Journal of Scientific & Industrial Research
Vol. 70, August 2011, pp. 601-609

Biomass production in short rotation effluent-irrigated plantations in North-West India

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Received 04 May 2011; revised 25 May 2011; accepted 01 June 2011

This study estimates above-ground biomass in high density plantations of six important semi-arid tree species at Palwal (70 km from Delhi) irrigated with secondary treated sewage water at the rate of 0, 25, 50 and 100% of daily net evaporation potential (EP). In 2.5 y old plantations (plant spacing, 2 m x 2 m for single stem species and 2 m x 1 m for multi-stem species), *Melia azedarach* showed fairly high biomass production (38.4 t/ha) followed by *Ailanthus excelsa* (27.2 t/ha). Order of biomass production (kg / tree) was: *Eucalyptus tereticornis* (24.1) > *A. excelsa* (21.8) > *M. azedarach* (12.6) > *Populus deltoides* clone G_{48} (8.3) > *Alstonia scholaris* (6.6)> *Pongamia pinnata* (3.7). Survival of plants after 2.5 y ranged from 25.2% in *P. deltoides* to 71.7% in *P. pinnata,* and had a significant effect on biomass production per unit area. ANOVA shows that levels of irrigation (0 - 100%) did not have statistically significant effect on plant growth. Correlation between diameter and biomass was found highly significant ($p< 0.01$) with R^2 nearing to 1.

Keywords: Biomass, Semi-arid trees, Sewage water irrigation, Short rotation plantations

Introduction

Wood production has become an environment friendly and prudent means of using effluent water. Choice of plant species and its successful establishment, however, decides effectiveness of plantations. Wood production trials at Palwal formed a part of a project funded by Engineering and Physical Sciences Research Council (EPSRC) of UK. The project involves generation of steam from biomass for the production of heat, electricity and cooling which, when operated collectively, is called tri-generation. Experiment at Palwal involved selection of appropriate species and testing of planting density and management options to optimize wood production per unit area.

Experimental Section

Experiment Description

There were four irrigation treatments and six species, replicated three times giving a total of 72 plots (Fig. 1a & b) covering an area of 1.3 ha at Palwal (70 km from Delhi) (longitude, 77.09'E; latitude, 28.45'N; altitude above sea level, 228 m; max. temp., 10-36°C; and min. temp., 6-19°C). Individual tree plots (12 m x 14 m) and tree species were completely randomized within each irrigation block, but irrigation treatments were not randomized. Site was prepared by ripping (38.1 cm), ploughing (30.5 cm) and harrowing to remove roots and scrubby plant material.

Tree Species

In order to maximize biomass yield per unit area, two close spacings [2 m x 2 m for single stem (SS) species (*Melia azedarach*, *Pongamia pinnata* and *Alstonia scholaris* with 84 plants per plot and 48 observation plants per plot) and 2 m x 1 m for multi-stem (MS) species (*Populus deltoides* clone G_{48}, *Eucalyptus tereticornis* and *Ailanthus excelsa* with 42 plants per plot and 20 observation plants per plot)] were adopted. SS species perform better at wider spacing. This, while comparing with MS species, reduces any difference that may occur as a result of tree density. Each plot had a single row of guard trees around its perimeter; not included in data collection.

