EFFECT OF FUELWOOD PLANTATIONS ON SOME PROPERTIES OF SODIC WASTELANDS

V.K. Garg* & R.K. Jain

National Botanical Research Institute, Lucknow, Uttar Pradesh, India

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GARG, V.K. & JAIN, R.K. 1996. Effect of fuelwood plantations on some properties of sodic wastelands. A field experiment was conducted at the Biomass Research Centre in Banthra, India with the objective to assess changes in sodic soil characteristics through addition of litterfall and root growth of *Dalbergia sissoo* and *Terminalia arjuna* plantations. The results showed an alteration in the physical and chemical properties of the sodic wastelands by the decreasing soil pH and ESP values and increasing organic carbon contents of the soils, more under the former than the latter species after a decade. There was a decrease in bulk density from 1.8 to 1.5 (10^3 kg m^{-3}) but an increase in soil porosity from 40 to 48% and water holding capacity from 2.9 to 4.5 g kg^{-1} at the surface (15 cm) layer under *D. sissoo*. Production of total litter mass was estimated at 5.0 and 5.4 t $ha^{-1}yr^{-1}$ for *D. sissoo* and *T. arjuna* respectively. Leaf litter played an important role in the circulation of nutrients by these species and higher amounts of N (88 kg ha^{-1}) and K (25 kg ha^{-1}) would be returned by the former, and Ca (64 kg ha^{-1}) and Mg (47 kg ha^{-1}) by the latter species. Return of P (6-7 kg ha^{-1}) was minimum by the leaf litter of both species. The amount of nutrient recycled by leaf litter was in the order of N>Ca>Mg>K>P. The study also indicated that *D. sissoo*, being capable of producing wider root spread and deep penetration, ameliorates sodic soils more efficiently than *T. arjuna* which has a poor fibrous and fine feeder root system.

Key words: *Dalbergia sissoo* - *Terminalia arjuna* - sodic wasteland - litter production - root growth

GARG, V.K. & JAIN, R.K. 1996. Kesan ladang kayu api ke atas beberapa ciri tanah tandus sodik. Satu eksperimen lapangan dijalankan di Pusat Penyelidikan Biojisim di Banthra, India untuk menentukan perubahan ciri-ciri tanah sodik melalui penambahan sarap dan pertumbuhan akar ladang *Dalbergia sissoo* dan *Terminalia arjuna*. Keputusan menunjukkan perubahan ciri-ciri fizikal dan kimia tanah tandus sodik dari segi pengurangan pH tanah dan nilai ESP dan penambahan kandungan karbon organik tanah. Perubahan lebih banyak berlaku pada spesies pertama berbanding dengan spesies kedua selepas satu abad. Terdapat penurunan di dalam ketumpatan pukal daripada 1.8 kepada 1.5 (10^3kg m^{-3}) tetapi peningkatan di dalam keliangan tanah daripada 40 hingga 48% dan keupayaan pegang air daripada 2.9 hingga 4.5 g kg^{-1} pada lapisan permukaan (15 cm) untuk *D. sissoo*. Penghasilan jumlah sarap jisim dianggarkan pada 5.0 dan 5.4 t ha^{-1} $tahun^{-1}$ bagi *D. sissoo* dan *T. arjuna* masing-masing. Sarap daun memainkan peranan penting di dalam kitaran nutrien oleh spesies-spesies ini dan jumlah yang lebih tinggi bagi N (88 kg ha^{-1}) dan K (25 kg ha^{-1})

*Corresponding author: *Soil Testing Laboratory, National Botanical Research Institute, Rana Pratap Marg, P.B. No. 436, Lucknow - 226 001, India*

akan dikembalikan oleh spesies pertama, dan Ca (64 kg ha^{-1}) dan Mg (47 kg ha^{-1}) oleh spesies kedua. Pengembalian P (6-7 kg ha^{-1}) oleh sarap daun kedua-dua spesies minimum. Jumlah nutrien yang dikitarkan oleh sarap daun berada di dalam susunan N>Ca>Mg>K>P. Kajian juga menunjukkan bahawa *D. sissoo* mampu menghasilkan penyebaran akar yang lebih luas dan penembusan yang dalam, membaikkan tanah sodik dengan lebih efisien berbanding *T. arjuna* yang mempunyai akar serabut dan sistem akar penyerap halus yang lemah.

