Fuelwood production in the degraded agricultural areas of the Aral Sea Basin, Uzbekistan

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The quantitative fuelwood properties measured in tree species suitable for phyto-remediation of marginal land in the Aral Sea Basin, illustrate the value of such plantations also for fuelwood production. The species ranking for the firewood value index, FVI, characterizing overall fuelwood quality, was as follows: *Elaeagnus angustifolia* › *Ulmus pumila* › *Populus euphratica*. The energy value of 1 ha of trees at 2 300 stems ha^{-1} after four years was: *P. euphratica* (10.3 tonnes of oil energy equivalent, toe), *E. angustifolia* (8.4 toe), *U. pumila* (6.4 toe).

Picture 1.
Farmers harvesting fuelwood from tree shelterbelts in Khorezm.
Photo A. Khamzina.

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RÉSUMÉ

PRODUCTION DE BOIS DE FEU DANS LES ZONES AGRICOLES DÉGRADÉES DU BASSIN DE LA MER D'ARAL EN OUZBÉKISTAN

Les petites plantations installées à des fins de phyto-remédiation dans des parcelles dégradées du bassin de la mer d'Aral (Asie centrale) sont des sources potentielles d'énergie pour les ménages ruraux, souvent sans accès au gaz. Des données sur les caractéristiques énergétiques des essences locales sont indispensables pour la sélection d'essences destinées au boisement de parcelles marginales. Les propriétés énergétiques – densité, cendres et valeur calorifique (indice énergétique du bois de feu, Fvi), rapport biomasse-cendres, humidité, carbone, azote – ont été étudiées dans le bois de *Elaeagnus angustifolia, Ulmus pumila* et *Populus euphratica,* pendant quatre ans. Les valeurs calorifiques du bois de fût sont assez stables : 19,0-19,2 MJ kg^{-1} pour *E. angustifolia,* 18,2-19,0 pour *U. pumila* et 18,3-19,3 pour *P. euphratica*. La densité du bois variait de 0,44 à 0,57 g cm^{-3}, et les cendres entre 0,6 et 11 % en raison de la salinité élevée. Les cendres sont la caractéristique la plus décisive pour la chaleur de combustion, comme l'indique sa relation inverse aux valeurs calorifiques (r^2 = 0,77). Il n'existe pas de corrélation entre valeur calorifique et densité du bois (r^2 = 0,02). En termes de Fvi, les essences se classaient : *E. Angustifolia* › *U. pumila* › *P. euphratica*. Après quatre ans, la valeur énergétique d'un hectare d'arbres plantés avec 2 300 tiges ha^{-1} suivait l'ordre : *P. euphratica* (10,3 t équivalent pétrole, tep), *E. angustifolia* (8,4 tep), *U. pumila* (6,4 tep), informant sur l'énergie équivalente potentielle des plantations d'arbres dans les terres marginales.

Mots-clés : phyto-carburant, indice de valeur énergétique (Fvi), tonne équivalent pétrole (tep), valeur calorifique, teneur en cendres, densité.

ABSTRACT

FUELWOOD PRODUCTION IN THE DEGRADED AGRICULTURAL AREAS OF THE ARAL SEA BASIN, UZBEKISTAN

Small-scale tree plantations established for phyto-remediation purposes on degraded land patches in the Aral Sea Basin in Central Asia may provide a source of energy for rural households, many of which have no access to gas supplies. Quantitative fuelwood properties such as wood density, ash content, calorific value (constituting the Firewood Value Index, FVI), biomass-to-ash ratio, moisture and C and N content in the wood of *Elaeagnus angustifolia* L., *Ulmus pumila* L. and *Populus euphratica* Oliv. were examined over four years. Stem-wood calorific values hardly varied over time and ranged within 19-19.2 MJ kg^{-1} for *E. angustifolia,* 18.2-19.0 MJ kg^{-1} for *U. pumila* and 18.3-19.3 MJ kg^{-1} for *P. euphratica*. Wood density varied from 0.44 to 0.57 g cm^{-3}. Ash content ranged within 0.6-11 % owing to the high salinity of the soil and groundwater. Ash content was the most decisive property influencing combustion heat, as evidenced by its inverse relationship with calorific values (r^2 =0.77). Calorific value and wood density were not correlated (r^2 =0.02). FVI was ranked as *E. angustifolia› U. pumila› P. euphratica*. The energy value of 1 ha of trees at 2 300 stems ha^{-1} after four years was ranked as *P. euphratica* (10.3 tonnes of oil energy equivalent, toe), *E. angustifolia* (8.4 toe), *U. pumila* (6.4 toe), illustrating the potential of tree plantations on marginal lands as a source of biofuel.

