



Restoration of ecosystem services through afforestation on degraded sodic lands in Indo-Gangetic plains

YASH PAL SINGH¹, GURBACHAN SINGH², VINAY K MISHRA³, SANJAY ARORA⁴,
BAJRANG SINGH⁵ and RAVINDRA K GUPTA⁶

ICAR-Central Soil Salinity Research Institute, Lucknow, Uttar Pradesh 226 002, India

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ABSTRACT

Afforestation with tree species on a highly degraded sodic lands in Lucknow (26° 47' N; 80° 46' E), Uttar Pradesh, India has improved the provisional biomass production and supportive (nutrient dynamics and soil ameliorative) services during ten years. Of the ten species studied, *Prosopis juliflora* produced highest (56.5 t/ha) above ground biomass at ten years age. *P. juliflora* had highest total N P K accumulation followed by *Acacia nilotica*, *Casuarina equisetifolia*, *Terminalia arjuna*, *Pithecellobium dulce* and *Pongamia pinnata* whereas, total Ca and Mg contents were relatively high in *T. arjuna* followed by *P. juliflora*, *A. nilotica* and *C. equisetifolia*. Tree leaves reported the highest nutrient concentration followed by branches and stem. *P. juliflora*, *A. nilotica* and *P. pinnata* were found more efficient in nitrogen recycling compared to other species. Corresponding to biomass production, *P. juliflora* also dominated in nitrogen uptake. However, nitrogen retranslocation was highest in *C. equisetifolia*. *P. juliflora*, although produced maximum areal biomass, was not as good in nitrogen use efficiency (NUE), indicating that it produced relatively less biomass per unit of N uptake. *T. arjuna* had the greatest phosphorus use efficiency (PUE) and the lowest infiltration rate and chemical indicators (pH, ESP) of sodic soils after ten years of planting was recorded with *P. juliflora* which was 20.12%, 557.50% and 9.23%, 48% higher over the initial and 9.02%, 122% and 7.29% , 43.2% higher over natural fallow respectively. Microbial biomass was relatively higher under *C. equisetifolia* and *P. juliflora* than rest of the tree species.

Key words: Afforestation, Degraded sodic soils, Ecosystem services, Nutrient dynamics, Soil restoration

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 ecosystem services (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. 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. About one billion ha of land around the world is suffering from some degree of salinization and sodification problems (FAO. 2007). Plant growth and nutrient availability in such lands is inhibited

due to low osmotic potential of soil solution, ion toxicity and ionic imbalance (Marschner 2012). Salts tend to accumulate in the upper surface and deteriorate soil physico-chemical properties (Prapagar *et al.* 2012) and also affect microbial activities (Chowdhury *et al.* 2011). Studies conducted on bioamelioration of barren sodic lands reported that in spite of slow growth afforestation reclaimed these lands (Singh *et al.* 2010, Singh *et al.* 2016) but very limited scientific information is available on whether nutrient removed from the soil during fuel wood production would be replenished naturally through nutrient recycling or requires fertilization to sustain the subsequent rotation. Therefore, it is imperative to know the nutrient loss in biomass harvesting and nutrient recycling efficiencies to maintain a sustainable production system. Hence, there is a need for more comprehensive inventory of nutrients for tree species used for sodic soils. Biomass production and nutrient use efficiencies of tree species growing in sodic environment are very little known therefore, an attempt has been made to develop a plantation on barren sodic land in subtropical plain zone of north India with the twin objectives of identification of suitable tree species for sustainable use of degraded sodic lands for higher biomass production, and harnessing their

Present address: ¹Principal Scientist (Agronomy) (ypsingh.agro@gmail.com), ²Ex-Chairman, ASRB (dr.gurbachan@gmail.com), ³Head & Principal Scientist (Soil Science) (vkmishra_63@yahoo.com), ⁴Principal Scientist (Soil Science) (aroraicar@gmail.com), ⁵Principal Scientist (NBRI, Lucknow) (bsingh471@rediffmail.com), ⁶Project assistant (ravi_biochem05@rediffmail.com).

amelioration potential for restoration of ecosystem services.

