Chapter 38
Integrating Agroforestry and Pastures for Soil Salinity Management in Dryland Ecosystems in Aral Sea Basin

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Abstract Salt-affected lands in the Central Asian region demonstrate the most characteristic features of natural continental terrestrial salinization, sodication, and alkalinization. Low organic matter (<1.0%), high salt contents, and poor water-holding capacity render these soils unproductive. The predominant salinity type is sulfate-chloride. The Na^+ and SO_4^{2-} are dominant ions. Total nitrogen and phosphorus ranged between 0.7–5.5 mg kg^{-1} and 10.0–18.26 mg kg^{-1}, respectively. Available potassium is low or moderate. Vegetation richness, botanic species diversity, and plant biomass were well integrated with soil moisture and soil salinity. A linear regression equation between apparent soil electrical conductivity (EM38) and quantitative Na^+ accumulation for 0–75 cm ($r^2 = 0.88$) soil profiles allowed us to identify the proportional contribution and interactive effects of each plant community

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(calculated for C_3/C_4 species abundance) at fine desert landscape scale. Foliar $\delta^{13}C$ (carbon discrimination) indexes as an indicator of long-term water-use efficiency in plants in a restored forest – pastures ecosystem showed that $\delta^{13}C$ of C_3 species increased with a decrease in soil water availability, suggesting that water-use efficiency increased with decreasing soil moisture and salinity. The C_4 species' occurrences were observed to be absent and/or scarce within relatively lower soil moisture microhabitats, whereas they occurred and/or even had a high abundance within relatively higher soil moisture microhabitats and salinity, suggesting limited moisture available was a key factor of limiting C_4 distribution in arid region. The suitable coexistence of C3/C4 into an integrated agroforestry – farming system comprising 12–15% of tree cover, 58% of alfalfa, and 27–30% of annual forage crops provides satisfactory drainage – control of these salt affected marginal lands preventing salts accumulation at the root zone area. Trees/shrub plantations were deeply planting (sticks tap into the water table) through seedlings transplanting in early spring or late autumn seasons. A limited irrigation with low-quality water has been applied during the initial stage of growth before sole reliance on available drainage water (EC 4.5–12.3 dS m^{-1}) resource becomes possible. The most promising plants including stands of native rangeland halophytes grown alone, or mixed with various traditional salt-tolerant trees, and fodder crops are addressed in this chapter.

Keywords Agroforestry • Aral Sea Basin • Dryland salinity • Marginal resources • Pastures

38.1 Introduction

Dryland salinity and associated water quality are recognized to be among most severe natural resource degradation problems in the marginal desert belt of Aral Sea Basin. Access to irrigation water in this region has drastically decreased in the last years, which caused additional obstacles to rangelands productivity and agricultural production (Lamers et al. 2005).

Replacement of deep-rooted, perennial native vegetation with shallow-rooted, annual agricultural crops and halophytic pastures has resulted in increased recharge causing shallow saline water tables leading to dryland salinity and loss of plant diversity. These results in greater amounts of water entering a groundwater system, water table rise, and the concentration of naturally occurring salts near the soil surface.

Natural arid desert ecosystems, additionally, are particularly susceptible to climate change and desertification. Slight changes in temperature or soil moisture and dissolved salts regime could therefore substantially alter the composition, distribution and abundance of species. Increased frequency of climatic extremes and changes in soil salinity induce changes in plant functional group composition with invasion of nonnative annual plant, which significantly reduce productivity in arid ecosystems. Therefore, functioning of these arid systems depends to a high degree on plant diversity. Considerable research has been conducted on soil-vegetation relationship in coastal salt marshes saline soils (Toft and Elliot-Fisk 2002). However, investigations identifying the major environmental factors associated with vegetation patterns on inland saline desert areas are scarce and limited to the descriptive botanic documentation of species. Previous studies have shown that many wild halophytes grow well in association with a variety of salt-tolerant traditional crops and often provide severe competition to tree/shrubs species, in natural and improved pastures both on saline and disturbed mine sites (Toderich et al. 2007, 2008). Carbon isotope composition ($\delta^{13}C$) of plant material is related to intrinsic water-use efficiency in C_3 plants (Farquhar et al. 1989). The positive correlation was found between the salinity and the $\delta^{13}C$ of leaf organic matter both in salt-tolerant species (Guy et al. 1980; Farquhar et al. 1982) and salt-sensitive species (Seemann and Critchley 1985). These reports indicate that salt stress may decrease the CO_2 concentration inside the leaf via the stomata closure and consequently increase the intrinsic water-use efficiency. There was, however, no report that presented the response of the $\delta^{13}C$ of leaf organic matter to the salinity.

Afforestation has proved to be effective in revegetating saline landscapes, providing valuable products to local pastoral communities from marginal degraded land, and makes use of the otherwise low-quality water, unproductive lands and lowers the elevated groundwater table via biodrainage (Heuperman et al. 2002; Marcar and Craw-Ford 2004; Khamzina et al. 2006). However, to ensure effective and sustainable outcomes, afforestation of marginal lands must be preceded by a comprehensive evaluation of appropriate both native and introduced tree species (Toderich et al. 2009). Utilization of native vegetation and revegetation has a most important role in raising oasis agriculture under saline environments (Gupta et al. 2009).

The present study aims to describe the spatial distribution of desert plant communities along soil salinity and moisture gradients to understand the relationship between different ecological types of halophytic vegetation and soil properties. The $\delta^{13}C$ and $\delta^{18}O$ data were used to assess the responses of native plants to salinity and the effect of salinization on natural vegetation in Central Asian dryland ecosystem. Native vegetation such as *Artemisia diffusa* and *Salsola paulsenii* are dominated in the plot of the lowest salinity. In this study three dominant shrubs analyzed in this study are *Artemisia diffusa*, *Tamarix hispida* (C_3 species), and *Haloxylon aphyllum* (C_4 species). The *T. hispida* distributed in the plots with high salinity is found frequently after salinization. *H. aphyllum* is planted as a sand shield in all plots.

It was expected that introduction and adaptation of native halophytes and exotic salt-tolerant crops have the potential to provide a break for improving the livelihood of farmer's income at abandoned degraded marginal areas. It is known that the soil and irrigation water salinity limits crop production, especially in arid and semiarid regions. Therefore, experiments on evaluation of indigenous and introduced salt-tolerant plants and halophytes for increasing food, forage, and grain production under soil and irrigation water salinity through farmer's participatory work were conducted in 2007–2009.

This chapter presents an analysis of revegetation technique to mitigate secondary salinity and improve productivity of degraded drylands ecosystems in Aral Sea Basin.

38.2 Material and Methods

38.2.1 Description of the Study Sites

The studies on cover desert vegetation along a salinity gradient were conducted in Kanimekh district at the research station of the Uzbek Research Institute of Karakul Sheep Breeding and Desert Ecology at an altitude of 113 m. The Kyzylkesek site was selected – an area located between two hot springs (vertical drainage flow) in Central Kyzylkum Desert – in order to determine spatial changes of vegetation as from the xerophytes in sandy dunes toward typical halophytes in wet salt depression (Fig. 38.1). Our findings showed that each zone differs by its relief, total soluble salts, floristic composition, and botanic diversity. This region has a typical inland arid climate with a hot, dry summer and cold winter: annual mean temperature is 11.4 °C, and annual mean precipitation is 120 mm, which distributes in the growing season from May to September.