Keywords: biofuel, firewood value index (FVI), tonnes of oil equivalent (toe), calorific value, ash content, wood density.

RESUMEN

PRODUCCIÓN DE LEÑA EN LAS ZONAS AGRÍCOLAS DEGRADADAS DE LA CUENCA DEL MAR DE ARAL EN UZBEKISTÁN

Las pequeñas plantaciones establecidas para la fitorremediación en parcelas degradadas de la cuenca del mar de Aral (Asia central) representan fuentes potenciales de energía para los hogares rurales, a menudo privados de acceso al gas. Se necesitan datos sobre las características energéticas de las especies locales para seleccionar aquéllas que van a destinarse a la repoblación de parcelas marginales. Se estudiaron las propiedades energéticas –densidad, cenizas y poder calorífico (valor energético de la leña, FVI), relación biomasa-cenizas, humedad, carbono, nitrógeno– de la madera de *Elaeagnus angustifolia, Ulmus pumila* y *Populus euphratica,* durante cuatro años. Los valores caloríficos de la madera de fuste son bastante estables: 19,0-19,2 MJ kg^{-1} en *E. angustifolia,* 18,2-19,0 en *U. pumila* y 18,3-19,3 en *P. euphratica*. La densidad de la madera variaba entre 0,44 y 0,57 g cm^{-3}, y las cenizas entre 0,6 y 11 % debido a la alta salinidad. Las cenizas son la característica más decisiva para el calor de combustión, tal y como indica su relación inversa con los valores caloríficos (r^2 = 0,77). No existe correlación entre poder calorífico y densidad de la madera (r^2 = 0,02). En cuanto al FVI, las especies se clasificaban así: *E. Angustifolia* › *U. pumila* › *P. euphratica*. Tras cuatro años, el valor energético de una hectárea de árboles plantada con 2 300 troncos ha^{-1} era el siguiente: *P. euphratica* (10,3 t en equivalente de petróleo [tep]), *E. angustifolia* (8,4 tep), *U. pumila* (6,4 tep), lo que nos informa acerca de la energía equivalente potencial de las plantaciones de árboles en tierras marginales.

Palabras clave: xilocombustible, índice de valor energético (FVI), tonelada equivalente de petróleo (tep), poder calorífico, contenido de cenizas, densidad.

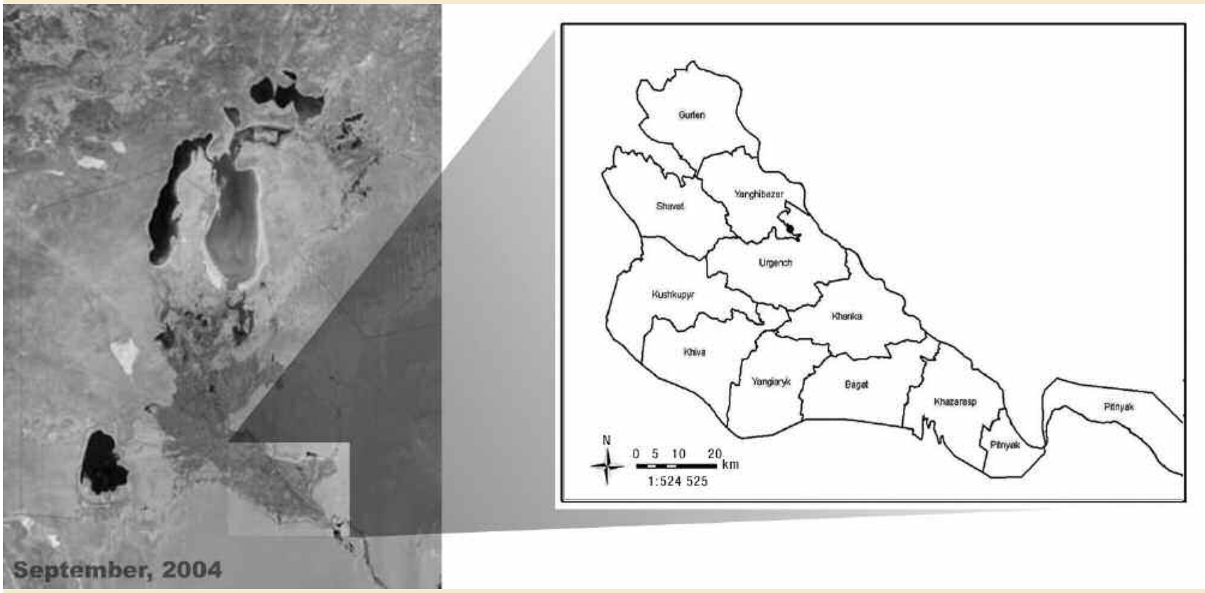
Picture 2.
Tree species included in the experiment: branchlets of *Elaeagnus angustifolia* L. (a), *Populus euphratica* Oliv. (b), *Ulmus pumila* L. (c).
Photos A. Khamzina.

