Pak. J. Bot., 48(1): 89-96, 2016.

BIOMASS PRODUCTION OF SOME SALT TOLERANT TREE SPECIES GROWN IN DIFFERENT ECOLOGICAL ZONES OF PAKISTAN

KHALID MAHMOOD*, M. ISMAIL CHUGHTAI, ABDUL RASUL AWAN AND RIAZ A. WAHEED

Nuclear Institute for Agriculture and Biology (NIAB), P.O. Box 128, Jhang Road, Faisalabad, Pakistan
**Corresponding author's e-mail: kmahmoodniab@yahoo.com*

Abstract

A study was carried out to evaluate the biomass production potential of salt tolerant tree species grown in saline environments. For this purpose, 5 sites near Badin, Gawadar, Lahore, Faisalabad and Peshawar in different ecological zones of Pakistan were selected. Plantations of 7 tree species common to all sites including *Eucalyptus camaldulensis, Phoenix dactylifera, Acacia nilotica, Acacia ampliceps, Prosopis juliflora, Casurina obesa and Tamarix aphylla* were selected for non-destructive biomass measurements. Five trees from each species at each site were assessed for plant height, girth at breast height, canopy area, canopy shape and number of branches. For destructive biomass estimation, six trees of four species (*Eucalyptus camaldulensis, Acacia nilotica, Prosopis juliflora* and *Tamarix aphylla*) were harvested at two sites near Lahore and Faisalabad. Biomass of whole tree and its components like stem, branches, twigs, leaves and fruits were determined. Soil and water resources of these sites were also characterized. Results indicated that *E. camaldulensis* produced maximum average biomass 329 kg in $8^{1/2}$ years at soil salinity (EC 1:1) 8.5 to 9.4 dS m^{-1} and *T. aphylla* produced 188 kg at soil salinity 12.8 dS m^{-1} in $9^{1/2}$ years. *A. nilotica* produced biomass 187 kg at 16.9 dS m^{-1} in 10 years at Faisalabad; while at Lahore, 369 kg in 18 years under soil salinity level 7.3 dS m^{-1}. *P. juliflora* produced minimum biomass 123 kg at soil salinity 7.1 dS m^{-1} in 8 years at Lahore and 278 kg at soil salinity 17.2 dS m^{-1} in 16 years at Faisalabad. Both soil and water quality was comparatively better at Gawadar and Faisalabad than other sites. Overall, it is concluded that studied tree species are good performer on salt-affected soils and can make saline areas productive.

Key words: Salt tolerant trees, Stress environments, Biomass production**.**

Introduction

Approximately 1000 M ha or 7% of the world's land-area is salt-affected. In Pakistan, about 6.3 M ha are believed to be affected by salinity (Qureshi & Barrett-Lennard, 1998). Pakistan is primarily an agricultural country with a variety of ecological, climatic and soil conditions. Despite vast land resources of about 79.6 M ha, only 27% of this total area is cultivated (Ahmed & Qamar, 2004).

Trees and shrubs are biomass resources often tolerant to adverse climatic conditions and generally require low management inputs. Their woody biomass can be obtained sustainably from indigenous or naturalized vegetation growing on extensive wastelands (Harris *et al.,* 2011). Tree species with potential of producing large volumes of straight branches and trunks are regarded as important fuel sources (Tewari *et al.,* 2003).

Wood is natural material with variations in physical, anatomical and mechanical properties. It has been used for many purposes because of its excellent characteristics such as a good strength to weight ratio and aesthetic appearance. It is used for pulp, packing, building construction, furniture, sports goods and for numerous industrial uses. Increased demand for wood has caused a dramatic decrease in forest resources. So, it is necessary to use appropriate production techniques for good yield to meet this ever-increasing demand (Ates *et al.,* 2009).

Tree plantation of suitable species on saline wastelands not only provides the green coverage but also gives good economical returns. Earlier studies in Pakistan and India, identified several woody species which are highly salt tolerant (>16 dS m^{-1}) like *Prosopis juliflora, Casurina obesa* and *Tamarix aphylIa* and moderately salt tolerant (4 to 8 dS m^{-1}) like *Eucalyptus camaldulensis, Eucalyptus microtheca* and *Acacia nilotica* (Gill & Abrol, 1991; Marcar *et al.,* 1995).

Eucalyptus camaldulensis is fairly fast growing timber species, introduced in Indo-Pak sub-continent from Australia. It is adapted to a variety of ecological conditions and consequently has been planted frequently on saline wastelands. Its annual average production is up to 25 m^3 ha^{-1} $year^{-1}$ as compared to conventional timbers like *Dalbergia sissoo* (7.5 m^3 ha^{-1} $year^{-1}$) and *Acacia nilotica* (15 m^3 ha^{-1} $year^{-1}$) and can be harvested in a short time as it attains a suitable diameter at breast height (Siddiqui & Mahmood, 1986).

Prosospis juliflora is an evergreen tree species introduced into the Indian sub-continent to Sindh province in 1877 from South America. It is fast growing and more adapted species to drought condition (Tesfaye-Abebe, 2004). Its presence in different ecological zones has reduced the threat to important indigenous tree species *A. nilotica* (Saxena & Venkateshwarlu, 1991). *P. juliflora* is widespread species on wastelands in arid zones and is highly suitable as a source of fodder and energy (Prasad, 2009).

Acacia nilotica is naturally found in the dry areas of Africa, from Senegal to Egypt and down to South in Asia eastward to India, Burma and Sri Lanka. The largest tracts are found in Sindh. *A. nilotica* plantations grow naturally in the agricultural fields and develop an important agroforestry system (Pandey *et al.,* 1999). This species is good performer under salt-affected soils. Due to high nutritive values in foliage, it can play an important role in improving the soil fertility and can also give good economic returns from the marginal lands (Pandey & Sharma, 2005; Shirazi *et al*., 2006).

