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Evaluating Multipurpose Tree Species for Biomass Production and Amelioration of Sodic Soil

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Ten multipurpose tree species were raised on sodic soil of Gangetic alluvium in north India (26°47′ N; 80°46′ E) with the objective to generate fuel wood in short rotations on sodic wastelands and their amelioration through plantation. All the species except *Prosopis alba* showed <10% mortality indicating the ability to establish under stress conditions. Maximum plant height was recorded with *Eucalyptus tereticornis* followed by *Casuarina equisetifolia* and *Prosopis juliflora*. *Acacia nilotica* outperformed the other species in terms of diameter at breast height (DBH) with a basal area of 13.04 m^2 ha^{-1} which was followed by *Prosopis juliflora* and *Casuarina equisetifolia* with a basal area of 9.92 and 9.64 m^2 ha^{-1}. Out of the ten species evaluated, aboveground biomass production of *Prosopis juliflora* was greatest among the *Terminalia arjuna, Azadirachta indica, Pongamia pinnata*, *Casuarina equisetifolia*, *Prosopis alba*, *Acacia nilotica*, *Eucalyptus tereticornis*, *Pithecellobium dulce* and *Cassia siamea* after ten years of growth period. As a result of plantation of these species on sodic soil, marked reduction in soil bulk density, pH, EC and exchangeable sodium percentage was observed, while there was increase in soil organic C content and infiltration rate after ten years of plantation. *Prosopis juliflora* was found to have maximum biomass production, recycle maximum N and C in soil through litter fall and thus having high sodic soil amelioration potential among the evaluated multipurpose tree species.

Key words: Sodic soils, multipurpose tree species, biomass production, Indo-Gangetic plains

Degradation of sodic lands due to accumulation of salts is frightening hazard to bring these soils under productive use and offer a great challenge for the restoration of these degraded lands (Qadir *et al.* 2006). With ever increasing population, increasing pressure on arable lands, lack of sustainable land uses and management, increasing food and energy security facing multiple challenges to find out solutions for alternate land uses of degraded lands (Muñoz-Rojas *et al.* 2015). Biomass production through plantation of tree species and establishing nutrient cycling on barren land are considered to be helpful in rehabilitating these lands and improving the quality of life (Lemenih *et al*. 2014; Tesfaye *et al.* 2015). Out of 6.73 million hectare (Mha) of salt-affected soils in India (NRSA and Associates 1996) nearly 2.8 Mha are sodic soils. These soils have been regarded as unfit for agriculture on account of high concentration of soluble salts capable of producing alkaline hydrolysis products such as Na_2CO_3, $NaHCO_3$ and sufficient exchangeable sodium to impart poor soil physical conditions. The presence of $CaCO_3$ concretions at various depths causes physical impedance for root proliferation, therefore, making it difficult for tree establishment. With the scarcity of fuel wood in many developing countries, various programmes of short rotation forestry were launched in the past two decades to full fill this basic need of rural communities (Barrett-Lennard *et al*. 1986; Lugo *et al*. 1990; Singh and Toky 1995). In India, sodic lands were generally allocated to the poor and land less peoples under poverty alleviation programme for rehabilitation and simultaneous improvement of the area (Singh 1989; Chaturvedi and Behl 1996). Despite the slow growth and low productivity, energy plantation established on barren sodic soils reclaimed the soils significantly (Garg and Jain 1992; Tripathi and Singh 2005; Singh *et al*. 2016). Since, the sodic soils are poor in fertility status and it is not ascertained whether nutrient removed from the soil during fuel

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wood production would be replenished naturally or require fertilization to sustain the subsequent rotation.

Very little information is available about biomass production of multipurpose trees species growing in sodic environment. Therefore, the present study was undertaken with the objectives to evaluate the effects of ten multipurpose tree species on above ground biomass production and effect on amelioration of sodic soils.