Introduction

Only 56% of the mainly rural population of Uzbekistan has access to public gas supplies, despite an annual gas production of 29 billion m^3 (UNFCC, 2001). Given the absence or uncertainty of gas and electric power supplies, a large part of the population uses fuelwood for cooking and heating. In most cases, trees are poached from government forest reserves, tree lines along roads, and from hedgerows along field borders (Picture 1), amounting to approximately 380.7 m^3 of illegal logging in 2004 (Vildanova, 2006).

Uzbekistan's National Action Program (NAP), established in 1999, advocated greater integration of trees in the agricultural landscape in order to combat land degradation and desertification. Recent research has underlined several tree species characterized by early establishment (Khamzina *et al.*, 2006a), high biomass production (Lamers *et al.*, 2005) and salt tolerance (Khamzina *et al.*, 2006b), and thus most suitable for afforesting agricultural land of marginal quality for crop production (Lamers *et al.*, 2005). Knowledge on biofuel potential of tree plantations is currently insufficient but can serve as an instructive and practical aid and should be included in financial valuations of tree plantings on marginal land.

The most suitable firewood species have high calorific values, high wood densities, high biomass to ash ratios and contain low amounts of ash and water (Bhatt and Todaria, 1992; Puri *et al.*, 1994). The calorific values on a dry and ash-free basis for species of the temperate zones ranged closely between 18 and 21 MJ kg^{-1}, due primarily to low variability in the chemical composition of the wood (Harker *et al.*, 1982). Shanavas and Kumar (2003) reported a negative relationship between calorific value and wood ash content for tree species in a humid climate. The mineral content in trees



Picture 3.
Satellite image of the Aral Sea area, location of the Khorezm Region and the experimental afforestation site.
Souce: GIS laboratory of the ZEF-UNESCO Khorezm project.

grown on marginal land characterized by soil salinity is relatively high (Khamzina, 2006), which may therefore decrease fuelwood quality.

Reported in this paper are the key quantitative fuelwood properties examined in Russian olive (*Elaeagnus angustifolia* L.), Siberian elm (*Ulmus pumila* L.) and Euphrates poplar (*Populus euphratica* Oliv.) (Picture 2). These species were selected for the afforestation of marginal lands (Khamzina *et al.*, 2006a, b; Lamers *et al.*, 2005), and used to assess the fuelwood quality and to quantify the bio-energy capacity of the plantations. Temporal changes in fuelwood quantity and quality were also evaluated in order to complement previous studies (e.g. Harker *et al.*, 1982; Shanavas and Kumar, 2003), which often compared trees of different ages and mainly at a single point in time.

Materials and methods

Samples were collected from experimental tree plantations (41°65' N latitude, 60°62' E longitude, altitude 102 m asl) established in the Khorezm Region in the northwest of Uzbekistan (Picture 3). A 3 x 3 split plot design was used (irrigation mode x tree species). The species *E. angustifolia*, *U. pumila* and *P. euphratica* were each subjected to deficit irrigation at 80-160 mm year^{-1}. Water was applied by drip or furrow irrigation during the first two years of growth, but ceased thereafter to achieve full reliance of the plantations on groundwater and precipitation. The soils at the study site had low fertility value, were highly salinized due to a shallow saline groundwater table (Picture 4), and were thus poorly suited for cultivation of annual crops (Khamzina *et al.*, 2008).

At 7, 19, 31, and 43 months after planting (MaP) 1-year-old saplings into the experimental plots, annual dry matter production of all tree fractions was determined (Picture 5). Each time, 36 trees (12 per species) were harvested (Khamzina *et al.*, 2008), while 9-15 representatives with leaf biomass production judged as average for a given species were sampled for quality analyses. Regularly shaped samples from the main stem (∅ ≥ 2 cm) and branches (∅ < 2 cm) were randomly selected as 10 cm increment cores, except at 43 MaP when 10 cm cores were collected from the main shoot at intervals of 0.5 m. The bark was not separated. Fresh mass was measured with a portable electronic scale to the nearest 0.01 gram: samples were stored in vacuum-sealed plastic bags, labelled and transported inside an ice box to the laboratory for analyses of wood density, calorific values, ash, moisture, and C and N contents.