Tamarix aphylla is widespread species throughout southeastern Europe, North Africa and Central Asia. It is fast growing, moderate sized evergreen tree with many stout spreading purplish brown and smooth branches. High salinity level in soil significantly reduced growth and biomass of *T. aphylla* (Orwa *et al.,* 2009). Its wood can be used as fuel and for making boards (Zheng *et al.,* 2007). *Tamarix* wood may also be suitable for making ploughs, wheels, carts, tool handles, brush-backs, ornaments, turnery and fruit boxes. Its twigs are used for basket making and bark is a rich source of tannins and mordant for dyeing (Orwa *et al.,* 2009).

Keeping in view the importance of woody biomass, this study was carried out to estimate the biomass production both non-destructive and destructive of some salt tolerant tree species in relation to soil conditions particularly salinity and water quality in different ecological zones of Pakistan.

Materials and Methods

A survey was conducted to select established salt tolerant plantations of different ages in different ecological zones of Pakistan (*lat.* 24^o and 37^{o}N and *long.* 61^o and 76^{o}E) to estimate their biomass characteristics. Climatically, Pakistan can be divided into 36 ecological zones. For biomass estimation of established salt tolerant tree species, following five sites were selected all over the Pakistan, two in Punjab and one each in other three provinces (Fig. 1).

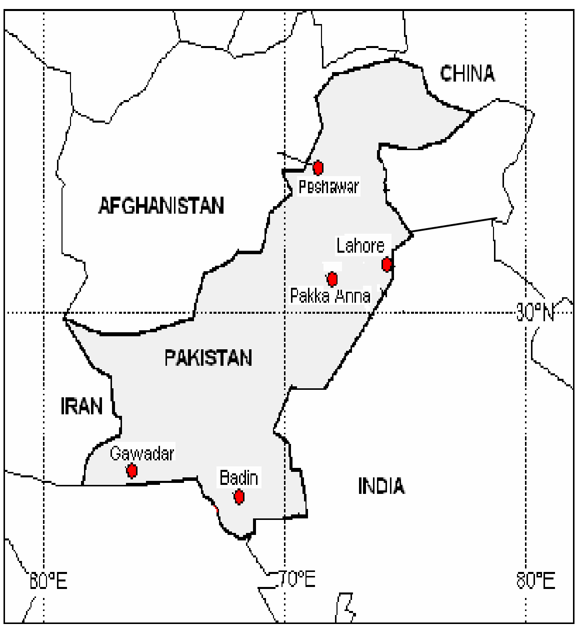

Fig. 1. Selected study sites in Pakistan.

Climatic conditions of study sites are described hereunder:

Badin: Badin is an agro-industrial district of Sindh province (*lat.* 24°.38'N *and long.* 68°.54'E). The climate as a whole is moderate but tampered by the sea breeze, making the hot weather comparatively cool. During the monsoon period, the sky is cloudy but there is very little precipitation. The climate in summer is generally moist and humid. The maximum temperature in the hot weather does not exceed 40ºC. Rainfall is highly erratic and unpredictable with an average of 259 mm.

Gawadar: Gawadar is a district of Baluchistan province located on the southwestern coast of Pakistan at the apex of the Arabian Sea and at the mouth of the Gulf of Oman (*lat.* 31º.24'N*, long.* 73º.05'E). The climate is mainly dry, arid and hot. The mean temperature in the hottest month remains 32°C while in coolest month 18°C. It is situated outside the monsoon belt but still receives light monsoon showers in summer. Annual average rainfall is only 100 mm.

Lahore: Biosaline Research Station-I, Lahore of Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad; comprises of 60 hectares of saline wasteland located at a distance of 18 km from Lahore City (*lat.*31º.30'N*, long.* 74º.20'E). The climate is semi-arid with rainy, long and extremely hot summers with warmest average temperature 41°C. The annual average rainfall is 350 mm.

Faisalabad: Biosaline Research Station-II, Pakka Anna of NIAB, Faisalabad, comprises of 400 hectares of salt-affected wasteland located at a distance of 50 km in South-West of Faisalabad City (*lat.* 31º.24'N, *long.* 73º.05'E). The climate is semi-arid with average rainfall 200 mm. In summer, mean temperature is 39ºC and in winter 14°C.

Peshawar: Peshawar is the capital of Khyber Pakhtunkhwa province (*lat.* 34°.0'N, *long.* 71°.6'E). The climate is semi-arid with very hot summers and mild winters. The mean warmest temperature is 32.5°C and the mean coolest temperature is 5°C. Peshawar is not in a monsoon region but still rainfall is received both in winter and in the summer. The highest winter rainfall recorded is 236 mm and in summer 402 mm. The relative humidity varies from 46-76%.

Salt tolerant trees/bushes growing for >4 years of age were considered for these studies. Tree species found at study sites were *Eucalyptus camaldulensis, Eucalyptus microtheca, Acacia stenophylla, Acacia ampliceps, Acacia nilotica, Prosopis juliflora, Parkinsonia aculeate, Tamarix aphylla, Casurina glauca, Casurina obesa, Azadirachta indica, Dalbergia sissoo, Syzigium cummuni, Zizyphus jujuba, Populus deltoides* and *Phoenix dactylifera*. But for non-destructive biomass estimation, following salt-tolerant tree species were selected (Table 1).

Five representative tree samples of a species in above said selected plantations at each site were described by different parameters like plant height, stem girth, main stem height, number of main branches and canopy shape for non-destructive biomass assessment. Only two sites, Lahore and Faisalabad were selected for destructive biomass estimation. Six trees of each species (*Eucalyptus camaldulensis, Acacia nilotica, Prosopis juliflora* and *Tamarix aphylla*) were harvested to measure whole tree and its components biomass like stem, branches, twigs, leaves and fruits. The tree logs of harvested samples were preserved for further wood quality studies.