MATERIALS AND METHODS

The experiment was conducted at Central Soil Salinity Research Institute (CSSRI), research farm, Shivri, Lucknow (26° 47' N; 80° 46' E), Uttar Pradesh during 1995-2015. The average annual rainfall of the experimental site was 800mm. The mean monthly temperature recorded during study period varied from 21°C in January to 40.5°C in June. The water table measured from the piezometers varied from 5-7m. The soil of the experimental field was highly sodic (pH (1:2) 10.5, EC 1.43 dS/m, ESP 89.0) having low organic carbon (0.8 g/kg), loam in texture on the surface and silty loam and silty clay loam in middle and clay loam in lower layers classified as Aquic Natrustalfs (Sharma *et al.* 2006). The bulk density (BD) determined using a core sampler of 10 cm diameter and 15 cm length varied from 1.48 to 1.64 g/cm³. The infiltration rate measured using double concentric infiltrometer was 4.0mm/day. Water holding capacity (WHC) and soil porosity determined using method prescribed by Keens box (Piper 1966) ranges from 3.2 to 3.8 g/kg and 34.2–36%, respectively. The calcic horizon begins from 80 cm depth with 40-60 cm thick CaCO₃ concretion layer. Soil pH was very high (>10.0) up to 45 cm soil depth and it decreased with increasing depth. Soil organic carbon, exchangeable cations, ESP and available nutrients like NPK were determined as per standard procedures (Jackson 1967). The initial properties of the experimental site are given in Table 1.

To monitor the changes in soil physico-chemical and

biological properties after ten years of tree plantation, in the year 2015, the soil samples from surface layer (0-15 cm) were collected from 5 places in each species and analyzed. The microbial biomass carbon (MBC), microbial biomass nitrogen (MBN) and microbial biomass phosphorus (MBP) were determined by the fumigation extraction method (Vance *et al.* 1987).

Six month old saplings of 10 tree species, viz. *Terminalia arjuna* Weight & Arn., *Azadirachta indica* A. Juss., *Prosopis juliflora* (Swartz) D.C., *Pongamia pinnata* (Linn.) Pierre, *Casuarina equisetifolia* (Linn.), *Prosopis alba* (Griseb), *Acacia nilotica* (L.), *Eucalyptus tereticornis* Sm, *Pithecellobium dulce* (Roxb.) Benth, and *Cassia siamea* Lam. raised in normal soil (pH 7.5, EC 0.67, SOC 2.13%) were planted in 45 cm diameter at the surface, 20 cm at the bottom and 120 cm deep auger holes filled with a mixture of original soil + 4 kg gypsum + 10 kg farm yard manure (FYM) + 20 kg silt at 4 m × 3 m row to row and plant to plant spacing in a Randomized Block Design (RBD) with three replications with an initial planting density of 833 trees/ha. Adjacent to the experimental field, a plot of 600 m² (12 m × 50 m) was kept as control (natural fallow) to monitor the ameliorative effect of afforestation over the control.

To measure plant growth, three trees representing high, medium and low height and DBH were selected from each replication. The observations on survival percentage, plant height, diameter at breast height (DBH) at 1.33 m above ground and crown diameter were reported on an average basis. To measure air dry tree biomass, three trees were harvested from the ground surface, stem, branches and

Table 1 Initial soil properties of experimental field selected for study (mean±SD)