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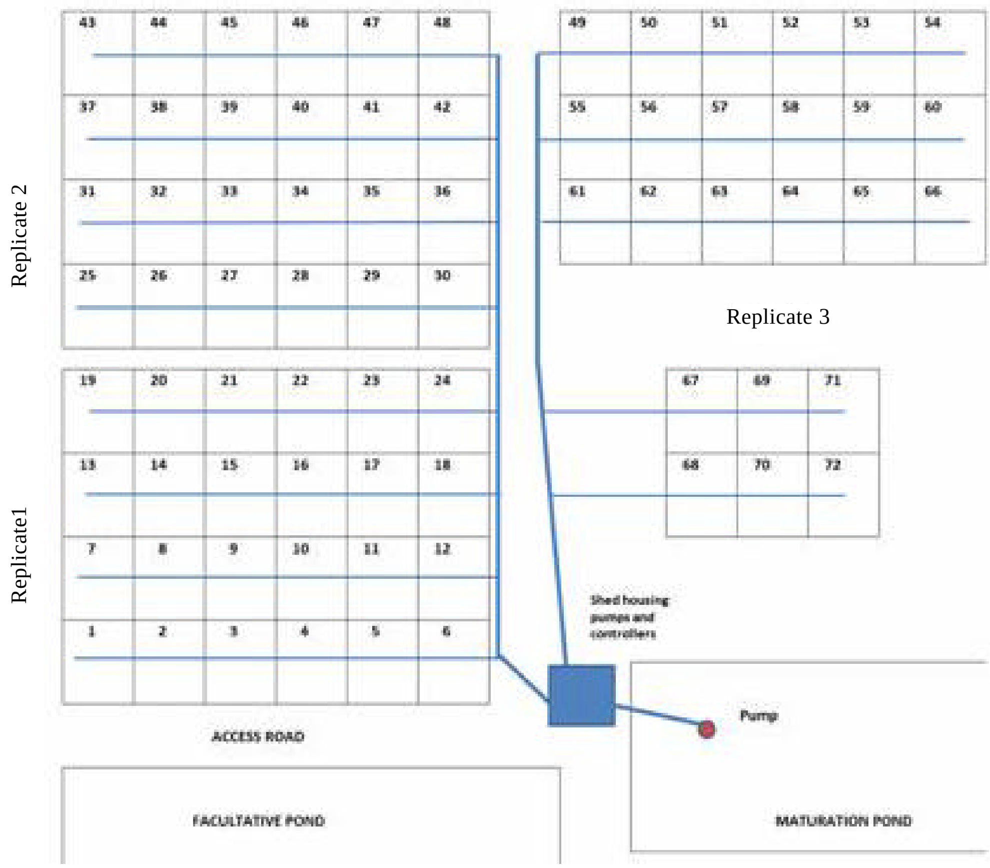
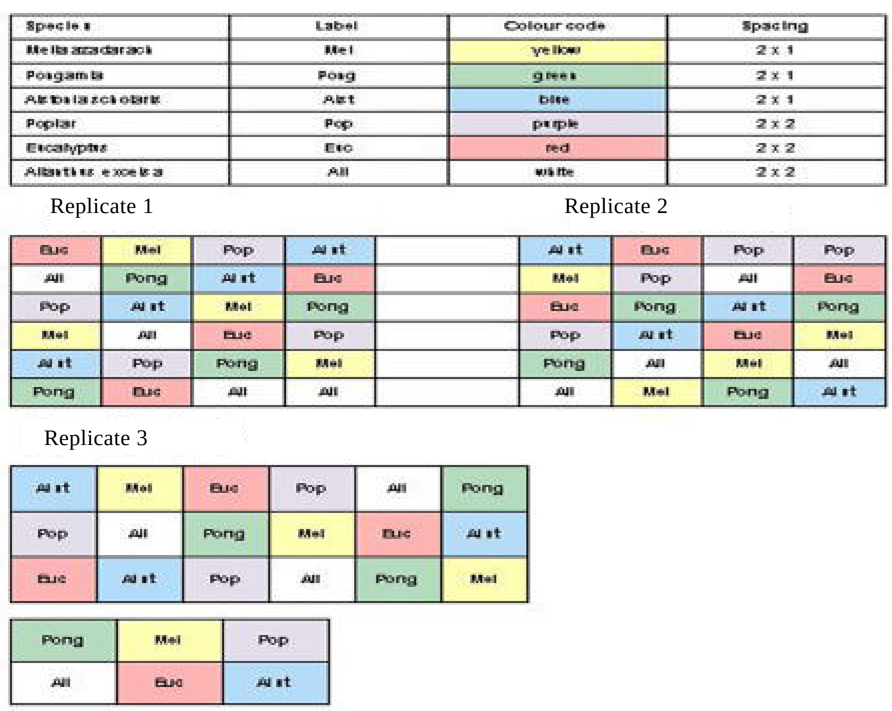


a)



b)

Fig. 1— a) Schematic plan of the trial layout at Palwal including plot numbers; b) Species distribution within trial

Table 1—Characteristic of effluent water collected from five ponds at Palwal

Pond No.	pH	EC umhos/cm	P mg/l	TSS mg/l	FOG mg/l	Total N mg/l	NH_4-N mg/l	NO_3-N mg/l	BOD mg/l
1	8.07	3336	9.47	81	2.80	40.0	34.17	3.72	40.33
2	8.28	3066	6.28	102	2.23	41.0	35.87	3.39	37.00
3	8.30	3163	7.09	108	1.87	37.5	3.57	3.57	26.67
4	8.25	3353	6.30	56	1.67	42.5	2.92	2.92	19.67
5	8.44	3390	5.53	49	1.23	45.0	4.05	4.05	12.00

Trial was planted in early April 2008. All plants except poplar and *Eucalyptus* were procured as 1 y old seedlings. *Eucalyptus* was clonal material of excellent quality supplied by Department of Environmental Sciences, G B Pant Agricultural University, Pantnagar. Saplings of poplar clone G_{48} were planted in January 2009 and some were planted in January 2010 to fill up the gaps. Irrigation equipment was not installed until May 2009 and during the interim, trial was irrigated using fresh water supplied from a tube well at a neighbour farm.

