Agroforestry Systems (2006) 66:129–141
DOI: 10.1007/s10457-005-4677-1

Assessing the potential of trees for afforestation of degraded landscapes in the Aral Sea Basin of Uzbekistan

A. Khamzina[1,]*, J.P.A. Lamers[1], M. Worbes[2], E. Botman[3] and P.L.G. Vlek[1]
*[1]ZEF (Center for Development Research), University of Bonn, Walter-Flex Str. 3, 53113 Bonn, Germany; [2]Institute for Plant and Animal Production in the Tropics, Georg-August University of Goettingen, Grisebachstr. 6, 37077 Goettingen, Germany; [3]Uzbek Forestry Research Institute, Darhan 702017, Tashkent, Uzbekistan; *Author for correspondence (e-mail:asia.khamzina@uni-bonn.de; phone: +49-(0228)-73-1918)*

Key words: Degraded land, Dry matter production, Feed value, Firewood value, Multipurpose trees, Root development.

Abstract

Land degradation is a serious hindrance to agricultural development in Uzbekistan, a country striving to rebuild its agricultural sector for self-sustained production. The potential of multipurpose trees for upgrading degraded land is enormous. However, knowledge is lacking about the establishment and growth characteristics of different species, the energy content of firewood and the nutritive value of fodder. This study presents such data for 10 selected local multipurpose species grown on gleyic solonchak soil. *Elaeagnus angustifolia* L. and *Tamarix androssowii* showed superior biomass growth, respectively producing up to 11.0 and 10.4 t ha^{-1} of utilizable aboveground dry matter (DM). *E. angustifolia* showed high potential for rapid establishment evidenced by root elongation of over 100 m $tree^{-1}$ at the age of 3 years. *T. androssowii*, *Prunus armeniaca* L. and *Populus nigra* var. *pyramidalis* Spach exhibited the greatest fuelwood characteristics, showing calorific values in the range of 14.4–16.2 MJ DM kg^{-1}. *E. angustifolia* and *Morus alba* L. demonstrated superior fodder potential given by the crude protein content of 216 and 117 g DM kg^{-1}. Recommendations on species selection are proposed based on various species characteristics. In assessing the potential of trees for afforestation of degraded land a reliable economic analysis of these aspects must be taken into account. When considering all characteristics concurrently, a mixture of species instead of monocrop cultivation seems to provide the best solution for improving degraded land.

Introduction

Land degradation, defined as the temporary or permanent lowering of the productive capacity of land, is widespread on approximately 447,000 km^2 of the Central Asian Republic of Uzbekistan, where natural arid and sandy deserts occupy around 80% of the land (Saigal 2003). Land degradation in the irrigated areas of Uzbekistan is caused by land salinization, rising ground water due to unsustainable agricultural practices, irrigation water scarcity, and seasonal and long-term drought (Saigal 2003). These processes are all at work in the Khorezm Region in northwest Uzbekistan and are exacerbated by its downstream location on the Amu Darya River in the proximity of the Aral Sea. With an area of approximately 455,000 ha, of which 260,000 ha are irrigated, Khorezm is one of the smallest administrative regions of Uzbekistan.

This study is part of a research program aimed at defining appropriate methods for withdrawing patches of degraded land out of agricultural use for afforestation. The research was conducted to determine the specific characteristics of 10 tree and shrub species that are being considered for integrating into woody fallow concepts for future land use systems. It is hoped that land degradation in the agricultural area of Khorezm can be partly remedied while concurrently increasing water and land use efficiency.

Few studies in Uzbekistan have addressed the suitability of indigenous and exotic tree and shrub species for use on degraded sites within irrigated areas. Experiments on solonchak soils (Makhno 1962; Fimkin 1983) focused mainly on an appropriate water–salt regime in the soil for the elaboration of irrigation scheduling for various tree plantations. These studies used biometric parameters as sole indicators of tree performance. Partial root excavations were conducted to obtain descriptive information about root stratification within soil horizons, but no attempt was made to estimate above and belowground biomass production. More recent studies in the Aral Sea Basin (Toderich et al. 2001) have examined the suitability of species of several genera such as *Salicornia*, *Halostachys* and *Haloxylon* for halophytic agroforestry and bio-saline agriculture. However, these findings have limited relevance for the afforestation of degraded agricultural land.

In addition to setting aside the degraded land, trees may also offer long-term solutions to existing firewood and livestock-fodder supply shortages. Wood is a source of heat currently used by many Uzbek households. An estimated 95% of the country's recent annual cut of 50,000 – 80,000 m^3 is used as firewood (UNFCC 2001). Demand for firewood is likely to grow as the costs of other energy sources, such as gas and electricity, rise and population growth continues at annual rates of about 2% (UNFCC 2001).

Trees and shrubs may also provide an alternative fodder source for animal production. Outside the vegetative season, typical local fodder sources are senescent grasses, straw from winter wheat, and hay from rice or alfalfa. However, local wheat straw has a low crude protein content (Tomms and Novikov 1966). Few data are currently available on the suitability of tree species in the Aral Sea Basin for their use as supplementary feed (Toderich et al. 2001; Gintzburger et al. 2003).

Incomplete data on key tree characteristics prevent decision-makers from formulating the highly needed strategies to afforest the degraded land areas in the Aral Sea Basin. This study was conducted to determine the multipurpose characteristics of 10 tree and shrub species that are being considered for their establishment on degraded land patches in the region.

Materials and methods

Description of the study sites

Research was conducted at the Khiva Research Station of the Uzbek Forestry Research Institute located at 41°41′ N latitude, 39°40′ E longitude and at an altitude of 113 m. The climate is arid, strongly continental, and known for its abundance of solar radiation and sparse precipitation (Glazirin et al. 1999). Precipitation averaged 101 mm year between 1990 and 2002 and fell mostly in spring and winter months. Precipitation for both study years 2002 and 2003 exceeded this recent average by 75% and 70%, respectively.

