1 GENERAL INTRODUCTION

1.1 Problem setting

Following the collapse of the Soviet Union in 1991, the five socialistic Central Asian republics declared their independence. Among these, Uzbekistan has the largest population numbering 24.3 million people in 2003, over 60 % of whom live in rural areas. The country relies heavily on irrigated agriculture, whose contribution to the national economy comprised 24% of the GNP, 60% of the foreign currency income, and 45% of employment (Uzgipromeliovodhoz, 2003). Uzbekistan is the main water consumer among the five Aral Sea Basin countries, annually using over 50 km^3 of water for agriculture, domestic and industrial purposes, which is about a half of the entire basin water budget (Djalalov et al., 2005). Together with Turkmenistan, Uzbekistan consumes 83% of the water resources generated in the Aral Sea Basin although the two countries "produce" less than 13% of this water. Between 1960 and 1999, the irrigated area in the Aral Sea Basin expanded from about 4.5 to almost 7.9 million ha, and this area was mainly allocated to the monoculture of the cash crop cotton (UNEP, 2000). However, a negative side effect of this impressive expansion is increasing land degradation and desertification (UNEP and Glavgidromet, 1999).

Land degradation is defined as a temporary or permanent decrease in the productive capacity of land caused by geological, geo-morphological and/or human-induced factors (Katyal and Vlek, 2000). A recent global assessment of land degradation showed that about 21% of the presently cultivated land has been irreversibly degraded (FAO, 2000). In Uzbekistan, about 24% of the land suffers from light to severe chemical and physical soil degradation mainly caused by agricultural activities. Of this, 13% has been severely degraded mainly during the past 40 years "with no possible reclamation at a farm level" (FAO, 2000).

Soil conditions heightening the risk of land degradation in Uzbekistan include salinity, sodicity, hydromorphy, soil shallowness, and risk of erosion (FAO, 2000). Among these, soil salinity and sodicity are the most severe affecting 53% of the country's arable land. The annual losses in Uzbekistan due to land degradation have been estimated as USD 31 million, while withdrawal of highly salinized land out of agricultural production has cost USD 12 million (World Bank, 2002). Uzbekistan's

Khorezm region in the lower reaches of the Amu Darya River is particularly threatened by secondary soil salinization with its entire irrigated land suffering from salinity (Uzgipromeliovodhoz, 2003). On the low-lying, flat land of Khorezm, the risk of soil salinization is aggravated by hydromorphic and poor drainage conditions.

The rapid expansion of irrigated agriculture in Central Asia has greatly reduced the flow of the two major rivers that naturally terminated in the Aral Sea, i.e., the Amu Darya and Syr Darya. This shortage has led to drying of the Aral Sea and desertification of its adjacent area, known worldwide as the "Aral Sea syndrome" (UNESCO, 2000). The desiccated bed of the Aral Sea has become one of the major sources of active wind erosion, which affects 56% of the irrigated area in Uzbekistan, imposing risk for land degradation. It has been estimated that during strong dust storms as much as 1.5-6.5 t ha^{-1} of dust containing 260-1,000 kg ha^{-1} of toxic salts is carried out from the former Aral Sea bed onto adjacent lands (UNEP and Glavgidromet, 1999). Khorezm, along with neighboring Karakalpakstan, is the largest populated area affected by the consequences of the Aral Sea disaster. Both areas have received relatively little international donor and research attention (Small and Bunce, 2003).

1.2 The potential and challenge of afforestation of degraded land

The reduction in natural desert, riparian and mountainous forest cover has also contributed to the advancing desertification process in the area. An overview of the forest resources in Central Asia for the period 1983-1993 show a 4-5-fold decrease, resulting mainly from agricultural expansion. In the past, large parts of the land under the desert saksaul (*Haloxylon* spp.) forest in the Bukhara Region, the riparian *tugai* forests of Khorezm, Karakalpakstan and the Ferghana Valley of Uzbekistan were handed over to the agricultural sector (Khanazarov and Kayimov, 1993), thus decreasing the forest cover to 7.7% of the country's territory by 1993. Of this, 85% is represented by the desert vegetation whose average height does not exceed 4 m (FAO, 2005). Another reason for the reduction in the forest cover is continuous anthropogenic pressure such as overgrazing, felling for fuelwood, and secondary soil salinization (UNEP and Glavgidromet, 1999).