Table 1. Salt tolerant plantations selected for non-destructive growth parameters.

Site	Province	Altitude (m)	Available salt tolerant tree/bush species
Badin	Sindh	100	*Eucalyptus camaldulensis, Phoenix dactylifera, Acacia nilotica, Casurina obesa, Prosopis juliflora*
Gawadar	Baluchistan	10	*Eucalyptus camaldulensis, Phoenix dactylifera, Acacia nilotica, Prosopis juliflora*
Lahore	Punjab	220	*Eucalyptus camaldulensis, Phoenix dactylifera, Acacia nilotica, Casurina obesa, Tamarix aphylla, Prosopis juliflora*
Faisalabad	Punjab	196	*Acacia ampliceps, Eucalyptus camaldulensis, Acacia nilotica, Prosopis juliflora, Phoenix dactylifera, Tamarix aphylla*
Peshawar	Khyber Pakhtunkhwa	560	*Acacia ampliceps, Eucalyptus camaldulensis, Acacia nilotica, Prosopis juliflora, Phoenix dactylifera, Tamarix aphylla*

At each site, soil profile was studied up to 180 cm depth. In between the selected trees/bushes, soil samples were collected from three random points at 0-15, 15-30, 30-60, 60-90, 90-120, 120-150 and 150-180 cm depths. Soil samples of each depth were thoroughly mixed to get a representative uniform composite sample of each soil profile. Similarly, water samples were also collected from direct irrigation sources or present in vicinity of the plantations from all selected sites. These sources included open wells, motor pumps, canals, tube-wells and drains.

Soil and water samples were analysed for physico-chemical parameters including pH, electrical conductivity (EC), major cations and anions, sodium adsorption ratio (SAR) and residual sodium carbonates (RSC). The pH and EC were measured by using pH and EC meters. Carbonates, bicarbonates, Na^+, Ca^{+2}+Mg^{+2}, Cl^- and SAR were determined following the methods of USDA Handbook-60. Soil particle analysis was done by Hydrometer method.

Results and Discussion

Soil conditions and water quality: At Badin site, the soil salinity ranged from 24.8 to 75 dS m^{-1} in top soil at 0-15 cm depth which gradually decreased downward up to 2.6 to 27 dS m^{-1} at 150-180 cm depth (Table 2). Similar decreasing trend was observed in SAR from top to downward. High clay contents (24-36%) were observed up to 30 cm depth that may adversely affect the root extension activity by restricting irrigation water supply. The groundwater contained high chloride contents 22.5 me L^{-1}, RSC 4.4 me L^{-1} and SAR up to 17.3 in all sources (Table 3). The tree plantations were selected on the basis of soil salinity status (SS) at 30 cm depth as *E. camaldulensis* (SS: 29.8 dS m^{-1}), *P. dactylifera* (SS: 29.8 dS m^{-1}), *A. nilotica* (SS: 48.9 dS m^{-1}), *C. obesa* (SS: 50.8 dS m^{-1}) and *P. juliflora* (SS: 75 dS m^{-1}).

Generally, the soil salinity ranged between 1.2 to 45.8 dS m^{-1} in top soil followed by a gradual decrease downward to a range of 2.3 to 8.9 dS m^{-1} at 120-150 cm depth at Gawadar site. Similarly, pH and SAR showed similar decreasing trend downward. The EC of all water sources ranged 5.11-69.9 dS m^{-1} indicating the highly brackish water with very high SAR from 21.5 to 91.5 (Table 3). The selected plantations with salinity level were *E. camaldulensis* (1.5 dS m^{-1}), *P. dactylifera* (5.9 dS m^{-1}), *A. nilotica* (45.8 dS m^{-1}) and *P. juliflora* (9.8 dS m^{-1}).

The maximum soil salinity was 14.1 dS m^{-1} at 90-120 cm depth at Lahore site. The pH ranged 7.4 to 8.8 in top soil that increased gradually downward up to 9.5 at 150-180 cm depth (Table 2). The maximum SAR was observed at 120-150 cm depth. The soil was generally compact limiting the hydraulic conductivity. The groundwater contained high RSC up to 12 me L^{-1} and SAR up to 20.7 (Table 3). The selected plantations on the basis of soil salinity status were *E. camaldulensis* (9.6 dS m^{-1}), *P. dactylifera* (2.5 dS m^{-1}), *A. nilotica* (7.3 dS m^{-1}), *C. obesa* (9.8 dS m^{-1}), *P. juliflora* (6.7 dS m^{-1}) and *T. aphylla* (9.4 dS m^{-1}).

Soil salinity ranged from 6 to 15 dS m^{-1} in the top soil profile and 5-21 dS m^{-1} in the vertical profile up to 180 cm depth (Table 2) at Pakka Anna (Faisalabad). Soil pH ranged from 8.1 to 9 in the top soil and increased downwards up to the studied depth rendering the soil saline-sodic character disastrous for normal plant root growth. The soil SAR was recorded up to 181 which is unfit for agricultural activity. The groundwater salinity ranged from 6.1 to 7.2 dS m^{-1}, chloride contents 21.5 to 47 me L^{-1}, RSC 23.5 me L^{-1} and SAR 29.6.

At Peshawar site, the soil salinity was up to 33.2 dS m^{-1} in top soil which gradually decreased downward up to 17.3 dS m^{-1}. Wide variations were observed in pH ranging from 7.8 to 9.2 in top soil that almost remained unchanged up to 90 cm depth. The groundwater SAR and RSC contents were above the safe limits. The selected plantations on different soil salinity status were *A. ampliceps* (1.2 dS m^{-1}), *E. camaldulensis* (33.2 dS m^{-1}), *A. nilotica* (1.5 dS m^{-1}), *P. juliflora* (11.1 dS m^{-1}), *P. dactylifera* (6.6 dS m^{-1}) and *T. aphylla* (11 dS m^{-1}).