Two sites characterized by differing soil texture were selected for establishing experimental plantations. Pits were dug at each site to describe the soil profile. Soils were sampled in layers according to each morphological horizon and analyzed for texture, bulk density, total N, available P and K, organic matter and solute content, as well as pH (KCl and H_2O). The analyses for determining the solute content were conducted in an aqueous extract of the soil (ratio 1:5). Chloride content was determined titrametrically. Sodium (Na) and exchangeable potassium (K) content was measured with a flame photometer using appropriate filters. A sulfurous extract was prepared to analyze organic matter content according to the Tyurin method. Total nitrogen (N) content was analysed using the Kjeldahl method. Available phosphorus (P) was measured with a colorimeter in ammonium carbonate extract. The soil was differentiated into seven size classes with the following diameters: 0.25, 0.1, 0.05, 0.01, 0.005, 0.001 and < 0.001 mm according to Kachinsky's method and converted to the FAO texture classification.

The soil type at the study site was determined as gleyic solonchak according to the FAO Classification (irrigated alluvial meadow soil according to Umarov (1985). Soil profiles represented two major soil textures: (1) a light sandy soil underlain by a loam layer from 105 cm downwards and (2) a more finely textured silt loam underlain by a loam layer from

Table 1. Concentration of Na^+, Cl^- and SO_4^{-2} ions (mg-eq per 100 g of soil), humus, N, P and K in 1 m soil horizon at study sites in Khorezm, Uzbekistan for the period 2002–2003.

Time	Humus %	N mg kg^{-1}	P_2O_5 mg kg^{-1}	K_2O mg kg^{-1}	Cl^-mg-eq	Na^+ mg-eq	SO_4^{-2}mg-eq
Loamy site							
Apr 2002	$0.5^{a\#}$	n/a	25.0^{a}	113.3^{a}	0.4^{a}	0.7^{a}	0.8^{a}
Oct 2002	n/a	n/a	n/a	n/a	0.7^{b}	1.3^{b}	1.7^{b}
Apr 2002	0.8^{a}	48.6	22.8^{a}	109.2^{a}	0.7^{b}	1.1^{ab}	1.3^{ab}
Oct 2003	0.8^{a}	0.1	1.6^{a}	107.2^{a}	0.5^{ab}	0.9^{ab}	0.9a
Sandy site							
Apr 2002	0.36^{a}	n/a	7.8^{b}	96.4^{a}	0.4^{a}	0.6^{a}	1.6^{a}
Oct 2002	n/a	n/a	n/a	n/a	0.8^{a}	1.1^{a}	1.9^{a}
Apr 2003	0.4^{ab}	17.8	3.3^{a}	70.7^{a}	0.7^{a}	1.1^{a}	2.0^{a}
Oct 2003	0.4^{b}	0.02	1.6^{a}	63.2^{a}	0.5^{a}	1.0^{a}	2.4^{a}
Analysis of variance, probability $> F$ ($= \alpha$)							
Time	0.015	< 0.001	0.08	0.484	0.01	0.687	0.031
Soil	< 0.001	0.062	0.17	0.031	0.816	0.06	0.632
Time*Soil	0.665	0.062	0.191	0.627	0.996	0.417	0.749

#Means with the same superscript within the column are not significantly different at $p < 0.05$.
n/a = not available.

85 cm downwards. Chemical analysis conducted for the period 2002–2003 showed that soil salinity at both sites did not increase significantly but remained slightly saline. Both plots were characterized by low humus and nutrient content. Over the two seasons, concentrations of N, P, and K decreased, especially P. During the study period humus content remained lower than 1% at the sites. The results of the soil chemical analysis are presented in Table 1.

The high ground water level, characteristic for the Khorezm Region, can be used as a source of moisture for the trees, if not highly saline. At the research station over the two vegetative seasons the ground water table averaged 110 cm and 90 cm below the soil surface at the loamy and the sandy site respectively. The mean electrical conductivity of ground water was 3.3 and 4.3 dSm^{-1} for the loamy and sandy sites.

Experimental design

Five hundred 1 year-old seedlings of 10 multipurpose tree and shrub species (50 seedlings per species) were planted following leaching at two sites with different soil textures which measured 0.14 ha each. The 10 native and exotic species were selected to represent a variety of life spans and tolerances to drought and salt load and included: apricot tree (*Prunus armeniaca* L.), black poplar (*Populus nigra* var. *pyramidalis* (Rozan) Spach), black willow (*Salix nigra* Marshall), Chinese cedar (*Biota orientalis* (L.) Franco), Euphrates poplar (*Populus euphratica* Olivier), Russian olive (*Elaeagnus angustifolia* L.), salt cedar (*Tamarix androssowii*), Siberian elm (*Ulmus pumila* L.), swamp ash (*Fraxinus pennsylvanica* Marshall), and white mulberry (*Morus alba* L.).

Initially, experimental design considered moisture regimes defined by the amount of water loss from the soil before the next irrigation event. Seedlings of each of the 10 tree species were completely randomized within each soil type and soil moisture regime. However, high precipitation during the vegetative season, the underground inflow from intensively irrigated rice fields in the vicinity and capillary rise interfered with the soil moisture regimes. As a result, the loamy site needed occasional irrigation while at the sandy site water was applied only once in the beginning of each season for salt leaching. Thus, design was a randomized incomplete block replicated six times and included two soil types and 10 tree species. Seedlings of tree species were planted between the ridge and bottom of the irrigation furrow at a spacing of 1×3.5 m, half way from the furrow bottom. The furrows prepared were 40 cm deep and 70 cm wide. The 3.5 m spacing between rows/plots was introduced to minimize possible competition of different tree species in the rhizosphere from horizontal extension of the root systems due to the high ground water table. Each plot consisted of two rows with 25–30 randomly planted saplings.

Biometric parameters and survival rates

Tree growth was determined by measuring the height and the diameter both at the beginning and at the end of the vegetative seasons. Over-bark stem diameter was measured at 5 cm above the base of the stem to the nearest millimeter using callipers. Survival rates were determined by the number of surviving trees counted at the onset and the end of both growing seasons. Dead trees were not replaced.