Introduction

Owing to the depleting sources of conventional energy, fuelwood production has come into prominence and stimulated forestry research programmes on either salt affected or other wastelands because of the vast availability of such lands in India and elsewhere (Kovda 1965, Toth 1981, Barrett-Lennard *et al.* 1986, Singh *et al.* 1989, Jain & Garg 1993). In an earlier study, Garg and Jain (1992) reported on an assessment of sodic soil amelioration by the influence of some fast growing fuelwood legumes grown under short rotation forestry practices. They also evaluated the potential changes in physical and chemical properties of sodic soil in relation to the distribution of tree roots and amount of litter added to the soil. This paper reports, as a continuation of previous studies, on the interaction of some other tree species, tolerant to alkali soil and of important commercial value, with sodic soil after a decade of growth. The objective of the study was to assess changes in sodic soil characteristics through the addition of litterfall and root growth.

Materials and methods

Study site

The experimental site lies between 80° 45-53'E and 26° 40-45'N located at Lucknow-Knapur highway about 23 km away from the National Botanical Research Institute, Lucknow, India. General relief of the site is flat with a gentle slope of about 1-1.5 per cent.

Site soils are Inceptisol with silty clay loam texture and characterised by high pH (9-10) and low organic matter. These soils are non-saline sodic with exchangeable sodium percentage (ESP) of 30-50 and EC <2 dS m^{-1}. Carbonate and bicarbonate of Na and Ca are dominant ions. The soil profile has restricted subsurface drainage with mottling of MnO_2 and roundish granules of iron 3-5 mm in size. Indurated pans comprising big size lime nodules ($CaCO_3$) of 10-31.5 mm are found at 45-75 cm depth of the soil profile. The water table is of 4-5 m depth. These soils often get waterlogged, particularly during rains, and impair root growth and function due to the adverse effect of oxygen stress. Some soil chemical properties of the site before the trees were planted are presented in Table 1.

Table 1. Chemical properties of soil profile at the Biomass Research Centre before the trees were planted

Depth (cm)	pH	EC ($dS\ m^{-1}$)	OC (%)	Exchangeable cations Na	K	Ca	Mg
				[c mol (+) kg^{-1}]			
0 - 15	9.7	0.41	0.03	9.18	0.88	8.25	5.00
15 - 45	10.4	0.41	0.03	18.09	0.80	8.25	4.25
45 - 75	10.8	0.60	0.03	21.60	0.72	4.25	1.25
75 - 105	10.5	0.41	0.27	18.36	0.72	4.00	1.00
105 - 135	9.9	0.41	0.60	11.61	0.64	3.25	2.75
135 - 165	9.3	0.41	0.60	5.67	0.56	4.75	1.25
165 - 195	8.9	0.40	0.60	2.97	0.56	10.50	1.50

Note: *Means are of three samples each representing one replication composited in turn from sampling of three soil pits.* Exchangeable cations were determined following 1.0 N (pH 7) ammonium acetate extraction.

Experimental

One-year-old seedlings of *Dalbergia sissoo* Roxb. Ex. D.C. and *Terminalia arjuna* Bedd. were planted in about one cubic metre pit already dug and filled with original soil without any soil amendment. Planting stock was procured from old plantations of these species located at Allen forest (Kanpur) and raised by the State Forest Department. Experimental plots measuring 40 × 40 m had 625 trees per plot spaced at 1.5 m with a mean of 3900 trees per hectare, arranged in randomised block design with three replications. Soil samples were drawn from May to June 1981, the planting time up to the year 1989, from the inner plots of 20 × 20 m to avoid boundary effects. Three pits were dug in each replicate under both the species and soil samples were collected from each pit at 15 cm intervals, depending on the penetration of tree roots, from different depths. Thus, three composite samples were made for each tree species for various depths. These samples were homogenised and processed for analysis to assess the changes in soil characteristics. Soil pH was determined in 1: 2 soil water ratio. Organic carbon was estimated by the modified Walkley and Black method. Total N was determined by the macro Kjeldahl procedure using a Tecator Kjeltec Auto 1030 Analyser (Jackson 1967). The exchangeable cations (Na^+, K^+, Ca^{++} and Mg^{++}) were extracted from the soil with neutral normal ammonium acetate solution and estimated by flame photo-meter for cation exchange capacity (CEC). Thereafter, exchangeable sodium percentage (ESP) was calculated from the formula ESP = exch. sodium content [C mol (+) 100 g^{-1}] × 100/CEC [C mol (+) 100 g^{-1}] (Richards 1954).

The bulk density (B.D.) was determined by drying and weighing a known volume of undisturbed soil samples. Particle density (P.D.) of the oven dried soil was determined when air was excluded using a pycnometer. Thereafter, soil porosity was calculated from the percentage of soil volume not occupied by the soil particles. The maximum water holding capacity (WHC) was determined gravimetrically after completely saturating the soil with water using circular metal boxes with perforated bottom (Richards 1954).