Experimental plantations were established in early April 2007–2009 on gleyic-sandy solonchak soils (Central Kyzylkum Desert) and silt loam texture (Amudarya river delta, Dashauz district, Turkmenistan), both underlain by a thin gypsum layer (a hydrated calcium sulfate accumulation, which is most pronounced within upper 100 cm). Therefore, the root zone before planting needs to be leached.

An agro-silvicultural trial of trees intercropped with deep-rooted, early maturing, and frost-tolerant legume was established in the Yangiobod farm, northern Tajikistan, in order to determine appropriate tree species and silvicultural techniques for converting degraded, salt-affected land patches into small-scale tree plantations. The plantations measured an area of 0.14 ha each. The preselected nine deciduous native and exotic species represented a variety of life spans and tolerances to drought and salt stress. One-year-old tree saplings were randomly planted on the shoulder of a 40-cm-deep irrigation furrow. The spacing of 5.0 m × 5.0 m avoided mutual shading during the experiment and allowed to plant annual crops and grasses between rows. Due to an adequate availability of saline irrigation water in the region throughout the study period, the presence of intensively irrigated rice fields in the vicinity, and a high groundwater table (GWT), the trees at the loamy site (in northern Turkmenistan) were only occasionally irrigated. The soil moisture at the sandy site remained close to field capacity; hence, only one irrigation event was necessary at the onset of each vegetation season.

The area was instrumented with a network of observation wells. The texture analyses of the sandy-gleyic solonchak soil at each installation point showed in

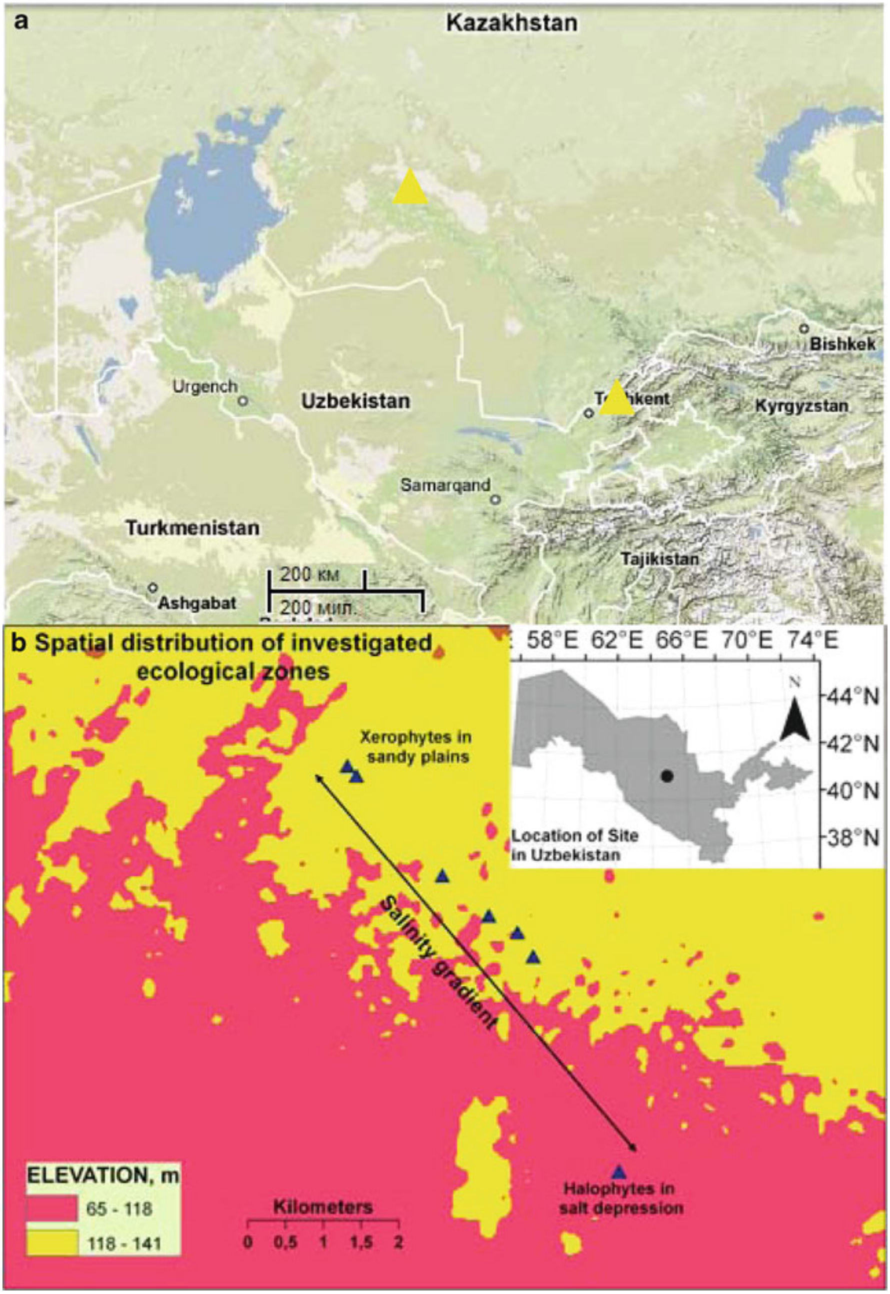

Fig. 38.1 Topographical landscape map of Central Asia. (**a**) Altitude maps in large and small scale (**b**). The circle in the large-scale map indicates the left figure area. Salinity gradient on microrelief level includes area between two artesian thermal springs (triangular showed the investigated plant community with the investigated area)

general a silt loam texture with a clay bank of varying thickness between 100 and 150 cm depth. Below this clay level, the profile typically consisted of fine sand.

The groundwater table (GWT) at the sandy site ranged between 0.7 and 1.3 m during the vegetation period, whereas the GW level at the loamy site varied from 1.0 to 1.3 m. The average GWT depth monitored at both sites was close to the long-term mean of 1.22 m for the region. During the observation seasons, the mean electrical conductivity (EC) of the GW was higher at the nonirrigated sandy site (4.3 dS m^{-1} vs. 3.3 dS m^{-1} at the silt loamy site). Both values exceeded the long-term mean salinity of 1.8 g L^{-1}. Spatial and temporal distribution of natural vegetation according to soil salinity level was studied based on plant vegetation type and soil salinity level.

38.2.2 Estimation of Dry Biomass

Aboveground biomass of investigated species was harvested at the end of October each year, and the harvested material was packed in paper bags in the field and then oven-dried at 65°C for 72 h in the laboratory. The dry weight of all the species was then combined to get the total biomass estimates.

38.2.3 Calibration of EM38

Electromagnetic induction conductivity device (EM38) was standardized at reference temperature of 25°C as EC increases at a rate of approximately 1.9% per 1 degree centigrade above 25°C. (Rhoades et al. 1999). The formula provided in Sheets and Hendrickx (1995) was used, that fits the curve to conversion table given in USDA (1954): $EC_{25} = EC_a \times [0.4470 + 1.4034\varepsilon^{(T/26.815)}]$, where EC_{25} is standardized EC_a and T-soil temperature (Akramkhanov et al. 2008; Hendrikx et al. 1992).