Dry matter production of above and belowground biomass

To determine biomass production, three to five trees per experimental plot were randomly selected 7 and 19 months after planting (MaP) and fresh weight of stem, branches, and leaves was measured.

Since belowground biomass development in the first year of establishment was expected to be more prominent than aboveground growth, tree root system development was considered as the primary measure of potential for rapid and early establishment. Therefore, root dry weight was determined as a proxy of the total root system size. Together with total root length these served as indicators of the potential for absorption nutrients and water. Following the harvest of aboveground fractions, tree roots were completely excavated with hand tools and sectioned into coarse (Ø > 3 mm) and fine roots (Ø < 3 mm). The roots were washed free of soil, weighed and oven dried. Coarse root length was measured with a measuring tape. The lengths of fine roots were determined using the line-intersect method.

All fractions were oven dried at 103°C till constant weight (MacDicken et al. 1991).

Crude protein and metabolizable energy content of leaves, and calorific values of firewood

Leaves sampled from three to four trees per species, were mixed and dried at 50 °C till constant weight, ground to pass through a 2 mm sieve, and analyzed for crude protein (CP) content. Organic dry matter digestibility (dO) and metabolizable energy (ME) content of leaves were determined using Close and Menke's (1986) *in vitro* gas technique, which is based on the gas (carbon dioxide and methane) production by leaves incubated with rumen liquor, and using a multi-regression equation for roughages. Gas production was analyzed with and without the addition of 200 mg polyethyleneglycol (PEG), which prevents tannin inhibition. CP content was determined using the Kjeldahl method (CP = nitrogen content *6.25).

Gross calorific value of firewood was determined at 7 and 19 MaP by burning wood samples in an oxygen bomb calorimeter. Mineral content was measured after ashing samples at 550 °C for 5 hours in a muffle furnace. Wood densities were determined by the displacement method as described in MacDicken et al. (1991). The Fuelwood Value Index (FVI) was calculated according to Bhatt and Todaria (1992).

Statistical analyses

All analyzed data were checked for normality and normalized with a logarithmic transformation when necessary. Analysis of variance (ANOVA) was performed using the General Linear Model (GLM) procedure. The mean effect of treatment variables (tree species, soil type and harvest date) and their interactions were compared at a $p < 0.05$ level of significance The Tukey Post Hoc test was used to compare individual treatment means where the ANOVA test indicated significant treatment effects. Since this study focused on species selection, all findings are expressed per tree rather than per hectare. All statistical analyses were performed using SPSS v11.0 software.

Results and discussion

Establishment and growth characteristics

At 7 MaP survival rates were generally lower for trees at the loamy site but at 19 MaP survival rates were similarly high (Table 2). The lowest survival rates observed at 7 MaP were for *P. euphratica* at both locations, and *P. armeniaca* on the sandy soil. Over 80% of the *P. euphratica* trees on the loamy soil and 26% on the sandy soil perished shortly after planting, but later their mortality decreased considerably. Throughout the second vegetative season no additional mortality was recorded for the exception of *P. armeniaca* at both sites and *P. nigra* at the sandy site.

The ability for belowground biomass development, which together with root elongation assures establishment of the saplings, differed significantly among species (Tables 2 and 3). At 7 MaP virtually all species had more belowground biomass in the sandy soil than their counterparts in the loamy soil (Table 2). This is reflected in higher fine and coarse root dry weights, particularly for *E. angustifolia*, *T. androssowii* and *B. orientalis*. However, at 19 MaP, species such as *P. armeniaca*, *B. orientalis*, *M. alba* and *S. nigra* grew better in the loamy soil, This soil type preference was also reflected in values of leaf and wood biomass of these species (Table 3). Total root length at 7 MaP was more variable, especially when fine and coarse root fractions were considered separately. At 19 MaP, both fractions showed larger total lengths for *P. armeniaca*, *B. orientalis*, and *M. alba* at the

Table 2. Survival, root dry matter (DM) and root length of ten tree and shrub species on two soil types in Khorezm, Uzbekistan, during the first 19 months after planting.

Species	Survival rate[#](%)		Root weight (g DM tree^{-1})		Root length (m tree^{-1})	
	Months after planting					
	0–7	7–19	0–7	7–19	0–7	7–19
Sandy soil						
Prunus armeniaca	85.2$^{ab@}$	85.2^{a}	24^{a}	29^{a}	3.1^{a}	4.3^{a}
Biota orientails	96.0^{ab}	100^{b}	18^{a}	56^{ab}	4.4^{ab}	22^{ab}
Elaeagnus angustifolia	100^{b}	100^{b}	205^{b}	842^{d}	10^{bc}	108^{b}
Fraxinus pennsylvanica	100^{b}	100^{b}	97^{ab}	309^{abc}	7.4^{abc}	71^{ab}
Morus alba	88.9^{ab}	100^{b}	74^{a}	134^{ab}	5.1^{ab}	38^{ab}
Populus euphratica	74.1a	100^{b}	87^{ab}	523^{bcd}	6.7^{abc}	90^{ab}
Populus nigra var *pyramidalis*	100^{b}	90.9^{a}	118^{ab}	635^{cde}	6.5^{abc}	103^{b}
Salix nigra	93.1^{ab}	100^{b}	110^{ab}	206^{abc}	6.0^{ab}	56^{ab}
Tamarix androssowii	100^{b}	100^{b}	344^{c}	1068^{e}	12^{c}	78^{ab}
Ulmus pumila	88.0^{ab}	100^{b}	134^{ab}	426^{abcd}	9.6^{bc}	76^{ab}
Overall means	92.5	97.6	121	418	6.0	66
Loamy soil						
Prunus armeniaca	100^{b}	95.8^{a}	20^{ab}	98^{a}	2.2^{a}	13^{ab}
Biota orientalis	95.5^{b}	100^{a}	8.1^{a}	62^{a}	3.9^{ab}	25^{abc}
Elaeagnus angustifolia	96^{b}	100^{a}	77^{bcd}	433^{ab}	7.3^{bc}	43^{bc}
Fraxinus pennsylvanica	100^{b}	100^{a}	70^{abcd}	147^{ab}	8.0^{c}	17^{abc}
Morus alba	92.0^{b}	100^{a}	63^{abcd}	378^{ab}	6.1^{abc}	44^{c}
Populus euphratica	18.5^{a}	100^{a}	n/a	91^{a}	n/a	8.4^{a}
Populus nigra var. *pyramidalis*	100^{b}	100^{a}	115de	435^{ab}	8.5^{c}	33^{abc}
Salix nigra	96.8^{b}	100^{a}	51^{abc}	576^{ab}	5.7^{abc}	36^{abc}
Tamarix androssowii	100^{b}	100^{a}	174^{e}	681^{b}	8.7^{e}	27^{abc}
Ulmus pumila	85.7^{b}	100^{a}	89^{cd}	374^{ab}	8.4^{c}	40^{abc}
Overall means	88.4	99.6	75	404	6.5	31
Analysis of variance, probability $> F$ ($=\alpha$)						
Species	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Soil	0.05	0.02	<0.001	0.045	0.18	<0.001
Treatment	0.49	0.80	0.016	0.071	0.108	0.002
Species* Soil	<0.001	0.01	<0.001	0.001	<0.419	0.001
Map		<0.001		<0.001		<0.001
Map*Species		<0.001		<0.001		<0.001
Map*Soil		0.043		0.875		<0.001
Map*Species *Soil		0.406		<0.001		<0.001