The RSC value of water sources ranged from 3.1 to 23.5 me L^{-1} at all sites except Gawadar. These values are above the suitable limit, i.e. $<$1.25 me L^{-1} as recommended by Muhammad (1996). Irrigation with wastewater may impact on groundwater quality. In well-drained soils, there is the possibility of movement of salts and other contaminants through the soil profile into unconfined aquifers (Bond, 1998). The SAR values of water sources at Gawadar, Peshawar and Faisalabad sites were up to 91.5 which are very high than the suitable limit, i.e. $<$6 for irrigation water. SAR is increased due to increase in Na^+ concentration. Excess levels of certain ions, such as Na^+, Cl^- cause ion-specific effects leading to toxicity in plants. Simmons *et al.* (2010) found that EC and SAR increased in wastewater-irrigated soils than freshwater-irrigated fields.

Table 2. Ranges of soil properties of selected plantations at the study sites.

Site	Soil profile (cm)	EC*$_{1:1}$ (dS m^{-1})	pH	SAR**	Sand (%)	Silt (%)	Clay (%)
Badin	0-15	24.8-75	7.76-8.4	34.7-177	52-66	4-20	24-36
	15-30	15.1-41	7.73-8.4	8.48-91.4	52-64	2-18	26-34
	30-60	8.5-28.8	7.79-8.5	18.4-41.8	54-64	10-18	24-28
	60-90	6.3-27.9	7.19-8.21	17.7-57.7	54-66	10-20	22-28
	90-120	3.8-27	7.62-8.23	7.5-51.5	51-66	16-30	14-27
	120-150	3-28.2	7.98-8.22	8.68-51.8	57-66	16-28	14-27
	150-180	2.6-27.2	8.06-8.21	7.1-49.3	45-66	18-30	14-29
Gawadar	0-15	1.2-45.8	7.68-8.12	6.41-42.6	70-84	2-3	14-29
	15-30	1.5-17.9	7.78-8.29	4.25-46.3	70-86	2-5	12-29
	30-60	1.7-11.6	7.90-8.33	6.11-47.8	72-73	1-4	23-27
	60-90	1.5-10.4	8.0-8.26	4.1-35.9	72-75	1-4	21-27
	90-120	1.7-7.0	8.0-8.22	7.71-24.9	77-81	1-6	12-28
	120-150	2.3-8.9	8.0-8.15	7.27-25.7	73-81	1-6	12-24
	150-180	2.4-9.0	7.80-8.21	7.11-31.8	72-75	1-4	21-26
Lahore	0-15	0.78-13.5	7.45-8.84	8.44-41.8	52-70	2-32	26-38
	15-30	0.96-5.58	7.72-8.64	10.7-49.6	32-66	2-30	28-40
	30-60	1.56-5.44	7.65-9.41	14.4-54.5	32-66	2-34	26-50
	60-90	0.95-6.52	7.8-9.96	18.9-108	24-64	2-38	26-46
	90-120	0.91-14.1	7.93-9.31	15.3-117	24-62	2-32	24-46
	120-150	1.39-7.38	7.96-9.81	23.4-168	24-64	2-44	26-42
	150-180	1.6-8.68	8.04-9.46	25.3-109	14-64	2-50	26-40
Faisalabad	0-15	6.06-15.0	8.07-9.04	29.2-96.8	26-68	2-40	29-48
	15-30	8.0-16.9	8.20-9.18	65.6-102	36-65	5-28	30-48
	30-60	5.0-21.0	8.20-9.10	42.7-150	44-68	4-24	28-50
	60-90	5.1-20.6	8.19-9.08	43.5-161	36-64	2-28	28-42
	90-120	5.3-19.6	8.28-9.19	65.2-181	44-64	6-32	18-40
	120-150	7.44-18.4	8.44-9.13	63.7-181	32-60	6-36	20-36
	150-180	7.47-20.1	8.38-9.10	67.3-189	32-64	6-40	17-37
Peshawar	0-15	1.2-33.2	7.8-9.20	5.8-87.6	43-67	8-30	24-26
	15-30	1.05-29.6	7.72-9.1	5.2-73.5	43-67	10-32	22-24
	30-60	1.37-20.0	7.08-9.17	7.5-85.4	42-75	0-36	22.-25
	60-90	1.57-22.4	7.73-9.18	4.3-68.6	43-81	0-34	19-22
	90-120	1.79-23.6	7.95-8.93	3.7-45.3	46-78	0-34	20-24
	120-150	1.44-19.6	7.82-8.65	8.5-39.1	60-78	2-20	20-22
	150-180	2.4-17.3	7.97-8.60	3.51-42.6	44-76	4-34	20-26

*EC: Electrical conductivity; **SAR: Sodium adsorption ratio

Table 3. Quality of irrigation waters used for selected plantations at the study sites.

Parameter	Study sites				
	Badin	Gawadar	Lahore	Faisalabad	Peshawar
EC (dS m^{-1})	0.3-3.93	5.11-69.9	0.55-1.75	6.1-7.2	0.74-3.01
pH	7.15-8.2	7.58-8.01	7.85-8.74	7.5-7.7	8.1-8.53
Chloride (me L^{-1})	1.7-22.5	5.0-77.5	0.75-4.0	21.5-47	1.5-14.0
RSC* (me L^{-1})	0-4.4	Nil	0.7-12.0	10.8-23.5	1.2-3.1
SAR	1.59-17.3	21.5-91.5	1.46-20.7	21.5-47	8.24-29.6

*RSC: Residual sodium carbonates

Table 4. Non-destructive description data of selected tree species at the study sites.