38.2.4 Soil Samples

Soil samples were collected from different depths (0–20, 20–40, 40–60, 60–90, 90–120 cm). Na^+ ions were analyzed by water extract from air-dry soil and plant samples (100 mg of sample) and detected on atomic adsorption spectrophotometer (Hitachi 2007, Japan). Salinity gradient was characterized by contents of Na^+ ions in the soil profiles. Modern techniques to predict trends of neo-halophylization process from soil and plant cover data were tested. The regression analysis was applied to investigate correlation between remote sensing data, Na^+ ion content, and EC values calculated from field data in order to predict soil salinity and vegetation changes.

38.2.5 Carbon Isotope Analysis of Desert Vegetation

The distribution and abundance of desert plant communities were examined. Plant species were collected along a sequence of increasing groundwater depths in eight transects. Isotope analysis, carbon, and oxygen isotope ratios were expressed by the following equation:

$$\delta^{13}\text{C or } \delta^{18}\text{O} = \left(\frac{R_{\text{sam}} - R_{\text{std}}}{R_{\text{std}}}\right) \times 1{,}000\ (‰)$$

where R_{sam} and R_{std} represent the $^{13}C/^{12}C$ or $^{18}O/^{16}O$ of the samples and standard, respectively. The PDB and VSMOW were used for standards of $\delta^{13}C$ and $\delta^{18}O$, respectively.

The photosynthetic organ samples (leaves and short pieces of stems at case of aphyllous species) were oven-dried at 70 °C for 48 h and finely ground. The $\delta^{13}C$ in the organic samples was analyzed using a continuous flow system of an elemental analyzer and an isotope ratio mass spectrometer (Flash 2000 and Delta S, Thermo Fisher Scientific) at Field Science Education and Research Center, Kyoto University, Japan.

38.3 Results and Discussion

Groundwater salinity varies in the range of 2,000–8,200 mg L^{-1}. Groundwater table fluctuates from 0.5 to 2.5 m during May–July at the dry solonchaks and experimental agricultural plots and up to 8.0 to 20.0 m in the virgin desert degraded rangelands area. The GW table under the plantations ranged during the observation period from 1.2 to 2.2 m below the soil surface. The EC of the GW under plantations varied between 0.4 and 4.2 dS m^{-1} while the range of EC values under the open field was 0.4–2.8 dS m^{-1}. Measurements of soil EC in the beginning and the end of the vegetation season indicated that the soil was of slight to medium salinity, although at the upper 40-cm horizon at some points, EC reached values of over 25 dS m^{-1}. Soil EC at the open field was in average about twice as low as that at the plantation area.

The organic matter of soil in the surveyed soils is less than 1%, while the cation-exchange capacity varies between 10 meq/100 g and 35 meq/100 g soil. Total nitrogen (N) and phosphorus (P) contents in salt-affected soils are low, usually ranging between 0.7–5.5 mg kg^{-1} and 10.0–18.26 mg kg^{-1}, respectively. Available potassium (K) content is classified as low or moderate (Fig. 38.2). The dominant cation is Na and the dominant anion is SO_4. Soil fertility of the desert saline soils is characterized as low; therefore, the cultivation of agricultural crops requires high inputs of chemical fertilizers and costly leaching practice to free root zone from salinity.

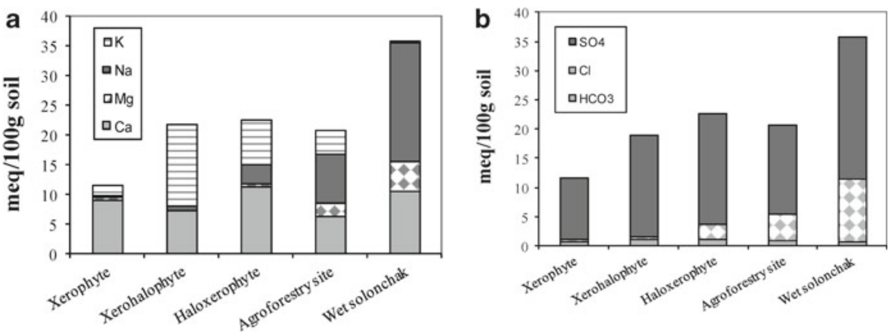

Fig. 38.2 Content of different cations (**a**) and anions (**b**) under different dominant plant communities along a salinity gradient

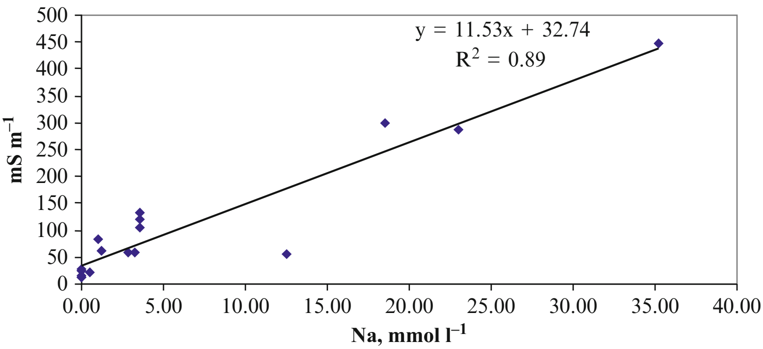

Fig. 38.3 Linear regression between apparent electrical conductivity (EM38) and Na^+ content across salinity gradient at the fine landscape level (Source: Shuyskaya et al. (2008))

Analysis of soil samples from five hot spot areas separately demonstrated significant differences of cations and anions content, strongly interrelated with the halophytic plant spectrum composition (Fig. 38.2).

Chemical analysis of soil showed that main type of mineralization is calcium-sodium and sulfate from anions. The virgin Artemisia rangeland and gray-brown stabilized sands with predominance xerophytes and xerohalophytes with the least content of salinity in soil solution is characterized by significant amount of Ca^{2+}, HCO_3^- ions, and the least content of Na^+, Mg^{2+}, and Cl^- compared with other tested sites.

The ability of up-taking and/or accumulation of sodium ion in the upper soils profile and electric conductivity value detected by EM38 were gradually raising according to floristic composition, spatial halophytic vegetation distribution, and relief characteristics. Electrical conductivity values were graphed, and the linear regression was fitted. In general, there is a good fit of the regression line that is demonstrated by high r^2 (Fig. 38.3).

It is evident from Fig. 38.3 that there is a positive correlation between sodium ion content and electric conductivity ($r^2 = 0.881$) at 0–75 cm of soil profiles. Results generally indicated that the salinity gradient, moisture, and available nutrient in soil are the important factors in controlling the temporal and spatial distribution of vegetation.

The salt-affected marginal lands in the plains and studied saline depression were classified into three habitat types: *A*-with shallow water table and moderate salinity (marginal old agricultural lands), *B*-with relatively deep water table and high salinity, and *C*-transitional habitats in which salinity and water table are not controlling factors (virgin Artemisia perennial pastures). The most important factors of zonal vegetation were soil salinity and the salt-tolerance limits of species. In general, the distinction of each ecological vegetation group differs according to relief, floristic composition, and ion concentration (halo accumulation plant ability) in the aboveground dry biomass. It was found that the most important direct source of soil salinization, as is seen in the Table 38.1, was shallow groundwater level calculated through the soil moisture content and soil salinity based on the content of Na^+ ions in the upper soil profiles. A very intensive process of soil salinization occurs in the areas located in the vicinity of settlements, animal drinking points, and artesian freely flowing wells along drainage channels and on small saline depressions (wet solonchaks-ecotype 5 in this research).