Wood density was estimated as the oven-dry mass of the core divided by its volume when still fresh, expressed in mg mm^{-3} or kg dm^{-3} (Cornelissen *et al.*, 2003). The green volume was measured according to the water volume displacement methodology (Cornelissen *et al.*, 2003). The dry matter of each core was determined by drying at 103 ± 2 °C to constant weight in a forced air convection oven.

The five-gram wood samples were weighed to the nearest mg in a porcelain crucible, dried at 103 ± 2 °C, cooled in a dessicator, ground in a mill to pass through a 1 mm mesh screen, and then thoroughly mixed. Duplicate samples (0.5 g) were placed in a muffle furnace and ashed for 6 hours at 550 °C. The ash was weighed and the ash percentage was estimated on the basis of the dry weight. The biomass-to-ash ratio was calculated as a proxy for the net quantity of fuel biomass (Bhatt *et al.*, 2004).

Gross calorific value of firewood was determined by burning wood samples in an oxygen bomb calorimeter (Shanavas and Kumar, 2003). The Firewood Value Index (FVI), which concurrently accounts for the calorific value CV [MJ DM kg^{-1}] and wood density D, [g cm^{-3}] as the desirable property, and the ash content CA [g DM g^{-1}] as the negative property, was calculated according to Bhatt and Todaria (1992).

$$FVI = \frac{CV \cdot D}{CA} \text{ [MJ cm}^{-3}\text{]}$$

The C and N content was measured with a mass spectrometer (except for the samples at 7 MaP when the analyzer was not available) and subsequently the Carbon-to-Nitrogen (C/N) ratio was estimated.

Cores from the same and different trees of the same species were regarded as replicates. The mean species effect was tested at a $p < 0.05$ level of significance. The Tukey Post Hoc test was used to compare individual species means where the analysis of variance indicated significant effects. The correlation between wood density, ash content, calorific values and moisture content was completed using linear regression analysis. All statistical analyses were performed with an SPSS 12.0.1 software package.

Picture 4.
Overview of the experimental site showing: severe secondary soil salinization in the spring of 2004 (a), tree plantations in the spring of 2006 (b).
Photos J. Lamers & A. Khamzina.

Table I.
Quantitative properties of stem wood measured in three tree species during four years, and levels of significance of species effects. Values with the same superscript within the row are not significantly different.

Item	Unit	*Elaeagnus angustifolia*	*Ulmus pumila*	*Populus euphratica*	Species effects (*p* value)
7 MaP (October 2003)					
Calorific value	MJ kg^{-1}	19.0[a]	18.2[a]	18.8[a]	n.s.*
Ash content	%	2.7[a]	6.0[a]	4.6[a]	n.s.
Wood density	g cm^{-3}	0.53[b]	0.57[c]	0.47[a]	‹0.001
FVI**	MJ cm^{-3}	0.46[a]	0.24[a]	0.25[a]	n.s.
Biomass/ash	-	36.6[a]	16.6[a]	21.8[a]	n.s.
19 MaP (October 2004)					
Calorific value	MJ kg^{-1}	19.1[a]	19.0[a]	19.3[a]	n.s.
Ash content	%	0.9[a]	2.4[c]	1.9[b]	‹0.001
Wood density	g cm^{-3}	0.53[b]	0.57[c]	0.47[a]	‹0.001
FVI	MJ cm^{-3}	1.08[b]	0.45[a]	0.49[a]	‹0.001
Biomass/ash	-	105.6[b]	41.2[a]	53.1[a]	‹0.001
N	%	0.81[b]	0.45[a]	0.33[a]	‹0.001
C	%	47.3[b]	46.9[a]	47.2[ab]	0.05
C/N	-	58.3[a]	104.7[b]	144.4[c]	‹0.01
31 MaP (October 2005)					
Calorific value	MJ kg^{-1}	19.1[a]	18.8[a]	18.3[a]	n.s.
Ash content	%	3.1[a]	3.9[a]	5.1[a]	n.s.
Wood density	g cm^{-3}	0.52[b]	0.56[c]	0.50[a]	‹0.001
FVI	MJ cm^{-3}	0.34[a]	0.28[a]	0.31[a]	n.s.
Biomass/ash	-	32.2[a]	25.5[a]	19.8[a]	n.s.
N	%	0.66[b]	0.32[a]	0.25[a]	‹0.001
C	%	45.7[a]	44.9[a]	44.9[a]	n.s.
C/N	-	69.2[a]	141.9[b]	181.0[c]	‹0.01
43 MaP (October 2006)					
Calorific value	MJ kg^{-1}	19.2[a]	18.9[a]	18.8[a]	n.s.
Ash content	%	1.0[a]	1.5[ab]	2.2[b]	0.07
Wood density	g cm^{-3}	0.51[b]	0.56[c]	0.44[a]	‹0.001
FVI	MJ cm^{-3}	1.12[b]	0.79[ab]	0.47[a]	0.06
Biomass/ash	-	96.1[a]	68.2[a]	44.4[a]	n.s.
N	%	1.37[b]	0.28[a]	0.48[a]	‹0.01
C	%	44.9[a]	44.2[a]	43.5[a]	n.s.
C/N	-	42.5[a]	159.1[c]	89.8[b]	‹0.001

*n.s.: not significant; **FVI: Firewood Value Index.

