BIOAMELIORATIVE ROLE OF TREE SPECIES IN SALT-AFFECTED VERTISOLS OF INDIA

B. N. Patil*, S. G. Patil, M. Hebbara, M. V. Manjunatha, R. K. Gupta & P. S. Minhas

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PATIL, B. N., PATIL, S. G., HEBBARA, M., MANJUNATHA, M. V., GUPTA, R. K. & MINHAS, P. S. 2005. Bioameliorative role of tree species in salt-affected Vertisols of India. A field experiment was conducted at the Agricultural Research Station, Gangavati, Karnataka, India to study the effect of tree species on bioamelioration of saline Vertisols. Six tree species, namely, *Casuarina equisetifolia, Acacia nilotica, Dalbergia sissoo, Azardirachta indica, Sesbania grandiflora* and *Hardwickia binata* were chosen for the experiment. Reduction in soil salinity, calcium carbonate and soil soluble sodium, bicarbonate, chloride, sulphate and sodium adsorption ratio was observed under all the tree species apart from improvement in organic carbon. Tree species such as *A. nilotica* and *C. equisetifolia* with higher biomass production exhibited greater bioamelioration potential in saline Vertisols.

Key words: Shallow water table – saline soils – biomass production – soil improvement

PATIL, B. N., PATIL, S. G., HEBBARA, M., MANJUNATHA, M. V., GUPTA, R. K. & MINHAS, P. S. 2005. Peranan spesies pokok dalam pembaikan biologi Verstisol masin di India. Satu eksperimen lapangan dijalankan di Stesen Penyelidikan Pertanian, Gangavati, Karnataka, India untuk mengkaji kesan spesies pokok terhadap pembaikan biologi Vertisol masin. Enam spesies pokok iaitu *Casuarina equisetifolia, Acacia nilotica, Dalbergia sissoo, Azardirachta indica, Sesbania grandiflora* dan *Hardwickia binata* dipilih untuk eksperimen ini. Pengurangan berlaku pada kemasinan tanih, kalsium karbornat, natrium larut, bikarbonat larut, klorida larut, sulfat larut dan juga nisbah jerapan natrium di bawah semua spesies pokok. Selain itu terdapat juga pembaikan karbon organik. Spesies pokok seperti *A. nilotica* dan *C. equisetifolia* yang mempunyai penghasilan biojisim yang lebih tinggi menunjukkan pembaikan biologi yang lebih tinggi di Vertisol masin.

Introduction

Salt-affected soils occupy 18 million ha in 15 states of India (Yadav 1998) and have become a major concern to planners. Adoption of intensive agriculture has further intensified the problems due to excess use of agricultural inputs such as fertilizers, plant protection chemicals and water, with no provision for drainage. The conventional engineering solutions to provide drainage are not only cost prohibitive but also time consuming. Revegetation efforts of such lands with new options are bioameliorative, besides providing cover, fuel, fodder, timber and control of soil

**Current address: Department Environmental Sciences, University of Agricultural Sciences, Dharwad*

and water erosion. The choice of proper tree species is thus largely governed by their ability to withstand hostile stress environment such as high salinity, sodicity and water logging. Genetic or species variation determines the ability of trees to withstand such unfavourable soil conditions. Keeping these in view, present investigation was initiated to evaluate the role of tree species for their bioameliorative potentials in salt-affected Vertisols.

Materials and methods

Field experiment was conducted from 1991 to 1997 on saline Vertisols of Tungabhadra irrigation project, south India. The experimental site lies between 75° 31' E longitude and 15° 15' N latitude with an altitude of 419 m above mean sea level. The climate is arid to semiarid and during the study period the average annual rainfall was 625 mm, with most of it in September and October.

Initial soil physico-chemical properties indicated that the soil (0–60 cm) comprised 23.1% sand, 29.5% silt and 47.4% clay. At 0–90 cm depth soil reaction and mean soil salinity (EC_e) range from 7.79 to 7.97 and 10.5 to 14.0 dS/m respectively (Table 1). Soil was medium deep varying from 0.75–1.00 m with calcic layer underneath. The average depth of water table was within 0.5 m during monsoon and 0.8 m during summer season.

The experiment followed a randomized complete block design with three replications and the performance of tree species, in particular their bioameliorative effects, under saline and shallow water table conditions was evaluated. Six tree species, namely, *Hardwickia binata, Sesbania grandiflora, Acacia nilotica, Dalbergia sissoo, Casuarina equisetifolia* and *Azardirachta indica* were selected for the experiment.

