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RESEARCH PAPER

Biomass and bio-energy production of ten multipurpose tree species planted in sodic soils of indo-gangetic plains

Y.P. Singh • Gurbachan Singh • D. K. Sharma

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Abstract: Ten multipurpose tree species, *Terminalia arjuna, Azadirechta indica, Prosopis juliflora, Pongamia pinnata, Casuarina equisetifolia, Prosopis alba, Acacia nilotica, Eucalyptus tereticornis, Pithecellobium dulce and Cassia siamea,* were raised in a monoculture tree cropping system on the sodic soil of Gangetic alluvium in north India (26º 47' N: 80º46' E) for 10 years to evaluate the biomass and bio-energy production. The soil was compact, sodic and impervious to water associated with nutrient deficiency or toxicity. Maximum plant height was recorded with *E. tereticornis* followed by *C.equisetifolia* and *P. juliflora*. *A. nilotica* performed better than the other species in terms of diameter at breast height (DBH) with a basal area of 13.04 $m^2 \cdot ha^{-1}$, followed by *P. juliflora* and *C. equisetifolia*. *P. juliflora* and *A. nilotica* produced nearly similar biomass of 56.50 and 50.75 $Mg \cdot ha^{-1}$, respectively, at 10 years; whereas, *A. indica, P. pinnata, C. siamea* and *P. alba* did not perform well. *P. juliflora* scored maximum in net biomass production and nutrient demand. Nutrient (N, P, K, Ca, and Mg) concentrations were higher in leaf component of *P. juliflora*. However, in woody components, there was little variation between the species. N removal for production of one ton of wood was lowest in *Acacia nilotica*, P in *T. arjuna*, K in *P. dulce* and Ca and Mg in *P. juliflora*. *P. juliflora* gave the highest energy production of 1267.75 $GJ \cdot ha^{-1}$ followed by *A. nilotica* with 1206 $GJ \cdot ha^{-1}$ and the lowest of *A. indica* (520.66 $GJ \cdot ha^{-1}$).

Keywords: biomass; sodic soils; Gangetic alluvium; multipurpose tree species; nutrient concentration; nutrient use efficiency.

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Y. P. Singh (✉)
Principal Scientist, Central Soil Salinity Research Institute, Regional Research Station, Jail Road, Lucknow (U.P.) India-226005
Tel. & Fax- 091-0522-2464664 ; E-mail: ypsingh_5@yahoo.co.in

Gurbachan Singh
Director, Central Soil Salinity Research Institute, Kachwa Road, Karnal, Haryana, India, 132001

D. K. Sharma
Head, Central Soil Salinity Research Institute, Regional Research Station, Jail Road, Lucknow (U.P.) India-226005

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Introduction

Geographically Indo-gangetic plains lies between 21º55' to 32º 39' N and 73º 45' to 88º 25' E comprising of the states of Punjab, Haryana, U.P. and part of Bihar (North) West Bengal (south) and Rajsthan (north). Salt affected soils of Indo-gangetic alluvium (2.7 million hectare) constitute centuries old barren sodic soils without any land use system (NRSA & Associates 1996). 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 $Na_2 CO_3$, $NaHCO_3$ and sufficient exchangeable sodium to impart poor soil physical conditions. The presence of $CaCO_3$ concretions at various depths (caliche bed) causes physical impedance for root proliferation, therefore, making it difficult for tree establishment. Dedicated efforts were made to rehabilitate these inhospitable soils under tree cover from past four decades (Yadav 1975 1980). Some indigenous species established on these soils suffer with stunted growth and poor yield (Chaturvedi and Behl 1996; Singh 1989). With the scarcity of fuel wood in many developing countries, various programmes of short rotation forestry were launched in the past two decades to meet out this basic need of rural communities (Toth 1981; Brady, 1990; Lugo et al. 1990; Singh and Mishra 1978). In India, sodic lands were generally allocated to the poor and landless peoples under poverty alleviation programme for rehabilitation and simultaneous improvement of the area (Singh 1989; Singh and Gill 1992; Chaturvedi and Behl 1996). Despite their slow growth and low productivity, energy plantation established on barren sodic soils reclaimed the soils significantly (Garg and Jain, 1992; Tripathi and Singh 2005). The sodic soils are poor in fertility status and it is not ascertained whether nutrient removed from the soil during fuel wood production would be replenished naturally or require fertilization to sustain the subsequent rotation, it is important to know the nutrient cost of wood production and nutrient loss in the removal of wood to maintain a sustainable production system.