[#]Harvested trees were considered as missing values.

[@]Means with the same superscript within the column are not significantly different at $p < 0.05$.

n/a = not available.

Table 3. Dry matter production of leafy and woody fractions of ten tree and shrub species on two soil types in Khorezm, Uzbekistan during the first 19 months after planting.

Species	Leaves (g DM tree^{-1})		Wood (g DM tree^{-1})	
	Months after planting			
	0–7	7–19	0–7	7–19
Sandy soil				
Prunus armeniaca	11$^{a\#}$	2.6$^{a@}$	21^{a}	42^{a}
Biota orientails	35^{ab}	105^{b}	30^{a}	77^{a}
Elaeagnus angustifolia	106^{b}	1092^{b}	255^{c}	2758^{c}
Fraxinus pennsylvanica	22^{a}	82^{b}	41^{ab}	222^{a}
Morus alba	24^{a}	63^{a}	52^{ab}	195^{a}
Populus euphratica	58^{ab}	564^{ab}	91^{ab}	1119^{ab}
Populus nigra var. *pyramidalis*	45^{ab}	274^{a}	138^{b}	840^{ab}
Salix nigra	34^{ab}	151^{a}	85^{ab}	403^{a}
Tamarix androssowii	229^{c}	1853^{c}	253^{c}	1780^{bc}
Ulmus pumila	29^{a}	181^{a}	75^{ab}	447^{a}
Overall means	61	481	103	837
Loamy soil				
Prunus armeniaca	8^{a}	67^{a}	31^{a}	174^{a}
Biota orientalis	15^{a}	235^{ab}	14^{a}	120^{a}
Elaeagnus angustifolia	48^{ab}	692^{bc}	118^{bc}	1591^{c}
Fraxinus pennsylvanica	19^{a}	42^{a}	46^{ab}	98^{a}
Morus alba	26^{ab}	203^{ab}	56^{ab}	461^{abc}
Populus euphratica	n/a	42^{a}	n/a	117^{a}
Populus nigra var. *pyramidalis*	67^{b}	265^{ab}	114^{cd}	682^{abc}
Salix nigra	29^{ab}	251^{ab}	82^{abc}	919^{abc}
Tamarix spp.	132^{c}	818^{c}	215^{d}	1378^{bc}
Ulrnus pumila	45^{b}	181^{a}	91^{abc}	360^{ab}
Overall means	44	329	89	731
Analysis of variance, probability $> F$ ($=\alpha$)				
Species	< 0.001	< 0.001	< 0.001	< 0.001
Soil	0.013	0.02	0.065	0.058
Treatment	0.080	0.351	< 0.001	0.136
Species*Soil	< 0.001	< 0.001	0.007	0.006
Map		< 0.001		< 0.001
Map*Species		< 0.001		< 0.001
Map*Soil		< 0.003		< 0.196
Map*Species*Soil		< 0.001		< 0.001

[#] Means with the same superscript within the column are not significantly different at $p < 0.05$.
[@] Untimely leaf fall.
n/a = not available.

loamy site, while the other species developed longer roots at the sandy site.

The species with the greatest total belowground biomass after 19 months on both soil types were *T. androssowii* and *E. angustifolia*. The same species developed the greatest total root length at 7 MaP. They were leading with respect to absolute wood and leaf production for both soil types, performing better on the sandy soil. However, growth rates of the short-living shrub species *T. androssowii* slowed down considerably on both soil types already during the second season (Table 4). In contrast, *E. angustifolia*, with high absolute dry matter production, maintained an outstanding relative growth in height and diameter throughout the observation period.

The high productivity of *T. androssowii* and *E. angustifolia* suggests considering them as the most promising candidates for afforestation of degraded sites where immediate benefits are needed. However, *Tamarix* spp. are often referred to as aggressive colonizers, since they tend to invade natural habitats and push out other species (Cleverly et al. 1997), Both *T. androssowii* and

Table 4. Growth rates in height and diameter of ten tree and shrub species on two soil types in Khorezm, Uzbekistan during the first 19 months after planting.