Effluent Application Rates

Data for evaporation potential (EP) in New Delhi area was used as starting point for determining hydraulic loading. Trial was an endeavour to establish optimal water application rate, which is highest biomass yield per unit of water added and efficacy of plantations at renovating effluent water; hence, irrigation rate brackets actual mean EP. Consequently, application rates selected were B_1 (0%), B_2 (25%), B_3 (50%) and B_4 (100%) of daily net EP (Fig. 1a). Municipal sewage wastewater treatment plant at Palwal comprised of 5 ponds, which were sampled in April 2008 to determine quality of each pond in order to select the most appropriate one for use in the experiment. Chemical analysis of water stored in these tanks was carried out (Table 1). There was a steady decline in total suspended solids (TSS) and total P content. Nitrogen concentrations were relatively high and maintained throughout the ponds. Concentrations of P and TSS indicated that final maturation pond was the most appropriate for experiment. pH and EC were more or less same in all ponds. Soil analysis showed wide variation in chemical contents as follows: pH, 7.0-8.6; EC_e, 0.1- 2.8 umhos/cm; organic carbon, 0.17-1.1%; total N, 252-378 mg/kg; available P, 5-10 mg/kg; available K, 100-250 mg/kg; available Na, 6.1-28.8 mg/kg; and available Ca, 10-29 mg/kg.

Measurement of Soil Moisture

Water supply to trees is not only determined by the amount of water added in irrigation, but also by the manner how soil retains water. This is a function of soil texture, structure, organic matter content and management. Hence, it is not just the amount of water present, but also how strongly it is retained by soil matrix that controls plant growth. Thus, for measurement of soil moisture, Profile Probe (PR2) was used down the soil profiles. Probe was inserted into a permanently fixed access tube and readings taken at 10, 20, 30, 40, 60 and 100 cm depths at weekly intervals. Readings were collected in a handheld logger (HH2, Delta T Devices, UK).

Regression Equations

Regression equations were obtained by taking height, diameter and diameter^2 x height as independent variables and biomass as dependent variable. These equations were developed on the basis of 25 trees of each species. Statistical analyses were carried out by online statistical package (http://202.141.47.5/opstat/).

Results

Survival after 2.5 year varied from 25.2% in *P. deltoides* clone G_{48} to 71.7% in *P. pinnata* (Table 2, Fig. 2). Among six species, survival (%) was significantly ($p<0.01$) different and decreased significantly over a period of 2.5 year. *E. tereticornis* and *P. deltoides*, two fast growing exotic species, could not establish well as survival decreased sharply from 93.3% and 100%, respectively, in first year, to 28.3% and 25.2%, respectively, in 3rd year.

Average collar diameter showed wide variation from 5.81 cm in *P. pinnata* to 11.66 cm in *A. excelsa* after 2.5 years of growth (Table 3). *P. deltoides* performed well during first year, and later on its growth was poor. *M. azedarach* and *A. scholaris* picked up growth faster during later years, relating to species tolerance towards saline and poor quality soil. Irrigations from 25% to 100% of EP could not improve increment in growth, thereby showing that although nutrients are available through irrigation, but establishing plants could not utilize it.

