilled water, then airdried and ovendried at 70 °C for 48 h, then ground in a Wiley mill, passed through a 16-mesh sieve, and stored in polyethylene bags. Samples of 1 g were digested in a di-acid mixture ($HNO_3:HCLO_4$, 3:1). The filtrate was preserved in 100 ml plastic bottles. The samples were analyzed for K by flame photometry and phosphorus was determined by the vanadomolybdophosphoric-yellow colour method (Jackson, 1967).

Growth Observations

Germination success, number of tillers per plant, ear length and spikelets per spike were recorded 10 days after germination, 60 days after sowing and at the grain-filling stage of wheat and oats, respectively. Plant height was measured at 30-day intervals from planting till maturity. Dry matter accumulation by both crops was determined at 60, 90 and 120 days' growth stages. At harvest, shoot and grain components of eight plants were sampled for yield determination.

RESULTS AND DISCUSSION

Soil Amelioration

The planting of *Prosopis*, *Terminalia*, *Eucalyptus*, *Albizia*, and *Acacia* trees had an ameliorating effect on the chemical properties of the soil (Table II). The effects were highly variable with respect to different tree species. The average pH (1:2) of 0–120 cm profile dropped from 10·2 to 9·18 in *Eucalyptus*, 9·03 in *Acacia*,

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Table II. Properties of the surface 30 cm soil used in the present study

Soils	pH	EC (dS m^{-1})	Organic carbon (%)	Available P (kg/ha)	Available K (kg/ha)
Eucalyptus	8·64	0·41	0·56	32·3	333·5
Acacia	8·58	0·28	0·73	46·4	389·5
Albizia	8·08	0·33	0·58	43·8	341·9
Terminalia	7·92	0·35	0·81	60·2	349·3
Prosopis	7·45	0·41	0·79	86·6	564·9
Cropland	8·86	0·86	0·38	27·7	188·4

8·67 in *Albizia*, 8·15 in *Terminialia* and 8·01 in *Prosopis* in a growth period of 20 years. Likewise soil electrical conductivity decreased greatly from the original levels, differences among the species being very small. Yadav (1980), Grewal (1984), Gill and Abrol (1991) and Singh and Singh (1993) also reported a similar reduction in pH and electrical conductivity by growing trees on sodic soils. This decrease is probably due to annual leaf litter additions to the soil by trees, and the production of organic acids in the soil such as carbonic acid through root respiration which results in solubilization of native, but otherwise insoluble, $CaCO_3$ present in enormous amounts in sodic soils. The released calcium from the insoluble $CaCO_3$ exchanges with the exchangeable sodium on the exchange complex and results in decreased sodicity.

A considerable increase in organic carbon content in the profile was observed under all the plantations, presumably due to litter returned to the soil by trees and root turnover. The increasing order of organic matter enriching the soil was: *Prosopis* > *Terminalia* > *Acacia* > *Albizia* > *Eucalyptus*. In *Eucalyptus*, organic carbon in the soil increased only up to 0–45 cm profile in depth, whereas in all the other tree species it increased in all the layers of the profile up to 120 cm in depth. The organic carbon status of the control farm soil, though improved appreciably during 20 years as a result of addition of crop residues and fertilizers, was still much less compared to the plantation soils. Low organic carbon build-up under *Eucalyptus* may be attributed to its lower litter yield compared with other trees. Gill, *et al*. (1987) reported that litter production in *Eucalyptus* was much less than in *Acacia* and *Prosopis* plantations of the same age and stocking rate. Field studies elsewhere (Tiedemann and Clemmedson, 1973, 1986; Rundel, *et al*., 1982) also found that soils under *Prosopis* canopies contain two to three times as much organic matter and N as soils away from *Prosopis* canopies.