Litter samples were collected by randomly placing a 50 × 50 cm wooden frame attached with nylon net at the base, at 12 locations under each species for three years from 1987-89. The litter samples were hand-picked periodically at one month intervals and separated into leaves, woody parts (twigs) and reproductive parts (flower and fruits). After separation, all samples were oven dried at 65 °C and weighed to determine the total yield of litter. Litter samples were then ground, oven dried and analysed for total N by the macro Kjeldahl method using a Tecator Kjeltec Auto 1030 Analyser. For P, K, Ca and Mg, a 1g litter sample was digested in triacid mixture of HNO_3, H_2SO_4, $HClO_4$ (10:4:1). Phosphorus was determined colorimetrically using the vanadomolybdophosphoric yellow colour method and K and Ca by flame photometry. Mg was determined by subtracting Ca from Ca+Mg, estimated by titration by the versenate method (Jackson 1967). Total nutrient accumulation in litter was estimated by multiplying concentration data by the litter mass to assess the nutrient likely returned to the soil via litter fall.

Three healthy and three poor growth (weak) trees as indicated by height and girth were excavated from 1 m^3 of soil to assess the distribution pattern of roots in the soil profile. The root system of each species was exposed and studied following the methods of Bohm (1979). Observations were recorded for root penetration, lateral root spread and distribution pattern of root in the soil profile.

Results and discussion

Soil characteristics

Soil organic carbon status at *D. sissoo* and *T. arjuna* sites was found to have gradually increased over a decade from 1981, the year of planting, at the 0-15 cm soil depth. A six times increase was observed beneath the former and about four times beneath the latter species. Organic C content also increased up to 30 cm depth in *T. arjuna* and up to 45 cm depth in *D. sissoo* in the soil profile. Although little differences were observed at deeper depths (45-60 cm) the absolute value of organic C was greater in *D. sissoo* than in *T. arjuna*. Like organic C, total N was also found to increase in the surface soil under both tree species. However, the total build-up of N status of soil was observed up to 30 cm depth in both species compared to the values in 1981. At deeper depths N differences were not apparent between the species (Figure 1). The accumulation of organic carbon and total N contents in the surface (15 cm) soil by these species was comparable to that of other fuelwood trees planted on such sites (Gill *et al.* 1987, Singh 1989, Garg & Jain 1992, Shukla & Misra 1993). Our study shows that the difference in accumulation of nitrogen and organic matter by these trees in the soil was probably due to the variation in the penetration and distribution of their roots in the soil profile (Figure 6) because they contribute much to the build-up of organic matter content in the soil (Pritchett 1979). It has been shown in studies on forest litter decomposition that the quality and initial N concentration of litter play a key role in the addition of organic matter and N to the soil (Gupta & Singh 1981, Melillo *et al.* 1982, Blair 1988, Blair *et al.* 1992). The present study shows that N concentration in the leaf litter of *D. sissoo* was greater than in *T. arjuna* (Table 3). Leaf tissues of the former species are soft, relatively lighter and smaller than those of *T. arjuna.* They were observed to disintegrate easily into small pieces and be incorporated quickly into the soil. However, the leaf lamina of *T. arjuna* is hard and more resistant to decomposition owing to the coriaceous properties of its leaf structure.

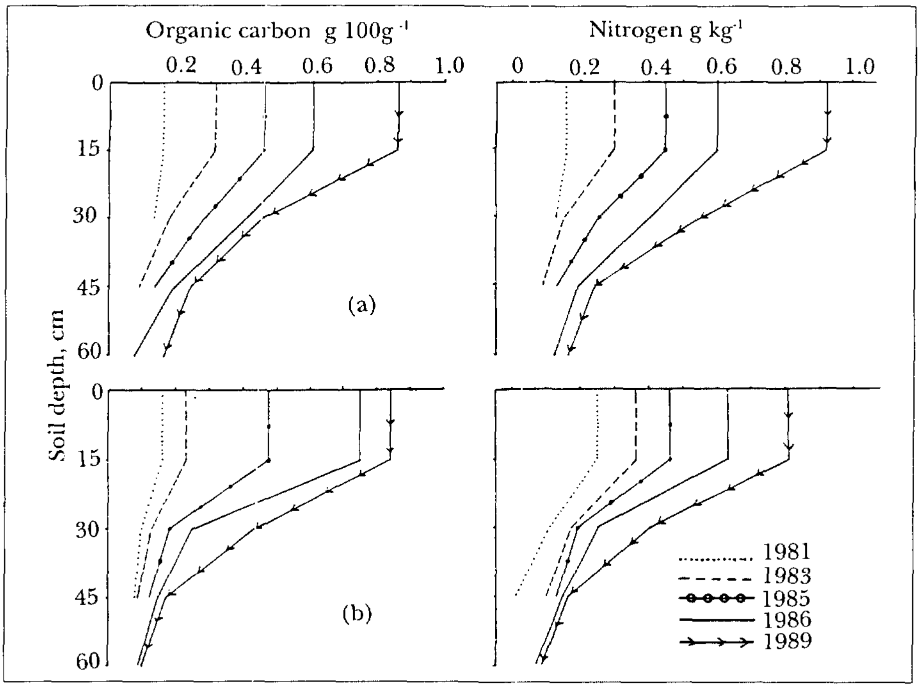

Figure 1. Accumulation of organic carbon and total nitrogen contents of sodic soil under (a) *Dalbergia sissoo,* and (b) *Terminalia arjuna*