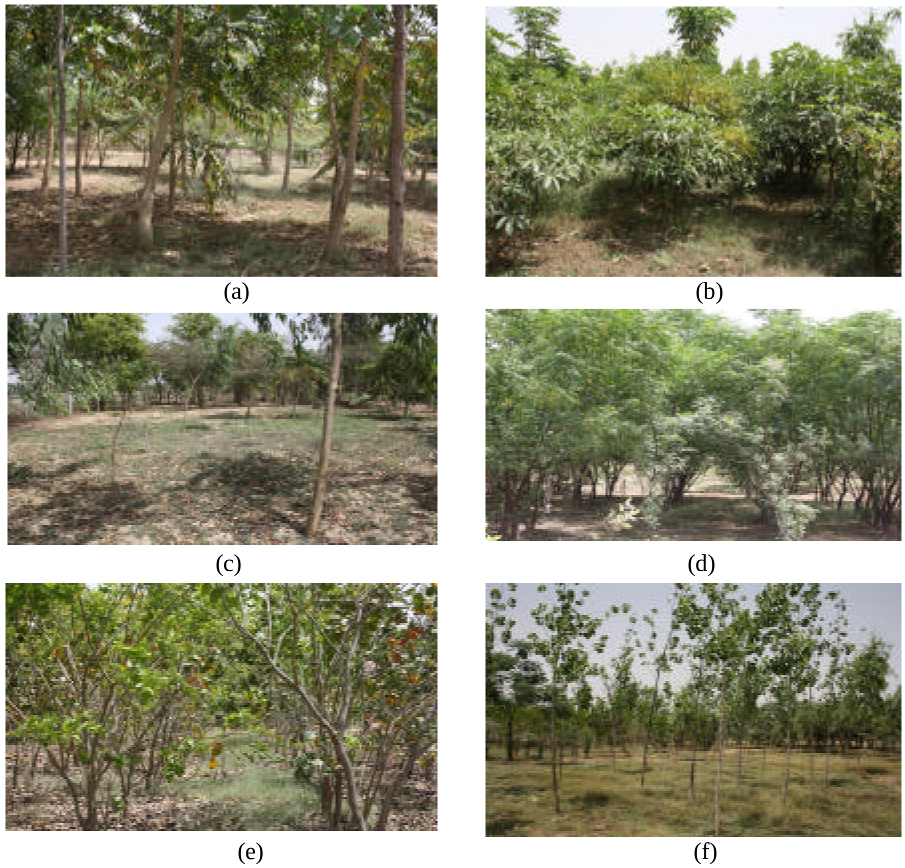


Fig. 2—(a) *Ailanthus excelsa*, (b) *Alstonia scholaris*, (c) *Eucalyptus tereticornis*, (d) *Melia azedarach*, (e) *Pongamia pinnata* and (f) *Populus deltoides* clone G_{48}

Table 2—Survival (%) of six tree species over a period of 2.5 years (June 2008 to Jan. 2011) at Palwal, north- west India

	May 2009					April 2010					January 2011				
	B_1	B_2	B_3	B_4	Mean	B_1	B_2	B_3	B_4	Mean	B_1	B_2	B_3	B_4	Mean
Eucalyptus tereticornis	93.3	98.3	83.	98.3	93.3	31.6	43.3	28.3	50.0	38.3	23.0	27.3	23.3	39.6	28.3
Populus deltoides	100	100	100	96.6	99.2	46.6	61.6	50.0	49.0	51.8	27.6	31.0	21.6	20.6	25.2
Ailanthus excelsa	68.3	85	60	68.3	70.4	55.0	78.3	51.0	55.0	59.8	43.6	74.3	37.0	45.0	50.0
Alstonia scholaris	93.6	97.6	94	96.3	95.4	45.3	52.6	53.3	56.6	52.0	35.6	45.0	44.6	47.3	43.2
Melia azedarach	95.6	60.6	91.6	90	84.5	76.3	68.6	77.3	72.0	73.6	67.3	61.6	64.6	50.0	60.9
Pongamia pinnata	95.3	98.3	97.3	98.3	97.3	84.6	89.3	87.3	89.6	87.7	52.6	75.6	74.0	84.6	71.7
Mean B	91.0	90.0	87.2	91.3		56.6	65.6	57.9	62.0		41.6	52.5	44.2	47.9	

Factors	C.D.	SE(d)	SE(m)	Factors	C.D.	SE(d)	SE(m)	Factors	C.D.	SE(d)	SE(m)
Factors(A)	9.82	4.86	3.43	Factor(A)	15.79	7.82	5.53	Factor(A)	14.23	7.05	4.98
Factor(B)	N/A	3.97	2.80	Factor(B)	N/A	6.38	4.51	Factor(B)	N/A	5.75	4.07
Factor (A x B)	N/A	9.72	6.87	Factor (A x B)	N/A	15.64	11.06	Factor (A x B)	N/A	14.10	9.97

Factor A, species; Factor B, irrigation intensity (B_1 0%, B_2 25%, B_3 50%, B_4 100% level of irrigation)

Table 3—Collar diameter (cm) (average of 10 randomly selected plants of each species) over a period of 2.5 years (June 2008 to Jan. 2011) at Palwal, north- west India