Materials and Methods

Site characteristics

The experiment was initiated at Shivri, Lucknow in north India (26°47′ N; 80°46′ E). Geographically this region is classified as Gangetic alluvial plains. A large tract of this alluvium constitutes abandoned sodic soils without any significant vegetation cover. The critical examination of the profiles revealed that the soil was alkaline, fine loamy, mixed, hyperthermic and classified as sodic Ustochrept (Sharma *et al*. 2011). The soil was having physical and nutritional problems because of poor soil water and soil air relations due to high bulk density (> 1.5 Mg m^{-3}), high pH (>10.0), low electrical conductivity (EC <3.0 dS m^{-1}) and high exchangeable sodium percentage (ESP > 85.0) (Table 1). The poor fertility of the soil is attributed to poor organic carbon (OC) content due to higher oxidation and dissolution of organic matter and low available N and excess amount of Na. The calcic horizons starts from 60 cm deep with thickness varying from 40 to 60 cm. Below the calcic horizon the soil was coarser and remain generally moist and free from calcareous salts. The annual rainfall varied from 700-1000 mm (long-term average 800 mm). More than 80% of the precipitation generally occurs during the monsoon season (July-September). The mean monthly temperature varied from 21 °C in January to 40.5 °C in June. Mean annual soil temperature ranges from 18.6 °C in winter to 32 °C in summer. The evaporation exceeds rainfall during all months except July and August. The groundwater table was measured from the piezometer at monthly interval during ten years of study period varied from 5-7 m.

Soil analysis

To diagnose the severity and extent of sodicity, soil profile up to 120 cm depth was dug-out and sampled before commencing the plantation and after 10 years of plantation in 2005. The soil samples were collected from under canopy of tree species and homogenized, passed through a 2-mm sieve and analyzed for soil characteristics. Soil pH was determined in 1:2 soil: water ratio. Organic carbon was determined according to the modified method of Walkley and Black (1934). Exchangeable cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) were extracted from the soil with neutral normal ammonium acetate solution. The concentration of Na^+ and K^+ were determined by flame photometer and Ca^{2+} and Mg^{2+} in the extract was determined through titration method (Jackson 1973). Exchangeable sodium percentage (ESP) was calculated from the formula described by Richards (1954). Soil bulk density was determined by core sampler method.

Plantation techniques

Nearly six months old saplings of ten tree species (*T. arjuna, A. indica, P. juliflora*, *P. pinnata, C. equisetifolia, P. alba, A. nilotica*, *E. tereticornis, P. dulce* and *C. siamea*) raised in a normal soil were planted in tractor operated auger holes of 45 cm diameter at the surface, 20 cm at the bottom and 120 cm deep keeping row to row and plant to plant spacing at 4 m and 3 m, respectively. The holes were filled with a uniform mixture of original soil + 4 kg gypsum + 10 kg FYM + 20 kg silt. Saplings were planted at a depth of 30 cm from the surface. For proper establishment of the saplings three irrigations were given at monthly interval.

Table 1. Soil properties of the experimental site

Soil depth (cm)	Bulk density (Mg m^{-3})	pH_2	EC_2 (dS m^{-1})	pHs	ECe (dS m^{-1})	ESP	Organic carbon (%)	$CaCO_3$ (%)	Na^+ (meq L^{-1})	$Ca^{2+} + Mg^{2+}$ (meq L^{-1})
0-15	1.64	10.46	1.43	9.94	2.08	89.0	0.08	2.41	24.17	9.00
15-30	1.57	10.55	2.42	10.08	3.15	82.6	0.08	1.26	21.30	9.00
30-45	1.55	10.60	1.00	10.17	1.48	80.2	0.06	2.32	34.43	7.50
45-60	1.51	10.51	0.64	10.12	1.02	78.0	0.08	8.92	21.65	7.50
60-90	1.50	9.95	0.44	9.51	0.82	76.0	0.08	11.69	17.57	7.50
90-120	1.48	9.68	0.28	9.29	0.74	76.0	0.06	12.46	10.96	6.00
Average	1.54	-	1.03	-	1.55	80.3	0.07	6.46	21.66	7.75