Tree species differ in their nutrient use efficiencies (NUE) for biomass production. Therefore, any species which is poor in nitrogen use efficiency may deplete the soil nutrients rapidly and threaten soil sustainability (Sanchez et al. 1985). The removal of nutrients can be altered by varying plantation and harvest design (Wang et al. 1991). The index of nitrogen use efficiency is a better indicator hence; there is a need for more comprehensive inventory of nutrient removal for tree species used in sodic soils. Very little information on biomass and bio-energy production and nutrient concentration of trees species growing in an environment of soil sodicity are available. Our objective was to examine the performance of ten multipurpose tree species under this stress, and thereby consequences on nutrient concentration of relatively tolerant and sensitive species.

Materials and Methods

Site description

The study was initiated during 1995 at experimental farm of Central Soil Salinity Research Institute, Regional Research Station, Lucknow situated 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 soil was alkaline, fine loamy, mixed, hyperthermic and classified as Typic Natrustalfs having physical and nutritional problems due to poor soil water cover and soil air relations caused by high pH (>10.0), low electrical conductivity (<3.0dSm^{-1}), high exchangeable sodium percentage (> 85.0) and very low water permeability (Table 1). A poor fertility of the soil is attributed to deficiency in organic carbon and 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 climate is semi- arid sub tropical and monsoonic receiving an average annual rainfall of 817 mm. Maximum rainfall is received between 23 to 40 standard weeks (June-October), amounting to 741 mm, which is 91% of the total annual rainfall. The average annual evaporation is 1580 mm. During the rainy season between 23 to 40 weeks (mid June to October), evaporation rate gradually decreases following rains. Mean maximum temperature of 39°C in the month of May and mean minimum temperature of 7.1°C in the month of January indicate a season climate. Mean annual temperature was recorded as 24.6°C where as mean annual soil temperature (MAST) and the mean winter soil temperature (MWST) were 31°C and 18°C, respectively. Figure 1 shows the graphical representation of climatic data of experimental farm Lucknow.

Planting techniques

Nearly six months old seedlings of ten multipurpose tree species *viz. Terminalia arjuna, Azadirechta indica, Prosopis juliflora, Pongamia pinnata, Casuarina equisetifolia, Prosopis alba, Acacia nilotica, Eucalyptus tereticornis, Pithecellobium dulce and Cassia siamea* raised in a normal soil were planted in 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, during July 1995. The auger holes were filled with a uniform mixture of original soil + 4 kg gypsum + 10 kg farm yard manure (FYM) + 20 kg silt. Seedlings were planted at a depth of 30 cm from the surface. The experiment was arranged in a Randomized Block Design with four replications. Each replication was having 180 trees covering 2160 m^2 lands. For proper establishment of the seedlings three irrigations were given at monthly interval during first year of planting.

Table 1. Initial soil physico-chemical properties of the experimental site at Lucknow, India.

Soil parameters	Soil depth (cm)				
	0-15	15-30	30-60	60-90	90-120
Sand (%)	63.40	48.00	42.00	57.00	52.50
Silt (%)	18.80	25.20	23.00	25.00	25.00
Clay (%)	17.80	26.80	35.00	18.00	22.50
Textural class	l	sil	cl	sil	cl
CEC (Cmol kg^{-1})	8.60	12.20	14.00	8.40	9.90
Organic matter (%)	0.08	0.08	0.06	0.08	0.06
ESP	89.00	82.60	80.20	76.00	60.40
pH (1:2)	10.50	10.60	10.40	9.80	9.70
EC(1:2) d Sm^{-1}	1.43	2.42	0.86	0.64	0.44
Ca^{++} + Mg^{++} (meql^{-1})	2.60	2.10	1.60	1.60	2.10
Na (meql^{-1})	242.00	119.00	52.70	9.00	5.00
K(meql^{-1})	0.22	0.12	0.04	0.03	0.01
CO_3 (meql^{-1})	188.00	84.00	26.00	2.00	1.00
HCO_3 (meql^{-1})	18.00	21.00	21.00	5.50	3.50
Cl (meql^{-1})	33.00	12.00	11.00	3.00	3.00
SO_4 (meql^{-1})	0.00	0.00	0.00	0.00	0.00
$CaCO_3$ (<2mm)	0.60	0.60	0.40	19.10	17.20