Soil samples (depth of 0–90+ cm) were drawn at planting and at 48, 60 and 72 months after planting and were analysed. Soil salinity, soil soluble sodium (flame photometry), Ca^{2+} + Mg^{2+} (versenate method), bicarbonate (acid-base titration) and chloride (by titration with silver nitrate) were determined in the saturation extract (Richards 1954). The sodium adsorption ratio (SAR) was calculated using soil soluble Ca^{2+} + Mg^{2+} and Na^{+}. Soil organic carbon, calcium carbonate and sulphate were determined by wet oxidation method (Jackson 1973), acid neutralization (Piper 1950) and turbidometric method (Verma *et al.* 1977) respectively.

Results and discussion

Salinity

During the study period, tree species displayed a marked variation in their ability to reduce soil salinity. Removal of salts from soil surface (0–30 cm) was evident. These salts were either redistributed within the soil profile or leached out. A decrease in salinity (> 36 months after planting) was 75% in *A. nilotica* followed by 74% in *C. equisetifolia* (Figure 1). These two species, with larger biomass production potential, canopy cover and soil organic matter content also had higher

Table 1 Initial soil physico-chemical properties of the experimental site

Properties	Soil depth (cm)				
	0-15	15-30	30-60	60-90	90+
Particle-size analysis (%)					
Clay	46.8	47.5	48.6	-	-
Silt	29.2	29.5	30	-	-
Coarse sand	5.4	6	6.8	-	-
Fine sand	18.7	17	14.6	-	-
Total sand	24	23	21.4	-	-
Texture class	c	c	c	cl	g
EC_e (dS/m)					
Range	1.3–42.9	1.3–32.8	1.8–27.3	2.1–22.9	2.6–21.0
Mean	14	12.3	12.5	11.7	10.5
pH mean	7.89	7.97	7.96	7.79	7.81
Soil OC ($g.kg^{-1}$)					
Range	3.9–10.5	1.2–9.7	1.2–8.1	1.9–8.1	1.0–4.7
Mean	7.6	5.5	4.3	3	3.1
$CaCO_3$ (%)					
Range	8.9–15.9	9.0–15.9	9.7–16.8	10.0–17.2	10.4–18.6
Mean	12.4	12.6	13	13.9	14.6
Soil soluble composition (1:2.5):	Cations (me/l)				
Na^+					
Range	2.6–172.1	2.6–158.3	3.5–133.9	5.2–104.6	4.4–100.0
Mean	116.8	93.6	100.8	86.8	84.2
K^+					
Range	0.06–0.54	0.03–0.32	0.05–0.29	0.03–0.26	0.04–0.19
Mean	0.43	0.29	0.28	0.24	0.25
Ca^{2+}					
Range	1.5–32.5	1.5–27.1	1.5–26.0	1.5–25.0	0.5–26.0
Mean	30.4	24.7	25.6	22.3	21.83
Mg^{2+}					
Range	0.5–17.5	0.5–19.0	0.5–19.8	0.5–19.0	0.5–15.5
Mean	12.8	10.1	11.2	9.6	8.7
	Anions (me/l)				
CO_3^{2-}					
Range	-	-	-	-	-
Mean					
HCO_3^-					
Range	1.2–7.2	1.0–7.7	1.4–5.8	1.4–6.8	0.4–7.5
Mean	8.9	6.6	6.5	3.8	6.5
SO_4^{2-}					
Range	1.5–181.2	1.5–176.9	3.0–168.3	7.7–202.2	5.3–214.0
Mean	122	109	112.8	105.5	98.1
Cl^-					
Range	1.0–97.0	1.0–53.0	1.0–32.0	1.0–25.8	1.0–19.0
Mean	27	14.6	10.6	8.7	10.4
SAR $(m.mol/l)^{1/2}$					
Range	2.6–34.4	2.6–33.0	3.5–28.2	5.2–22.2	6.2–22.0
Mean	15.2	15	15.5	15.2	15.8

bioameliorative effects (Figure 2). Larger canopy decreased salinity by reducing evaporation and upward salt flux. Species such as *D. sissoo, S. grandiflora* and *H. binata* only showed marginal reduction in soil salinity. Despite its slow growth *A. indica* decreased soil salinity. A considerable decrease in soil salinity has been reported when intertree row spaces were utilized for growing grass (Maliwal *et. al.* 1990). Although soil salinity was reduced in the initial years, a slight increase was observed at the end of the study period, i.e. at 72 months after planting, due to higher evapotranspiration (Huperman *et al.* 2002). Accumulation of salts in the root zone is potentially a major limitation of trees in saline discharge areas, which is in agreement with Morris (1991).