Soil pH declined over a decade from 9.8 to 8.4 and from 9.4 to 8.5 in the surface (15 cm) depth under *D. sissoo* and *T. arjuna* respectively. While the decrease was more pronounced in the former than in the latter species, at deeper depths (30-60 cm) it was not remarkable. Similarly, soil ESP decreased under both species after a decade at 0-15 cm depth. However, this decrease was slightly greater under *D. sissoo* than under *T. arjuna* despite their almost identical initial values in 1981 at this depth. In general, the decrease in soil ESP became less apparent, especially beyond this depth, under *D. sissoo* (Figure 2). Likewise, a gradual depletion of exchangeable Na^+ was also recorded due to the growth of these species, i.e. about 50% in the surface (15 cm) layer under *D. sissoo* and 31% under *T. arjuna.* On the other hand, exchangeable Ca^{++} content of the soil showed an appreciable increasing trend under these tree species. This increase was greater at the surface (15 cm) layer under *D. sissoo* than under *T. arjuna*. At deeper depths (15-60 cm), less differences were observed in exchangeable Na^+ and Ca^{++} between the two species (Figure 3). The relative changes in chemical properties of sodic soil supporting these species can be attributed to the roots having different penetration and distribution patterns in the soil profile (Figure 6). The fibrous and deep penetrating roots of *D. sissoo* may absorb water from soil layers below the surface resulting in a decrease of evaporation from the sodic soil and reduction of Na accumulation near the soil surface. Another factor for the depletion in exchangeable Na^+ contents in the soil may be due to biological production of carbonic acid (H_2CO_3) by tree roots causing a reduction in soil pH which solubilises the native $CaCO_3$ present in the sodic soil and increases the Ca^{++} content in the soil solution, sufficient to replace the Na^+ effectively, thus causing a decline in the soil ESP. This phenomenon is well reflected in the results of our study (Figure 3).

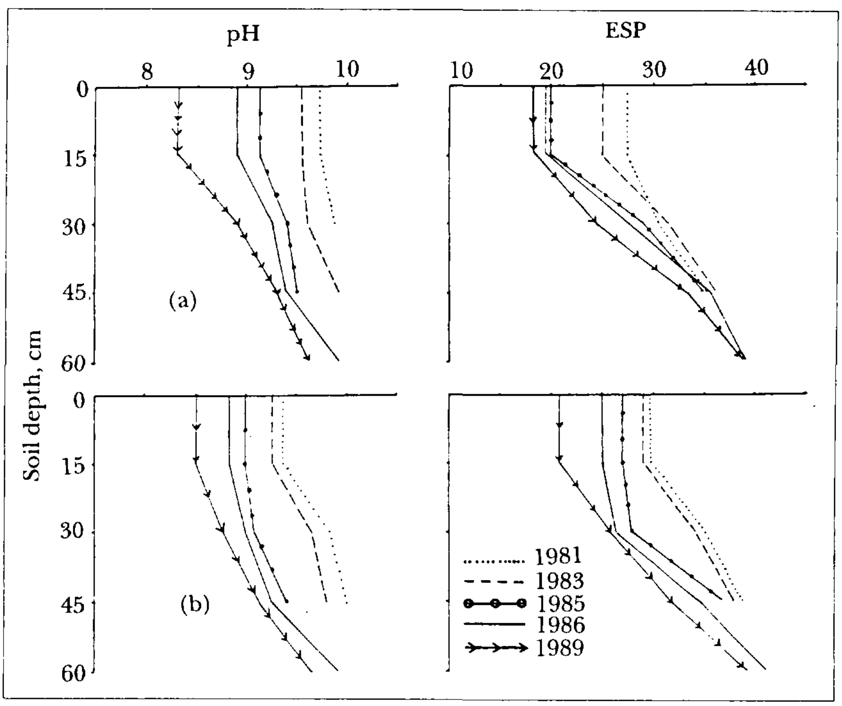

Figure 2. Reduction in soil pH and ESP (exchangeable sodium percentage) content of sodic soil under (a) *Dalbergia sissoo*, and (b) *Terminalia arjuna*