Plant composition, soil salinity, water table level, and pasture yield were quantified in five main ecological zones. Afforestation program was performed to test the importance of farming practice in the mitigation of salinity and decreasing water table. On the high end of the gradient, soil salinity and sodicity (a measure of exchangeable sodium) were high in the *Climacoptera lanata* zone [(EC = 5.3 dS m^{-1}), sodium adsorption ratio-SAR = 44.0 (mmoles L^{-1})$^{0.5}$] and extreme in the *Tamarix hispida* zone [(EC = 21 dS m^{-1}), SAR = 274 (mmoles L^{-1})$^{0.5}$]. Natural species produced maximum biomass in the zone where they originated, not in any other higher or lower vegetation zone. The *Tamarix* species, H. *apphyllum*, and annual halophytes, which were distributed across nearly all sites, had low frequency of occurrence. Based on this, we have distinguished common growth forms into distinct groups corresponding to different groundwater levels. Three clearly defined groups of growth forms were strongly associated with three distinct groundwater zones, ranging from <3, 3–5 to >5 m, respectively. Four taxa groups were found to correspond to the three groundwater zones and to several other environmental factors that suggest a major botanical gradient exists relating to groundwater depth than to the secondary gradients like soil moisture and pH and to a lesser extent, alkalinity and mineralization.

As seen from Table 38.1, the dominating life forms are halophytes (chamaephytes) in sites of high salinity and xerophytes (therophytes) in sites of low salinity. Spatial and temporal variations in the standing crop biomass were pronounced. The accumulation of green biomass started during spring and reached a maximum in autumn, when photosynthetic activity was maintained to account for transpiration losses. There was a general trend of increasing salinity and concentration of different ions along the salinity gradient. The periodical variation in the water table was

Table 38.1 Description of halophytic plant communities in the Karakata salt depression, Central Kyzylkum

	Biotope/ecological groups	Description of plant communities	Water table depth (m)	Improvement practice	Soil salinity level as per sodium content (Na^+, meq/100 g)	Halophytic pasture yield (t ha^{-1})[a]	Moisture (%)
1.	Sandy and gray-brown desert soils/ aboriginal psammophytic pastures (xerophyte)	*Ferula assa-foetida*, *Aellenia subaphylla*, *Ammothamnus lehmannii*, *Astragalus villosissimus*, *Artemisia diffusa*, *Salsola praecox*, *Turnefortia* sp., *Calligonum leocacladum*, *Stipa* sp., *Ammodendron connolly*	20–28	No	Low (0.3–0.5)	0.7	2.8
2.	Sagebrush with ephemers (Artemisia spp.) sandy desert (xerohalophyte)	*Artemisia diffusa*, *Haloxylon aphyllum*, *Peganum harmala*, *Salsola* sp., *Climacoptera lanata*	20–18	No	Low (0.2–1.2)	2.48	3.3
3.	Haloxylon forest (haloxerophyte)	*Peganum harmala*, *Haloxylon aphyllum*, *Alhagi pseudalhagi*, *Salsola* sp., *Sueda* sp., *Climacoptera lanata*	4–6	No	Low-moderate (3.5–7.0)	1.5	7.9
4.	Desert salt-affected soil improved through an agro-silvi-pastoral model	Aboriginal strips of halophytes with *Climacoptera lanata* mixed with moderately salt-tolerant tree-shrubs-traditional crops (*Sorghum*, *Pennisetum-Amaranthus* etc., crops)	1.5–2.8	Without irrigation and fertilizers (control)	Moderate (7.9–12.0)	4.7	8.1

5.	Desert salt-affected soil improved through an agro-silvi-pastoral model	Aboriginal strips of halophytes with *Climacoptera lanata* mixed with moderately salt-tolerant tree-shrubs-traditional crops (*Sorghum*, *Pennisetum*-*Amaranthus* etc. crops)	0.9–2.0	Irrigation with saline water, without fertilizers	Moderate (7.9–12.0)	21.8	8.1
6.	Desert salt-affected soil improved through an agro-silvi-pastoral model	Aboriginal strips of halophytes with *Climacoptera lanata* mixed with moderately salt-tolerant tree/shrubs traditional crops (*Sorghum*, *Pennisetum*-*Amaranthus* etc., crops)	0.9–2.0	Irrigation with saline water and fertilizers	Moderate (7.9–12.0)	43.6	8.1
7.	Wet solonchak/hyperhalo-phytes (pure stands)	*Tamarix hispida*, *Salicornia europea*, *Sueda* sp., *Climacoptera lanata*, *Aeluropus littoralis*, *Halostachys caspia*, *Halimochnemis strobilaceum (belangeriana)*	0.5–0.9	No	High (17.5–34.0)	11.5	8.9

[a]Calculated for *Climacoptera lanata* under different agropastoral management practices

insignificant, while a significant drop in salinity and the concentration of different ions were detected in spring, which was attributed to the diluting effect of rainwater during that season.

As indicated in Fig. 38.2, we used five halophytic vegetation types to build a species-area curve by calculating the cumulative number of species according to soil anions/cations changes, which correspond with habitats heterogeneity and species diversity at fine landscape scale, like Karakata flat salt depression. In this situation, rangelands productivity sharply declined, and it was mostly determined by development of monospecific dominant vegetation stands. During extension of the process of neo-halophylization, previously high productive rangelands became converted into saline pastures covered by halophytes, which differed by their salt-tolerance limit and vegetation composition, as seen on Fig. 38.2 and Table 38.1. Based on accumulation of Na^+ in the soil profile over the entire studied area, the key halophytic plant communities were distributed as strong ecological groups starting from nonsaline (psammophytes and xerophytes) through moderate saline (xerohalophytes and haloxerophytes) to highly saline habitats or salt marshes (hyperhalophytes) habitats. Thus, patterns at Karakata saline depression arise from counter-directional stress gradients: a gradient from low salinity to extremely high soil salinity and shallow water table, which strictly dominate the vegetation zonation. Therefore, we assume that the restoration of the salt-affected/waterlogged regime of these lands to a natural desert regime through afforestation farming system may be sufficient to reestablish many of the natural biodiversity/ecosystem functions.

The distribution of halophytic vegetation is related to interspecific and intraspecific plant species competition, grazing capacity, and land management. Desert topographical features and salinity gradient are of primary importance in determining the contribution of species with different photosynthetic pathways or taxonomic relations in forming of core ecological plant community types or vegetation units.

38.3.1 Plant Density of C_3*- and* C_4 *Species Related to Na and K Accumulation and Biomass Productivity*

The C_3 species such as *A. lehmannii*, *A. diffusa*, and *Alhagi. pseudalhagi*, which occurred mostly on 1–3 ecological zones (Table 38.1), and some of tree species accumulate insignificant amount of sodium in leaves (0.63–7.34 g kg^{-1} of dry matter). Considerably high content of sodium (about ten times higher) was found in the leaves of *P. harmala* (52.33 g kg^{-1}) which is one of the plant components of haloxerophyte vegetation association. Such C_4 species as *H. aphyllum*, *S. paulsenii*, *and T. hispida* accumulate 20–90 g kg^{-1} of sodium in green aboveground part. The representatives of C_4 species (*C. lanata*, *Suaeda* sp.) of haloxerophyte plant association are capable to accumulate up to 300 g kg^{-1} of sodium.