Maximum build-up of phosphorus and potash in the surface layer was under *Prosopis* canopies. The phosphorus build-up in the surface layer under different species increased in the order: *Eucalyptus*, *Albizia*, *Acacia*, *Terminalia*, *Prosopis*. Similarly, on the basis of K build-up, the species could be grouped in the ascending order: *Eucalyptus*, *Albizia*, *Terminalia*, *Acacia*, *Prosopis*. The build-up of P and K in surface soil (0–15 cm) under *Prosopis* was 110·5 and 701·5 kg ha^{-1}, respectively. It may be attributed to greater total litter production and better intrinsic quality of *Prosopis* litter than other species.

Crop Growth

Fertility build-up under the plantation soil was clearly reflected in the growth responses of both wheat and oat crops raised on these five soils. Germinations per pot counted 10 days after the sowing date were almost the same in plantation soil and the reclaimed sodic control farm soil (cropland soil). The mean plant height of wheat recorded at 30-day intervals from sowing to maturity was significantly better in *Prosopis*, *Acacia*, and *Terminalia* soils than in *Eucalyptus*, *Albizia* and cropland soils (Figure 1a). At maturity, the mean height was at a maximum in *Terminalia* soil (85·2 cm) and a minimum in *Eucalyptus* soil (74·0 cm). The mean plant height attained by oats at 60, 90 and 120 days after sowing was significantly better in plantation soils than in cropland soil (Figure 1b). The oats achieved maximum height in 120 days in *Terminalia* soil (106·5 cm) followed closely in the *Prosopis* soil (102·4 cm) and minimum in cropland soil (78·0 cm). The fertility and

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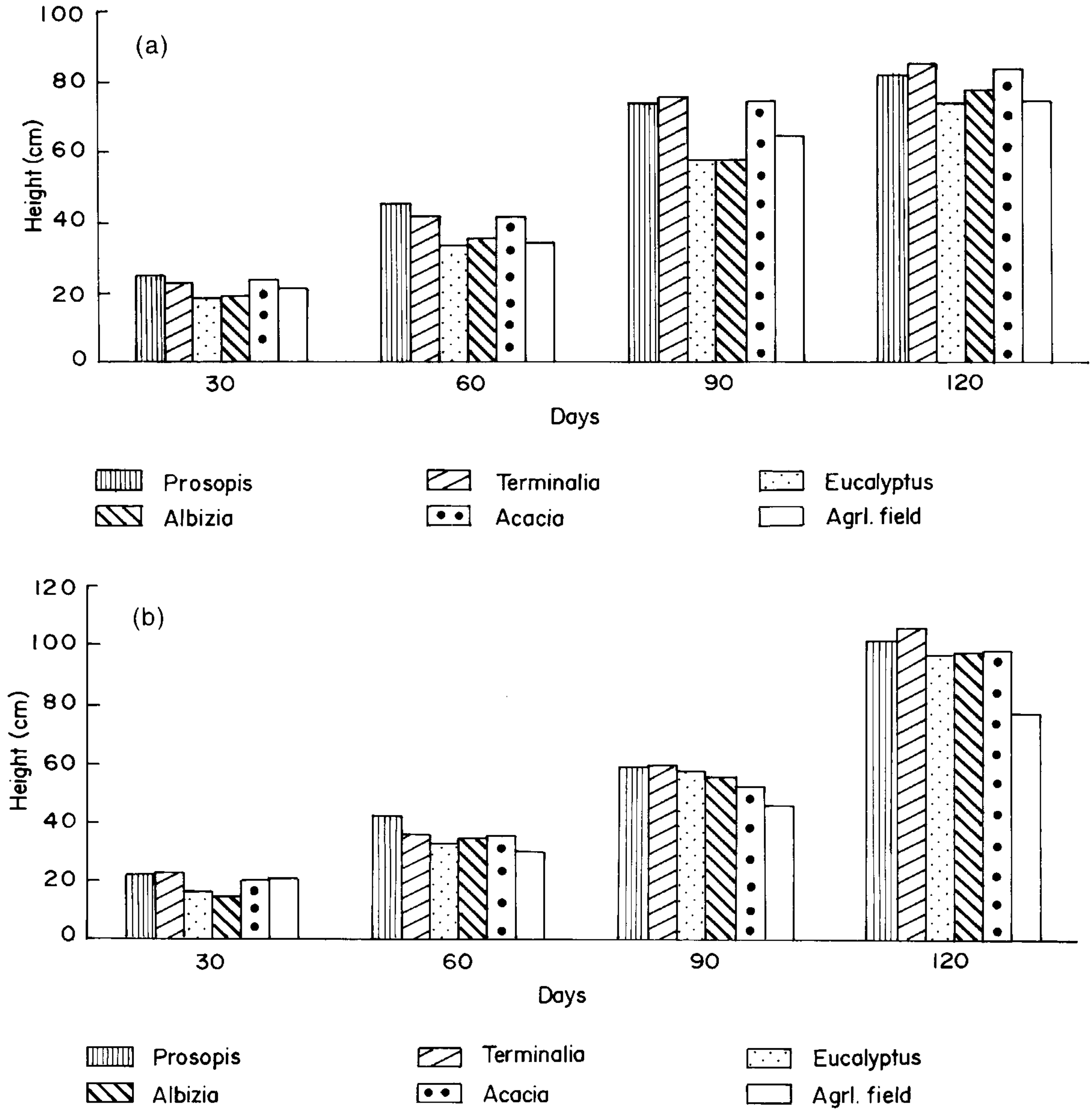