Biomass estimation

Plant survival and growth observations were taken annually. Circumference and diameter of the trees were measured at breast height level (1.3 m) every year with a diameter tape. Four trees of each diameter class from all species were marked for annual increment. A total of 40 sample trees representing the entire size variations amongst the ten species were harvested from the ground surface and their stem, branch and leaves were separated and weighed on air dry basis. Natural grasses regenerated under the tree canopy were harvested annually and weighed for air dry weight. Basal area is the cross sectional area of the stem at breast height level. The data were analyzed statistically using SPSS soft ware version 7.5 (Anon 1997).

Annual litter fall

Three litter collectors were placed under each tree species. A total of 30 litter collectors each of 0.50 m^2 were placed under the ten tree species. Litter collection was made monthly in each plot for a period of one year. About 50 g of air dried litter was enclosed in nylon net bags (15 cm × 25 cm) of 1 mm mesh. The collected litter was oven dried at 65±1° C and analyzed for different nutrients. The nutrient concentration was multiplied by annual litter fall to obtain the amount of nutrients transferred to the forest floor. Carbon and N sequestered by the species were estimated based on the N and C content in the leaf litter for each species and the quantity of litter fall per annum.

Results and Discussion

Survival and growth performance

The performance of different tree species was evaluated on the basis of survival %, growth (height, diameter at breast height (DBH), crown diameter and basal area) (Table 2). All the species had > 95 % survival except *P.alba* (50%), *C. siamea* (94%) and *A. indica* (90%) (Gill *et al*. 1990; Singh *et al*. 2011; Singh *et al*. 2017). Maximum plant height was recorded with *E. tereticornis* followed by *C. equisetifolia* and *P. juliflora. Acacia nilotica* outperformed the other species in terms of DBH with a basal area of 13.04 m^2 ha^{-1} which was followed by *P. juliflora and C.equisetifolia* with a basal area of 9.92 and 9.64 m^2 ha^{-1}. All other species had basal area below 8.5 m^2 ha^{-1}. Tree growth is influenced by a number of factors including genotypes, agro-climatic conditions and cultural practices. Adequate supply of nutrients is of utmost importance and depends on soil conditions. Correlation coefficients (r) calculated for height and diameter was positive and statistically significant in *P. juliflora*, *P. pinnata, P. dulce, A. nilotica*, *C. equisetifolia, T. arjuna, E. tereticornis and A. indica,* compared to non-significant positive relation in *C. siamea* (0.63) and *P. alba* (0.56) having lower 'r' values. *P. juliflora* recorded highest crown diameter (8.87m) followed by *C. equisetifolia* (8.75 m) and *A. indica* (7.53 m).

Biomass Production

Above ground biomass production was greatest in *P. juliflora* (56.50 Mg ha^{-1}) and *Acacia nilotica* (50.75 Mg ha^{-1}) corresponding to their fast growth and high yield in sodic soil over the biomass yield of other species tested in the study (Table 3). Lugo *et al.* (1990) and Singh *et al*. (2008) have reported the similar trend of above ground biomass production in tropical tree plantations. The annual increment in above ground biomass production between 2-4 and 4-6 years age of *P. juliflora* was 67.7 and 17%, respectively and after that there was 22 and 7%

Table 2. Mean growth of ten multipurpose tree species aged ten years on sodic soils