Potassium was accumulated approximately in the same amount (6.9–28.11 g kg^{-1}) in both C_3 and C_4 studied plants. In the green part of C_3 species, the content of potassium has increased twice than the content of sodium (2.0 and 0.8 kg ha^{-1}) in xero-

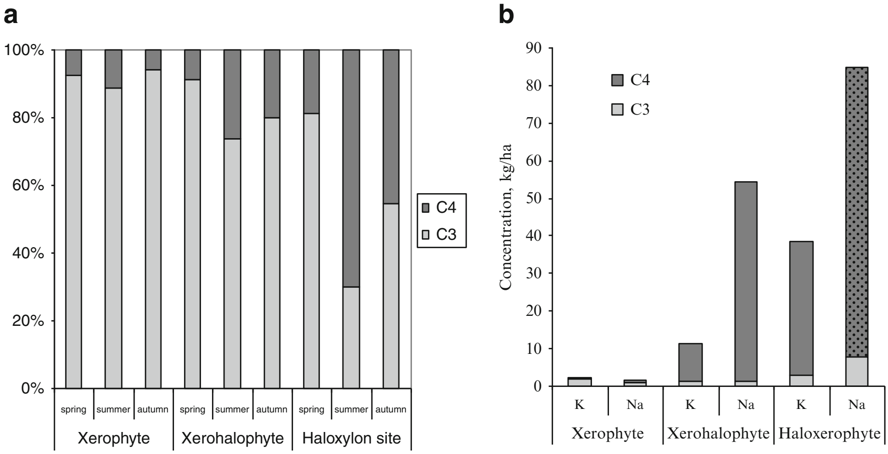

Fig. 38.4 Ratio of species with C_3 and C_4 types of photosynthesis (**a**) and contribution of C_3 and C_4 species in accumulation of sodium and potassium in plant communities (**b**)

phyte plant community. Slightly increased content of potassium (1.3 kg ha^{-1}) over the sodium (1.1 kg ha^{-1}) was also observed in xerohalophyte plant community. The opposite trend was observed in haloxerophyte plant community being 2.8 times higher content of sodium than potassium representing the values of 7.9 and 2.8 kg ha^{-1}, respectively. Accumulation of high amount of sodium was detected in C_4 plants. In green part of C_4 species, the content of sodium has considerably increased from 2 to 8.6 times over the content of potassium for all plants (Fig. 38.4).

Proportion of species with C_3 and C_4 types of photosynthesis at the three plant communities considerably differentiated along the spatial and temporal scales (Fig. 38.4a, b). The highest density of xerophyte and xerohalophyte plant communities belongs to C_3 species consisting of 89–94% and 74–91%, respectively. The ratio of C_4 plants showed smaller values than C_3 plants for both plant communities. As its name implies, the plant density of haloxerophyte community represented considerably rapid changes during the seasons in terms of the ratio of C_3 and C_4 plants. In spite of the dominancy character of C_3 species in haloxerophyte community, the proportion of C_4 species is noticeably increased than in other plant communities. The contribution of C_4 species showed 19–70, and 45% during spring, summer, and autumn seasons, respectively. However, during the summer season, relatively increased values of C_4 species are observed for all plant communities.

Results showed that ratio of C_3 and C_4 plants in vegetation communities differs both along the salinity gradient and on seasons of the year. Along the salinity gradient, the ratio of C_3:C_4 species (in average by all seasons) is represented as 10:1, 10:2, and 10:9 for xero-, xerohalo-, and haloxerophyte plant communities, respectively. Regular prevalence of C_3 species is observed, as proportion of C_4 species in the flora of desert vegetation of Uzbekistan does not exceed than 4% (Pyankov et al. 2001; Toderich et al. 2007; Shuyskaya et al. 2012). Nevertheless, proportion of C_4 species

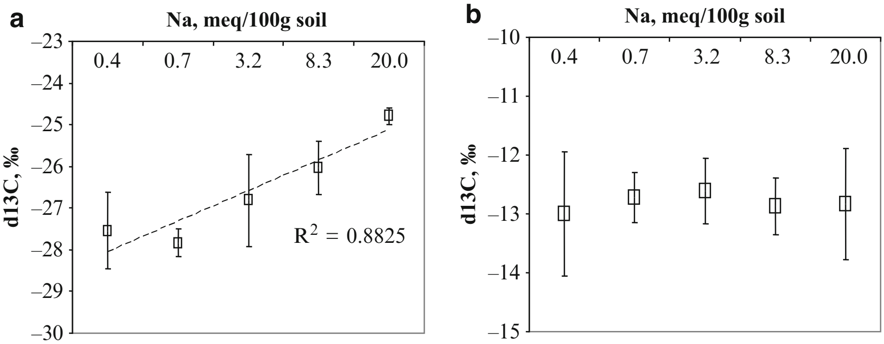

Fig. 38.5 Leaf carbon isotope ratio of (**a**) C_3 and (**b**) C_4 species along salinity gradient

is increased along the salinity gradient, and in haloxerophyte plant community, its amount becomes comparable to the proportion of C_3 species. The C_4 species are mostly dated to the salt-affected soils, and Na^+ is essential for C_4 species (for the translocation of pyruvate across the chloroplast envelope) where it functions as a micronutrient, and to some extent, all Chenopodiaceae species (studied C_4 chenopods) are halophytes (Akhani et al. 1997; Toderich et al. 2007) from one side. From other side, in case of vegetation cover of Karakum desert (Pyankov et al. 2002) and grasslands of Argentina (Feldman et al. 2008), the increased amount of C_4 species comparatively to C_3 species has shown along the gradient of deterioration of soil condition and soil salinization. Significant dependence of C_3 species on soil salinization indicates about the reduction of carbon isotope discrimination (d13C value) of studied C_3 species along the salinity gradient (from −27.39 to −24.79‰). A 2% difference in d13C value of C_3 plants indicates a difference in water-use efficiency of about 30% (Ehleringer and Cooper 1988). In this case, C_4 species demonstrates independence of d13C value along the salinity gradient (Fig. 38.5b). All studied C_4 species are halophytes and accumulate sodium ten times more than C_3 species. In most species, Na^+ does not act as a nutrient in the sense that it is strictly required for growth, but its addition to the growth medium may promote growth of many plants when the K^+ supply is limited (Flowers and Lauchli 1983) and in particular, the growth of salt-tolerant and halophytic plants by contributing to turgor formation. Although the availability of Na^+ as a "cheap" osmoticum is generally beneficial, a large excess of Na^+ ions over K^+ is not. As has been pointed out by Yeo (1998), one of the key elements in salinity tolerance is the capacity to maintain a high cytosolic K^+/Na^+ ratio. In the present study, potassium has been accumulated in a comparative amount. In connection with this evidence, the ratio of K^+ to Na^+ in C_3 species is more than in C_4 species, particularly in xerophytes and xerohalophytes plant communities. From other side, the percentage ratio of K^+ comparatively to N for C_4 species decreased considerable with less variation than C_3 species along the salinity gradient which says about high sensitivity of C_3 species to salinization of soils. The percentage ratio