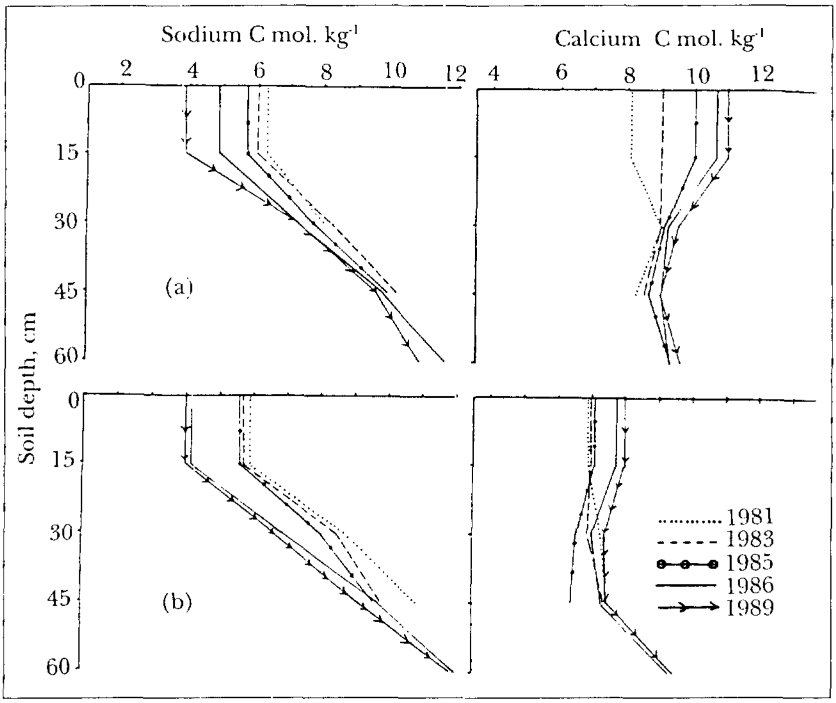

Figure 3. Changes in exchangeable sodium and calcium contents of sodic soil under (a) *Dalbergia sissoo,* and (b) *Terminalia arjuna*

Some of the important soil physical properties determined under these tree species are presented in Table 2. It can be seen that bulk density decreased more markedly under *D. sissoo* than *T. arjuna* and soil porosity and water holding capacity (WHC) increased greater in the former than in the latter species at the surface (15 cm) layer over a decade compared to the adjacent unplanted site. Similar results due to the growth of tree plantations on sodic soil have been observed by Shukla and Misra (1993). The possible reason for the higher value of bulk density at the unplanted site may be due to the greater compaction and defloculation of soil particles restricting capillary pores (Pandey & Pathak 1975). A greater increase in moisture content of the soil under *D. sissoo* than under *T. arjuna* could be ascribed partly to the build-up of organic matter in the soil and partly to the development of a deep and fibrous root system by the former species which acts as a biodrain. Increase in soil moisture through incorporation of humus has also been reported by Biswas and Ali (1969).

Table 2. Changes in some physical properties of sodic soil (0-15 cm depth) in *D. sissoo* and *T. arjuna* plantations

Tree species	Bulk density (10^3 kg.m^{-3})	Porosity (%)	Water holding capacity (g kg^{-1})
D. sissoo	1.50[b]	48	4.5
T. arjuna	1.55[b]	45	4.0
Unplanted site	1.80[a]	40	2.9

Note: Numbers in the same column followed by different letters are significantly different (p = 0.05; *t* - test)

Litter mass and nutrient return

The total litter mass yield estimated was 5.0 and 5.4 t ha^{-1} y^{1} for *D. sissoo* and *T. arjuna* respectively. Leaf mass (91 - 93%) dominated the litter of the two species, and woody components as twigs comprised only 2.3 - 5%. Reproductive parts of the planted species accounted for 1-3% and other unidentified miscellaneous parts constituted 1-2% (Table 3). The peak litterfall period was in December for *D. sissoo* and March for *T. arjuna*. The total litterfall pattern for different month is presented in Figure 4. Results of this study are in general agreement with those of others (Bray & Gorham 1964, Gill *et al.* 1987, Garg & Jain 1992), except for *D. sissoo* showing a slightly higher value than that reported by Sharma *et al* (1988), which may be due to edaphic factors.

Table 3. Mean annual litter mass and nutrients in different components of fuelwood trees

Tree species	Components	Litter mass (kg ha^{-1})	N	P	K	Ca	Mg
			(g kg^{-1})				
D. sissoo	Leaf	4867 ± 53	18.0	1.2	5.2	12.9	6.8
	Woody parts	12 ± 2	6.9	0.7	2.0	14.0	2.2
	Reproductive parts	157 ± 5	20.6	2.3	1.9	12.4	6.2
T. arjuna	Leaf	5359 ± 46	8.6	1.4	3.7	12.0	8.9
	Woody parts	31 ± 4	9.0	1.0	0.9	16.0	15.0
	Reproductive parts	3 ± 0.2	7.0	1.0	0.5	10.2	10.0

Note: Means (± s.d.) are over years. Each year there were 12 samples per month.