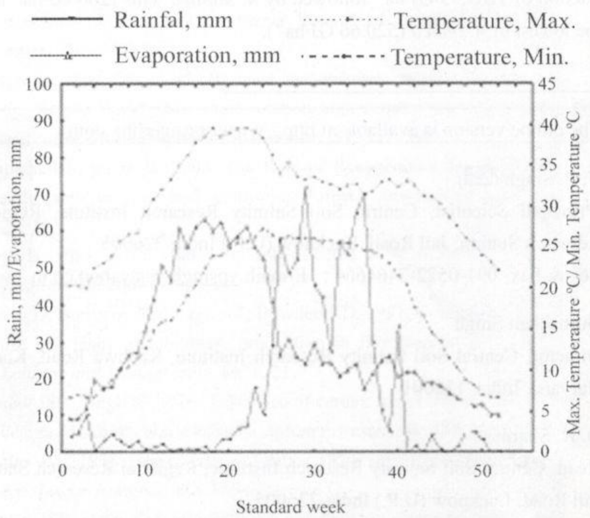

Fig. 1 Climatic features of the experimental site

Biomass

Plant survival and growth observations were initiated from first year onwards. Circumference and diameter of the trees were measured at breast height level (1.3 m) every year with a diameter tape. Four randomly selected trees representing the entire size variations amongst the ten species were marked and harvested after every two years from the ground surface and their stem, branch and leaves were separated and weighed on air dry basis for biomass estimation using a stratified sampling procedure. Basal area and crown diameter were calculated after ten years. The mean annual increment (MAI) in biomass yield was calculated on two year basis. A regression equation of the following form based on Gompertz relation growth model using curve expert version 1:3 for calculating the annual increment was fitted.

$$Y = ae^{-eb^{-cx}} \quad (1)$$

where, Y is the biomass yield (tons·ha^{-1}), a,b and c are regression constants, x is the age of the plant, and e is constant

The biomass yield of natural grasses regenerated under the tree canopies of different species was measured on annual dry weight basis.

Regression constants and r^2 values for biomass production and partitioning in stem, branch and leaves were calculated by using following regression equation:

$$Y = ae^{-e^{b-cx}} \quad (2)$$

where, a, b and c are regression constants, x is the age of the plants;e is constants

Wood samples were collected to study the heat of combustion of different plant components of ten tree species. The calorific value of the samples was measured using calorimeter (Parr Instruments, USA). To compare the magnitude of wood energy harvested per hectare by different species, the calorific value of wood of different species was multiplied by their respective woody biomass yield.

Nutrient analysis

Random samples of stem, branches and leaves were collected from ten year old plantations. Five composite samples from representative plants were taken for each of the plant component from twelve trees of different sizes and dried at 65°C to a constant weight. Samples ground in a Wiley mill passing through 0.1mm mesh sieve were processed for nutrient analysis. Nitrogen content in the plant component was estimated on a Tecator kjeltec auto 1030 N- analyzer after sulphuric acid digestion (Kalra and Maynard 1991). Phosphorus was determined by spectrophotometer using vanadomolybdo phosphoric yellow colour method. Potassium and calcium were determined through flame photometer and magnesium by titration using versenate method (Jackson, 1967). Nutrient uptake was calculated by multiplying the value of different components of aerial biomass by their respective nutrient concentration.