Tree Species	Survival (%)	Height (m)	DBH (cm)	r*	Crown diameter (m)	Basal area (m^2 ha^{-1})
Terminalia arjuna	100	4.96	9.20	0.63	2.40	5.53
Azadirachta indica	90	5.01	8.46	0.82	7.53	4.68
Prosopis juliflora	100	8.14	12.32	0.98	8.87	9.92
Pongamia pinnata	100	5.87	9.27	0.98	5.42	5.61
Casuarina equisetifolia	97	8.25	12.24	0.85	8.75	9.64
Prosopis alba	50	5.85	8.46	0.56	3.00	4.68
Acacia nilotica	96	6.83	14.12	0.67	7.20	13.04
Eucalyptus tereticornis	99	9.31	11.10	0.48	4.80	8.05
Pithecellobium dulce	100	6.39	10.15	0.96	5.80	6.73
Cassia siamea	94	4.10	5.63	0.43	4.18	2.06
LSD (P=0.05)	NS	0.96	6.50	-	1.12	1.6

r = Height × DBH

Table 3. Above ground biomass production by ten years old multipurpose tree species planted on sodic soils

Tree species	Biomass ($Mg\ ha^{-1}$)				Natural grass ($Mg\ ha^{-1}$)
	Stem	Branch	Leaf	Total	
Terminalia arjuna	23.78	10.70	7.13	41.62	5.20
Azadirachta indica	11.17	6.21	1.84	19.22	5.28
Prosopis juliflora	27.73	26.60	2.17	56.50	6.25
Pongamia pinnata	9.05	14.45	3.10	26.60	3.75
Casuarina equisatifolia	28.60	9.15	4.35	42.10	2.73
Prosopis alba	14.70	11.10	1.95	27.75	5.25
Acacia nilotica	22.15	26.14	2.46	50.75	6.35
Eucalyptus tereticornis	24.40	5.27	2.10	31.77	5.34
Pithecellobium dulce	23.50	6.81	1.94	32.25	5.21
Cassia siamea	14.30	5.65	1.70	21.65	5.35
LSD (P=0.05)	2.43	4.63	1.21	5.42	0.24

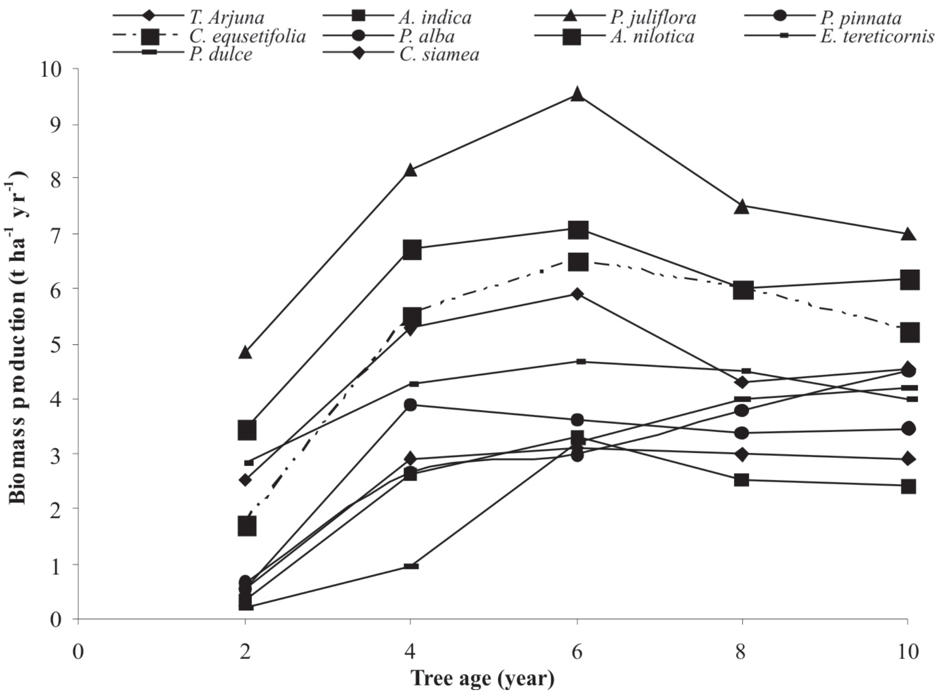

Fig. 1. Annual increment in biomass production of ten years old tree species planted on sodic soil

reduction in annual biomass increment between 6-8 and 8-10 years age, respectively. However, in *A. nilotica,* the annual increment between 2-4 and 4-6 years age was 94.5 and 5.5%, respectively (Fig. 1). Therefore, growth of *Prosopis juliflora* and *A.nilotica* up to six years of planting was quite encouraging. The growth of *T. arjuna, A. indica*, *P. alba*, *E. tereticornis*, *P. dulce* and *C. siamea* affected due to soil sodicity and low soil fertility which in general led to stressed growth.