Soil parameters	Soil depth (cm)					
	0-15	15-30	30-45	45-60	60-90	90-120
Sand (%)	63.4±1.20	48.3±1.26	48.6±2.12	42.0±3.20	57.4±1.50	52.5±2.20
Silt (%)	18.8±2.00	22.5±3.20	38.0±2.52	23.0±3.20	28.7±4.00	25.0±4.32
Clay (%)	17.8±1.20	26.8±0.68	35.0±1.10	31.8±0.86	43.6±0.85	33.9±1.10
Textural class	l	sil	sil	cl	sicl	cl
BD (g/cm ³)	1.64±0.04	1.57±0.02	1.55±0.03	1.51±0.04	1.50±0.02	1.48±0.02
IR (mm/ day)	4.0±0.02	-	-	-	-	-
WHC (g/ kg)	3.2±0.02	3.6±0.03	3.5±0.01	3.8±0.02	3.8±0.03	3.3±0.01
Porosity (%)	35.5±1.20	36.1±0.09	36.0±2.00	35.4±1.50	34.2±3.02	35.4±2.00
pH(1:2)	10.5±0.10	10.6±0.10	10.6±0.20	10.4±0.10	9.8±0.20	9.7±0.20
EC(1:2)(dS/m)	1.43±0.10	2.42±0.10	2.02±0.08	0.86±0.12	0.64±0.10	0.44±0.08
ESP	89.0±2.64	82.6±4.00	82.0±3.50	80.2±2.50	80.0±4.00	66.0±3.00
OC (g/ kg)	0.8±0.02	0.8±0.01	0.6±0.03	0.8±0.01	0.8±0.02	0.6±0.02
Available N (mg/ g)	42.0±0.62	27.9±0.25	24.3±0.20	20.9±0.40	20.10±0.35	18.09±0.42
Available P (mg/ g)	11.6±0.32	11.1±0.25	10.4±0.12	10.6±0.08	10.8±0.10	9.6±0.12
Available K (mg/ g)	173.8±21.3	171.4±22.5	143.0±23.6	179.90±16.5	129.2±12.8	75.3±14.2
CaCO ₃ (g/ kg)	14.1±0.20	2.6±0.10	23.2±0.06	37.7±0.04	89.4±0.12	116.9±0.05
Ca ⁺⁺ (cmol/ kg)	14.2±0.03	11.8±0.06	7.5±0.04	6.4±0.02	5.6±0.01	5.2±0.10
Mg ⁺⁺ (cmol/ kg)	1.32±0.002	3.61±0.003	4.12±0.06	8.30±0.003	7.60±0.004	5.32±0.002
Na ⁺ (cmol/ kg)	8.63±0.23	11.61±0.26	11.73±0.12	8.16±0.25	6.54±0.20	5.00±0.12

leaves were separated and weighed separately. Litter collectors of 1 m × 1 m size with 0.5 mm mesh steel net were placed under each tree species in each replication to measure litter fall yield. The basal area (m²/ha) was calculated from the measurement of land area of each species divided by the area covered under each species.

Composite samples of stem, branch and leaves taken from 12 trees were dried at 65±1°C to a constant weight and grinded in a Wiley mill passing through 0.1 mm mesh sieve. Total nitrogen, phosphorus, potassium, calcium and magnesium were determined by standard methods (Tandon 2005). The collected litter was oven dried at 65°C and analyzed for different nutrients and uptake was estimated. The nutrient concentration was multiplied by annual litter fall to obtain the amount of nutrients transferred to the forest floor. Nutrients associated with the net primary production were considered as gross nutrient uptake. The difference in nutrient concentration between leaf and litter indicates retranslocation by subtracting A-B as under:

A= Concentration of nutrient in green foliage × leaf biomass

B= Concentration of nutrient in litter fall × leaf biomass

Subtracting retranslocation from gross uptake provides net uptake. Nutrient use efficiency was calculated as above ground biomass produced per unit of nutrient uptake (i.e. net primary production (NPP) divided by gross nutrient uptake).

Data obtained from field experiment was statistically analyzed using MSTAT-C version 2.1 developed by Russel (1994). The treatment comparisons were made using t-test at 5% level of significance.

RESULTS AND DISCUSSION

Plant growth and biomass production: The performance of tree species under highly sodic soil was monitored on the basis of their % survival and growth. After ten years of planting, survival varied from 50–100%. The maximum height was attained by *E. tereticornis* followed by *C. equisetifolia*, *P. juliflora* and *A. nilotica*. Among the species evaluated, the growth in *C. siamea* and *T. Arjuna* was poor. Highest DBH was recorded in *A. nilotica* (14.12 cm) followed by *P. Juliflora* (12.32 cm) and *E. tereticornis* (11.10 cm) however, maximum crown diameter was recorded in *P. juliflora* followed by *A. nilotica* whereas *C. siamea*, *A. indica* and *T. arjuna*. *A. nilotica* and *P. juliflora* also outscored in basal area too (Fig 1).