Results

Survival and growth performance

The performance of different tree species was evaluated on the basis of survival % and growth (height, diameter at breast height, crown diameter and basal area) (Table 2). All the species had over 95% survival except *C. siamea* (94%) and *A. indica* (90%) and *P. alba* (50%). Maximum plant height was recorded with *E. tereticornis* followed by *C. equisetifolia* and *P. juliflora*. *A. nilotica* performed better than the other species in terms of diameter at breast height (DBH) with a basal area of 13.04 m^2·ha^{-1}, followed by *P. juliflora and C. equisetifolia,* with a basal area of 9.92 m^2·ha^{-1}and 9.64 m^2·ha^{-1}, respectively. These results are in agreement with those of Yadav and Singh 1970; Gill and Abrol 1986; Gill and Gupta 1990; Singh et al. 1993. All other species had basal area of below 8.5 m^2 ·ha^{-1}. Correlation coefficients (r) calculated for height and diameter was strongly positive in *P. juliflora, P. pinnata, P. dulce, A. nilotica C. equisetifolia, T. arjuna, E. tereticornis and A. indica,* whereas, *C. siamea* (0.43), *E. tereticornis* (0.48), *P. alba* (0.56), *T. arjuna* (0.63) and *Acacia nilotica* (0.67) were having lower *r* values. *P.juliflora* recorded highest crown diameter (8.87m) followed by *C. equisetifolia* (8.75 m), *A. indica* (7.53 m) and *A. nilotica* (7.20 m).

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

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

Biomass production

Among the ten species *P. juliflora* gave the maximum dry biomass of 56.50 Mg·ha^{-1} with about 96% biomass allocated to stem and branch wood followed by *A. nilotica* having dry biomass about 50.75 Mg·ha^{-1} with 95% biomass in wood components (Table 3). This is because of their fast growth and higher yields in sodic soil (Lugo et al. 1990; Singh et al. 1993). Highest portion of dry biomass (76.8% and 72.9%) in stem part was recorded with *E. tereticornis and P. dulce,* respectively, because of less number of branches; whereas, the share of dry biomass through branches was higher (54.3%) in *P. pinnata*, while *T.*

arjuna, showed relatively high proportion of foliar biomass (7.13 Mg·ha^{-1}) because of broad laminar morphology.

Highest annual increment in biomass yield (13.78 Mg·ha^{-1}) was observed in *P. juliflora* between stand age of two and four years followed by *A. nilotica* (9.44 Mg·ha^{-1}), *T. arjuna* (9.40 Mg·ha^{-1}) and *C. equisetifolia* (8.98 Mg·ha^{-1}) whereas, it increased linearly in *P. dulce* up to the age of 8 years (Table 4). The annual increment of other species like *A. indica*, *P. pinnata*, *P. dulce* and *C. siamea* suffered heavily during early growth period due to high sodicity and low soil fertility which in general led to stressed growth. The values of regression constants (a, b and c and r^2 values are given in Table 5.

Table 3. Dry biomass production and allocation into stem, branch and leaf components in ten species and under story biomass yield in sodic soils.

Species	Tree biomass (Mg·ha^{-1})				Under story biomass yield ((Mg·ha^{-1})
	Stem	Branch	Leaf	Total	
T. arjuna	23.78	10.70	7.13	41.62	5.2
A. indica	11.17	6.21	1.84	19.22	5.28
P. juliflora	27.73	26.60	2.17	56.50	6.25
P. pinnata	9.05	14.45	3.10	26.60	3.75
C. equisetifolia	28.60	9.15	4.35	42.10	2.73
P. alba	14.70	11.10	1.95	27.75	5.25
A. nilotica	22.15	26.14	2.46	50.75	6.35
E. tereticornis	24.40	5.27	2.10	31.77	5.34
P. dulce	23.50	6.81	1.94	32.25	5.21
C. siamea	14.30	5.65	1.70	21.65	5.35
CD.(P=0.05)	2.43	4.63	1.21	5.42	0.24

Table 4. Annual biomass increment and r^2 values for biomass production in ten species

Species	Annual increment (Mg ha^{-1})					r^2
	0-2 years	2-4 years	4-6 years	6-8 years	8-10 years	
T. arjuna	4.99	9.40	5.18	1.93	0.63	0.996
A. indica	2.33	4.3	3.02	1.46	0.61	0.991
P. juliflora	9.23	13.78	7.46	2.89	1.00	0.996
P. pinnata	2.4	5.18	4.84	3.08	1.65	0.997
C. equisetifolia	3.97	8.98	7.69	4.43	2.14	0.999
P. alba	3.54	6.12	4.07	1.89	0.77	0.996
A. nilotica	6.66	9.44	7.28	4.25	2.18	0.996
E. tereticornis	5.09	7.43	4.61	2.08	0.83	0.996
P. dulce	0.44	3.01	6.58	7.69	6.39	0.999
C. siamea	2.61	5.96	3.65	1.46	0.5	0.996

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}). A higher natural grass yield under *A. nilotica* and *P. juliflora* cover story than in the open was also reported by Diaz et al. (1984).