Table II.
Fuelwood production and estimated energy value of 5-year-old plantations with a density of 2 300 trees ha^{-1} based on conversion into oil and coal equivalents.

	Unit	*Elaeagnus angustifolia*	*Ulmus pumila*	*Populus euphratica*
Stem production	kg per tree	6.2	6.3	6.2
Branch (∅ ≥ 2 cm) production	kg per tree	4.9	2.3	7.7
Plantation density	trees ha^{-1}	2 300	2 300	2 300
Total wood production	t ha^{-1}	25.5	19.8	32.0
Calorific value of stem wood	MJ kg^{-1}	19.1	18.7	18.8
Energy of stem wood	MJ per tree	118.4	117.8	116.6
Energy of branch wood (∅ ≥ 2 cm)	MJ per tree	93.6	43.0	144.8
Biofuel capacity	MJ ha^{-1}	487 623	369 886	601 036
TOE (1 tonne of oil equivalent) = 42 MJ kg^{-1}*	tons	8.2	6.4	10.3
TCE (1 tonne of coal equivalent) = 29.3 MJ kg^{-1}	tons	16.6	12.6	20.5

* Based on the average conversion factor of 1 tonne of fuelwood = 0.3215 tonne of oil equivalent (toe).

Results

Calorific value

The calorific values (Table I) ranged from 18.2 MJ kg^{-1} (*U. pumila* in 2003) to 19.3 MJ kg^{-1} (*P. euphratica* in 2004) and did not differ significantly among tree species (Table I). Based on the 43 MaP observations and the average conversion factor (UNECE, 2007) of 1 tonne of fuelwood = 0.3215 tonne of oil equivalent (toe), the energy value from 1 ha of trees at 2 300 stems ha^{-1} was ranked as *P. euphratica* (10.3 toe) › *E. angustifolia* (8.4 toe) › *U. pumila* (6.4 toe), which illustrated the potential energy value from tree plantations on marginal land (Table II).

Ash content

Ash contents showed temporal and inter-species differences. At all four harvesting periods, stem wood from *E. angustifolia* contained the lowest amount of ash among the three species (Table I). The ash content varied from 0.9% (at 19 MaP) to 3.1% (at 31 MaP). Whilst at 7 and 19 MaP, the ash content in *U. pumila* stem wood was higher than in *P. euphratica*, at 31 and 43 MaP, the latter contained higher ash percentages than the stem wood of *U. pumila*.

C and N content

The wood N content of all species was relatively low. During all observation periods except at 43 MaP, it ranked as *E. angustifolia* › *U. pumila* › *P. euphratica*. In contrast, the wood C content was fairly stable over the years and among the species (Table I).

Wood density

Wood density ranged from 0.44 to 0.57 g cm^{-3} (Table I), and always ranked as *U. pumila› E. angustifolia* › *P. euphratica*. The wood density was consistent over the years for *U. pumila* and *E. angustifolia,* but not for *P. euphratica*.

Firewood Value Index

At all observation periods except at 31 MaP, the FVI was considerably higher for *E. angustifolia* (Table I). At 7 and 43 MaP, the FVI of *P. euphratica* was the lowest among the three species, whilst at 19 and 31 MaP the FVI of *U. pumila* was the lowest.

Relationships between quantitative properties

With all species, the calorific value was strongly and negatively correlated with the ash content despite the inter-annual differences. In contrast, calorific value and wood density were very weakly correlated (Figure 1) as were wood density and ash content ($r^2 = 0.06$). The wood moisture content of individuals (data not shown) and of all species together was only very weakly correlated ($r^2 = 0.03$, P › 0.1) with combustion heat (Figure 1).