Figure 1. Periodic increment in height growth of (a) wheat and (b) oat crops in different soils

amelioration effects of tree plantations were clearly reflected in the height observations on both test crops. Similarly, tillers per plant of both test crops recorded 60 days after sowing were significantly more in plantation soils than in cropland soil (Table III). Tillers were almost 2·5 times more in *Prosopis* and *Acacia* plantation soils compared to the cropland soil (Figure 2a and 2b). Further, both test crops produced significantly more tillers in *Prosopis* and *Acacia* soils than in *Terminalia*, *Eucalyptus* and *Albizia* soils. Other important yield components of wheat and oat crops, such as ear length, spikelets per plant, also increased with tree-induced changes in soil properties. These responses were consistent with earlier studies (Mass and Grieve, 1990; Nicolas, *et al*., 1993) showing that tillering and yield were highly sensitive to salt stress.

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Table III. Growth and yield attributing characteristics of wheat and oat crops grown in plantation soils and in a reference farm soil

Soil	Wheat				Oats		
	Germiniation after 10 days (%)	Tiller per plant	Ear length (cm)	Grains per ear	Germination after 10 days (%)	Tiller per plant	1000 grains wt. (g)
Prosopis	93	7·7	11·5	54·0	97	11·0	38·5
Terminalia	97	5·7	10·2	49·0	100	8·0	32·8
Eucalyptus	93	4·0	10·1	45·3	97	6·8	31·1
Albizia	87	4·7	11·3	48·0	97	8·2	29·2
Acacia	93	7·0	11·1	52·0	93	10·3	38·7
Cropland	87	3·0	9·7	43·0	93	4·7	32·3
CD (0·05)	NS	0·86	0·31	2·6	NS	1·2	2·2

CD: critical difference or least significant difference.

Table IV. Grain and straw yields of wheat and oats in a sodic soil reclaimed through tree plantations and on a reclaimed sodic farm soil

Soils	Wheat		Oats	
	Grain (yield gram per pot)	Straw	Grain (yield gram per pot)	Straw
Prosopis	61·7	87·5	87·9	111·1
Terminalia	44·0	38·5	45·8	62·8
Eucalyptus	32·3	25·3	42·7	58·5
Albizia	45·3	43·5	52·8	66·9
Acacia	55·7	68·8	61·6	67·5
Cropland	13·3	15·4	24·3	26·7
CD (0·05)	2·8	2·0	7·0	9·4