Species	Growth in height (%)		Growth in diameter (%)	
	Months after planting			
	0–7	7–19	0–7	7–19
Sandy soil				
Prunus armeniaca	2[a#]	n/a	87[a]	14[a]
Biota orientails	76[a]	32[a]	243[abc]	74[a]
Elaeagnus angustifolia	182[d]	84[a]	267[e]	149[a]
Fraxinus pennsylvanica	49[a]	68[a]	162[bcd]	75[a]
Morus alba	76[bcd]	34[a]	201[cde]	75[a]
Populus euphratica	46[a]	78[a]	112[ab]	118[a]
Populus nigra var. *pyramidalis*	30[a]	27[a]	77[ab]	78[a]
Salix nigra	320[e]	80[a]	66[a]	151[a]
Tamarix androssowii	65[a]	39[a]	243[de]	60[a]
Ulmus pumila	98[a]	55[a]	124[abc]	109[a]
Overall means	125	57	148	101
Loamy soil				
Prunus armeniaca	20[a]	27[a]	53[ab]	88[a]
Biota orientalis	50[a]	96[a]	42[a]	137[ab]
Elaeagnus angustifolia	88[a]	195[b]	43[a]	246[b]
Fraxinus pennsylvanica	46[a]	46[a]	105[abc]	70[a]
Morus alba	124[a]	42[a]	169[cd]	144[ab]
Populus euphratica	63[a]	31[a]	50[a]	68[a]
Populus nigra var. *pyramidalis*	31[a]	45[a]	80[abc]	83[a]
Salix nigra	541[b]	60[a]	74[ab]	145[ab]
Tamarix androssowii	112[a]	66[a]	142[bcd]	122[ab]
Ulmus pumila	193[bc]	52[a]	203[d]	162[ab]
Overall means	156	68	98	129
Analysis of variance, probability $> F$ ($=\alpha$)				
Species	< 0.001	< 0.001	< 0.001	< 0.001
Soil	0.291	< 0.001	0.100	0.024
Treatment	0.535	0.310	0.060	0.355
Species *Soil	< 0.016	< 0.001	< 0.001	0.367
Map		< 0.001		0.211
Map*Species		< 0.001		< 0.001
Map*Soil		0.356		< 0.001
Map*Species *Soil		< 0.001		0.002

[#]Means with the same superscript within the column are not significantly different at $p < 0.05$.
n/a = not available.

E. angustifolia are known for their ability to self propagate by vigorous sprouting and intensive control measures are recommended (Tesky 1992). Although both species have the capability to grow on saline soils and accumulate soluble salts in their aboveground tissues, *Tamarix* plantations may not benefit the environment in the long-run, since at a later stage these salts are released back to the soil via salt glands (Forestry Compendium 2000). Given these characteristics of *T. androssowii*, this species does not seem to have great potential for the afforestation of salt-affected land.

According to Olson and Knopf (1986), *E. angustifolia* can behave invasively in riparian ecosystems, displacing native riparian vegetation and choking irrigation ditches. However, it is also capable of growing in the desert and in dry (150 mm annual rainfall) areas of Western Asia (Forestry Compendium 2000). Previous research in the Khorezm region characterized this species as tolerant to soil salinity in conditions of reduced irrigation (Makhno 1962). Since it is known to cope with chemically contaminated environments, *E. angustifolia* has been used to re-vegetate land polluted by paper mill wastewater (Wagner and Dietrichson 1994), or potassium (Heinze and Liebman 1998) and bentonite mine spoilings (Uresk and Yamamoto 1994). In addition, *E. angustifolia* can fix nitrogen, which may enrich degraded soils in the long run. Based on these findings we propose that *E. angustifolia* has a high potential for the afforestation of degraded soils in the study region.

During the study period *P. nigra* var. *pyramidalis* and *U. pumila* ranked in the upper quartiles according to root system development, often immediately behind *T. androssowii* and *E. angustifolia* (Table 2). *P. nigra* var. *pyramidalis* maintained high absolute values of aboveground biomass regardless of soil type (Table 3). In the meantime, this species showed quite stable but moderate relative growth rates in height and diameter (Table 4).

In Uzbekistan *P. nigra* var. *pyramidalis* is considered slightly or moderately salt tolerant (Blinovsky 1956; Makhno 1962) provided when sufficient soil moisture is available. Under conditions of soil water shortage this species matures rapidly, dries from the top, and becomes susceptible to harmful insects (Rovsky 1963). These characteristics are unfavorable for the afforestation of degraded soils in the study area.

U. pumila, the only species with a relatively high life expectancy, showed a high potential for rapid root system development (Table 2). Production of leafy and woody biomass by this species was moderate which is compensated by relatively high growth rates, at least in loamy soils (Tables 3 and 4).

Experience worldwide has shown that *U. pumila* presents a number of characteristics that are suitable for the afforestation of degraded soils. *U. pumila* is very tolerant to saline-alkali soil and can survive in soils with pH values of up to 9. In addition, it can endure low soil moisture and ambient humidity (Blinovsky 1956; Makhno 1962; Forestry Compendium 2000). Although it does not seem to be susceptible to Dutch elm disease (*Grapiiiuin ulrni* Schw) (Rovsky 1963), in Khorezm *U. pumila* is known to be quite sensitive to black oak beetle (*Monacliamus gallo provincialis*) which may reduce farmers' willingness to plant this species. It is cultivated throughout the world on roadsides and used for afforestation of desert, barren and saline-alkali lands, and as forest windbreaks (Forestry Compendium 2000).

The native poplar species, *P. euphratica*, which displayed high values of leaf and wood production, appeared to be the most sensitive to soil type, with mean values of aboveground matter on the loamy soil amounting to only 9% of that at the sandy site. Similarly, it had slow longitudinal growth and low root dry matter production at the loamy site while exhibiting superior belowground development at the sandy site, particularly in radial extension of coarse roots. Some *P. euphratica* root systems in sandy soil reached up to 10 m in radius and produced numerous root suckers. Also, among only a few species studied, *P. euphratica* showed increased growth rates in height and diameter at 19 MaP (Table 4).

In the Khorezm Region *P. euphratica* is the predominant tree species in natural *tugai* forests where it withstands periodical waterlogging. *P. euphratica* is remarkably salt tolerant once established (Novikov 1950; Skupchenko 1950; Blinovsky 1956; Wang Shiji et a1. 1996). Moreover, *P. euphratica* can endure high limestone contents in the soil (Wang Shiji et al. 1996). Despite these advantages, *P. euphratica* seems only partly suitable for the afforestation of degraded soils since it is also known for its vulnerability and high mortality at an early age (Wang Shiji et al. 1996), which is confirmed by the findings in the present study.