	May 2009					April 2010					January 2011				
	B_1	B_2	B_3	B_4	Mean	B_1	B_2	B_3	B_4	Mean	B_1	B_2	B_3	B_4	Mean
Eucalyptus tereticornis	1.75	1.46	1.17	1.45	1.46	4.03	4.79	5.63	4.75	4.80	5.78	6.63	7.68	8.48	7.14
Populus deltoides	3.25	3.60	3.81	3.32	3.49	6.07	5.48	6.71	5.93	6.05	9.73	7.41	7.24	6.84	7.80
Ailanthus excelsa	3.34	4.71	4.72	3.43	4.05	8.21	11.20	11.62	8.89	9.98	9.83	12.63	12.27	11.91	11.66
Alstonia scholaris	1.64	2.69	3.13	2.84	2.57	4.68	6.81	8.09	6.13	6.43	6.90	8.20	10.11	8.09	8.32
Melia azedarach	2.16	2.16	3.05	2.70	2.52	4.24	5.70	6.88	5.71	5.63	4.81	8.23	7.06	4.55	6.16
Pongamia pinnata	2.03	2.41	2.16	2.89	2.37	4.67	5.41	5.40	5.10	5.14	4.98	6.46	6.43	5.40	5.81
Mean B	2.36	2.84	3.00	2.77		5.32	6.56	7.39	6.08		7.00	8.26	8.46	7.54	

Factors	C.D.	SE(d)	SE(m)	Factors	C.D.	SE(d)	SE(m)	Factors	C.D.	SE(d)	SE(m)
Factors(A)	0.628	0.311	0.22	Factor(A)	1.457	0.721	0.51	Factor(A)	1.44	0.713	0.504
Factor(B)	N/A	0.254	0.179	Factor(B)	1.19	0.589	0.417	Factor(B)	N/A	0.582	0.412
Factor (A x B)	N/A	0.622	0.44	Factor (A x B)	N/A	1.443	1.02	Factor (A x B)	N/A	1.426	1.009

Factor A, species; Factor B, irrigation intensity (B_1 0%, B_2 25%, B_3 50%, B_4 100 % level of irrigation)

Table 4—Height (m) (average of 10 plants of six tree species) over a period of 2.5 years (June 2008 to Jan. 2011) at Palwal, north- west India

	May 2009					April 2010					January 2011				
	B_1	B_2	B_3	B_4	Mean	B_1	B_2	B_3	B_4	Mean	B_1	B_2	B_3	B_4	Mean
Eucalyptus tereticornis	1.43	1.43	1.21	1.56	1.41	3.85	5.02	5.08	4.54	4.62	5.32	7.43	9.71	10.23	8.17
Populus deltoides	4.82	5.04	4.86	4.82	4.88	6.41	5.93	6.42	5.57	6.08	6.41	5.70	8.28	6.10	6.62
Ailanthus excelsa	0.78	1.12	1.06	0.74	0.92	2.95	2.89	4.32	2.86	3.25	4.83	6.80	6.40	5.41	5.86
Alstonia scholaris	0.80	1.11	1.27	1.16	1.09	1.82	2.36	2.58	2.36	2.28	3.34	3.20	3.31	2.91	3.19
Melia azedarach	1.09	0.98	1.28	1.33	1.17	2.60	2.96	3.90	3.14	3.15	2.85	4.41	7.20	3.16	4.40
Pongamia pinnata	1.04	1.17	1.06	1.53	1.20	2.67	2.69	2.48	2.62	2.61	3.34	3.49	4.12	4.34	3.82
Mean B	1.66	1.81	1.79	1.85		3.88	3.64	4.13	3.51		4.34	5.17	6.50	5.36	

Factors	C.D.	SE(d)	SE(m)	Factors	C.D.	SE(d)	SE(m)	Factors	C.D.	SE(d)	SE(m)
Factors(A)	0.344	0.17	0.12	Factor(A)	1.004	0.497	0.351	Factor(A)	1.266	0.627	0.443
Factor(B)	N/A	0.139	0.098	Factor(B)	N/A	0.406	0.287	Factor(B)	1.033	0.512	0.362
Factor (A x B)	N/A	0.341	0.241	Factor (A x B)	N/A	0.994	0.703	Factor (A x B)	N/A	1.253	0.886

Factor A, species; Factor B, irrigation intensity (B_1 0%, B_2 25%, B_3 50%, B_4 100 % level of irrigation)

After 2.5 years, maximum height was attained by *E. tereticornis* (8.17 m) and *P. deltoides* (6.62 m), and it was 1.5-2.0 - fold greater than that of other four species (Table 4). *P. pinnata* apparently seems to be highly successful as having 71.7% survival, but could not do well in terms of increment in height (3.82 m after 2.5 y). Height remained an important parameter particularly for establishment of plantations against grazing by wildlife and cattle. This parameter, however, was not statistically dependent upon the level of irrigation by effluent.