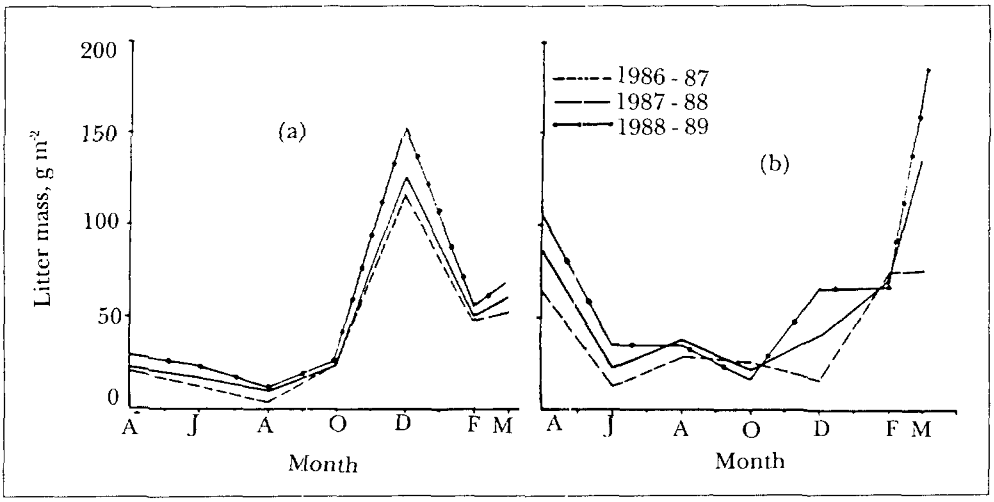

Figure 4. Monthly distribution pattern of total litter mass in (a) *Dalbergia sissoo*, and (b) *Terminalia arjuna* plantations

Most of the nutrients in the litter of these species stands were in the leaf followed by the twig and reproductive parts. The mean concentration of N in the leaf litter of *D. sissoo* was much higher than in that of *T. arjuna*. The concentration of leaf P and Ca varied little in both species. Leaf K status was higher in *D. sissoo* than *T. arjuna*, whereas the trend for leaf Mg was reversed (Table 3). An estimate of the mean annual nutrients likely to return to the surface soil by way of the different components of litterfall assessed was found in the order of N>Ca>Mg>K>P. Since the amounts of nutrient recycled by the leaf were much higher than by the woody or reproductive parts of these species. Hence, the amounts of nutrient released by leaf litter of these species are presented in Figure 5. The leaf litter of *D. sissoo* gave the higher amounts of N (88 kg ha^{-1}) and K (25 kg ha^{-1}), while more Ca (64 kg ha^{-1}) and Mg (47 kg ha^{-1}) would be returned by the leaf litter of *T. arjuna*. Both species would return a very low quantity of P, i.e. at 6 and 7 kg ha^{-1} by *D. sissoo* and *T. arjuna* respectively. Thus, the circulation of nutrients by leaf litter would be in the order of N>Ca>Mg>K>P. This trend may be ascribed to the differences in composition of nutrients in the leaf litter of these tree species (Table 3). Thus, it is clear that the higher concentration of N in the leaf litter of *D. sissoo* would cause it to recycle N more efficiently than *T. arjuna* and add higher organic carbon by virtue of its litter decomposition. The other factor responsible for the increased concentration of N in the former species may be due to the effective contribution of *Rhizobium* in fixing N symbiotically. Likewise, the higher concentration of K in *D. sissoo* is due to its efficient uptake of K from sodic soil which contains illite, a dominant clay mineral, with a good K reserve (Pal & Mondal 1980). The low leaf litter composition of P reflects the inherent deficiency of P in sodic soil (Garg 1987). The concentrations of Ca and Mg in the leaf litter of these species arise from their being less mobile constituents of cell wall or chlorophyll.