The stem and branches contributed 34-77% and 17-54%, respectively in above ground biomass production. The foliage constituted 4 to 17% with the greatest value in *T. arjuna* and *P. pinnata* on account of a broad laminar morphology (Table 3). The higher productivity of above ground biomass recorded with *P. juliflora* and *A. nilotica* can be attributed to their greater tolerance to soil sodicity (Jain 1995; Singh *et al*. 2010). Therefore, *P. juliflora* and *A. nilotica* are highly biomass producing species under barren sodic soils of Indo-Gangetic Plains. Maximum under story biomass yield (6.35 $Mg\ ha^{-1}$) was recorded under the canopy of *A. nilotica* and minimum with *P. pinnata* (3.75 $Mg\ ha^{-1}$) and *C. equisetifolia* (2.73 $Mg\ ha^{-1}$). Maximum litter biomass obtained under *P. juliflora* (6.1 $Mg\ ha^{-1}$) canopies followed by *C. equisetifolia* and *A.nilotica* (Table 4). Gill *et al*. (1987) and Singh *et al*. (2010) have also reported the similar trend in plantations raised in a sodic soil. The winter months accounted for 40-55% of total litter fall which was

Table 4. Litter yield and amount of N and C recycled through litter by different species ten years after plantation

Tree species	Litter fall yield ($Mg\ ha^{-1}$)	Nitrogen and carbon content (%) in leaf litter		N recycled ($Mg\ ha^{-1}\ yr^{-1}$)	C sequestered ($Mg\ ha^{-1}\ yr^{-1}$)
		N content (%)	C content (%)		
Terminalia arjuna	5.1	0.84	44.8	0.043	2.28
Azadirachta indica	2.8	1.10	44.6	0.031	1.24
Prosopis juliflora	6.1	1.55	45.6	0.094	2.78
Pongamia pinnata	5.0	1.70	45.0	0.085	2.25
Casuarina equisetifolia	5.7	0.85	44.2	0.048	2.51
Prosopis alba	2.0	1.10	44.3	0.022	0.88
Acacia nilotica	5.4	1.68	44.7	0.090	2.41
Eucalyptus tereticornis	1.3	0.88	45.3	0.011	0.59
Pithecellobium dulce	2.4	0.86	45.0	0.029	1.08
Cassia siamea	1.3	0.78	42.4	0.010	0.55
LSD (P=0.05)	0.76	0.21	2.3	0.012	0.48

Table 5. Ameliorative effect of different tree species on physicochemical properties of soil (0-15 cm) ten years after plantation

Tree species	pH_2	EC_2 ($dS\ m^{-1}$)	OC (%)	pHs	ECe ($dS\ m^{-1}$)	ESP	Bulk density ($Mg\ m^{-3}$)		Infiltration rate ($mm\ day^{-1}$)
							0-7.5cm	7.5-15 cm	
Terminalia arjuna	9.84	0.39	0.35	9.42	0.61	55	1.47	1.52	21.20
Azadirachta indica	9.81	0.33	0.27	9.40	0.54	51	1.48	1.56	21.70
Prosopis juliflora	9.53	0.30	0.43	9.06	0.48	46	1.32	1.46	26.30
Pongamia pinnata	9.74	0.61	0.40	9.28	0.77	49	1.36	1.57	24.30
Casuarina equisetifolia	10.00	1.26	0.36	9.49	1.39	66	1.21	1.42	25.80
Prosopis alba	9.89	0.63	0.33	9.34	0.84	59	1.37	1.61	20.00
Acacia nilotica	9.70	0.77	0.35	9.26	0.91	51	1.29	1.58	21.90
Eucalyptus tereticornis	9.80	0.86	0.24	9.33	0.98	57	1.38	1.51	19.70
Pithecellobium dulce	9.95	0.70	0.27	9.51	0.86	60	1.25	1.58	23.10
Cassia siamea	10.01	0.69	0.26	9.75	0.87	66	1.46	1.48	15.80
Natural fallow	10.28	1.24	0.12	9.86	1.38	81	1.50	1.57	11.80
LSD (P=0.05)	0.42	ns	0.14	0.28	ns	21.2	0.06	0.04	8.62