Equations were developed between diameter and/ or height and biomass on the basis of 25 trees of each

Table 5—Regression equations and co-efficient of correlations between collar diameter (cm), height (m) and biomass (kg) developed on the basis of 25 trees of each species

Eucalyptus tereticornis		*Alstonia scholaris*	
Biomass =	$-10.175+4.797^{**}$ D (R^2 = 0.918)	Biomass=	$-0.060+0.800^{**}$ D (R^2 = 0.957)
Biomass =	$-5.310+3.760^{**}$ H (R^2 =0.76)	Biomass=	$-0.206+2.609^{**}$ H (R^2=0.729)
Biomass=	$-11.390+3.674^{**}$ D $+1.194^{**}$ H (R^2 = 0.831)	Biomass=	$-0.611+0.674^{**}$ D $+0.587^{**}$ H (R^2=0.97)
Biomass=	$4.797+0.306^{**}$ D x H (R^2 =0.858)	Biomass=	$2.846+0.148^{**}$ D x H (R^2 = 0.918)
Biomass=	$10.736+0.023^{**}$ D^2 x H (R^2 = 0.773)	Biomass=	$4.243+0.009^{**}$ D^2 x H (R^2 = 0.883)
Populus deltoids		*Melia azedarach*	
Biomass=	$-6.327+1.873^{**}$ D (R^2=0.83)	Biomass=	$-2.588+2.040^{**}$D (R^2=0.89)
Biomass=	$-3.698+1.959^{*}$ H(R^2=0.23)	Biomass=	$-2.959+3.786^{**}$H (R^2=0.702)
Biomass=	$-3.297+2.175^{**}$ D -0.909^{*} H (R^2=0.86)	Biomass=	$-2.573+2.045^{**}$D -0.013NS H (R^2=0.89)
Biomass=	$-2.108+0.210^{**}$ D x H (R^2 =0.753)	Biomass=	$5.905+0.185^{**}$ D x H (R^2 =0.796)
Biomass=	$1.841+0.014^{**}$ D^2 x H (R^2 =0.799)	Biomass=	$9.432+0.009^{**}$ D^2 x H (R^2 =0.674)
Ailanthus excelsa		*Pongamia pinnata*	
Biomass=	$-1.979+2.038^{**}$ D (R^2=0.91)	Biomass=	$0.103+0.665^{**}$ D (R^2=0.88)
Biomass=	$-8.734+6.158^{**}$H (R^2=0.58)	Biomass=	$-0.483+1.717^{**}$H (R^2=0.78)
Biomass=	-6.183+1.784 D +1.347 H (R^2=0.927)	Biomass=	$-0.227+0.531^{**}$D + 0.408^{NS} H (R^2=0.89)
Biomass=	$6.436+0.232^{**}$ D x H (R^2 = 0.918)	Biomass=	$2.031+0.105^{**}$ D x H (R^2 =0.819)
Biomass=	$14.439+0.008^{**}$ D^2 x H (R^2 = 0.806)	Biomass=	3.021+0.007 D^2 x H (R^2 = 0.748)

*Significant at 0.01 level; NS, not significant; D, diameter; H, height

Table 6—Density of surviving trees/ha in January 2011 after 2.5 years of growth

Species	B_1	B_2	B_3	B_4	Mean
Eucalyptus tereticornis	575	675	583	990	707
Populus deltoides	690	775	540	515	630
Ailanthus excelsa	1090	1857	925	1125	1250
Alstonia scholaris	1780	2250	2230	2365	2155
Melia azedarach	3365	3080	3230	2500	3045
Pongamia pinnata	2630	3780	3700	4200	3585

B, irrigation intensity (B_1 0%, B_2 25%, B_3 50%, B_4 100%)

Table 7—Biomass* (kg/tree) in January 2011 after 2.5 years of growth

Species	B_1	B_2	B_3	B_4	Mean
Eucalyptus tereticornis	17.6	21.6	26.6	30.5	24.1
Populus deltoides	11.9	7.5	7.2	6.5	8.3
Ailanthus excelsa	18.1	23.7	23.0	22.3	21.8
Alstonia scholaris	5.5	6.5	8.0	6.4	6.6
Melia azedarach	7.2	14.2	11.8	6.7	12.6
Pongamia pinnata	3.2	4.2	4.2	3.5	3.7

*Calculated on the basis regression equations developed between diameter and biomass through harvest of 25 trees of each species (The most ideal equation was with diameter and biomass); B, irrigation intensity (B_1 0%, B_2 25%, B_3 50%, B_4 100%)

species. Very high correlation co-efficient (R = nearing to 1) were obtained between diameter and biomass although height also correlated significantly with biomass (Table 5). In some cases, if height was combined with diameter, it reduced correlation value. Similarly, diameter x height or diameter^2 x height also gave lesser values of co-efficient of determination. Linear regression equations based upon diameter were therefore, used to estimate biomass per tree and per unit area taking into account the surviving density.