In 1999, Uzbekistan prepared its National Action Programme to combat land desertification in the country (UNEP and Glavgidromet, 1999). Program measures included land afforestation particularly on the desiccated bed of the Aral Sea (Khanazarov and Novitsky, 1990), as well as on its periphery, to protect agricultural land from wind erosion and sand deposition. Within irrigated areas, tree shelterbelts have been planted to protect the adjacent cropped fields. These measures have been guided by previous numerous studies throughout Uzbekistan (Botman, 1988; Kayimov, 1986; Kayimov, 1993), which noted the ameliorative effects of the shelterbelts such as yield increases on adjacent agricultural fields by 15-20%.

In the meantime, afforestation of degraded land, abandoned from agricultural use, has not received much attention, although various studies in Uzbekistan have examined the salinity tolerance of various tree species and the use of saline water for forest production (Fimkin, 1972). For afforestation of marginal land, species selection based on thorough screening must be addressed. However, past species assessment studies have mostly used the limited conventional height/diameter measurements to evaluate tree performance (Fimkin, 1983; Makhno, 1962). In a few cases, tree above-ground dry matter production was measured (Khanazarov and Kayimov, 1993), and even less information has been collected on root biomass, structure, and dimension although these are key physiological parameters for the assessment of species suitability for afforestation (Heuperman et al., 2002).

Fast root growth and biomass development, characterizing ease of establishment on marginal land, are important but not exhaustive features that suitable species must possess. Knowledge of the water use characteristics of salinity-tolerant species would facilitate the selection of appropriate trees for planting over the predominant shallow groundwater tables (GWT), which would enhance water discharge through biodrainage and, by this, mitigate the problem of waterlogging (Heuperman et al., 2002). However, available information on transpiration by various species under the typical agro-climatic conditions in Khorezm has been largely insufficient and needs to be supplemented to make better-informed decisions on the selection of tree species for afforestation. To date, most studies have used destructive gravimetric measurements of leaf water loss, which have a number of limitations. No data from direct non-destructive measurements, such as those using a sap flow meter or porometer, commonly used elsewhere to determine tree water use (e.g., Heuperman et al., 2002), have been found for tree species in Central Asia.

In addition to using selection criteria measuring the ecological advantages of various species on marginal land, tree species should be selected that provide direct benefits to farmers, such as producing wood for fuel and construction and/or fodder for livestock (Lamers, 1995; Rockwood et al., 2004). Although fuelwood consumption is significant in Uzbekistan (UNFCC, 2001), no comprehensive database on fuelwood characteristics has been established yet. The information on fodder quality of perennial vegetation in Uzbekistan mostly covers rangeland species, while data on tree feed is sparse (Gintzburger et al., 2003).

Field experiments with trees are usually long-term; however, there is often an urgent demand for species assessment. Therefore, there is an interest in complementing the conventional methods of tree-growth evaluation employed by foresters with appropriate assessment methods used in ecologically oriented studies that estimate relative growth rates and are of very short-term duration (e.g., Poorter, 2002; Poorter and de Jong, 1999). A combination of these methods may offer additional options for early assessment of growth, thus counterbalancing the disadvantages of both methods and providing for better-informed species selection decisions.

The establishment of forest on marginal lands, even with salt-tolerant species, requires irrigation during the initial stage of growth before sole reliance on available groundwater resources can become possible. However, the availability of irrigation water, particularly on marginal lands is limited. Hence, there is a need for assessment of water saving techniques, such as irrigation via drip, which has been adopted for tree growing in other arid regions of the world (Andreu et al., 1997; Levy et al., 1999). A large body of literature on the use of drip irrigation in Uzbekistan exists (SANIIRI, 1995), but there is little information on the use of this technology for forest establishment on marginal lands.