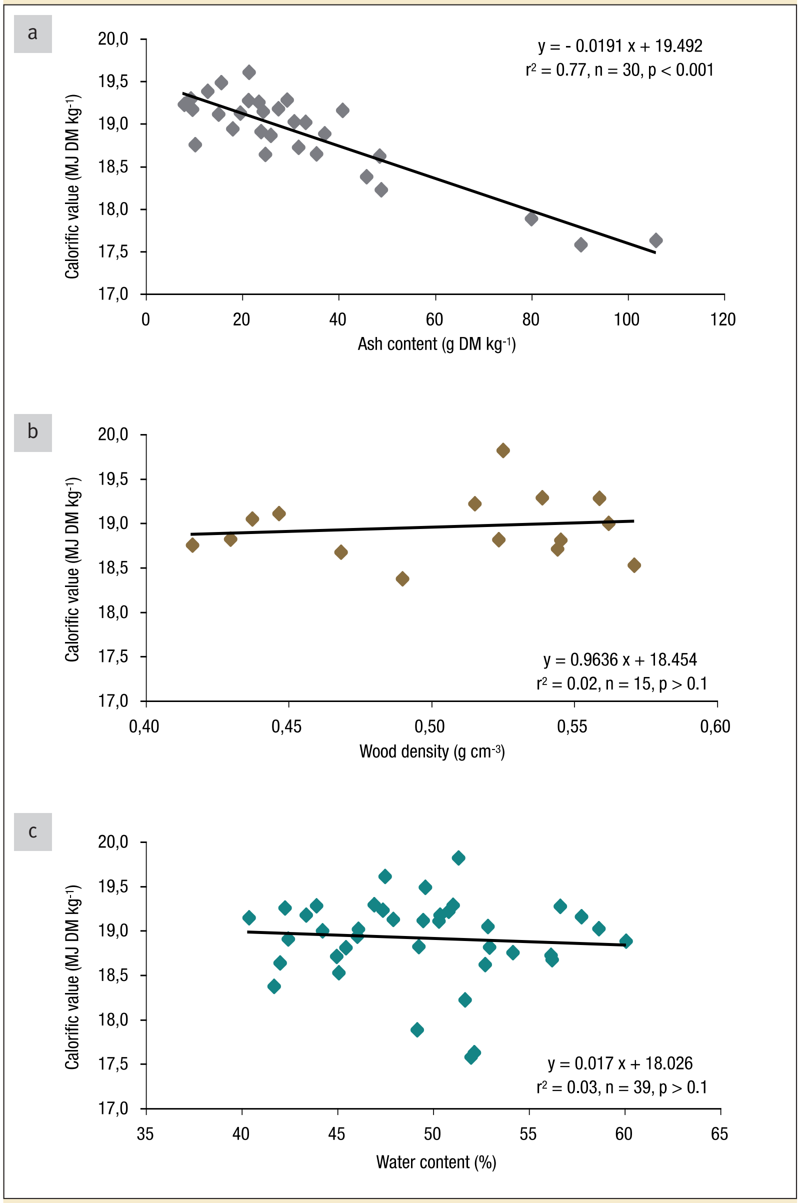


Figure 1.
Relationships between combustion heat *vs.* ash content (a), combustion heat *vs.* wood density (b), and combustion heat *vs.* wood water content (c) for *E. angustifolia*, *P. euphratica*, and *U. pumila*. Best-fitting equations with r^2 values, number of samples (n), and levels of significance (p) are given inside the charts.

The wood C/N ratios varied from 33 to 69 for *E. angustifolia*, from 104 to 159 for *U. pumila,* and from 90 to 181 for *P. euphratica*. The wood of *E. angustifolia* had the lowest C/N ratio for all observations periods.

The biomass/ash ratio was highest for *E. angustifolia* at all harvest periods. Similarly to the ash content ranking, at 7 and 19 MaP the biomass/ash ratio was lowest for the stem wood of *U. pumila,* and at 31 and 43 MaP lowest for *P. euphratica.* This ratio had a tendency to increase over time for all species, with the exception of the growing season in 2005, which was the year after irrigation ceased.

Discussion

Little attention has been given to the contribution of small-scale tree plantations established on marginal land patches to the rural energy supply in Central Asia. There is no documentation on qualitative fuelwood properties, such as the speed of burning, presence of sparks or toxic smoke when burnt, or on quantitative fuelwood characteristics such as calorific value, wood density, and ash content of tree species grown in these arid regions. Insufficient research in this area is an obstacle to firewood farming initiatives on degraded lands that are otherwise little for cultivation and/or have been abandoned.