B. orientalis and *P. armeniaca* generally had the lowest belowground biomass and aboveground dry matter at both sites. The growth performance of the remaining species included in the experiment was rather moderate or weak depending on the parameter used for assessment (Table 7), and therefore cannot be recommended. Yet, aside from the key capability of rapid establishment and growth on different soil types and under different soil moisture and salinity regimes, the assortment of trees species for the afforestation of degraded sites needs more than one evaluation criteria as reported elsewhere (Lamers et al. 1994). Farmers are seldom interested in a single benefit of trees and shrubs regardless of the reason for planting them. Therefore, the ability of trees to produce useful by-products to compensate landowners in part for crop production losses must be considered as well.

Nutritional value of leaves

Fodder trees and shrubs could fill the feed gap which exists in Khorezm. However, leaves from

S. nigra and *T. androssowii* have a limited potential as fodder due to the presence of tannins that reduce palatability, digestibility and protein availability. This was indicated by the metabolizable energy (ME) contents measured with and without the tannin inhibitor PEG (Table 5). The highest crude protein (CP) concentration was found in leaves of N-fixing *E. angustifolia*, whereas the lowest concentration was found in *S. nigra*. *E. angustifolia* also had the highest CP:ME ratio. The high content of CP and the modest content of ME combined with the relatively high organic matter digestibility of *M. alba*, *E. angustifolia* and *U. pumila* indicates that these species are potentially good feed.

An ME content of 6–7 g kg^{-1} of dry matter (DM) equals the quality of crop residues of several cereals (Close and Menke 1986), which is met by all species studied, except *T. androssowii*. A ME content of 8–9 g DM kg^{-1} equals that of medium quality hay, which is matched by *E. angustifolia* and *M. alba*. Feed with a dO of 70% or more is considered to be of good quality (Close and Menke 1986), which was found for *M. alba* only. In general, the CP:ME ratios in the leaves of studied species were lower than those found in the leaves of tree species in other semi-arid regions (Lamers et al. 1994).

Although fodder production by the screened trees is likely to be insufficient to relieve feed bottlenecks *per se*, the higher contents of nutritive substances in leaves of species like *E. angustifolia*, *M. alba* and *U. pumila* offer possibilities as supplementary feed to the low-quality roughages such as wheat stalks used throughout the off-season in Khorezm. If, for example, livestock were fed with a mixture of this low quality roughage and the leaves of superior fodder species, farmers would save a considerable amount of crop residues. A Tropical Livestock Unit (TLU) of 250 kg live mass needs 1 g of CP per kg live mass per day for maintenance. Assuming that this need is to be satisfied by wheat stalks with a CP content of 46 g CP kg^{-1} (Tomms and Novikov 1966), then one TLU would need 5.4 kg of wheat straw per day. If the straw is mixed with 10% *E. angustifolia* leaves with a CP content of 216 g CP kg^{-1} (Table 5), then one TLU would need only 4.0 kg day^{-1} of this mixture, or about 27% less wheat straw per day. Throughout the off-season of 150 days, a farmer would thus need a total amount of 60 kg of tree leaves. Based on the results from the 3 year-old *E. angustifolia*, this would require about 60 trees or a land surface of about 2200 m^2. Obviously, mature trees will produce much more leaf dry matter. The use of *E. angustifolia* leaves as feed is not common in the region, possibly due to a lack of knowledge about its high nutritious value, but low usage might also be related to the high labour costs needed to defoliate the thorny twigs.

Table 5. Contents of crude protein (CP), metabolizable energy (ME), the ratio CP:ME and the organic dry matter digestibility in leaves (d0) of ten tree and shrub species 19 months after planting compared to the values of common feed in Khorezm, Uzbekistan.

Species	CP (g DM kg^{-1})	ME (g DM kg^{-1})	ME (PEG)#(g DM kg^{-1})	CP:ME (g CP MJ^{-1})	dO(%)
Prunus armeniaca	101	12	12	8	66
Populus nigra var. *pyramidalis*	106	8	8	13	59
Salix nigra	83	8	8	11	58
Biota orientalis	100	9	9	11	51
Populus euphratica	100	8	9	12	59
Elaeagnus angustfolia	216	9	9	25	60
Tamarix androssowii	99	6	7	16	58
Ulmus pumila	100	9	10	11	61
Fraxinus pennsylvanica	99	8	8	12	58
Morus alba	117	11	11	11	74
Dry alfalfa@	116	n/a	n/a	n/a	n/a
Wheat grass hay@	85	n/a	n/a	n/a	n/a
Wheat stover@	46	n/a	n/a	n/a	n/a
Silage@	29	n/a	n/a	n/a	n/a
Corn hay@	21	n/a	n/a	n/a	n/a

#with 200 mg of polyethylenglycol.
@by Tomms and Novikov (1966).
n/a = not available for the study region.

Although *M. alba* showed good potential as a fodder tree, in Khorezm Region it plays a major role in sericulture, which leaves little room to expand its potential as a provider of fodder for ruminants. Obviously, to determine the real feeding value of the examined fodder trees, the feed intake and live weight increments of livestock fed with different diets should be studied in *vivo*.

Fuelwood characteristics

Although Uzbekistan has increased its oil and gas condensates as well as natural gas at the expense of coal since independence in 1991, not more than 44% of the rural population has access to gas supplies for heating and cooking (UNFCC 2001). Even though wood felling is permitted on condition of compulsory subsequent reforestation, the growing dependence on and demand for domestic firewood is satisfied through uncontrolled cutting. This increases both the need and opportunities for private reforestation initiatives.

Calorific values of the analyzed wood samples lay between 7.6 and 16.2 MJ DM kg^{-1} (Table 6). The measured calorific values are in general lower than those observed in previous studies (Harker et al. 1982). Consequently, the firewood value index (FVI) was low for all of the tested species and ranged between 0.06 and 0.55.