Crop Yields

Grain and straw yields of test crops were significantly higher in five soils taken from tree plantations compared to the control farm soil (Table IV). Yields of both crops increased in the ascending order: Cropland soil *Eucalyptus*, *Terminalia*, *Albizia*, *Acacia*, *Prosopis*. Wheat and oat grain yields achieved in the *Prosopis* soil were 4·5 and 3·5 times higher, respectively, than that obtained on the control farm soil, suggesting that prolonged afforestation may restore productivity of abandoned soils much above the agricultural production levels. A similar trend was observed in straw yields of both crops. The root biomass of both crops was also markedly higher in *Prosopis* and *Acacia* soils (Figure 3a, 3b). These observations supported our earlier assumptions (Singh, *et al*., 1993) and similar views held by others (Ahmed, 1991) that sodic soils may be rehabilitated to full agricultural productivity by *Prosopis* plantations in 8 to 15 years. These assumptions, however, were based purely on the improvements in soil properties brought about by trees rather than growing crops on such soils as used in the present study. Higher yields of wheat and oat crops in *Prosopis* and *Acacia* soils than in the other three soils is probably due to better organic matter and nutrient status of these soils. Among the five tree species, the yields were lowest in *Eucalyptus* soil, suggesting its poor reclaiming effects on sodic soils. Being a non-leguminous species, *Eucalyptus* may not reclaim sodic soils at the same pace as many of the leguminous trees such as *Prosopis*, *Acacia* and *Albizia* species. Moreover, *Eucalyptus* leaves contain more sodium concentration than *Acacia* and *Prosopis* trees of the same age.

A large fraction of sodium is thus returned to the soil through litter fall every year. Since germination, growth and yield of both crops was better in all the five plantation soils than in the control farm soil, the possibility of an accumulation of growth inhibiting allelochemicals in the soil is ruled out.

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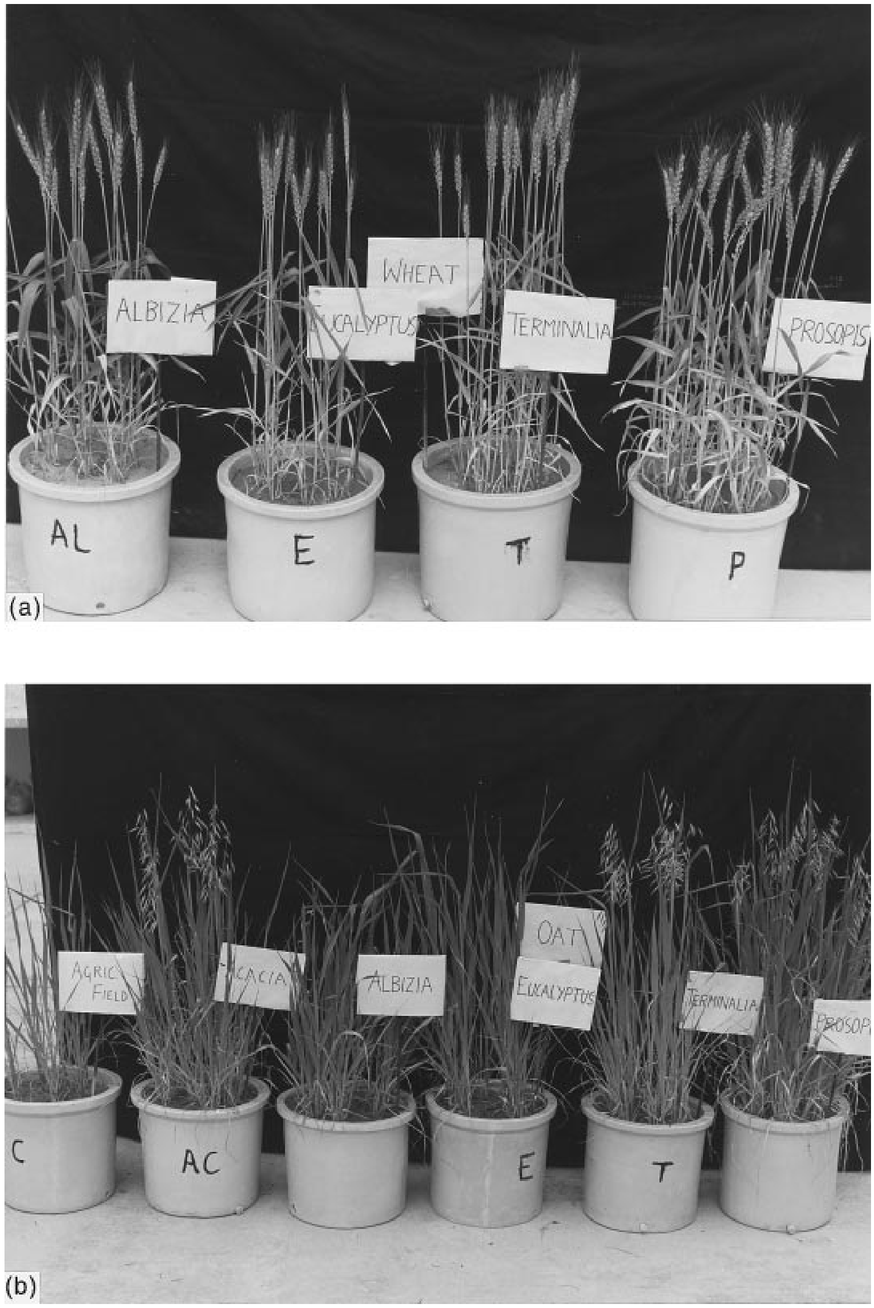