Calorific value

Many studies have reported the fuelwood properties of a wide range of tree species (Harker *et al.*, 1982; Puri *et al.*, 1994; Shanavas and Kumar, 2003), but only a few of these species can be grown in the extremely continental climate of Uzbekistan in general, and the Khorezm Region in particular. Furthermore, the reported utility values of the vegetation commonly found in arid Uzbekistan (e.g., Walter and Breckle, 1986) rarely include combustion heat properties and energy status. In a recent study on nine tree species in the Khorezm Region, such information was reported, but only for 2-3 year-old trees (Khamzina *et al.*, 2006a).

Harker *et al.* (1982) summarized the calorific values of tree tissues for 402 species from temperate regions, and concluded that the combustion heat value varied significantly between bark, sapwood and heartwood. This agreed with the conclusions by Shanavas and Kumar (2003) studying 45 species grown in a humid climate. The reported calorific values of stem wood ranged from 15.6 to 23.7 MJ kg^{-1} for hardwoods and from 18.6 to 28.4 MJ kg^{-1} for softwoods (Harker *et al.*, 1982; Shanavas and Kumar, 2003). These results were similar to the calorific values of the tree species investigated by this study. As found in the current study, combustion heat hardly changed over the four-year period, which is in line with findings of Wenyuan (1997) where calorific values of 18-19 MJ kg^{-1} for *E. angustifolia* in arid regions of China were reported, and which remained similar over a three-year study period. Shanavas and Kumar (2003) also found insignificant differences in the calorific values of the basal, middle and top parts of a bole, which indirectly represented the age of the wood. Given the low temporal variation in the calorific values of stem wood, the results of the current study along with those of Wenyuan (1997) and Puri *et al*. (1994) provide evidence that the calorific value can be determined at an early stage in plantation growth, and can therefore be used as a criterion for selecting tree species for fuelwood farming.

Picture 5.
Fuelwood harvest at the experimental afforestation site in Khorezm.
Photo A. Khamzina.

Ash content

The ash contents of *E. angustifolia*, *U. pumila* and *P. euphratica* were high compared to the reported values of 116 species in temperate regions, which ranged from 0.1% to 3.4% and averaged 1.04% (Doat, 1977). High ash contents reduce the calorific value, as concluded from the examination of trees grown in humid and semi-arid regions (e.g., Puri *et al*., 1994; Shanavas and Kumar, 2003). Since the wood ash content is a result of growth processes, it is affected by factors influencing the growth of perennial energy crops, such as soil salinity (Zobel and Talbert, 1984). Conclusions from studies on the mechanisms of salt tolerance in woody species underscored their ability to exclude salts from root uptake. However, under high soil salt concentrations, salt uptake becomes less restricted and trees subsequently partition the salts into their perennial components (Allen *et al*., 1994). The high soil salinity levels found during the study period (up to 36 dS m^{-1} in the 1 m topsoil layer) are therefore a plausible explanation for the high mineral content in stem wood. Consequently, the previously documented negative relationship between ash content and combustion heat (Shanavas and Kumar, 2003) was particularly strong in the present study, owing to the high soil salinity. The biomass/ash ratios, which denote the amount of net biomass used as fuel, have been only sporadically reported (Bhatt *et al*., 2004), but are consistent with those observed in the current study.

Wood density

In contrast to the strong linear relationships between wood density and energy values (Ellis, 1980; Shanavas and Kumar, 2003), these two parameters were not correlated in the present study. However, the results reported by Shanavas and Kumar (2003) were obtained by examining 45 species that clearly provided a wide range of values through which the interdependencies of the parameters examined could be captured, which was not the case in the present study covering only three species. Inter-species differences in wood density are often attributed to a genetic trait, which is then expressed by different lignin and resin contents (Shanavas and Kumar, 2003). Because of these components, wood density may vary not only among species, but also during the lifespan of trees (Bhatt and Todaria, 1992), and among individuals of the same species (Shanavas and Kumar, 2003). Since in-depth chemical wood analyses fell beyond the scope of this study, the absence of such data limits a plausible explanation for the within-species differences in wood density that appeared during the trial period.

Firewood Value Index

Previous research (Bhatt and Todaria, 1992; Puri *et al*., 1994; Bhatt *et al*., 2004) showed that high calorific value, high wood density, low ash percentage, low N content, low wood moisture and a high biomass/ash ratio are highly desirable fuelwood properties, although the most decisive are calorific value, wood density and ash content (Bhatt and Todaria, 1992). Consequently, the high density wood of *U. pumila* is less suitable for fuel than that of *E. angustifolia*, owing to its high ash content and moderate biomass/ash ratio, but more suitable than the stem wood of *P. euphratica*, as substantiated by the resultant FVI, which ranked as *P. euphratica* < *U. pumila* < *E. angustifolia*.