Above ground biomass varied from 19.22 to 56.50 t/ha amongst species. Maximum above ground biomass (56.50 t/ha) was recorded with *P. juliflora* followed by *A. nilotica* (50.75 t/ha) and *C. equisetifolia* (42.10 t/ha) which was significantly higher over rest of the tree species. *A. indica*,

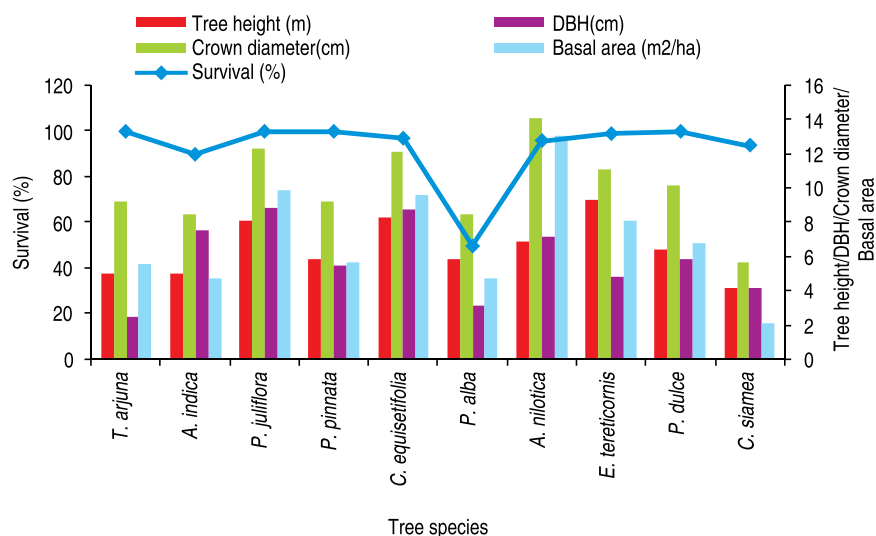


Fig 1 Mean growth of ten multipurpose tree species aged ten years on sodic soils.

C. siamea, *P. pinnata* and *P. alba* suffered from the sodicity stress and poor fertility for low biomass production (Fig 2). Biomass allocation among the above ground plant components varied amongst the species and on average stem (58%) > branch (34%) > and leaf (8%) contributed in decreasing order. The above ground biomass of *P. juliflora* and *A. nilotica* increased from 11 to 160% higher over the other species tested. The higher biomass productivity with *P. juliflora* and *A. nilotica* can be attributed to their good growth, more number of branches, plant height and better tolerance to soil sodicity (Singh *et al.* 2011). Mean and current annual increment (MAI and CAI) were also greatest for *P. juliflora* and *A. nilotica*.

Nutrient accumulation: Total nitrogen accumulation in aboveground standing trees varied from 108.79 to 320.37 kg/ha corresponding to biomass and nutrient concentrations in plant parts. Branches contributed more N in *P. juliflora* than the stem and leaves. Similarly, total P and K accumulation was greater in *P. juliflora* followed by *A. nilotica*. The highest nutrient accumulation in *P. juliflora* and *A. nilotica*

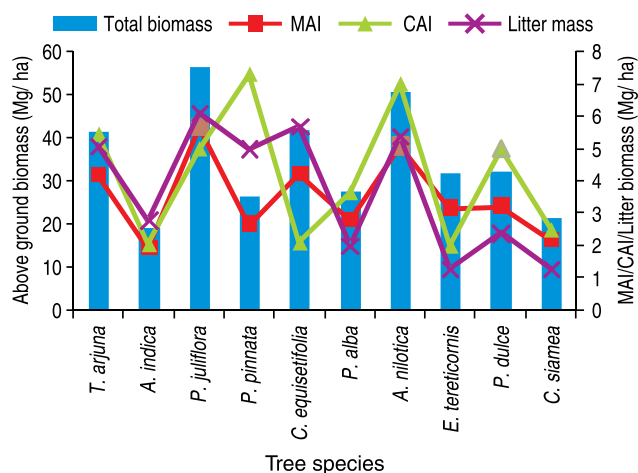


Fig 2 Total biomass, MAI, CAI and litter of 10 multipurpose tree species at ten years of growth.

may be because of more number and vigorous branches and it was in order of branches>stem>leaves whereas, in other species the order of nutrient accumulation changed as stem>branch>leaf. Nitrogen accumulation in *P. juliflora*, *P. pinnata*, *C. equisetifolia*, *P. alba*, *A. nilotica*, *P. dulce* and *C. siamea* was greater than P, K, Ca and Mg. However, Ca storage in *T. arjuna* and *A. indica* was greater than N due to slow growth. *P. juliflora*, *A. nilotica* and *P. pinnata* contributed greatest amount of N transfer through litter fall compared to other species. This may be due to more number of branches and high litter biomass as compared to other species. However, maximum P, K, Ca and Mg were transferred through the litter fall of *C. equisetifolia*, *P. juliflora*, *P. juliflora* and *T. arjuna*, respectively (Table 2).