The Khorezm region has been targeted in the current study as it is one of the areas in Central Asia most strongly affected by land degradation. It is hoped that the findings of this study will support efforts of afforestation of the degraded landscapes not only in the intervention region but also in other areas of Central Asia suffering from similar problems of land degradation.

1.3 Research objectives

Considering the existing data gaps and the deficiencies in proven methodological approaches to tackle them, the overall goal of this research was to identify appropriate tree species and irrigation techniques for afforesting degraded land in the Khorezm region. This information is expected to aid decision-making in the region regarding landscape ecological improvements via bio-amelioration. The specific research objectives were to:

i. Determine the most suitable tree species for afforestation based on the morphological and physiological characteristics of trees including root establishment, dry matter production and growth rates, as well as water use and salinity tolerance, and the socio-economic criteria such as quantity and quality of fuelwood and fodder;
ii. Evaluate plantation establishment, growth and water use on marginal land for tree species selected as a result of (i).
iii. Assess and compare the suitability of water saving drip and traditional furrow irrigation techniques for forest establishment on marginal land.

1.4 Outline of the thesis

The thesis is structured into eight chapters. Following this general introduction, the geographical, agro-climatic and other key characteristics of the Khorezm study region are described in Chapter 2 to facilitate understanding of the empirical findings presented in the subsequent chapters. Chapter 3 presents and discusses the results of the comprehensive assessment of 10 multipurpose tree and shrub species planted on experimental plots with two different soil types to determine species suitability for afforestation. Chapter 4 contributes to the subject of appropriate tree species selection methodologies by presenting results of an alternative, eco-physiological approach for combination with the conventional biomass production assessment used in Chapter 3. Chapter 5 presents findings on water use characteristics of the tree species and discusses their biodrainage potential. Chapter 6 discusses the results of the evaluation of establishment and growth of the three species selected as most suitable (Chapter 3) under various irrigation modes on marginal land. Chapter 7 is dedicated to the water use performance of the three tree species grown on marginal land and the estimation of potential biodrainage effect of the afforestation. Although each chapter includes a set of conclusions and recommendations relevant to that chapter, Chapter 8 provides an overall summary of conclusions and recommendations.

2 STUDY REGION

2.1 Geographical and demographical information

The Khorezm Region is located in the northwest of Uzbekistan, in the lower reaches of the Amu Darya River, which is the major water source for all water sectors in Khorezm. This smallest administrative district of Uzbekistan covers an area of about 5,600 km^2 and is spread between 60.05 and 61.39 N and 41.13 and 42.02 E of the Greenwich meridian, or about 225 km south of the remainders of the Aral Sea (Figure 2.1).