Next to wood density and ash content, moisture content is often considered of critical importance (Harker *et al*., 1982). Shanavas and Kumar (2003), who examined wood and other tree fractions of a wide range of tree species, monitored only a moderate, quadratic fit

($r^2 = 0.2$) between moisture content and calorific value. Whilst the energy content of fresh wood, as compared to dry wood, is potentially identical, the moisture content influences the weight of the wood (which is important during transport) and the ignition time (SHANAVAS and KUMAR, 2003). JIMÉNEZ and GONZÁLEZ (1991) have cautioned that the biomass moisture should always be below 60%, because at higher moisture contents the net calorific energy released during burning is wasted on the evaporation of the wood water (ELLIS, 1980), and in the worst case, net values may even drop to zero or below (HARKER *et al.*, 1982).

Other qualitative fuelwood properties may affect the selection of species for biofuel plantations, such as combustion without producing (toxic) smoke and sparks, the speed of drying and the completeness of combustion (PURI *et al.,* 1994; SHANAVAS and KUMAR, 2003). A high wood N content produces high levels of nitrogen oxide emissions during combustion, which renders wood less suitable as fuelwood (PURI *et al.*, 1994), but this should be of less concern for the species studied, which showed fairly low wood N concentrations.

Bio-fuel capacity of the plantations

Based on the energy value of 1 ha of trees at 2 300 stems ha^{-1} four years after planting, the species were ranked as *P. euphratica* (10.3 toe) › *E. angustifolia* (8.4 toe) › *U. pumila* (6.4 toe). Given that annual per capita energy consumption in Uzbekistan in 2004 amounted to 24 159 kilowatt/hour (IAEA, 2006), and based on the conversion of 1 MJ = 0.28 kilowatt/hour (FOGT, 2006), 1 ha of 5-year-old trees could respectively cover the average annual per capita energy needs of 89 (*P. euphratica),* 72 (*E. angustifolia*)*,* and 55 (*U. pumila*) people. Energy supplies in Uzbekistan are still highly subsidized, as reflected in the domestic natural gas price of only 20 540 UZS (about 15 USD) per thousand cubic meters, compared to 54 000 UZS (ca 43 USD) for business, industrial and agricultural sectors, as against an export price of 110 USD for the same quantity. Although Uzbekistan currently possesses fossil energy reserves, recent estimates indicate that with present consumption rates and their expected increase due to high birth rates, Uzbekistan's natural gas reserves may last for about 33 more years (ESHCHANOV, 2006). Given that a large part of the rural population still has limited or no access to the national gas supply (UNFCC, 2001), and given the expected increase in demand, reflections on alternative energy sources are necessary (Picture 6). Alternatives may then include the use of trees planted on degraded soils for both phyto-remediation purposes and the provision of phyto-fuel. Small-scale tree plantations may gain further significance in Khorezm because of the growing importance of livestock in rural livelihoods and the fact that livestock feed often needs to be cooked in the wintertime, which increases the consumption of fuelwood.

Picture 6.
Farmers in Khorezm largely rely on fuelwood for household needs.
Photo A. Khamzina.

Conclusions

The quantitative fuelwood properties, such as calorific value, wood density, ash, moisture, C and N content, measured during four years in three tree species selected as suitable for phyto-remediation of marginal land, revealed varying suitability for their use as biofuel. *U. pumila* stem wood had high wood density, but owing to its high ash content and moderate biomass-/ash ratio, it was found to be less suitable as fuelwood compared to *E. angustifolia*, but more suitable than *P. euphratica*. Consequently, the species pattern for the FVI, characterizing overall fuelwood quality, followed the order of *P. euphratica* ‹ *U. pumila* ‹ *E. angustifolia*. Due to the highly saline growth environment, ash content was the most important factor influencing combustion heat. However, despite the high ash content in the stem wood, the calorific values of the tree species examined fell within the range reported for trees from non-saline environments, indicating high quality fuelwood.

The energy value of 1 ha of 5-year-old plantations with 2 300 stems ha^{-1} followed the pattern of *P. euphratica* (10.3 toe) › *E. angustifolia* (8.4 toe) › *U. pumila* (6.4 toe). This illustrates the considerable energy value that could be obtained and the scope for meeting rural energy demand from tree plantations on degraded lands assessed as unsuitable for crop cultivation.

Acknowledgements
The German Ministry for Education and Research (BMBF; project number 0339970A) supported this study financially. Additional funds from DAAD (German Academic Exchange Service) are gratefully acknowledged. The research was conducted at the premises of the Urgench State University in Khorezm under the ZEF/UNESCO landscape restructuring project. The authors gratefully acknowledge the comments of two anonymous reviewers on an earlier version of this manuscript.

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