Nutrients dynamics and use efficiency: Aggregate nutrient fluxes were derived integrating all tree species for biological cycle of nutrients (Table 3). Of the gross annual uptake of N, about 51.9% are returned through litter fall, while 19.4% is retained in standing stock and 28.7% N is used in retranslocation for next year growth. Corresponding figures for P are 27.7% (return), 7.9% (retention) and 64.4% (retranslocation) of the total P uptake. The return, retention and retranslocation of K were 40.1%, 3.6% and 79.8% respectively. Retranslocation of N was highest (30.81 kg/ha) in *C. equisetifolia* followed by *P. juliflora* (29.47 kg/ha)

Table 2 Total nutrient accumulations in different plant components and leaf litter of tree species planted on sodic soil

Tree species	Comp- onents	Nutrient accumulation (kg/ha)				
		N	P	K	Ca	Mg
<i>T. arjuna</i>	Total*	254.26	30.31	224.2	329.19	73.10
	Litter	42.84	6.63	7.65	34.17	26.52
<i>A. indica</i>	Total	108.79	19.32	91.89	119.28	20.63
	Litter	30.81	3.92	8.96	15.12	7.84
<i>P. juliflora</i>	Total	320.37	71.65	335.05	275.78	42.74
	Litter	94.55	6.12	52.46	37.82	21.96
<i>P. pinnata</i>	Total	210.13	29.26	179.99	208.07	28.30
	Litter	85.10	7.52	31.52	23.12	16.21
<i>C. equisetifolia</i>	Total	274.81	46.58	194.50	256.56	41.17
	Litter	48.45	9.12	23.94	29.07	17.10
<i>P. alba</i>	Total	146.73	32.97	157.23	135.99	26.04
	Litter	22.12	2.40	11.80	10.61	6.42
<i>A. nilotica</i>	Total	291.49	62.27	222.36	284.94	38.08
	Litter	90.72	5.41	15.12	23.22	14.04
<i>E. tereticornis</i>	Total	141.44	24.88	161.90	203.81	29.86
	Litter	11.44	1.82	2.08	9.49	4.68
<i>P. dulce</i>	Total	206.44	29.10	143.93	198.98	27.89
	Litter	29.04	3.84	10.32	12.48	8.64
<i>C. siamea</i>	Total	174.32	20.77	118.43	167.10	24.37
	Litter	10.14	1.82	5.22	11.18	10.92

*Total uptake includes Stem+ Branch+ Leaf

Table 3 Integrated nutrient flux during ten years of tree species planted in sodic soil

Nutrient fluxes	Nutrients (kg/ha/yr)				
	N	P	K	Ca	Mg
Gross uptake	61.97	14.01	27.42	27.85	15.01
Net uptake	44.19	4.99	11.99	23.21	12.47
Retention	12.05	1.11	0.99	6.35	1.02
Retranslocation	17.78	9.02	21.90	4.64	2.54
Return	32.14	3.88	10.99	16.86	11.45

and lowest (9.09 kg/ha) with *A. indica*. The retranslocation of P, K, Ca and Mg was highest in *P. alba*, *P. juliflora*, *P. dulce* and *P. alba* respectively. Highest nitrogen use efficiency was recorded with *E. tereticornis* followed by *P. alba* and *P. juliflora*. This is because of poor N uptake. *P. juliflora*, although produced highest areal biomass, was not as good in N use efficiency, indicating that it requires more nutrients to produce biomass. *T. arjuna* had the greatest Phosphorus use efficiency (PUE) and the lowest with *A. nilotica*. The corresponding values for Ca and Mg use efficiency were greatest with *P. juliflora* and *A. nilotica*, respectively. Thus, the quantity of nutrients return through litter fall assumes considerable importance in maintaining soil sustainability if frequent harvesting and removal takes place in short rotation fuel wood forestry programmes. So the selection of species should be primarily based on their conservation potential, instead of a high biomass production value.

Effect of tree species on soil physico-chemical properties: Soil bulk density (BD) decreased significantly under afforestation over the initial and natural fallow. Maximum reduction in BD over the initial (20.12%) and natural fallow (9.02%) was recorded under *C. equisetifolia* followed by *P. juliflora*, *P. dulce*, and *A. nilotica*. Water holding capacity also increased up to 64.7% over natural fallow under *P. juliflora* (Table 4). Highest improvement in infiltration rate (122.8%) over natural fallow was recorded under *P. juliflora* and minimum (33.8%) under *C. siamea*. The improvement in physical properties may be due to reduced sodicity, addition of leaf litter, and increase in microbial activities due to tree roots, better plant growth, and fine root decay (Singh *et al.* 2004).