Site	Location	Species	Age (year)	Shoot height (m)			Crown height (m)			GBH (m)		
				Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.
Badin	Mirza Farm	*E. camaldulensis*	8	2.89	1.94	3.8	14.69	13.83	15.5	0.29	0.26	0.4
	Liaqat Farm	*A. nilotica*	15	2.37	1.81	2.9	12.75	11.9	14	0.33	0.25	0.5
	Brohi's Land	*P. juliflora*	10	0.49	0.31	0.7	8.36	7.32	9.69	0.38	0.28	0.5
	Parihar Farm	*P. dactylifera*	15	1.64	1.28	1.8	11.6	9.82	12.9	0.49	0.4	0.6
	Parihar Farm	*C. obesa*	10	2.13	1.51	2.9	5.45	4.84	6.06	0.86	0.68	1.1
Lahore	Hectare 4	*E. camaldulensis*	8	2.98	1.85	4.2	13.09	8.15	21.6	0.14	0.07	0.2
	Hectare 12	*A. nilotica*	18	2.36	2.14	2.6	10.96	9.28	14.5	0.21	0.15	0.3
	Hectare 58	*P. juliflora*	8	0.74	0.36	1.12	6.30	5.67	7.47	0.45	0.41	0.5
	Hectare 7	*P. dactylifera*	16	1.73	1.28	2.6	6.14	5.15	8.46	0.48	0.17	1.3
	Hectare 24	*C. obesa*	14	2.99	2.46	3.9	13.83	10.3	16.2	0.15	0.11	0.2
	Hectare 26	*T. aphylla*	10	0.88	0.80	0.96	7.86	7.01	8.53	0.63	0.56	0.7
Gawadar	Pasni	*E. camaldulensis*	15	4.05	2.01	5.5	20.54	18.78	22.7	0.34	0.32	0.8
	Nagore Sharif	*A. nilotica*	14	1.53	1.25	1.9	7.81	7.42	8.34	0.44	0.32	0.5
	City Graveyard	*P. juliflora*	15	2.13	0.89	3.5	9.39	7.57	10.6	0.35	0.27	0.5
	Mauza Bandri	*P. dactylifera*	15	7.1	5.51	9.2	9.96	7.65	11.6	0.39	0.32	0.5
Peshawar	Gul Zaman Farm	*E. camaldulensis*	8	0.73	0.68	0.8	9.53	6.85	12.3	0.33	0.21	0.4
	LF[1]	*A. nilotica*	20	4.01	3.08	5.2	17.81	12.81	22	0.42	0.25	0.5
	MDF[2]	*P. juliflora*	9	0.71	0.31	0.9	5.6	5.11	6.36	0.18	0.12	0.2
	MDF	*P. dactylifera*	12	4.86	3.85	5.6	8.8	5.85	10.6	0.38	0.34	0.4
	Basra Farm	*T. aphylla*	12	1.09	0.94	1.2	10.24	8.17	11.8	0.24	0.2	0.4
	MSA[3]	*A. ampliceps*	4	0.64	0.21	1	6.09	5.31	6.58	0.15	0.12	0.2
Faisalabad	Hectare 36	*E. camaldulensis*	9	4.62	3.06	6.4	32.48	14.82	77	0.18	0.17	0.2
	Hectare 60	*A. nilotica*	10	2.46	1.81	3	11.09	9.18	12.7	0.15	0.08	0.2
	Hectare 29	*P. juliflora*	16	1.08	0.83	1.4	3.43	1.65	4.31	0.35	0.20	0.5
	B-Block	*P. dactylifera*	15	3.48	2.44	5.2	7.13	4.64	9.65	0.88	0.8	1
	Hectare 43 W	*T. aphylla*	9	0.83	0.75	0.91	7.46	6.46	8.47	0.55	0.53	0.6
	Hectare 27	*A. ampliceps*	13	2.27	1.81	3	13.08	12.04	14	0.19	0.14	0.3

[1]LF: Locomotive factory, [2]MDF: Military dairy farm, [3]MSA: Mardan SCARP area

Non-destructive biomass estimation: At all study sites, five trees/bushes of each species were selected randomly with almost uniformity with respect to vigour and soil for non-destructive biomass data. These selected trees were described by different growth parameters like plant height; stem girth, main stem height, number of main branches and canopy radius and shape. The shapes of selected plantations were described as the *E. camaldulensis* shaped spherical, oval and cylindrical, *A. nilotica* and *P. dactylifera* umbrella like, *C. obesa* cone like and *P. juliflora* was mushroom shaped with 2 to 3 braches at almost all sites. The averages of some growth parameters are given in Table 4.

Destructive biomass estimation: For destructive biomass data, four tree species, *viz*. *E. camaldulensis, A. nilotica, P. juliflora* and *T. aphylla* were selected as common at two sites (Lahore and Faisalabad). Six trees of each species were harvested for biomass assessment for various plant components like stem, branches, twigs, leaves and fruits. These species were evaluated for biomass production in relation soil conditions (Fig. 2). *P. juliflora* can tolerate salinity level up to 35 dS m^{-1} while *A. nilotica* and *E. calmadulensis* can tolerate salinity level up to 25 dS m^{-1} (Khan & Qaiser, 2006).