The spread of calorific values of the different species may be accounted for by the variation in both the proportion and calorific values of the five main wood components – resins, cellulose, hemicellulose, lignin and mineral matter (Tillman 1978). The relatively low calorific values observed in the 3 year-old species are most likely due to the high ash (mineral) contents. The mineral content, which ranged between 14% and 62%, was found to be significantly higher than in previous studies. Doat (1977) analyzed the wood ash content of 116 mature species and found an average of 1.04% while observing a range of 0.1 – 3.4%, although some samples contained more than 10% of ash. In this study ash content averaged 30% for the young trees, where the wood of *B. orientalis* had the highest ash content and consequently the lowest calorific value. Besides the high ash content, the low calorific values of the young wood may be due to a low wood density, which corresponds to a soft wood texture of younger trees. The lower calorific values of softwood are explained by its lower content of hemi-cellulose in combination with higher content of lignin when compared with hardwood (Doat 1977).

Relatively high calorific values were measured for *P. nigra* var. *pyramidalis* followed by *T. androssowii* and *P. armeniaca*, whereas *B. orientalis* displayed the lowest values. The higher calorific values found for *P. nigra* var. *pyramidalis* and *T. androssowii* wood is due to the relatively short lifespan of these species. Being fast starters, these species developed sufficient wood densities at 19 MaP. In contrast, species with a relatively long life span such as *U. pumila* and *M. alba* showed relatively low calorific values although they are hard wood species (Harker et al. 1982).

Table 6. Reference gross calorific value (CV), actual gross calorific value, ash content, wood density, firewood value index, and wood production of ten tree and shrub species 19 months after planting in Khorezm, Uzbekistan.

Species	Reference CV (MJ kg^{-1})	Actual CV (MJ kg^{-1})	Ash content (%)	Wood density (g cm^{-3})	Fire wood index	Wood production (kg DM $tree^{-1}$)
Prunus armeniaca	n/a	14.7	19.5	0.48 ± 0.14	0.392	108
Biota oreintalis	n/a	7.6	62.2	0.50 ± 0.03	0.061	99
Elaeagnus angustifolia	n/a	12.8	30.7	0.53 ± 0.04	0.220	2220
Morus alba	19.3#	13.6	26.7	0.46 ± 0.16	0.255	328
Populus euphratica	20. 7#	12.6	32.3	0.40 ± 0.08	0.183	673
Populus nigra var. pyramidalis	n/a	16.2	14.0	0.42 ± 0.14	0.545	711
Salix nigra	17.9#	12.0	35.4	0.46 ± 0.15	0.186	683
Tamarix androssowii	n/a	14.4	20.1	0.67 ± 0.09	0.481	1529
Ulmus pumila	17. 7#	13.2	31.3	0.54 ± 0.10	0.239	408

#by Harker et al. (1982).
n/a = not available.

Table 7. Summary of performance indicators of ten tree and shrub species in two soil types in Khorezm, Uzbekistan.

Species	*Prunus armeniaca*	*Biota orientalis*	*Elaeagnus angustifolia*	*Morus alba*	*Populus euphratica*	*Populus nigra* var. *pyramidalis*	*Salix nigra*	*Tamaricx androssowii*	*Ulmus pumila*
Survival	−	±	+	±	−	−	+	+	±
Root establishment	−	−	+	±	+	±	±	+	±
Aboveground dry matter production	−	±	+	±	±	±	±	+	±
Growth	−	−	+	±	±	±	+	±	+
Supplementary feed	±	−	+	+	±	±	−	−	+
Fire wood index	+	−	±	±	−	+	±	+	±
Overall potential for afforesting degraded land	−	−	+	±	±	±	±	+	±

Legend: + = High potential, ± = medium potential, − = low potential.

Conclusion and recommendations

The findings from the screening of the 10 tree species offer a spectrum of options for afforesting degraded land. In order to implement afforestation for the rehabilitation of marginal patches of irrigated land in the Aral Sea Basin, the ideal multipurpose species should combine a number of features such as: high survival rates, quick growth, halophytic and xerophytic characteristics, and high utility value of firewood or foliage.

The overall ranking of the trees, weighing all parameters concurrently (Table 7), showed that *T. androssowii* and *E. angustifolia* had the highest potential for growing on both loamy and sandy soils, which represent the dominant textures in the region. In contrast, the potential of *U. pumila*, *P. nigra* var. *pyramidalis*, and *P. euphratica* differed according to the parameter observed (roots or aboveground matter) or the soil type. Species such as *B. orientalis*, and *P. armeniaca* showed the lowest potential on both soil types. Analysis of leaf digestibility and CP content showed the high potential of *M. alba*, yet the moderate ability of this species to develop leaf biomass rapidly limits its usefulness for marginal land plantations. In contrast, *E. angustifolia* combined fast growth with a fodder quality sufficiently high to be used during the off-season, when feed availability is limited.

The analysis of calorific values of wood showed the different potential of the species for fast developing of valuable fuel wood. The long fallow periods needed to achieve the high calorific values of the most suitable species can be compensated by the introduction of a mixture of species rather than a monocrop. Fast starters with short life expectancies such as *E. angustifolia*, *P. nigra* and *T. androssowii* are able to obtain relatively high calorific values and produce comparatively high biomass during the initial years and may thus be combined with slow-starter species that offer advantages in the longer term. Last but not least, *T. androssowii*, *E. angustifolia*, *U. pumila*, and *P. euphratica* are known to be salinity-tolerant, an important feature in the region.

Farmers in the Aral Sea Basin can be expected to adopt and invest in land afforestation systems only if their immediate financial profitability is assured. Yet, the cultivation of trees requires a waiting period. However, the use of multipurpose species, as investigated in this study, promises the farmers a return from those areas of their land where crops are no longer profitable. The expansion and commercialization of non-timber forest products has the potential to increase cash income of rural Uzbek households. No data on the economy of non-timber forest products in Central Asian countries were found at present, and providing such data will be imperative for economic studies.

Another aspect that remains unstudied is the degree to which this type of afforestation effort can contribute, at a larger spatial scale, to carbon sequestration. The present study has shown that several tree species exist which provide both a multipurpose use and a potential for afforestation. If carbon trading benefits can be added to the benefits from non-timber forest products, this would create a "win–win" situation from both ecological and economic points of view.