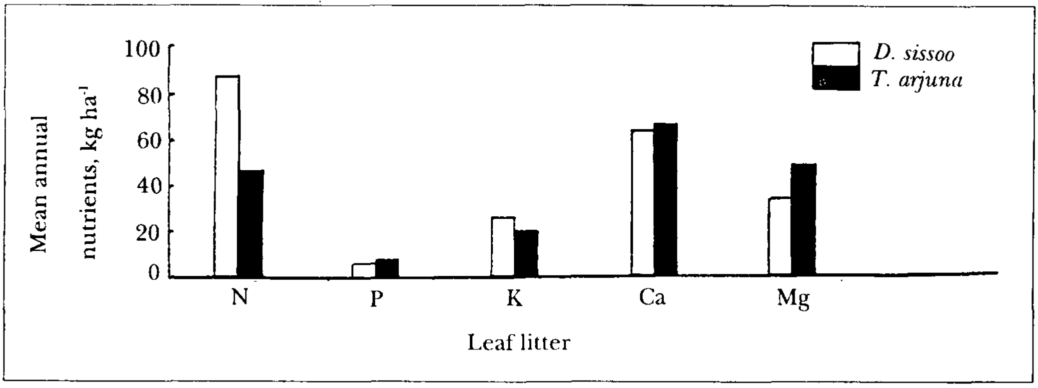

Figure 5. Estimates of mean amounts of nutrient recycled to the soil by leaf fall

Root habit and distribution

Apart from a proportionate variation in root spread and penetration, no distinct differences were observed between the root systems of healthy and poor growth trees of the two species due to local site conditions (Figure 6). Generally, tree rooting habit and configuration are under genetic control; however, they are good indicators of the volume of soil occupied by a particular root system (Pritchett 1979). In addition, the distribution of root also affects the edaphic factors (Sutton 1969). Thus, the root system of healthy trees of both species is being considered and discussed to evaluate the changes in the sodic soil condition due to tree root growth. Our study shows that although both tree species develop primary roots, their capability of horizontal spread and penetration into the soil depth is comparatively 30 - 40% better in *D. sissoo* than in *T. arjuna.* The bulk of compact fibrous and fine feeder roots of the former species was found in the 0 - 30 cm surface of soil, while such roots were confined only to 15 cm of soil in the latter species. The main root of *D. sissoo* took a first turn at 30 cm and a second at 50 cm depth of soil; this may be due to the presence of a caliche layer of $CaCO_3$ nodules. There was an indurated calcareous pan below the 50 cm depth which did not allow the main root of *T. arjuna* to penetrate but secondary roots proliferated there (personal observation). Therefore, major changes in sodic soil properties were noticed under *D. sissoo* up to the 30 cm depth and up to the 15 cm layer under *T. arjuna* due to preponderance of a fine root system which is important in water and nutrient absorption, bringing changes in physico-chemical properties of the sodic soil (Figures 1 & 2). These results are in general agreement with observations made of the root growth pattern of *Prosopis juliflora* planted at such sites (Garg & Jain 1992).

The present study thus clearly indicates that *D. sissoo* trees are more capable of producing a wider root spread and deeper penetration and are therefore liable to ameliorate sodic soil more efficiently than *T. arjuna* trees.

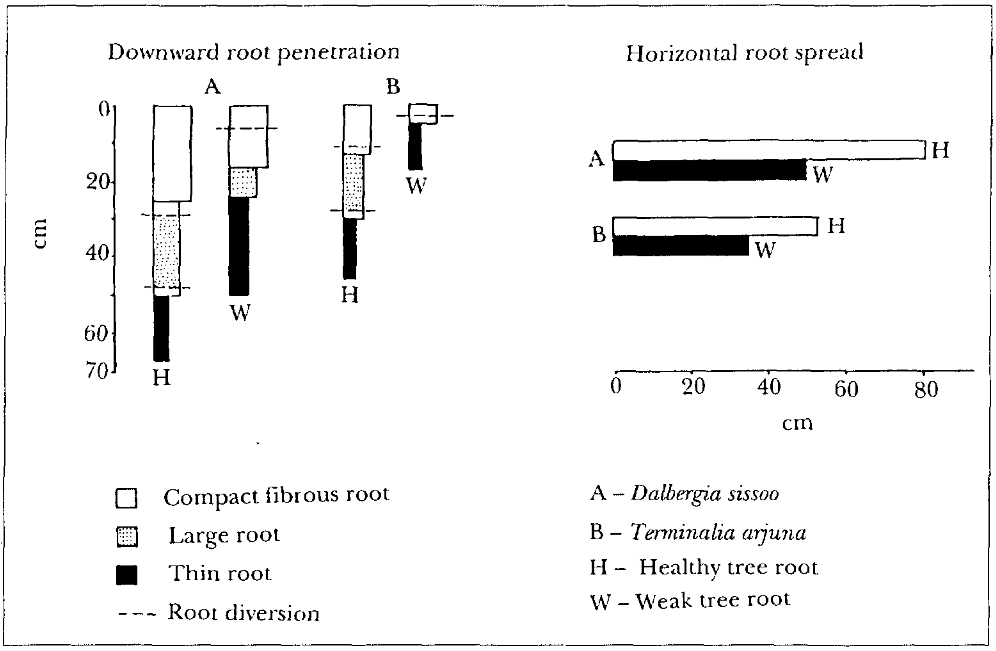

Figure 6. Root distribution pattern in soil profile

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References

BARRETT-LENNAND, E.G., MALCOM, C.V., STERN, W.R. & WILKINS, S.M. (Eds.) 1986. *Forage and Fuel Production from Salt Affected Wasteland.* Elsevier Amsterdam.