Figure 2. Growth performance of (a) wheat and (b) oat crops in different soils

Chemical Composition

Phosphorus and potassium concentrations in grain, straw and root parts of wheat and oat crops was measured to assess the effect of the fertility status of the test soils (Tables V and VI). Phosphorus concentration in both the crops was maximum in grains and minimum in root parts; whereas potassium concentration was highest in straw. Concentration of both elements in plant tissues increased with soil

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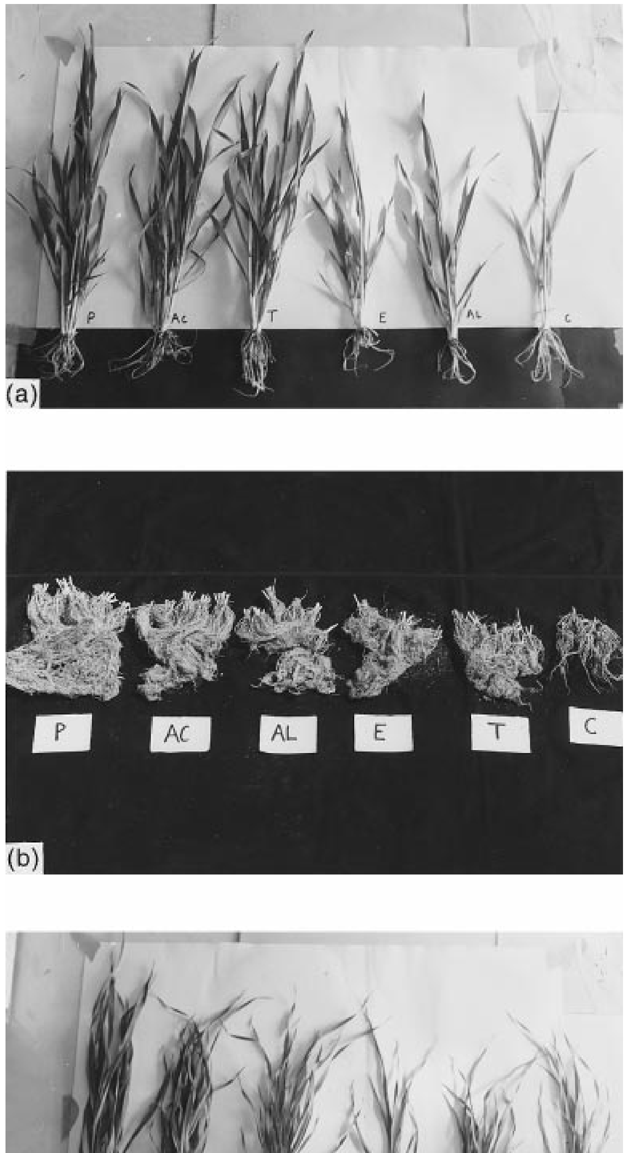