At Lahore site, *E. camaldulensis* produced biomass 299 kg in 8 years at soil salinity 4.3-8.6 dS m^{-1} while at Faisalabad 333 kg in nine years at soil salinity 9.4-14.9 dS m^{-1}. The average biomass produced about 37 kg annually at both sites. Soil salinity was more at Faisalabad. Mahmood *et al.* (2011) reported that *E. camaldulensis* produced fresh timber up to 200 kg under saline well-drained conditions (average EC_e of 10 dS m^{-1} at 0-90 cm). The SAR of soil in sampled plot (*E. camaldulensis* plantation at Lahore) was up to 32.3 while at Faisalabad, the SAR was recorded up to 150. The moisture content in *E. camaldulensis* biomass was comparable, i.e., 60% at Lahore and 59% at Faisalabad (Table 5).

Similarly, *Acacia nilotica* produced 369 kg average biomass during 18 years of growth at BSRS, Lahore (soil salinity 7.3 dS m^{-1}) while 187 kg in 10 years at Faisalabad (soil salinity 8.2 dS m^{-1}). The annually increased biomass was 18.8 kg at Faisalabad site which less than Lahore site (20.4 kg) may be due to high salinity level in both water and soil. The moisture content in *A. nilotica* biomass was 64.9% at Lahore site and 60.6% at Faisalabad site. *A. nilotica* produced 77 t ha^{-1} standing biomass in 8 years of growth and after 4 years, 52 t ha^{-1} with average production 9-13 t ha^{-1} $year^{-1}$ (Singh & Toky, 1995). Maguire *et al.* (1990) also reported that *A. nilotica* can produce up to 40 t ha^{-1} $year^{-1}$ of dry-weight of total above-ground biomass. The average biomass of *Prosopis juliflora* was recorded 118 kg at Lahore site (soil salinity 7.1 dS m^{-1}) while 278 kg at Faisalabad site (soil salinity 17.2 dS m^{-1}) with moisture content 58.7 and 70.7%, respectively. The age of *P. juliflora* plantation was 8 years at Lahore site and 16 years at Faisalabad. *P. juliflora* grows well in areas having high salinity or alkalinity levels, can tolerate as high as pH 9.5 (Singh *et al*., 1993). *P. juliflora* grows rapidly on all kinds of soil, with mean annual increments of 66 cm in height, 1.73 cm in breast height diameter and a total yield of 50-60 t ha^{-1} after 10 years and 75-100 t ha^{-1} after 15 years (Vimal & Tyagi, 1986). *P. juliflora* could yield up to 52.3 t ha^{-1} biomass in 6 years (Khan & Qaiser, 2006). James *et al.* (2008) concluded that increased availability of fuel, fodder and other benefits depend on the quantity of biomass a tree species can produce. So, suitability of tree species to site conditions may be assessed on the biomass yield (Dagar, 2014).

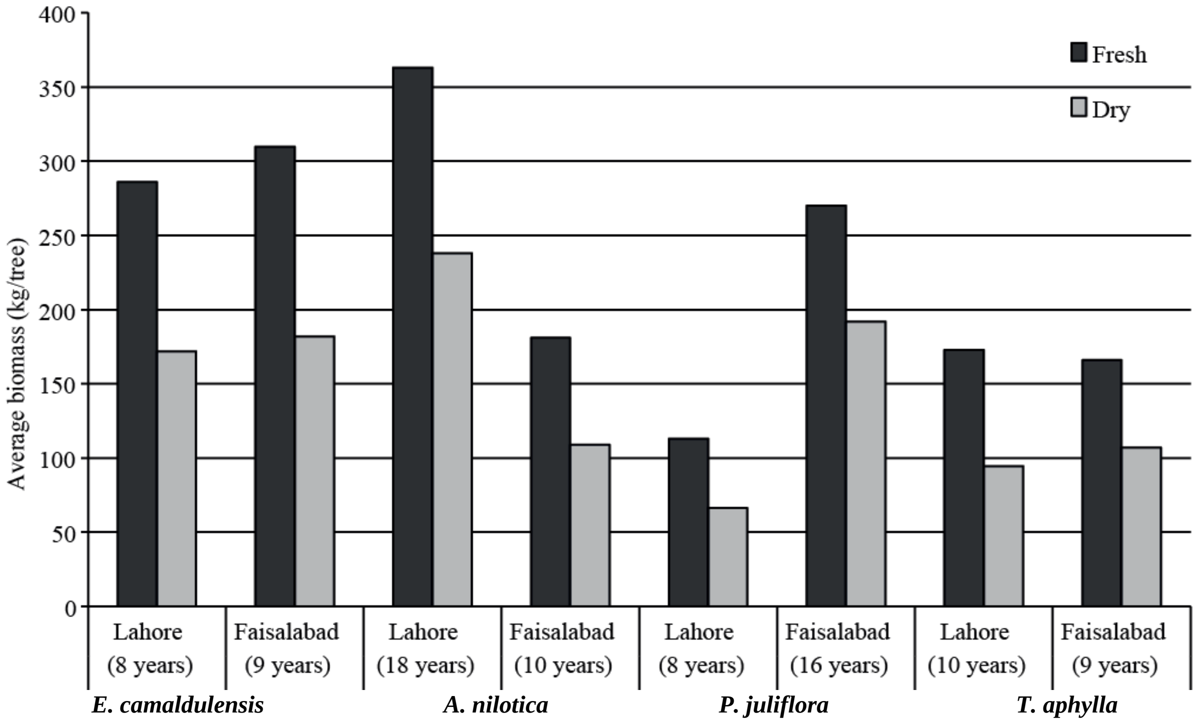

Fig. 2. Comparison for biomass production among different tree species.

The average biomass of *T. aphylla* was similar; 188 kg at Lahore site while 189 kg at Faisalabad site with moisture content 54.8 and 64.3%, respectively (Table 5). The age of *T. aphylla* plantation was 10 years at Lahore site and 9 years at Faisalabad site. The soil salinity in *T. aphylla* plantation at Lahore site was 8.4 to 12.8 dS m^{-1} at 180 cm depth in Hectare 26 while at Faisalabad site soil salinity was observed 9.8 dS m^{-1} in Hectare 43 W. The groundwater electrical conductivity was 1.75 dS m^{-1} at Lahore site while 6.9 dS m^{-1} at Faisalabad site, indicating overall more adverse soil and water salinity levels at Faisalabad site.