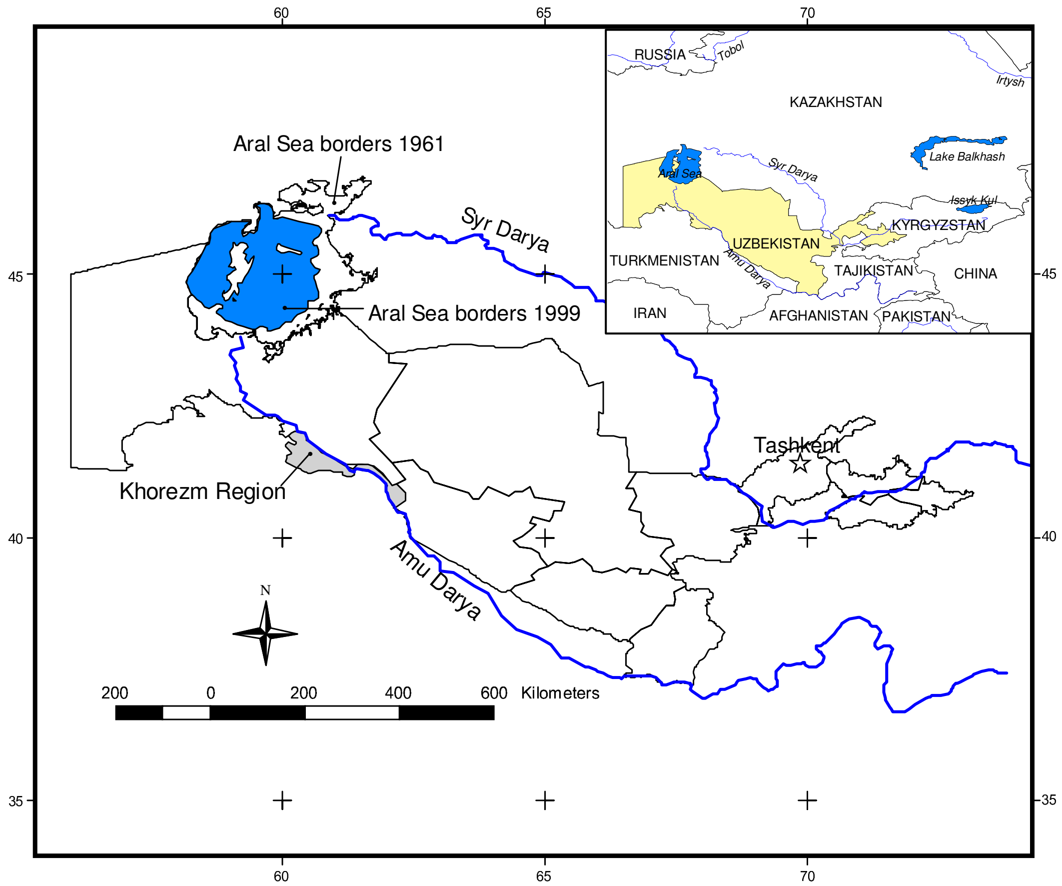

Figure 2.1: Location of the study region

Given its downstream location on the Amu Darya, Khorezm is one of the final receivers of the river’s water supply — a supply that in recent years has become reduced and increasingly unstable because of upstream utilization (Djalalov et al., 2005). Khorezm has become particularly susceptible to short- and long-term droughts, of which the most recent during the 2000 and 2001 growing seasons resulted in major crop failures (WHO, 2001). Consequently, the agricultural GDP has become one of the lowest in Uzbekistan (Djalalov et al., 2005). The socio-economic and public health situation in the region has been further compromised by the geographic proximity to the ecologically degraded Aral Sea area.

Khorezm borders the Karakum and Kizilkum deserts to the south and east, the Amu Darya River to the northeast, the Autonomous Republic of Karakalpakstan to the north, and the Republic of Turkmenistan to the southwest. The population numbered some 1.4 million in 2002, with a density of 228 persons per km^2 (Djalalov et al., 2005). The population growth rate has averaged 2.8% over the past 11 years (MMS, 1999). Khorezm is divided into ten administrative districts and has an administrative center in the capital city of Urgench, which is inhabited by 137,600 people. About 77% of Khorezm's population resides in rural areas and is engaged in cotton, wheat and rice production, as well as in animal husbandry and sericulture (Djalalov et al., 2005).

2.2 Climate

The Khorezm Region belongs to the Central Asian semi-desert zone with an extremely continental climate (Glazirin et al., 1999). The long-term annual precipitation of 80-100 mm falls mostly outside the growing season in the fall-winter period (Figure 2.2).