High density was obtained after 2.5 years in case of *P. pinnata* (3585 stems/ha) and *M. azedarach (*3045 stems/ha) followed by *A. scholaris* (2155 stem/ha) and lower in the remaining three species (Table 6). For an energy plantation, in which species are to be regenerated through coppicing, density of more than 2500 stems/ha seems to be reasonably good.

Highest weight (Table 7) was of individual tree of *E. tereticornis* (24.1 kg/tree) followed by *A. excelsa* (21.8 kg/tree) with the low values of *P. pinnata* (3.7 kg/tree)

Table 8—Biomass* (t/ha) of six tree species

Species	B_1	B_2	B_3	B_4	Mean	Anticipated biomass yield** t/ha
Eucalyptus tereticornis	10.1	14.5	15.5	30.2	17.0	60.2
Populus deltoides	8.2	5.8	3.9	3.3	5.2	20.7
Ailanthus excelsa	19.7	44.0	21.3	25.1	27.2	54.5
Alstonia scholaris	9.8	14.6	17.8	15.1	14.2	33.0
Melia azedarach	24.2	43.7	38.1	16.7	38.4	63.0
Pongamia pinnata	8.4	15.8	15.5	14.7	13.3	18.5

*Estimated on the basis of biomass/tree and density of surviving trees; **This is assumed that all trees would have survived, because at 2.5 years of age, plants were not competing with each other; B, irrigation intensity (B_1 0%, B_2 25%, B_3 50%, B_4 100 %)

and *A. scholaris* (6.6 kg/tree). In 2.5 years old plantations, over all above-ground biomass was significantly ($p<0.01$) higher for *M. azedarach* (38.4 t/ha) and it was 2.8-fold and 2.7-fold higher than *P. pinnata* and *A. scholaris,* respectively (Table 8). *A. excelsa* (27.2 t/ha) ranked second while *P. deltoides* performed poor. If it is assumed that all trees of *E. tereticornis* and *A. excelsa* were to survive, plot would have produced biomass to the tune of 60.2 t/ha and 54.5 t/ha, respectively after 2.5 years accumulating biomass at reasonably high rate (Table 8). A perusal of data shows that values come at par with *M. azedarach* showing importance of survival and establishment of plantations.

Discussion

Due to firewood shortage in arid and semi-arid regions of the world, there is increasing interest in short rotation high density plantations[1]. In such landscapes, soil is nutrient poor, saline or alkaline and receives scanty rainfall that is unable to support high potential for production of biomass. High density plantations after 2.5 years in present study carried out at Palwal, accumulated fairly high amount of above-ground biomass up to 38.4 t/ha in *M azedarach* (15.36 t/ha/y) and 27.2 t/ha in *Ailanthus excelsa* (11 t/ha/y). Values of biomass production in these species, tolerating saline soil, compares favorably with forests of India, where values are reported[2-4] to range from 18 to 22 t/ha/y. High values have been reported for well managed agroforestry systems[5] (20-26 t/ha/y), for 4-y old plantations of *Prosopis juliflora* in semi-arid region[6] (30 t/ha /y) and a standing biomass of *Leucaena leucocephala* (112 t/ha), *E. tereticornis* (96 t/ha) and *Acacia nilotica* (52 t/ha) after 4 years with a initial plant spacing of 2 m x 2 m in North India[7]. Extremely high values of biomass production have also been reported in 5-y old plantations of *Casuarina equisetifolia* (36 t/ha/y) in Puerto Rico[8,9] and of short rotation high density plantations of *A. nilotica* (35-41 t/ha/y) in an irrigated semi-arid region of Pakistan[10]. Growth in terms of diameter, height and biomass production in *M. azedarach* and *A. excelsa* was reasonably good, in spite of uneven soil with salinity and poor in organic carbon. Survival was good for *A. scholaris* (43.2%) and *P. pinnata* (71.7%), but biomass production was restricted by poor diameter and height increments, which were, however, not statistically dependent upon the levels of irrigation by effluent water. Plants allocate proportionately more biomass underneath than making increment in height and diameter, which may be an important characteristic of native arid and semi-arid species as a strategy to survive harsh environment[11]. Variation in shoot extension and biomass production is also related to leaf longevity and flushing behavior of these species[12]. *P. deltoides* clone G_{48} is a very fast growing exotic species in nutrient and water rich soils of northern India but could not perform well in present experiment due to soil salinity. Thus, *A. excelsa* and *M. azedarach* showed promising performance in poor quality soil. Generally, initial stocking rates are in the order of 1000-1200 trees/ha, with a plant spacing of 3 m x 3 m. Close spacing (1 m x 1 m) although reduces cost of branch pruning, however, cost of harvesting after a short rotation (2 y) would be more, particularly for labour intensive regions. Ideal spacing, keeping in view the quality and size of firewood, cost of harvesting, and availability of better price in the market, could be 2 m x 2 m covering 2500 stems/ha. This density also facilitates coppicing of promising tree species for biomass production (*M. azedarach, E. tereticornis* and *A. excelsa*).