Biomass harvested was segregated into its components like twigs and thin branches (fuel wood) and timber (branches and trunk with more than 20 cm girth). Correlation between height, girth at breast height and total biomass was worked out and it indicated a good relationship among these parameters. Therefore, regression equations were also developed for estimating the biomass production using two easily measurable parameters like height and GBH (Table 6).

The salt tolerant tree species like *Prosopis juliflora, Acacia nilotica, A. ampliceps, Tamarix aphylla, Eucalyptus camaldulensis, Phoenix dactylifera* and *Casurina obesa* can be successfully introduced on saline waste lands to get good biomass production consist on fodder, food, timber and fire-wood. The production can be further enhanced by their pruning at regular intervals.

Table 5. Comparison for biomass components among different salt tolerant tree species.

Hectare No.	Species	Leaf wt. (kg)	Pods/Fruit wt. (kg)	Stem wt. (kg)			Total Biomass (kg)		Moisture content (%)
				Main stem	Branches	Twigs	Fresh	Dried	
	Biosaline Research Station-I, Lahore								
04	*E. camal*	12.5±3.7	0.77±0.7	229±46.2	49.5±22.1	7.58±2.5	286±56.7	172±41.5	60.1±7.2
12	*A. nilotica*	4.8±2.1	1.78±2.1	189±65.2	152±64.8	21.9±4.1	363±125	238±88.9	64.9±2.8
58	*P. juliflora*	7.9±2.2	0.90±1.3	56±6.21	40.4±17.7	17.1±3.1	113±15.2	66.5±11.8	58.7±6.1
26	*T. aphylla*	14.6±4.2	-	114±26.4	48.9±9.71	10.1±1.38	173±28.4	94.5±13.9	54.8±3.0
	Biosaline Research Station-II, Faisalabad								
36	*E. camal.*	22.9±5.3	-	238±52.9	56.9±25.3	15.9±5.1	310±61.2	182±34.2	59.1±6.4
60	*A. nilotica*	6.7±4.3	-	72±7.3	74.1±18.1	35.3±4.0	181±15.4	109±14.8	60.6±8.6
29	*P. juliflora*	7.8±4.2	-	152±56.4	84.7±33.9	32.9±10.5	270±91.9	192±72.6	70.7±17.7
43	*T. aphylla*	23.1±4.0	-	104±17.8	43.7±13.6	17.7±4.5	166±21.2	107±18.1	64.3±5.8

Values are averages of six tree samples ± standard deviation

Table 6. Regression equations b/w biomass and height or GBH of different species (n=12).

Tree species	Parameters	Equations	r	R^2
Eucalyptus camaldulensis	Height vs. Total biomass	$\hat{y}$ = 31.351x-183.27	0.9192	0.8449
	GBH vs. Total biomass	$\hat{y}$ = 8.4097x-128.99	0.9178	0.8423
Acacia nilotica	Height vs. Total biomass	$\hat{y}$ = 105.14x-613.23	0.8171	0.8046
	GBH vs. Total biomass	$\hat{y}$ = 18.735x-804.44	0.8665	0.8163
Prosopis juliflora	Height vs. Total biomass	$\hat{y}$ = 52.997x-90.479	0.8241	0.7820
	GBH vs. Total biomass	$\hat{y}$ = 24.047x-257.38	0.8810	0.8564
Tamarix aphylla	Height vs. Total biomass	$\hat{y}$ = 35.143x-76.909	0.8587	0.7374
	GBH vs. Total biomass	$\hat{y}$ = 3.5952x-17.262	0.8740	0.7639

"$\hat{y}$" is total biomass (kg) and "x" is height (ft) or GBH (cm); r: Correlation coefficient; R^2: Coefficient of determination

Conclusions

The saline wastelands of Pakistan have significant potential to produce wood biomass; especially fuel wood species produce good volumes of branches and trunks which are used by local populations and re-grow rapidly after cutting. Results of biomass estimation both destructive and non-destructive parameters indicated that studied tree species are good performer under salt-affected soils and can make such barren areas productive. Short- and long-term strategies, combined with optimal management of soil and water, need to be carefully established and monitored for sustainable biomass production. These salt tolerant trees can be an alternative to conventional agriculture. Trees on saline wastelands not only produce timber for construction but also function as windscreens, source of energy, add organic matter, break through hard pans, control soil erosion and also improve soil conditions for conventional agriculture.

Acknowledgements

This study was conducted as part of an EU-funded Biosaline Agroforestry Project-BIOSAFOR (www.oasefoundation.eu/project_sub/308) through OASE Foundation, Amsterdam and International Centre for Biosaline Agriculture (ICBA), Dubai. The authors would like to thank the project partners, especially Dr. Shoaib Ismail (ICBA) and Mrs. Jeannette Hoek (OASE Foundation) for their help and support.

References

Ahmed, M. and I. Qamar. 2004. Productive rehabilitation and use of salt-affected land through afforestation (A review). *Science Vision,* 9(1-2): 1-10.

Ates, S., M.H. Akyildiz and H. Ozdemir. 2009. Effects of heat treatment on calabrian pine (*Pinus brutia* Ten.) wood. *Bio. Res.,* 4(3): 1032-1043.

Bond, W.J. 1998. Effluent irrigation - an environmental challenge for soil science. *Aust. J. Soil Res.,* 36(4): 543-556.