composed of about 75-80% foliage. The amount of N recycled and C sequestered in soil through litter fall was calculated on the basis of N and C content in the leaf litter for each species. The maximum N content recycled through litter fall was estimated to be 0.094 $Mg\ ha^{-1}\ yr^{-1}$ in *Prosopis juliflora* plantation followed by 0.90 $Mg\ ha^{-1}\ yr^{-1}$ in *A. nilotica* and 0.85 $Mg\ ha^{-1}\ yr^{-1}$ in *P. pinnata* while minimum of 0.10 $Mg\ ha^{-1}\ yr^{-1}$ in soil under *C. siamea* plantation. Similarly, C sequestration in soil due to litter fall was estimated to be maximum (2.78 $Mg\ ha^{-1}\ yr^{-1}$) under *Prosopis juliflora* plantation followed by *C. equisetifolia* (2.51 $Mg\ ha^{-1}\ yr^{-1}$) and *A. nilotica* (2.41 $Mg\ ha^{-1}\ yr^{-1}$) while minimum under *E. tereticornis* (0.59 $Mg\ ha^{-1}\ yr^{-1}$) (Table 4).

Soil amelioration

Tree plantations on sodic soils ameliorate the soil in terms of decreasing soil pH, EC, ESP and increasing in organic carbon. A marked reduction in soil pH, EC and bulk density was recorded after ten years of plantation. The maximum reduction in soil pH was noticed under *P. juliflora* plantation which might be due to the maximum amount of total biomass and litter fall. Mishra *et al*. (2003) and Singh *et al*. (2014) have also reported higher soil amelioration in terms of decreased soil pH with *P. juliflora.* The degree of improvement was linked to the total biomass production, annual litter fall and its quality, root spread and weight and the level of management practices. The organic carbon content of the surface soil (0-15 cm) under *P. juliflora, P. pinnata* and *C.equisetifolia* increased by almost four to five times during this period. Earlier workers have also reported the overall higher improvement in the soil organic carbon under *P. juliflora* (Mishra *et al*. 2004; Tripathi and Singh 2005). The improvement in organic carbon led to improvement in their bulk density and infiltration characteristics (Singh and Gill 1992; Singh *et al*. 2011). Highest reduction in bulk density at 0-7.5 and 7.5-15 cm soil depth was recorded under *C. equisetifolia* (1.21 and 1.42 Mg m^{-3}) and *P. juliflora* (1.32 and 1.46 Mg m^{-3}), respectively over the initial value of 1.57 and 1.60 Mg m^{-3}. Highest infiltration rate was recorded under *P. juliflora* canopies (Table 5).

Conclusions

Based upon the results of this investigation, species like *P. juliflora*, and *A. nilotica* were identified highly promising to grow on degraded sodic soils, alleviate sodicity and improvement in soil fertility. It is concluded that the establishment and performance of these tree species in terms of their survival, growth and biomass production was also better than the other species evaluated under study. *P. juliflora* found most effective salt tolerant species as evident from the improvement in soil organic carbon and reduction in soil pH and exchangeable Na^+. The study indicates that sodic lands ameliorated by growing of these tree species for 10 years can be put under crop production. The results of this investigation will be highly useful for the public and private organizations for planning energy plantation and amelioration of sodic soils.

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