Acknowledgements

This study was funded by the German Ministry for Education and Research (BMBF; project number 0339970A) and by the Ministry for Schools, Science and Research of the State of Northrhine-Westfalia. The results were obtained at the experimental research station of the Uzbek Forestry Research Institute in Khiva, and within the framework of ZEF/UNESCO landscape restructuring project. We are grateful for the valuable comments from two anonymous reviewers on the earlier version of this manuscript.

References

Bhatt B.P. and Todaria N.P 1992. Firewood characteristics of some mountain trees and shrubs. Commonw. Forest. Rev. 71(3/4): 183–185.

Blinovsky K.V. 1956. Trees and shrubs for planting in populated areas of Northern and Southern Turkmenistan. Proceedings of Turkmen Botanical Garden, 2nd ed., Ashgabad, pp. 13–20. (in Russian).

Cleverly J.R., Stanly D.S., Sala A. and Devitt D.A. 1997. Invasive capacity of *Tamarix ramosissima* in Mojave Desert floodplain: the role of drought. Oecologia 111: 12–18.

Close W. and Menke KB. 1986. Selected topics in animal nutrition. Manual prepared for the 3rd Hohenheim course on animal nutrition in the tropics and semi-tropics, 2nd ed.. Deutsche Stiftung fur Internationale Entwicklung (DSE), pp. 255.

Doat J. 1977. Le pouvoir calorifique des bois tropicaux. Bois et Forets des Tropiques 172: 33–55.

Fimkin V.P. 1983. Recommendations on assortment of tree and shrub species for salt-affected soils in Golodnaya Steppe. Middle-Asian Forest Research Institute, Ministry of Agriculture of Uzbek SSR, Tashkent, pp. 1–13. (in Russian).

Forestry Compendium. 2000. Global Module (Data base). CAB International, Wallingford, UK.

Gintzburger G., Toderich K.N., Mardonov B.K. and Mahmudov M.M. 2003. Rangelands of the arid and semi-arid zones in Uzbekistan. V. Howe and CIRAD Editing and Publication Service, France, pp. 426.

Glazirin G.E., Chanishev S.G. and Chub V.E. 1999. Brief outlines of climate in Uzbekistan. Chinor ENK – Galaba, Tashkent, pp. 29. (in Russian).

Harker A.P., Sandels A. and Butley J. 1982. Calorific values for wood and bark and a bibliography for fuelwood. London WC1X 8LU. Overseas Development Administration, Tropical Products Institute 56/62 Grays Inn Road, pp. 20.

Heinze M. and Liebmann H. 1998. Afforestation of potassium mine spoil in the southern Harz region. AFZ/Der Wald, Allgemeine Forst Zeitschrift fur Waldwirtschaft and Umweltvorsorge 53: 1287–1289.

Lamers J.P.A., Michels K. and Vandenbeldt R.J. 1994. Trees and windbreaks in the Sahel: establishment, growth, nutritive and calorific values. Agrofor. Syst. 26: 171–184.

MacDicken K.G., Wolf G.V. and Briscoe C.B. 1991. Standard research methods for multipurpose trees and shrubs. Winrock International Institute for Agricultural Development, AK, USA, pp. 56.

Makhno G. 1962. elaboration of methods for forest Management on salt-affected soils in khorezm region. Middle-Asian Forest Research Institute, Ministry of Agriculture of Uzbek SSR, Tashkent, pp. 213. (in Russian).

Novikov G.S. 1950. Biological features of deciduous tree species as a basis for designing plantations along Main Turkmen Channel. Proceedings of the 2nd session of the Academy of Sciences of Turkmen SSR, Ashgabad, pp 13–20. (in Russian).

Olson T.E. and Knopf F.L. 1986. Naturalization of Russian olive in the western United States. Western J. Appl. Forest. 1: 65–69.

Rovsky V.M. 1963. tree species of uzbekistan (fast-growing, industrial, and fruit species). State edition of Uzbek SSR, Tashkent, pp. 130. (in Russian).

Saigal S. 2003. Uzbekistan: issues and approaches to combat desertification. Asian Development Bank, Tashkent, pp. 51

Skupchenko 1950. Management of germination of *Populus euphratica* seedlings. The Academy of Sciences of Kazakh SSR, Vestnik J. 7: 13–19. (in Russian).

Tesky J.L. 1992. *Elaeagnus angustifolia*. In: Fischer W.C. (ed.), The Fire Effects Information System (Data base). USDA-Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory, Missoula, MT, USA.

Tillman D.A. 1978. Wood as an energy resource. Academic Press, London, pp. 252.

Toderich C.H., Goldshtein R.I., Aparin W.B., Idzikowska K. and Rashidova G.S. 2001. Environmental state and an analysis of phytogenetic resources of halophytic plants for rehabilitation and livestock feeding in arid and sandy deserts of Uzbekistan. Springer Verlag Heidelberg, Germany, pp. 154–165.

Tomms M.F. and Novikov E.A. 1966. General zootechny. In: Inoyatov N. and Yokubov A. (eds), 3rd edition. O'qutivchi publisher, Moscow, pp. 570.

Umarov M.U. 1985. Soils of Uzbekistan. FAN State edition Tashkent, pp. 95–101. (in Russian).

UNFCC (Initial National Communication of the Republic of Uzbekistan under the UN Framework Convention on Climate Change) 2001. Uzbekistan: Country study on climate change, phase 2. Expedited financing of climate change enabling activities. Project implementation report. Main administration under the Cabinet of Ministers, Uzbekistan 127 pp.

Uresk D.W. and Yamamoto T. 1994. Field study of plant survival as affected by amendments to bentonite spoil. Great Basin Nat. 54: 156–161.

Wagner M.R. and Dietrichson J. 1994. Preliminary trials of woody biomass species tolerance to irrigation with pulp and paper mill wastewater. Proceedings from the International Energy Agency, The Bioenergy Agreement Task VIII meeting, Biri Norway.

Wang Shiji, Chen Binghao and Li Huqun 1996. Euphrates poplar forest. China Environmental Science Press, Beijing, pp. 17–151.