pH

Soil pH increased marginally under all the trees studied (Table 3). Increase in soil pH was higher in surface layer of the soil (0–30 cm) compared with subsurface. Increase in pH is an evidence of leaching of saline soils (Maliwal *et al.* 1990, Drechsel *et al.* 1991, Vadiraj 1993).

Organic carbon

Figure 2 shows that soil organic carbon was higher when litterfall (biomass) under tree cover was greater, as seen in *Acacia nilotica* (10.0 g kg^{-1}) and *C. equisetifolia* (9.0 g kg^{-1}). This observation concurs with findings by Suwalka and Qureshi (1995). Slow growing species, such as *H. binata* and *A. indica*, have lower biomass production and thus contribute little to soil organic carbon.

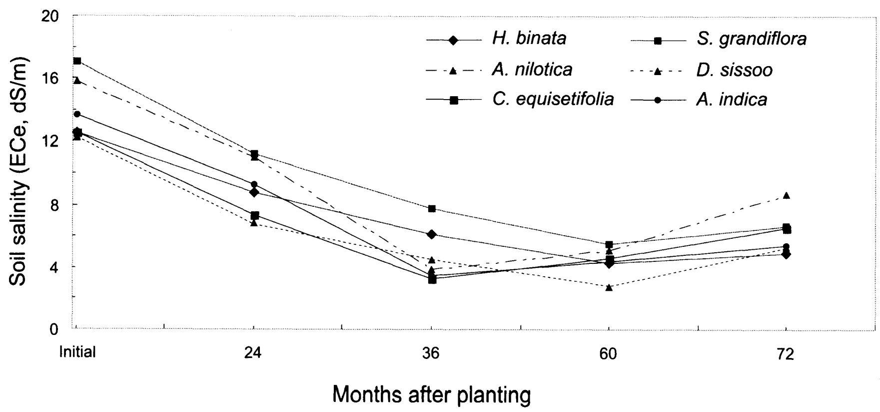

Figure 1 Effect of tree species on soil salinity (0–30 cm)

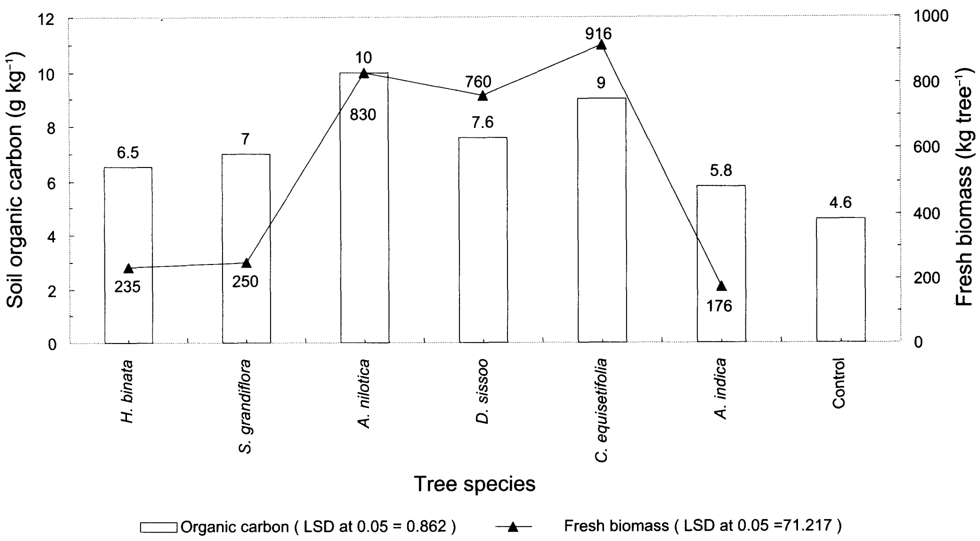

Figure 2 Effects of tree species on soil organic carbon and fresh biomass yield

Soluble sodium

Soil soluble sodium decreased considerably after 48 months of planting (Table 2). The highest decrease was observed in *A. nilotica* (63.3%) followed by *S. grandiflora* (62.6%) and *C. equisetifolia* (59.2%). In contrast, *H. binata* (44.9%), *A. indica* (30.5%) and *D. sissoo* (21.2%) remained less effective in improving soil properties. Efficiency decreased with decrease in the level of any particular ion. Generally, our study showed a net removal of sodium from the soil under all tree species. Soil soluble sodium decreased as the depth of soil increased irrespective of tree species and *A. nilotica, C. equisetifolia* and *S. grandiflora* facilitated downward flux of sodium into the lower horizons.