Soil pH (0-15 cm) reduced to 9.53 from 10.50 after ten years of tree plantation. The results indicated that decrease in soil pH and EC was more with *P. juliflora* plantation. Soil organic carbon (SOC), which is principal indicator of soil fertility enhanced about five times from the initial and three times from the natural fallow. Highest increase in organic carbon was recorded under *P. juliflora* (4.31 g/kg) followed by *P. pinnata* (4.00 g/kg) and *C. equisetifolia* (3.62 g/kg) (Table 4). Highest reduction in ESP over the initial (48.3%) was recorded in *P. juliflora* followed by *P. pinnata* (44.9%) and *A. nilotica* (42.6%) whereas minimum with *C. siamea* (25.8%). This is due to addition of more organic matter, higher soluble Ca and lower CaCO₃ contents, root exudates

Table 4 Ameliorative effect of different tree species on physico-chemical properties of soil (0-15 cm) (mean±SD)

Tree species/soil properties	<i>T. arjuna</i>	<i>A. indica</i>	<i>P. juliflora</i>	<i>P. pinnata</i>	<i>C. equisetifolia</i>	<i>P. alba</i>	<i>A. nilotica</i>	<i>E. tereticornis</i>	<i>P. dulce</i>	<i>C. siamea</i>	Natural fallow	Initial
Soil physical properties												
Bulk density (g/cm ³)	1.49±0.003	1.52±0.002	1.39±0.001	1.46±0.003	1.31±0.001	1.49±0.01	1.43±0.005	1.44±0.02	1.41±0.004	1.47±0.002	1.44±0.003	1.64±0.02
Soil porosity (%)	43.51±1.32	42.60±1.53	47.55±1.52	44.65±0.91	50.35±1.15	43.75±1.32	45.85±1.45	45.50±1.50	46.60±1.62	44.55±1.34	42.05±1.20	35.50±1.15
Water holding capacity (%)	41.10±2.32	32.40±2.12	43.20±3.10	35.60±1.53	38.20±2.10	32.30±2.32	42.20±2.20	41.30±1.65	36.20±1.54	36.20±2.10	26.23±1.63	3.20±2.45
Infiltration rate (mm/day)	21.20±3.25	21.70±2.20	26.30±3.12	24.30±1.10	25.80±2.10	20.00±1.52	21.90±1.40	19.70±0.92	23.10±2.12	15.80±3.10	11.80±1.25	4.00±0.08
Soil chemical properties												
pH ₂	9.84±0.04	9.81±0.05	9.53±0.04	9.74±0.02	10.00±0.03	9.89±0.04	9.70±0.05	9.80±0.02	9.95±0.05	10.01±0.03	10.28±0.05	10.50±0.05
EC ₂ (dS/m)	0.39±0.10	0.33±0.11	0.30±0.12	0.61±0.16	0.68±0.08	0.63±0.12	0.77±0.10	0.86±0.08	0.70±0.10	0.69±0.12	1.24±0.12	1.43±0.10
ESP	55±1.12	51±2.20	46±1.32	51±1.52	66±2.34	59±2.12	49±1.62	57±0.85	60±1.20	66±2.10	81±2.12	89±2.64
OC (g/kg)	3.50±0.02	2.71±0.04	4.31±0.02	4.00±0.01	3.62±0.02	3.33±0.01	3.51±0.03	2.42±0.02	2.70±0.04	2.60±0.03	1.22±0.04	0.80±0.01
Na ⁺ (cmol/kg)	1.55±0.02	1.44±0.01	1.00±0.03	1.35±0.05	1.21±0.02	1.32±0.04	1.42±0.01	1.50±0.03	1.48±0.04	1.46±0.05	1.55±0.04	12.68±1.12
Ca ⁺⁺ (cmol/kg)	11.31±0.12	12.36±0.14	14.20±0.51	11.23±0.21	10.30±0.32	11.23±0.12	10.22±0.21	8.65±0.42	9.52±0.12	8.63±0.23	7.53±0.32	5.32±0.12
Available N (mg/g)	54.50±1.10	51.07±0.65	61.90±0.42	53.61±0.63	58.72±0.54	56.50±1.23	56.44±0.54	47.61±0.75	54.30±0.85	51.80±1.12	43.00±0.75	42.00±0.76
Available P (mg/g)	37.17±0.32	21.65±0.52	45.40±0.32	34.62±0.45	38.24±0.52	33.50±0.61	37.25±0.45	21.61±0.35	33.40±0.71	24.70±0.56	15.76±0.42	11.60±0.31
Available K (mg/g)	228.1±21.30	193.73±22.12	273.42±16.50	229.56±26.30	242.02±22.50	212.10±13.42	234.01±11.22	183.83±13.28	212.30±8.93	183.26±15.50	172.66±17.68	173.80±11.26