Nutrient concentration

Concentration of macronutrients in different parts of the trees showed highest values in leaves (Table 6) because of their more active role in metabolic activities followed by branches and stem (Driessche 1974; Lea 1979). The mean N content in leaf varied from 1.10% in *C. equisetifolia* to 2.68% in *P. juliflora*. *P. juliflora* had greater N concentration in leaf and ground litter. However, greater N concentration in branches and stem was recorded with *P. pinnata*. The *P. pinnata* had a higher P concentration (0.25%) in foliage, followed by *P. juliflora* (0.18%). However, *P. juliflora* had higher P concentration in stem (0.11%) and branch (0.14%), followed by *A. nilotica* (0.11% in stem and 0.13% in branch).

Table 5. Regression constants and r^2 values for biomass production and partitioning in ten multipurpose tree species.

Species	Plant part	a	b	c	r^2
Terminalia arjuna	Stem	30.765	1.806	0.504	0.99
	Branch	10.743	1.556	0.436	0.96
	Leaves	5.401	1.459	0.364	0.98
	Total	46.559	1.721	0.481	0.99
Azadirechta indica	Stem	15.216	2.035	0.516	0.99
	Branch	6.149	2.195	0.602	0.99
	Leaves	24.903	1.654	0.086	0.98
	Total	24.488	1.891	0.478	0.99
Prosopis juliflora	Stem	48.175	1.300	0.268	0.98
	Branch	27.392	2.010	0.593	0.99
	Leaves	35.033	1.688	0.054	0.99
	Total	70.242	1.923	0.555	0.99
Pongamia pinnata	Stem	24.448	1.517	0.233	0.99
	Branch	12.726	2.394	0.587	0.99
	Leaves	7.731	1.738	0.249	0.98
	Total	37.782	1.827	0.388	0.99
Casuarina equisetifolia	Stem	41.141	1.871	0.437	0.99
	Branch	9.191	3.331	0.713	0.99
	Leaves	7.564	1.778	0.299	0.99
	Total	58.066	1.915	0.426	0.99
Prosopis alba	Stem	26.213	1.287	0.239	0.96
	Branch	13.821	1.921	0.452	0.99
	Leaves	2.311	1.355	0.307	0.96
	Total	34.087	1.872	0.489	0.98
Acacia nilotica	Stem	32.475	1.376	0.383	0.99
	Branch	25.969	2.084	0.563	0.99
	Leaves	9.329	1.392	0.162	0.99
	Total	66.167	1.510	0.388	0.99
Eucalyptus tereticornis	Stem	32.338	2.062	0.592	0.99
	Branch	7.105	1.100	0.236	0.99
	Leaves	14.760	1.329	0.092	0.99
	Total	41.840	1.763	0.492	0.99
Pithecellobium dulce	Stem	70.984	2.274	0.238	0.99
	Branch	12.095	3.179	0.556	0.99
	Leaves	3.254	1.872	0.300	0.99
	Total	69.825	2.321	0.300	0.99
Cassia siamea	Stem	18.184	3.485	0.938	0.99
	Branch	12.290	1.740	0.281	0.99
	Leaves	1.233	2.642	0.923	0.99
	Total	28.936	2.184	0.561	0.99

The K levels in leaf (1.84%), branches (0.63%) and stem (0.46%) was greater in *P. juliflora* followed by *P. pinnata* and *P. alba*. It was noted that Ca and Mg concentration in foliage of *P. juliflora* was very similar to those of *P. pinnata,* although the two species performed differently in terms of growth. However, *T. Arjuna* recorded the highest concentration of these nutrients in branches. The nutrient concentration in plant parts under sodic soil conditions differ from species to species, location to location and even age of the plant in the same species on the same site (Singh 1982; Singh 1998). This may be attributed due to disturbed ionic equilibrium of soil solution which causes abnormal nutrient uptake (Naidu and Rangasamy 1993). A direct correlation between nutrient content and productivity was not established.