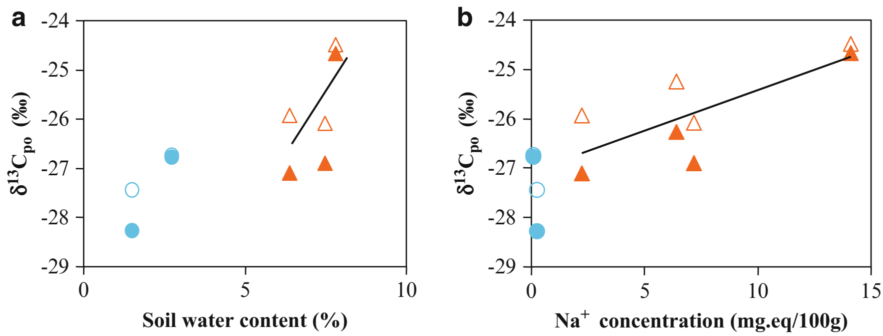

Fig. 38.6 The $\delta^{13}C_{om}$ in *A. diffusa* (*circles*) and *T. hispida* (*triangles*) plotted against mean water content in the soil of 0–120 cm depth. Open and solid symbols refer to the data for 2007 and 2008, respectively. Dashed and solid lines are simple regression lines for *A. diffusa* of 2007 and 2008, respectively. Results were considered statistically significant at $p<0.05$

of K comparatively to N decreased with high variability from 2.33 times in xerophyte plant community to 0.35 times in haloxerophyte plant community. However, the amount of potassium for C_3 species is increased in haloxerophyte plant community.

Despite significant differences in $\delta^{13}C$ seasonal means for the four species, the results demonstrate a significant convergence in the responses of $\delta^{13}C$ values and water-use efficiency (WUE) to seasonal variations in environmental factors among the species investigated, and that the $\delta^{13}C$ signature for each species gives a strong indication of environmental variables including soil and water salinity.

The results showed that the mean Na^+ concentration in the soil of 0–120 cm depth ranged from 0.1 to 9.0 meq/100 g soil. The mean water content in the soil of 0–120 cm depth ranged from 1.5 to 7.8 water/soil %. Comparing between C_3 species, the $\delta^{13}C_{om}$ was significantly higher in *T. hispida* than in A. *diffusa*. The $\delta^{13}C_{om}$ of *T. hispida* was significantly higher in plot 7, in which Na^+ concentration in soil was the highest, than in plots 1, 5, and 6. The $\delta^{13}C_{om}$ of a C_4 species, *H. aphyllum* ranged from −13 to −12‰. *T. hispida* and *H. aphyllum* could depend on water in the deep layer of the soil at least in plots 1 and 5 and probably in the other plots though there was no direct evidence (Fig. 38.6a, b). *T. hispida* may be able to maintain transpiration low and increase intrinsic water-use efficiency even in high-salinity zones because they depend on less-salinity water in the deeper layer of the soil and exclude excessive salts by salt glands if they absorb much salts.

Results suggest that *H. aphyllum* may keep transpiration low at a wide range of soil moisture and salinity. Simple correlations between the distributional/spatial behavior of species and salinity and the concentration of individual ions were generally low, while correlations with combinations of ions in the form of ratios (notably sodium and potassium adsorption ratios) were higher.

Xerophyte plant community is characterized with the lowest value of rangeland productivity consisting of 300 kg of biomass per hectare. More than 90% of biomass proportion of xerophyte plant community is represented by C_3 species. The

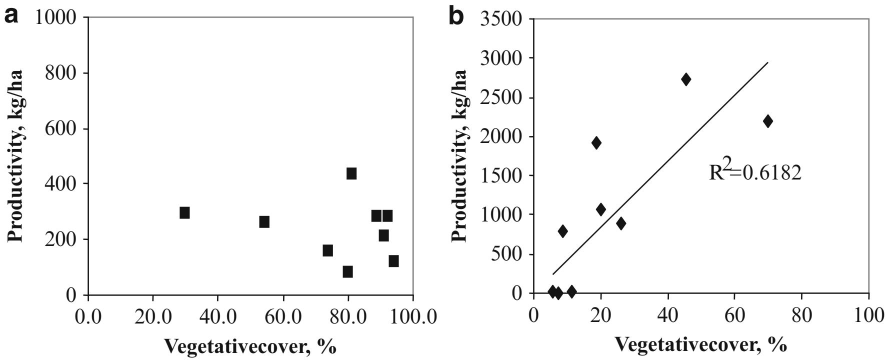

Fig. 38.7 Correlation between biomass and vegetative cover of C_3 (**a**) and C_4 (**b**) species

total productivity of all plants in xerohalophyte plant community is 1,000 kg ha^{-1} of which 15% belongs to C_3 species and 85% to C_4 species. The ratio of C_4 species is considerably increased in productivity of haloxerophyte plant community and covered 87% of total biomass. Only 8.6–18.4% of total biomass belongs to C_3 species. Haloxerophyte plant community is characterized with highest biomass among other plant communities – 2.600 kg ha^{-1} (Fig. 38.7a, b). Seasonal dynamics of total biomass production of vegetation communities is characterized by increased trend during the vegetation period reaching the highest values in autumn seasons for the amount of C_4 species. However, there is opposite dynamics of biomass depending on the photosynthesis type plants: decreased trend for C_3 and increased trend for C_4 species during the seasons. The halophytic pasture yields expressed as t ha^{-1} dry weight for representative biotopes as is shown in Table 38.1 increased with radical changes in soil salinity and water table level. Haloxerophytes and halophytes (salt-loving plants) usually produce huge green biomass due to juicy stems and leaves. The highest yield of dry biomass was observed for halophytic plant communities, which were the first colonizers of salt marshes or wet solonchaks biotopes.

In this study, it was found that among cited plant resources, there are a number of both C_3 and C_4 plants suitable for reclamation of salt-affected and waterlogged drylands that could be proven very useful in demonstration trials. However, these areas have been abandoned by agropastoralists and are not yet widely used as part of the arid fodder production system. The rangelands grazing capacity and yield of green/dry biomass significantly increase, when agro-silvi-pastoral management practices are applied. Based on the map vegetation pattern distribution and on ground data, we found that there were only a few core species, which determine productivity of rangelands of the studied biotopes/niches. Assessing the grazing potential of degraded rangelands by mapping zonal halophytic vegetation allowed us to identify salt pioneer plant species for each studied zone in order to initiate the reclamation process of saline-prone soils. Among frequently found species, there were *C. lanata*, *Kochia scoparia*, *Atriplex nittens*, *Salsola rigida*, *Halothamnus subaphylla* (Chenopodiaceae), and *Glycyrrhiza glabra* (*Fabaceae*) annual and perennial species, growing well both on salty crusts (solonchak-alkaline soils), on clay and gypsum deserts, on takyr, and on high-saline sandy soils. Therefore, we consider these species as a model plant for calculation of rangeland productivity both on virgin area and under cultivation (agro-silvi-pastoral model) by using supplement irrigation with low-quality water and application of fertilizers (Toderich et al. 2008).