Soluble bicarbonate

Soil solution remained free of carbonates as soils were predominantly saline. Soluble bicarbonates decreased with time irrespective of tree cover and all species had a net flushing effect (Table 2). Of the six species studied, *A. nilotica* removed bicarbonates most effectively, i.e. 77%. This was followed by *C. equisetifolia* (75%) and *D. sissoo* (66%). *Acacia indica* (14%) continued to be least effective in bioamelioration of soil. Flushing of bicarbonate was higher in the surface (0–30 cm) layer.

Soluble chloride

All tree species, except *A. indica,* decreased soluble chloride. *Acacia nilotica, S. grandiflora* and *H. binata* flushed out more chloride than the rest of the species

Table 2 Effects of tree species on soil pH and soil solution composition

	Soil depth (cm)							
	0–30		30–60		60+		Mean	
	BP	48 MAP	BP	48 MAP	BP	48 MAP	BP	48 MAP
Soil pH								
H. binata	7.65	8.27	7.82	8.27	7.9	8.3	7.79	8.28
S. grandiflora	7.8	8.16	7.94	8.14	7.94	8.22	7.89	8.17
A. nilotica	7.87	8.13	7.84	8.13	8	8.07	7.9	8.11
D. sissoo	7.93	8.22	7.89	8.19	8	8.14	7.94	8.18
C. equisetifolia	7.89	8.26	7.94	8.25	8.05	8.14	7.96	8.22
A. indica	7.69	8.03	7.87	8.16	7.94	8.1	7.83	8.1
Control	7.93	*	7.96	*	7.8	*	7.89	*
Soil soluble sodium (me/l)								
H. binata	58.1	29.8	46	25.6	37.5	22.8	47.2	26
S. grandiflora	91.5	32.2	75.4	26.1	65.2	28.4	77.4	28.9
A. nilotica	38.8	9.2	40	11.5	32.6	20.1	37.1	13.6
D. sissoo	17.6	4.8	15.4	12.3	12.3	18.8	15.1	11.9
C. equisetifolia	24.8	4.1	25	7.4	15.1	14.8	21.6	8.8
A. indica	36.1	17.4	26.6	20.4	24.7	22.8	29.1	20.2
Control	105.2	*	100.8	*	85.5	*	97.2	*
Soil soluble bicarbonate (me/l)								
H. binata	3	1.3	2.9	1.6	2.6	1.3	2.8	1.4
S. grandiflora	4.4	1.8	3.8	1.9	3.8	2	4	1.9
A. nilotica	2.7	0.6	2.9	0.7	3.7	0.7	3.1	0.7
D. sissoo	3.6	0.7	3.1	1.1	2.4	1.3	3	1
C. equisetifolia	2.9	0.8	3.6	0.7	3.5	0.8	3.3	0.8
A. indica	2.7	2.5	3	2.6	3.1	2.3	2.9	2.5
Control	7.7	*	6.5	*	5.2	*	6.5	*
Soil soluble chloride (me/l)								
H. binata	21.5	5.4	7	5.9	4.3	5.9	10.9	5.7
S. grandiflora	21.7	4.8	5.9	5.4	5.9	6.7	11.1	5.6
A. nilotica	7.4	1.4	3.1	2.2	3.4	3.5	4.6	2.4
D. sissoo	3.3	1.4	2	2	2.4	3.4	2.6	2.3
C. equisetifolia	3.8	1.1	1.9	1.8	2.3	4.7	2.7	2.5
A. indica	6	4.2	3.3	5.4	2.1	5.6	3.8	5
Control	20.8	*	10.6	*	9.5	*	15.7	*
Soil soluble sulphate (me/l)								
H. binata	60	25.8	51.7	22.1	88.6	20.3	66.7	22.7
S. grandiflora	76.4	30.1	90.4	25.8	122.7	27.9	96.5	27.9
A. nilotica	60.8	8.6	58.1	10.7	65.2	20.2	61.3	13.1
D. sissoo	10.6	4.3	19.8	12.9	24.6	19.6	18.3	12.2
C. equisetifolia	14.8	4.2	22.1	6.7	33.8	13.2	23.5	8
A. indica	29.5	18.8	41.9	20.4	54.8	21	42	20
Control	115.5	*	112.8	*	101.8	*	110	*
Soil soluble SAR (m.mol/l) $^{0.5}$								
H. binata	14.7	19	14.6	15.1	13.5	13.3	14.3	13.4
S. grandiflora	24	16.2	20.7	13	19.6	15.2	21.4	14.8
A. nilotica	12.1	7.3	12.7	9.1	14	12.3	12.9	9.6
D. sissoo	8.2	4.5	8.8	8.4	7.7	10.7	8.2	7.8
C. equisetifolia	13.9	4	14.9	5.5	11	9.8	13.3	6.4
A. indica	14.2	8.7	12.3	9.1	13.1	11.6	13.2	9.8
Control	15.1	*	15.5	*	15.5	*	15.4	*