Dagar, J.C. 2014. Greening salty and waterlogged lands through agroforestry systems for livelihood security and better environment. In: *Agroforestry systems in India: livelihood security & ecosystem services*. (Eds.): Dagar, J.C., A.K. Singh and A. Arunachalam. Advances in Agroforestry 10. Springer Publishers, 273-332 pp.

Gill, H.S. and I.P. Abrol. 1991. Salt affected soils, their afforestation and its ameliorating influence. *Int. Tree Crops J.,* 6: 239-260.

Harris, P.J.C., J.E. Wright and E.J. Trenchard. 2011. Potential for rainfed woody biomass production for energy conversion in drought and salinity affected areas of Northern India. *J. Sci. Ind. Res.,* 70: 577-582.

James, B.K., R.D. Lasco, L.U.D. Cruz, R.E.D. Cruz and T. Hussain. 2008. Effect of vascular arbuscular mycorrhiza (VAM) fungi inoculation on coppicing ability and drought resistance *Senna spectabillis*. *Pak. J. Bot.,* 40(5): 2217-2224.

Khan, M.A and M. Qaiser. 2006. Halophytes of Pakistan: characteristics, distribution and potential economic usages. In: *Sabkha Ecosystems*. (Eds.): Khan, M.A., G.S. Kust, H.-J. Barth and B. Böer. Vol. II, Springer, Netherlands, pp. 129-153.

Maguire, D.A., G.F. Schreuder and M. Shaikh. 1990. A biomass/yield model for high-density *Acacia nilotica* plantations in Sindh, Pakistan. *Forest Ecology and Management*, 37(4): 285-302.

Mahmood, K., A.R. Awan and M.I. Chughtai. 2011. *Eucalyptus camaldulensis*: A tree for waterlogged and saline wastelands. NIAB Nr. 4.

Marcar, N.E., D.F. Crawford, P.M. Leppert, T. Jovanovic, R. Floyed and R. Farrow. 1995. *Trees for saltland: a guide to selecting native species for Australia*. CSIRO Australia. 72 p.

Muhammad, S. 1996. Soil salinity, sodicity and water logging. pp. 472-506. In: *Soil sciences*. (Eds.): Rashid, A. and K. S. Memmon. National Book Foundation Islamabad, Pakistan.

Orwa, C., A. Mutua, R. Kindt, R. Jamnadass and S. Anthony. 2009. Agroforestree Database: a tree reference and selection guide, version 4.0.

Pandey, C.B. and D.K. Sharma. 2005. Ecology of *Acacia nilotica* based traditional agroforestry system in Central India. *Bull. NIE*, 15: 109-116.

Pandey, C.B., K.S. Pandya, D. Pandey and R.B. Sharma. 1999. Growth and productivity of rice (*Oryza sativa*) as affected by *Acacia nilotica* in a traditional agroforestry system. *Trop. Ecol.,* 40: 109-117.

Prasad, M.N.V. 2009. *Prosopis juliflora*-economic and environmental benefits. In: *Proceeding of National Symposium on Prosopis:* Ecological, Economic Significance and Management Challenges. pp. 88-93.

Qureshi, R.H. and E.G. Barrett-Lennard. 1998. *Saline Agriculture for Irrigated Land in Pakistan: A Handbook.* ACIAR Monograph No. 50, Australian Centre for International Agricultural Research, Canberra, Australia.

Saxena, S.K. and J. Venkateshwarlu. 1991. Mesquite: an ideal tree for desert reclamation and fuel wood production. *Indian Farming*, 41: 15-21.

Shirazi, M.U., M.A. Khan, Mukhtiar Ali, S.M. Mujtaba, S. Mumtaz, M. Ali, B. Khanzada, M.A. Halo, M. Rafique, J.A. Shah, K.A. Jafri and N. Depar. 2006. Growth performance and nutrient contents of some salt tolerant multipurpose tree species growing under saline environment. ***Pak. J. Bot***., 38(5): 1381-1388.

Siddiqui, K.M. and I. Mahmood. 1986. A note on physical and mechanical properties of *Eucalyptus camaldulensis, E. cidrophora* and *E. kitsoniana*. ***Pak. J. For.***, 36: 133-139.

Simmons, R.W., W. Ahmad, A.D. Noble, M. Blummel, A. Evans and P. Weckenbrock. 2010. Effect of long-term un-treated domestic wastewater re-use on soil quality, wheat grain and straw yields and attributes of fodder quality. ***Irrig. and Drain. Sys.,*** 24(1-2): 95-112.

Singh, G., N.T. Singh and J.C. Dagar. 1993. Mesquite for development of salt-affected soil. Wastelands News VIII: 71-74.

Singh, V. and O.P. Toky. 1995. Biomass and net primary productivity in *Leucaena*, *Acacia* and *Eucalyptus*, short rotation, high density ('energy') plantations in arid India. ***J. Arid Environ.,*** 31(3): 301-309.

Tesfaye-Abebe. 2004. Growth performance of some multipurpose trees and shrubs in the semi-arid areas of Southern Ethiopia. *Agroforestry system*, 26: 237-248.

Tewari, P, J.C. Tewari, D. Tripathi, S. Kaushis, L.N. Harsh and P. Narayan. 2003. Utilization of domestic fuel wood in atypical village of Indian hot arid zone. ***J. Trop. For. Prod.,*** 9: 1-14.

Vimal, O.P. and P.D. Tyagi. 1986. *Fuel wood from Wastelands*. Yatan Publications, New Delhi. 376 p.

Zheng, Y., Z. Pan, R. Zhang, J. Labavitch, D. Wang, S. Teter and B. Jenkins. 2007. Evaluation of different biomass materials as feedstock for fermentable sugar production. ***Appl. Biochem. Biotech.,*** 137: 423-435.

(Received for publication 30 March 2015)