Table 6. Nutrient concentrations in plant components and litter of ten tree species.

Species	Component	Nutrient content (%)				
		N	P	K	Ca	Mg
Terminalia arjuna	Stem	0.36	0.06	0.43	0.60	0.06
	Branch	0.51	0.05	0.54	1.21	0.15
	Leaf	1.47	0.15	0.90	0.80	0.60
	Litter	0.84	0.13	0.15	0.67	0.52
Azadirechta indica	Stem	0.43	0.08	0.36	0.68	0.08
	Branch	0.51	0.12	0.52	0.52	0.07
	Leaf	1.21	0.16	1.02	0.60	0.40
	Litter	0.84	0.14	0.32	0.54	0.28
Prosopis juliflora	Stem	0.47	0.11	0.46	0.55	0.07
	Branch	0.61	0.14	0.63	0.39	0.03
	Leaf	2.68	0.18	1.84	0.90	0.60
	Litter	1.70	0.10	0.86	0.62	0.36
Pongamia pinnata	Stem	0.53	0.11	0.46	0.62	0.04
	Branch	0.63	0.08	0.61	0.85	0.07
	Leaf	2.13	0.25	1.50	0.94	0.47
	Litter	1.55	0.15	0.63	0.46	0.32
Casuarina equisetifolia	Stem	0.46	0.10	0.34	0.63	0.07
	Branch	0.61	0.12	0.54	0.54	0.06
	Leaf	1.10	0.14	1.10	0.62	0.36
	Litter	0.85	0.16	0.42	0.51	0.30
Prosopis alba	Stem	0.43	0.11	0.43	0.54	0.07
	Branch	0.51	0.12	0.58	0.38	0.04
	Leaf	1.38	0.16	1.62	0.74	0.58
	Litter	1.10	0.12	0.59	0.53	0.32
Acacia nilotica	Stem	0.53	0.11	0.35	0.75	0.06
	Branch	0.62	0.13	0.46	0.40	0.06
	Leaf	1.68	0.16	1.00	0.58	0.28
	Litter	1.14	0.10	0.28	0.43	0.26
Eucalyptus tereticornis	Stem	0.34	0.08	0.46	0.54	0.08
	Branch	0.54	0.05	0.54	1.10	0.12
	Leaf	1.43	0.13	1.01	0.67	0.54
	Litter	0.88	0.14	0.16	0.73	0.36
Pithecellobium dulce	Stem	0.50	0.07	0.38	0.63	0.06
	Branch	0.61	0.11	0.54	0.54	0.08
	Leaf	1.21	0.16	0.90	0.73	0.43
	Litter	0.86	0.16	0.43	0.52	0.36
Cassia siamea	Stem	0.43	0.07	0.43	0.80	0.08
	Branch	0.61	0.12	0.74	0.68	0.12
	Leaf	1.34	0.15	0.89	0.84	0.53
	Litter	0.78	0.14	0.40	0.86	0.84

Energy production

Leaves had slightly higher heat of combustion (21.40-23.71 MJ·kg^{-1}) whereas; it was lowest in stem (20.45–23.23 MJ·kg^{-1}) (Table 7). The calorific values of stem and branches exhibited less variation, with *A. nilotica* having the highest heat combustion in both stem and branches (23.23 and 24.24 MJ·kg^{-1} respectively). The differences in total energy production and its allocation to different plant parts, led to variation between biomass yield and its allocation to stem, branch and leaves per hectare. *P. juliflora* gave the highest energy harvest of 1 267.75 GJ·ha^{-1} followed by *A. nilotica* with 1206.0 GJ·ha^{-1} and the lowest of *A. indica* (520.66 GJ·ha^{-1}).

Nutrient cost of wood production

Highest N cost for production of one ton of wood (stem + branch) was measured in *C. siamea* and minimum with *E. tereticornis*. Cost of P for producing one ton of wood was maximum in *P. dulce* and minimum with *T. arjuna*. K need was very high for *P. pinnata* in comparison with the other species. However, *T. arjuna* need higher quantity of Ca and Mg (Fig. 2). Thus, for the harvest of one ton of wood, different quantities of nutrients will be lost from the soil by the different species.