SD, Standard deviation

and advancement of CO₂ through decomposition of litter that helps to mobilize the inherent Ca which hasten the reclamation process by replacing the exchangeable Na from the soil. Highest Ca⁺⁺ concentration (14.2 cmol/kg) was recorded under *P. juliflora* stand and this rise was about 88.6% over the natural fallow and 165.4% over initial. Highest improvement in available N, P, and K contents were recorded under *P. juliflora* which was 43.9%, 188.1%, and 58.3% higher over the natural fallow and 47.4%, 291.4% and 57.3% over the initial N, P, and K contents in the soil.

Biological properties: In surface soil, maximum microbial biomass carbon (MBC) was recorded in *C. equisetifolia* followed by *P. juliflora* and *A. nilotica*. Maximum microbial biomass nitrogen (MBN)

was recorded under *P. pinnata* followed by *A. nilotica* and *P. juliflora* soils which were significantly higher over the natural fallow. The highest microbial biomass phosphorus

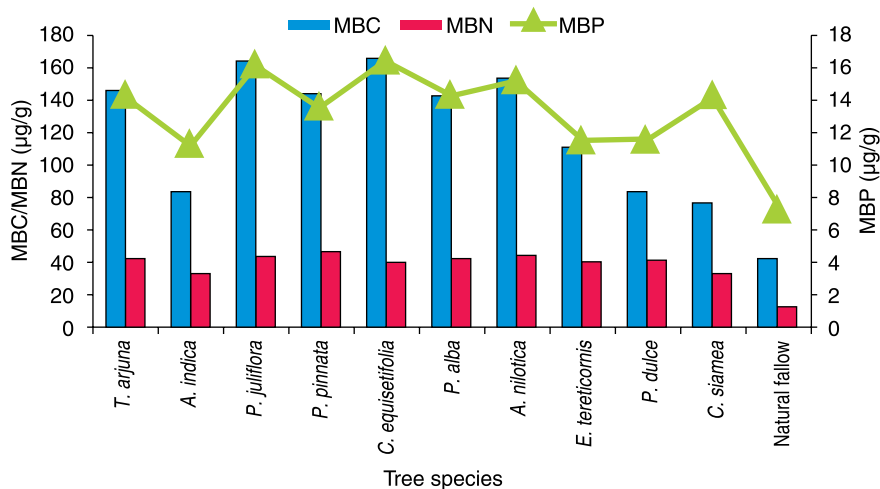


Fig 3 Biological properties of rehabilitated and natural fallow sodic land at 0-15 cm soil depth

(MBP) was recorded under *C. equisetifolia* and lowest under *A. nilotica* which was about two times greater than natural fallow. The increment in MBC, MBP and MBN under *C. equisetifolia* and *P. pinnata* from the natural fallow was up to the levels of 290.8% 126.02% and 279.5%, respectively (Fig 3). This may be due to addition of organic matter, increasing biological activities in the rhizosphere zone and increasing nutrient availability to the plants (Singh *et al.* 2015).

Restoration of sodic soil under tree plantation has improved provisional and supporting ecosystem services and promising species are identified as *P. juliflora*, *A. nilotica* and *C. equisetifolia* for this purpose. *P. juliflora* being a high biomass producer also alleviates sodicity stress to considerable extent. However, *C. equisetifolia* also found promising for improving soil physical and biological properties. It is concluded that the degraded sodic lands can be restored for productive purposes by planting *P. juliflora*, *A. nilotica* and *C. equisetifolia* for afforestation on sodic soils of Indo-Gangetic plains.

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