38.3.2 Agro-Silvi-Pastoral Experiments to Improve Productivity of Marginal Salt-Affected Lands

Results of present study indicate the coexistence of C3 and C4 species is facilitated because C3 species can colonize nutrient-rich microsites, while C4 species canopy nutrient-poor microsites. Comparing different species within a small-scale habitat along a salinity gradient, we found that short-lived annuals or herbaceous species had significantly lower values than perennial species. Therefore, an agroforestry model by using native tree/shrubs plantation intercropped between rows with annual halophytes and forage crops was established on saline marginal lands. The selection for trees with low $\delta^{13}C$ (carbon isotope discrimination index) and, therefore, high transpiration efficiency, has the potential to increase total tree biomass growth in water-limited arid saline environments. Trees/shrub plantations were deeply seedlings planting (sticks tap into the water table) in early spring or late autumn seasons. These were initially irrigated with low-quality water during the initial stage of growth before sole reliance on available drainage water (higher salinity; EC 4.5–12.3 dS m^{-1}) before the trees/shrubs can rely on the available groundwater resources. Soil salinity at root zone was about 45 dS m^{-1}. The salinity level of the groundwater range between 8.0 and 16.5 dS m^{-1}, though inappropriate for the common local agricultural crops, did not restrict growth of these tree species. Due to soil moisture by the groundwater and irrigation (although applied at deficit rates), the trees tolerated the strong soil salinity without inhibition in survival and growth rate. The assessment of tree performance in the region during the first 3 years on marginal land showed high growth rates, which were comparable to those reported for trees on irrigated agricultural land (Khamzina et al. 2008).

The results (Table 38.2) revealed that the leading tree species with regard to survival rate, growth characteristics, and adaptability to high-saline natural environment proved to be *H. apphyllum*, *Salsola paletzkiana*, *S. richteri* at saline sandy sites, followed by *E. angustifolia*, *Populus euphratica*, *P. nigra* var. *pyramidalis*, *Robinia pseudoacacia*, *Morus alba*, *and M. nigra*, whereas fruit species such as *Cynadon oblonga*, *Armeniaca vulgare*, *Prunus armeniaca*, and species of genera Malus. These plant species, though desirable from the farmer's financial viewpoint, showed low biodrainage potential. Aboveground dry matter (DM) production for 2007–2008 seasons were in the order of *A. ampliceps*>*E. angustifolia*>*M. alba*,

Table 38.2 Performance indicators of native and introduced of C_3/C_4 tree and shrubs species under condition

Parameters species	Growth rate (at first year)	Root establishment	Reproduction	Aboveground DM	Biodrainage; feed and firewood value	Soil salinity level	Winter frost tolerance	Rate survival (%)
Haloxylon aphyllum[a]	+	±	a.b.c	+	±	+	+	±
Tamarix hispida		+	Invasive	±	±	+	+	+
T. androsovii	±	+	Invasive	±		+	+	±
Populus alba	±	±	a.b	±		+	±	+
P.nigra var. pyramidalis	±	±	a.b	±	+	±	+	−
P.euphratica	±	±	a.b	±	+		±	−
Salix babylonica	±	±	a.b.c	±	±	+	±	−
Hyppophae ramnoides	±	±	a.b.c	±	±	+	±	+
Elaeagnus angustifolia	+	+	a.b.c	+	+	+	±	+
Robinia pseudoacacia	−	+	a.b.c	+	+	±	+	±
Morus alba	+	±	a.b	+	−	±	±	+
Morus nigra	+	±	a.b	+	±	±	±	±
Malus domestica	±	±	a.b	±	±	−	−	±
Malus silvestris	±	_	a.b	±	±	±	+	±
Cynadon oblonga	±	±	a.b	±	±	±	−	+
Armeniaca vulgare	±	±	a.b.c	±	±	±	−	+
Thuja occidentalis	−	_	b	−	−	−	±	−
Persimmon diospyros	+	+	a.b.	+	+	+	±	−
Rosa canina L.								
Atriplex undulata[a]	+	+	a.b.c	−	+	+	+	+
Artemisia diffusa	+	+	a.b.c	+	−	−	+	+

+ high potential, ± medium potential, − low potential
[a]C_4 species, while others tested species belong to C_3

M.nigra>*P. euphratica*>*R. pseudoacacia*>*T. occidentalis* among the species tested. These species combined fast growth with a moderate ability to develop leaf biomass rapidly and showed characteristics of feed quality sufficiently to be used during the off-season. Genus *Tamarix*, with high absolute values of aboveground biomass, was very tolerant to saline-alkali soil with pH values of up to 8.5.

The overall ranking of the trees, weighing all parameters, concurrently shows that species of genus *Tamarix* and *Elaeagnus angustifolia* have the highest potential for growing on both loamy and sandy soils, which represent the dominant soil textures in the region. As results, at marginal sites where a shallow, slightly-to-moderately saline groundwater is available throughout the growing season, *Elaeagnus angustifolia*, *Robinia pseudoacacia*, and newly introduced *Acacia ampliceps* showed the fastest growth and highest water use. This indicates the suitability for planting on low-fertility saline lands. Preliminary outcomes of the study on salt-affected soils have also indicated that tree plantations with *E. angustifolia*, *Populus nigra var. pyramidalis*, *and Morus* spp. have potential for increasing the soil organic matter due to the relatively rapid leaf litter decomposition. *Morus nigra* and *Cydonia oblonga* showed reasonable DM production on degraded land, with high biomass allocation toward the root fraction. Among tree species, Poplar (*Populus alba*, *P. nigra var. pyramidalis*, and *P. euphratica*) showed maximum growth for all parameters studied followed by mulberry (*Morus nigra*). The *Populus diversifolia* which displayed high rates of leaf and wood production appeared to be the most sensitive to saline sandy-soil type. Similarly, it had slow longitudinal root growth and low root DM production at sandy site while exhibiting superior belowground development at the sandy loamy soils. Introduced coniferous species *Thuja occidentalis* was the only species that showed poor growth under furrow irrigation at the Dashauz province and at the second year died due to its high sensitivity to frosts.

Evaluation of survival rate, performance, and productivity including biomass and seed production of nonconventional tree/shrubby halophytes firstly introduced in Central Asian flora including *Acacia ampliceps*, *Atriplex nummularia*, *A. undulata*, and *A. amnicola* by Dubai-based International Center for Biosaline Agriculture showed its high potential for the reclamation of salt-affected marginal lands. All species tolerated average root zone salinity of 8–16.8 dS m^{-1}. Seedlings of *Acacia ampliceps* were obtained from by direct seed sowing in the field (February 2006) and through the establishment in plastic bags. The growth rate was very fast at 12–18 cm month at the rooting stage and 25–30 cm month, when the basal stems develop a woody character. Plant growth of *A. ampliceps* raised from direct seeding was much higher than with similar plants grown after transplanting by seedlings (from plastic bags). Among shrubs, *Atriplex* spp. dog rose and redberry showed a high seed germination and survival rate. Among *Atriplex* spp., highest seed germination (approximately 89%) under field condition was observed for *Atriplex undulata*, which showed a rapid growth rate and accumulation of biomass. Being grown at a high plant density of 10–12 plants m^{-2} (normal density of this shrub is 4 plants m^2) in the first year, this species with its large canopy can occupy the interrow spaces forming a dense mono-compo-