Table 7. Energy values of different plant components in ten tree species.

Species	Calorific Values (MJ·kg^{-1})			Total energy
	Stem	Branch	Leaf	(GJ·ha^{-1})
Terminalia arjuna	22.57	21.60	23.24	933.53
Azadirechta indica	20.60	20.54	21.42	520.66
Prosopis juliflora	22.53	23.20	23.71	1267.75
Pongamia pinnata	21.60	21.60	22.34	576.85
Casuarina equisetifolia	22.20	22.14	22.21	934.11
Prosopis alba	21.46	22.20	23.21	607.13
Acacia nilotica	23.23	24.24	23.64	1206.32
Eucalyptus tereticornis	20.45	22.43	21.40	662.12
Pithecellobium dulce	21.50	21.60	22.64	696.26
Cassia siamea	21.40	21.68	22.58	466.89

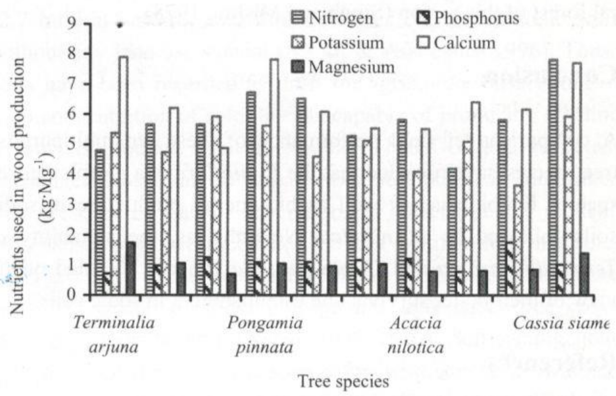

Fig. 2 Nutrient use efficiency by 10 multipurpose tree species on the basis of nutrient requirement for per unit of biomass production in sodic soil.

Discussion

Tree growth is affected 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. Most nutrients are more available in low pH soils and nutrient availability is therefore a limiting factor in alkali soil sites (Brady 1990). Species raised on highly sodic soils generally suffer high mortality, although there was very less mortality in these tree species. All the species showed <10% mortality indicating the ability to establish under stress conditions (Table 2).

Maximum biomass production was found in *P. juliflora* (Table 3). The higher productivity of above ground biomass of *P. juliflora* can be attributed to their greater tolerance to soil sodicity (Singh and Gill 1992; Jain 1995). Above ground biomass of *P. juliflora* was estimated at 1.06 $Mg \cdot ha^{-1}$ after 3.5 years of planting on highly alkali soils without any soil treatment, with large improvements in yield with gypsum amendments incorporated at planting (Singh 1989). In our study *P. juliflora* produced 9.23 $Mg \cdot ha^{-1}$ after 2 years with incorporation of gypsum in auger holes. Biomass production of several leguminous tree species including Prosopis species under green house conditions after two years growth was predicted, and found that *P. alba* produced the highest biomass (14.5 $Mg \cdot ha^{-1}$) compared with other species.

Annual increment in biomass production of *P. juliflora* between stand age of two and four years was higher due to high sodicity tolerance, and fast growth in sodic soils whereas, the annual increment of other species like *A. indica*, *P. pinnata*, *P. dulce* and *C. siamea* suffered heavily during early growth period due to high sodicity and low soil fertility which in general led to stressed growth.

Nutrients concentration in different parts of the trees in sodic soil conditions differ from species to species, location to location and even age of the plant in the same species on the same site. Because of disturbed ionic equilibrium of sodic soils the nutrient uptake is abnormal. Therefore, variation in nutrient concentration cannot be critically distinguished between N fixture and non-N fixture species. N concentration in foliage of the tree species in our study is slightly lower (Table 6) than those reported for natural forest of this region (Singh and Mishra, 1978).

Conclusion

A comparison of field performance of these ten multipurpose tree species have revealed that the *P. juliflora* is a promising tree species for biomass as well as bio-energy production in sodic soils followed by *A. nilotica*. Nevertheless, the suitability of *Terminalia arjuna* and *C. equisetifolia* can not be ruled out in view of their better survival and establishment in sodic soils.

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