Studies conducted in Australia[13-17] to understand environmental sustainability of effluent irrigated plantations, biomass production potential and water and nutrient dynamics under a range of species, sites and climate, showed that choice of tree species is a basic consideration in any effluent-irrigated plantation. Here majority of plantations were planted with just six species [Tasmanian blue gum (*E. globulus*), flood gum (*E. grandis*), river red gum (*E. camaldulensis*), Sydney blue gum (*E. saligna*), spotted gum (*E. maculata*) and radiata pine (*Pinus radiata*)]. Choice of species also varied depending upon availability of market or processing industry, ability to grow in that climate and soil type. Because of fast growth rate of the trees and potential of nutrient overloading, effluent-irrigated plantations in Australian arid and semi arid climates are best managed on short rotation (5-10 y) with plant spacing of 3 m x 3 m or as agroforestry systems[18].

Effluent-irrigated plantations have potential of generating firewood to saw-logs. Preference of irrigating tree plantations, rather than agricultural crops, is often attributed to high growth rates, which can be achieved in dry regions, because water limitation to plantation productivity is removed and effluent usually contains more nutrients than required. Ability of plantations to act as carbon sink to offset greenhouse gas emissions offers additional economic and environmental incentives for fast growing effluent irrigated plantations. Also, it produces feedstock for bio-energy processes and meet out daily firewood requirements of poor people living around urban areas. One of the economic benefits of sustainable irrigated plantations is improved quality of surface water for consumption and protection of soil and groundwater resources and even for support of precision farming such as production of vegetables and fruit through drip or sprinkler irrigation. In UK, crops management techniques of willows (*Salix* spp), poplars (*Populus* spp) and eucalypts (*Eucalyptus* spp) have been fully mechanized and commercial markets are expanding rapidly[19].

Key potential risks to sustainable effluent irrigation plantations could be excessive leaching of nitrate or salts into groundwater, which could render soil infertile in long-term and reduction in physical quality of soil due to increase in sodicity. pH of secondary treated municipal effluent ranges from 6.8 to 9.6 and concentration of Na from 50 to 250 mg per kg[18]. Increased sodicity may also lead to water logging, reduced growth of trees and increased salinity. Accumulation of heavy metals and trace elements in soil with effluent irrigation should not be a serious risk as typical values (mg/kg) of heavy metals (Cd<0.005, Cr< 0.02, Cu<0.04, Pb<0.008, Ni<0.004, Zn<0.04) in secondary effluent are lower than recommended values for irrigation water[20].

Conclusions

M. azedarach and *A. excelsa* are observed the best options for biomass production for very short (2.5 years) rotation effluent irrigated plantations. Non significant effect of irrigation treatments, 0-100% of EP, on biomass production has to be seen that the data presented pertain to only 2.5 years primary plantations. As these approach 5-6th year of growth, their evapotranspiration and nutritional demands would increase, and water and nutrients (particularly nitrogen) component of effluent in the experiment would reflect as enhanced biomass. Another significant observation is that even 100% EP treatment does not have any negative effect on biomass, indicating that effluent did not have any ingredients deleterious for the growth and development of trees.

Acknowledgements

Authors thank Prof P K Sen, IIT Delhi and Dr Philip A Davies, School of Engineering and Applied Sciences, Aston University, Birmingham, UK for providing financial support under EPSRC- EP/E044360/1. Authors also thank Prof Rajiv Angrish of CCS HAU, Hisar for giving critical suggestions to improve manuscript; Dr O P Sheoran, Computer section of CCSHAU, Hisar for help to analysis data; Mr Mohan Lal Sehgal, IIT, New Delhi for administrative help toward establishment of plantations; and Miss Neha Bhardwaj for compiling data.

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