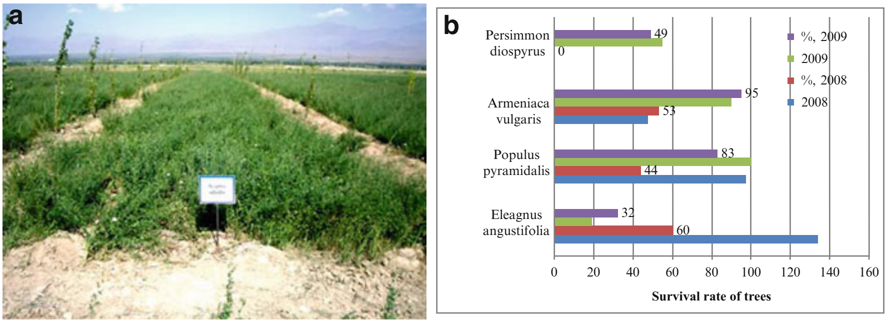

Fig. 38.8 Agroforestry trial at the second year of tree planting. (**a**) Performance of fruit trees planted into an agro-silvi-pastoral system at Yangiobod Farm, northern Tajikistan ((**b**) average for 2008–2009)

nent halophytic pasture. The biomass produced in 1.5 years was 5.6 kg m^{-2} and was readily browsed by cattle and small ruminants. Biomass of *Atriplex undulata* at the Akdepe experimental site increased with high density level of plant per square meter (5.0–5.8 thousand plant ha^{-1}). Replacement of 30% of individuals has been done in August 2006 in order to maintain the stand and decrease plant density.

Low seed germination of about 55% was observed in *Atriplex nummularia* and *A. amnicola* (only four shrubs of the latter plant survived). Comparative studies on seasonal plant performance and accumulation of green biomass in *Acacia ampliceps*, *A. nummularia*, *A. amnicola*, and *A. undulata* were observed after transplantation into the open field.

The findings from the screening of six multipurpose tree species (MTS) at Yangiobod Farm, northern Tajikistan, showed high survival and quick relative growth rates. As shown in Fig. 38.8, the most promising are *Populus euphratica*, *P. pruinosus*, *P. nigra var. pyramidalis*, *Elaeagnus angustifolia*, *Armeniaca vulgaris*, and *Diospyros virginiana L.* cultivated in mixed stands with various traditional salt-tolerant fodder crops.

Trees/shrubs plantation requires limited irrigation during the initial stage of growth before sole reliance on available drainage water (EC ≈ 4.0–6.3 dS m^{-1}) resources becomes possible. Species of *Elaeagnus angustifolia* having an exceptional ion-salt translocation/bioremediation mechanism might be referred to as aggressive colonizers since they tend to invade natural habitats and push out less salt-tolerant species; however, further monitoring is necessary. Trees planted at the Yangiobod trial, especially Elaeagnus, offer possibilities as supplementary feed to the low-quality roughages throughout the off-season. Seasonal differences in soil water uptake for various combinations of tree cover, alfalfa, and annual forage crops communities like barley, sorghum, corn, and pearl millet should be developed and documented. The optimal integrated agroforestry farming system comprising 12% tree cover, 30% alfalfa, and 58% annual forage crops of virgin pastures with traditional agriculture practice provides satisfactory drainage control of saline environments preventing salt accumulation at the root zone area.

38.4 Conclusions and Recommendations

The results of this study showed that spatial and temporal changes of natural rangelands vegetation in the arid area affected by salinity in order to initiate different revegetation strategies. Information about soil ion content, electrical conductivity, performance of indicator species, and biomass clearly indicates which plant species are most likely to contribute to the reclamation process of saline soils. Plant species diversity and distribution is determined by local soil specificity, i.e., its physical and chemical composition, microrelief, and soil moisture. The climate itself as has been noted by Shuyskaya et al. (2008) plays a secondary role. We also found that halophytes as underutilized plant resources grow well in association with a variety of arid/semiarid rangeland species and often provide severe competition to perennial species, both in natural and improved pastures. Incorporation of fodder halophytes into the agro-silvi-pastoral system or domestication of wild halophytes species represents low-cost strategies for rehabilitation of desert degraded rangelands and abandoned farmer lands affected both by soil and water salinity. Late summer and early autumn time should be considered as the optimal period for transplanting of all the above-mentioned nonconventional halophyte species. Introduction of strip-alley livestock-farming system increased the productivity of rangelands by 2.0–2.5 times and decreased further degradation of rangelands. The proposed system of creation of agro-phytocenosis by mixture of natural halophytes (list of plants was developed by the present studies) with salt-tolerant crops, fodder legumes, and grass allows getting forage for animal almost all around the year. Salt-tolerant crops cultivated into an agro-silvi-pastoral model benefit from the improvement of soils and microclimatic conditions provided by the shrubs. A considerable reduction in wind speed and potential evapotranspiration, buffered temperatures, and decrease in the intensity of sand storms were observed. First screening of wild halophytes for their gradual domestication should be done based on the following criteria: ash composition of forages, nutritional values, and needs of farmers.

Integrated Biosaline Agriculture Program for sustainable use of marginal mineralized water and salt-affected soils for food-feed crops and forage legumes developed will assist to improve food security, alleviate poverty, and enhance ecosystem health in smallholder crop-livestock systems. Such diversification of agroecosystems and development of new agricultural capacities could increase income source of rural poor and farmers, which so far are often dependent on two major crops (e.g., cotton and wheat). Furthermore, the activities proposed here will also contribute to large-scale biomass production, which will build up the soil organic matter. It will thus also contribute to make the poor farmers more resilient against climate change. The evaluation, domestication, and large-scale utilization of native and introduced halophytes and salt-tolerant plant resources in sole or mixed farming system would have a significant impact on salinity control and remediation as well as on the economic development of arid/saline lands commonly observed in the whole Aral Sea Basin. Although, the cultivation of trees requires a waiting period, 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 have the potential to increase the cash income of rural Uzbek households. An aspect that remains unstudied is the degree to which this type of afforestation effort can contribute, on a larger spatial scale, to carbon sequestration; however, methane emissions from unfertilized poplar plantations as well as natural Tugai vegetation are below the detection limit. If carbon trading benefits can be added to the benefits from non-timber forest products, this would create a "win-win" situation from both an ecological and economic point of view (Gintzburger et al. 2005).

Planting herbaceous fodder crops between fruit and fodder trees on intensive agroforestry plantations leads to increase the productivity of degraded lands. Better plant growth, accumulation of green biomass, and consequently yield of both fresh and dry matter were significant for alfalfa both in pure stand and mixed artificial agrophytocoenosis, including trees. The agroforestry concept evaluated in this study provides a means of on-farm drain water management, thus alleviating the need for expensive and potentially hazardous evaporation ponds. Moreover, it could create conditions for maintaining the investigated target remote desert and semidesert areas as viable farming regions. Immediate actions to direct research toward reclamation of saline-prone and desert lands, generation of useful non-timber products, and achieving co-benefits of C sequestration by conserving natural resources and reducing poverty through improving household food and nutrition security should be further investigated.

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