BP=before planting; MAP=months after planting; * not measured studied, ranging from 48–50% (Table 2). Bioameliorative effects of *D. sissoo* (11%) and *C. equisetifolia* (7%) were marginal. Soil under *A. indica* had a build up of 32% chloride. Our study also showed that the tree species were more efficient in removing chloride from the surface (0–30 cm) than from lower layers of soil.

Soluble sulphate

Soluble sulphate decreased under all tree covers but *A. nilotica* was the most efficient with 79% reduction (Table 2). Efficiency was least under *D. sissoo* (33%). As in the rest of the parameters studied, removal of sulphate was also more effective in the top 0–30 cm layers.

Sodium adsorption ratio

Tree species except *D. sissoo* decreased sodium adsorption ratio at 48 months of planting (Table 2). *Casuarina equisetifolia* was very effective in reducing sodium adsorption, i.e. as much as 52% followed by *S. grandiflora* (30%) and *A. nilotica* (25%). The decreases in other species were not comparable with *C. equisetifolia*. *Casuarina equisetifolia* also caused more than 71% reduction in sodium adsorption from the surface layer (0–30 cm), followed by *D. sissoo* (45%). Decrease in sodium adsorption ratio under vegetative covers has been reported elsewhere (Khanna 1994, Suwalka & Qureshi 1995).

Calcium carbonate

Calcium carbonate ($CaCO_3$) decreased under tree covers after 48 months of planting and all species mobilized non-labile $CaCO_3$ in soils (Figure 3). The decrease in $CaCO_3$ was highest under *A. nilotica* (32%) followed by *D. sissoo* (30.3%) and *H. binata* (26.3 %) due to higher biomass addition and increased organic carbon in soil (Figure 2). A higher decrease in $CaCO_3$ was due to increased microbial activity in litterfall and subsequent release of organic acids (Mongia & Bandyopadhyay 1992).

Conclusions

Tree species with higher biomass potential increased soil organic carbon and caused soil salinity to decrease. Soluble sodium, bicarbonate, chloride and sulphate as well as sodium adsorption ratio decreased under all the trees studied. Reduction in soil $CaCO_3$ suggested solubilization of native calcium carbonate due to decomposition of litterfall by microbes.

Among the trees studied, *A. nilotica* was most effective in the bioamelioration of salt-affected Vertisols, followed by *C. equisetifolia, D. sissoo* and *S. grandiflora. Hardwickia binata* and *A. indica* were less effective. Hence, species such as *A. nilotica* and *C. equisetifolia* are recommended for afforestation of saline soils.