BOHM, W. 1979. Method of studying root system. *Ecological studies* 33 : 5 -14.

BISWAS, T.L. & ALI, M.H. 1969. Retention and availability of soil water as influenced by soil organic carbon. *Indian Journal of Agriculture Science* 37 : 618 - 624.

BLAIR, J.M. 1988. Nitrogen, sulfur and phosphorus dynamics in decomposing deciduous leaf litter in the southern Applachians. *Soil Biology and Biochemistry* 20(5): 693 - 701.

BLAIR, J.M., CROSSLEY, D.A., JR. & CALLAHAM, L.C. 1992. Effects of litter quality and microarthopods on N dynamics and retention of exogenous ^{15}N in decomposing litter. *Biology and Fertility of Soils* 12: 241-252.

BRAY, J.R. & GORHAM, E. 1964. Litter production in forests of the world. *Advances in Ecological Research* 2: 101-158.

GARG, V.K. 1987. Soil-chemical appraisal. Pp. 15 - 18 in Khoshoo, T.N. (Ed.) *Ecodevelopment of Alkaline Land Banthra - A Case Study.* NBRI, CSIR, PID, New Delhi.

GARG, V.K. & JAIN, R.K. 1992. Influence of fuelwood trees on sodic soil. *Canadian Journal of Forestry Research* 22 : 729 - 735.

GILL, H.S., ABROL, I.P. & SAMRA, J.S. 1987. Nutrient recycling through litter production in young plantations of *Acacia nilotica* and *Eucalyptus tereticornis* in a highly alkaline soil. *Forest Ecology and Management* 22 : 57 - 69.

GUPTA, S.R. & SINGH, J.S. 1981. The effect of plant species, weather variables and chemical composition of plant material on decomposition in a tropical grassland. *Plant and Soil* 59 : 99 - 117.

JACKSON, M.L. 1967. *Soil Chemical Analysis.* Prentice-Hall of India Pvt. Ltd., New Delhi : 183 - 226.

JAIN, R.K. & GARG, V.K. 1993. Role of multipurpose tree species (MPTS) in the management of sodic lands. Pp. 47 - 51 in Mehrotra, N.K. & Garg, V.K. (Eds.) *Management of Productivity Constrained U.P. Soils.* Lucknow Chapter Indian Society of Soil Science. NBRI, Lucknow, India.

KOVDA, V.A. 1965. Alkaline soda-saline soils. *Agrokem Talajt* 14 : 15 - 48.

MELLILO, J.M., ABER, J.D. & MURATORE, J.F. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. *Ecology* 63 : 621 - 626.

PAL, D.K. & MONDAL, R.C. 1980. Crop response to potassium in sodic soils in relation to potassium release behaviour in salt solution. *Journal of Indian Society of Soil Science* 28 : 347 - 354.

PANDEY, R.N. & PATHAK, A.N. 1975. Physical properties of normal and salt affected soils of Uttar Pradesh. *Indian Journal of Agricultural Research* 9(2) : 63 - 70.

PRITCHETT, W.L. 1979. *Properties and Management of Forest Soils.* John Wiley & Sons Inc. New York : 156-172.

RICHARDS, L. (Ed.) 1954. *Diagnosis and Improvement of Saline and Alkali Soils.* U.S. Salinity Laboratory Staff, U.S. Department of Agriculture Handbook 60.

SHARMA, D.C., TANEJA, P.L. & BISHT, A.P.S. 1988. Biomass productivity and nutrient cycling in a *Dalbergia sissoo* plantation. *Indian Forester* 114 : 261 - 268.

SHUKLA, A.N. & MISRA, P.N. 1993. Improvement of sodic soil under tree cover. *Indian Forester* 119 : 43 - 52.

SINGH, B. 1989. Rehabilitation of alkaline wasteland on the Gangetic alluvial plains of Uttar Pradesh, India through afforestation. *Land Degradation and Rehabilitation* 1: 305 - 310.

SINGH, G., ABROL, I.P. & CHEEMA, S.S. 1989. Effect of gypsum application on mesquite (*Prosopis juliflora*) and soil properties in an abandoned sodic soil. *Forest Ecology and Management* 29 : 1 - 14.

SUTTON, R.F. 1969. *Form and Development of Conifer Root Systems.* Technical Communication 7. Commonwealth Agricultural Bureau, Oxford, England. 131 pp.

TOTH, B. 1981. Afforestation on salt affected soils in Hungary. *Agrokem Talajt* 30 : 205 - 212.