Figure 3. Root development of (a) and (b) wheat and (c) oats in different soils

nutrient availability; however, the response was more pronounced when expressed in uptake terms. Phosphorus concentration in grain, straw and roots of both crops was markedly less when these crops were grown on *Eucalyptus* and *Albizia* soils compared to other treatments. Low phosphorus concentration in former soils is presumably due to low phosphorus status of these soils. The P concentration in whole plant

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Table V. Phosphorus and potassium concentration in different parts of oats grown in different soils

Soils	P (%)			K (%)		
	Grain	Straw	Root	Grain	Straw	Root
Prosopis	0·23	0·110	0·095	0·43	2·41	0·25
Terminalia	0·28	0·093	0·087	0·44	2·08	0·16
Eucalyptus	0·17	0·081	0·066	0·42	2·12	0·22
Albizia	0·13	0·072	0·067	0·46	2·51	0·18
Acacia	0·24	0·150	0·134	0·45	2·62	0·19
Cropland	0·23	0·138	0·087	0·43	2·53	0·15
CD (0·05)	0·10	0·019	0·021	NS	0·22	0·08

Table VI. Phosphorus and potassium concentration in different parts of wheat grown in different soils

Soils	P (%)			K (%)		
	Grain	Straw	Root	Grain	Straw	Root
Prosopis	0·34	0·053	0·103	0·43	2·12	0·25
Terminalia	0·33	0·038	0·085	0·44	1·88	0·16
Eucalyptus	0·24	0·029	0·058	0·36	1·99	0·22
Albizia	0·21	0·020	0·056	0·37	1·91	0·18
Acacia	0·33	0·042	0·142	0·43	1·85	0·19
Cropland	0·37	0·045	0·085	0·45	1·67	0·15
CD (0·05)	0·12	0·018	0·026	NS	0·28	NS

tissues (average of grain, straw and root) was highest in *Prosopis* soil followed closely by the cropland soil. Higher P concentration in tissues of wheat and oat in cropland soil may be attributed to reduced dilution effects as the total biomass of both crops in this treatment was much less than in plantation soils. The effect of different soils on K concentration in wheat and oat grains was not significant. However, wheat straw contained significantly more K when grown on *Prosopis* and *Albizia* soils than on cropland soil. On the other hand, oat straw retained significantly higher K in *Acacia*, cropland, *Albizia* and *Prosopis* soils than in *Eucalyptus* and *Terminalia* plantation soils. Potassium in the root segment of both the crops was highest (0·25 per cent) in *Prosopis* soil and minimum when these were grown on cropland soil (0·15 per cent).

CONCLUSIONS

It was concluded that amelioration of abandoned sodic soils by growing trees is feasible. In some specific situations, where amendments are not available or costly, this approach may be a promising alternative for reclamation and revegetation of sodic soils. Further, from the consideration of soil amelioration, raising of *Prosopis* and *Acacia* plantations may be a better practice in sodic soils. The rehabilitation effects were further confirmed by the present pot trials which assessed the productivity of most common agricultural crops (wheat and oats) grown on plantations and cropland soils. The results indicated that sodic soils reclaimed by tree plantations, particularly by *Prosopis* and *Acacia*, can be used for raising wheat and oat crops. The yield levels of wheat and oats achieved in the *Prosopis* soil (which were 4·5 and 3·5 times higher respectively for wheat and oats than was obtained on the control farmland), suggested that prolonged afforestation of sodic soils by such trees may restore productivity of once-abandoned soils much above the present agricultural production levels. Our results further suggest that prolonged occupation of sodic soils by trees did not result in accumulation of germination and growth inhibiting allelochemicals in the soil which may adversely affect the agricultural crops when grown on such soils. In this study, the crop stand and productivity was many times better in plantation soils than in no-tree control farm soils.

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