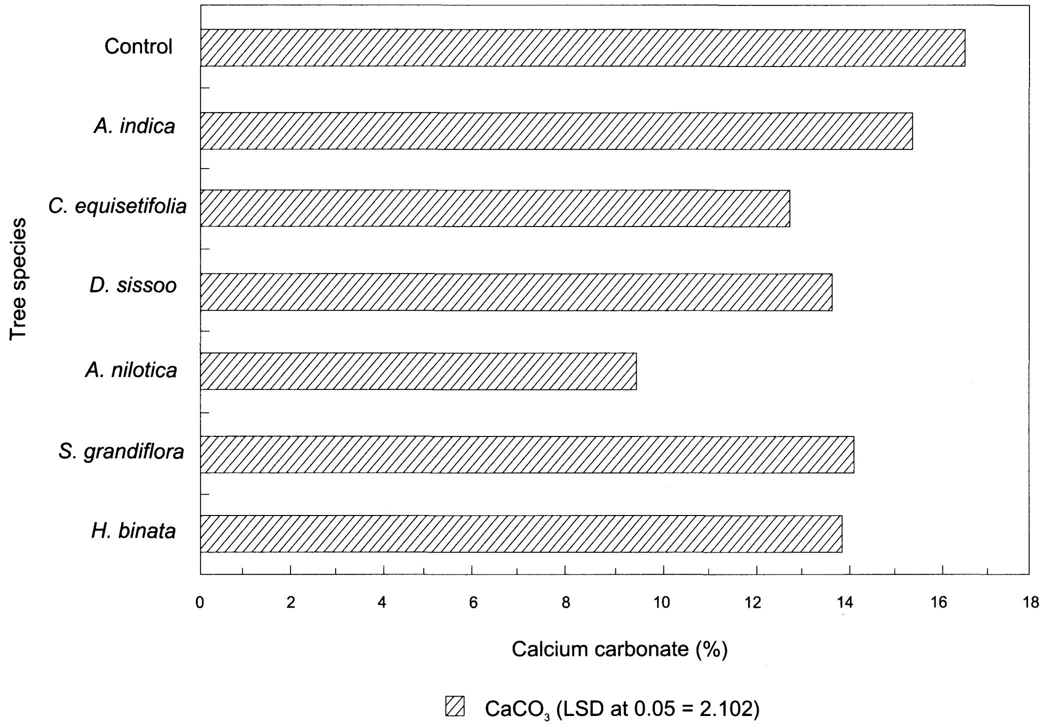

Figure 3 Influence of tree covers on soil calcium carbonate after 48 months of planting

References

Drechsel, P., Glaser, B. & Zech, W. 1991. Effect of four multi purpose tree species on soil amelioration during tree fallow in Central Tago. *Agroforestry Systems* 16:193–202.

Huperman, A. F., Kapoor, A. S. & Denecke, H. W. 2002. *Biodrainage Principles, Experiences and Applications.* Knowledge Synthesis Report No. 6, FAO-IPTRID.

Jackson, M. L. 1973. *Soil Chemical Analysis.* Prentice Hall of India Pvt. Ltd., New Delhi.

Khanna, S. S. 1994. Management of sodic soils through tree plantation. *Journal Indian Society of Soil Science* 42: 498–508.

Maliwal, G. L., Nadiyadara, S. H., Punjani, S. H. & Patel, C. L. 1990. Changes in soil properties as influenced by *Prosopis juliflora* and crop covers in salt affected soils. *Annuals of Arid Zone* 30: 57–60.

Mongia, A. D. & Bandyopadhyay, A. K. 1992. Physico-chemical changes occurring in soils of tropical forest after clear-felling for high value plantation crops. *Journal Indian Society of Soil Science* 40: 420–424.

Morris, J. D. 1991. Water table and soil salinity beneath tree plantations in ground water discharge areas. Pp. 82–83 in *Proceedings of the Third Australian Forest Soils and Nutrition Conference.* Australia.

Piper, C. S.1950. *Soil, Plant and Water Analysis.* Prentice Hall, New York.

Richards, L. A. 1954. *Diagnosis and Improvement of Saline and Alkali Soils.* USDA, Agriculture Handbook No. 60. United States Government Printers Office, Washington, District Columbia.

Suwalka, R. L. & Qureshi, F.M. 1995. Amelioration of some sodic soils in arid regions of Rajasthan. *Journal Indian Society of Soil Science* 43: 660–662.

Vadiraj, B. A. 1993. The influence of *Casuarina* age on soil characteristics in Karnataka. *Journal of Tropical Forest Science* 9: 55–62.

VERMA, B. C., SWAMINATHAN, K. & SUD, K. C. 1977. An improved turbidometric procedure for the determination of sulphate in plants and soils. *Talanta* 24: 49–51.

YADAV, J. S. P., 1998. Introduction to seminar. Pp. 3–6 in *Proceedings of the National Seminar on Water Management for Sustainable Agriculture. Problems and Perspectives for the 21st Century.* 15–17 April 1998. Indian Agricultural Research Institute, New Delhi. Water Technology Center and Water Management Society of India, New Delhi.