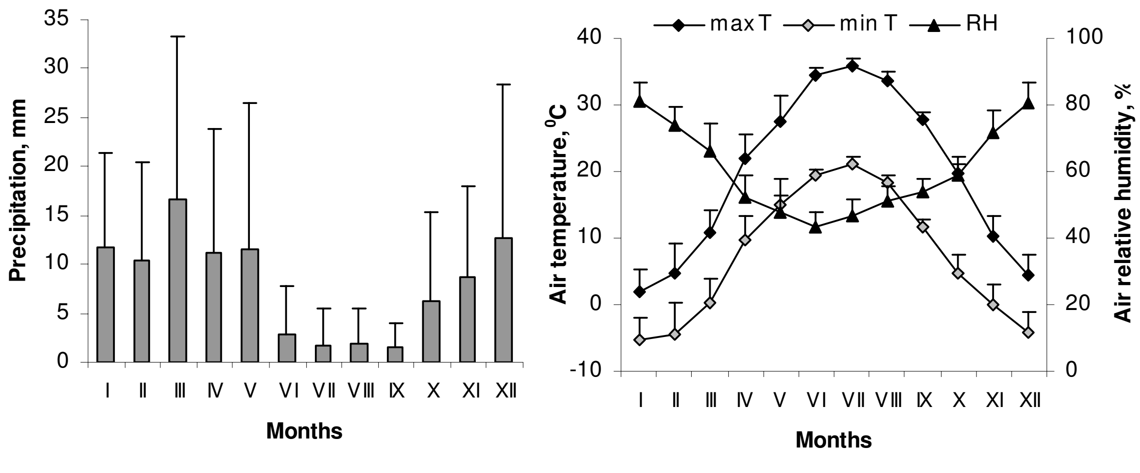

Figure 2.2: Average precipitation, maximum and minimum air temperature (Tmax and Tmin), and relative air humidity (RH) for the period 1980-2000 (Source: Urgench meteorological station)

The precipitation is greatly exceeded by the local evapotranspiration potential of about 1,600 mm $year^{-1}$ (Glavgidromet, 2002). As such, large-scale crop cultivation inevitably requires irrigation. The mean annual air temperature is approximately 13°C, while the absolute daily maximum and minimum temperatures may reach +45°C and -28°C, respectively (Djalalov et al., 2005). For the period 1980-2000, the coldest month was January with a mean temperature of -2.2°C, while the monthly temperature of the hottest month, July, averaged 28.2°C. Mean relative air humidity ranged from 43 to 81% throughout the year (Figure 2.2). The yearly frost-free period averaged 205 days.

Wind activity is observed throughout the year mostly from the northern-east direction with an average wind speed of 1.4-5.5 m s^{-1} for the period 1982-2000 (Glavgidromet, 2002). Detailed meteorological information for the three study years 2002-2004 is presented in subsequent chapters.

2.3 Relief, geomorphology, hydrogeology and soils

Formation of the soil lithological profile in Khorezm was chiefly influenced by the meandering Amu Darya River which carried and deposited sediments along its banks and in depressions (Nurmanov, 1966). According to Fayzullaev (1980), alluvial deposits along the meanders mostly consist of sand, while depressions are mainly filled with loam and clay. Subsequently, soils originating from these alluvial deposits are heterogeneously stratified and, within the area currently used for agriculture, dominated by clayey, loamy and sandy-loamy textures (Nurmanov, 1966).

According to the FAO classification, four soil types can be identified within Khorezm: mostly aridic and gleyic calcaric (sodic) Arenosols and calcaric Cambisols, while gleyic humus Fluvisols are commonly found along the Amu Darya River (SAE, 2001). Organic matter in these soils ranges from 0.7 to 1.5 g 100 g^{-1}, while the cation exchange capacity varies between 5-10 cmol(+) kg^{-1}. Total nitrogen (N) and phosphorus (P) contents in Khorezm soil types are also low, usually ranging between 0.07-0.15% and 0.10-0.18%, respectively. Available potassium (K) content is classified as low or moderate (Fayzullaev, 1980). Consequently, the natural fertility of the soils in Khorezm is characterized as rather low, and cultivation of most agricultural crops requires high inputs of chemical fertilizers.

The relief of the Khorezm Region is mostly flat with insignificant slopes. Slow lateral groundwater (GW) flow, averaging 19-26 mm $year^{-1}$ (Kats, 1976), as well as prevailing heavy soil textures and climate aridity restrict GW outflow and increase evaporative losses. These adverse natural drainage conditions, aggravated by excessive