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Seasonal Dynamics of Asiatic Desert C_3/C_4 Species Related to Landscape Planning and Rehabilitation of Salt Affected Lands

Elena SHUYSKAYA*[1], Toshpulot RAJABOV[2], Naoko MATSUO[3], Kristina TODERICH[2], Liliya GISMATULLINA[2], Pavel VORONIN[1] and Norikazu YAMANAKA[4]

Abstract: This paper considers how salt and drought tolerant C_3/C_4 arid/semiarid plants in pure or mixed stands can control salinity, improve rangelands productivity and reverse desertification in Central Asian arid and semiarid zones. Spatial distribution of C_3/C_4 photosynthetic types within different desert vegetation plant communities differs by seasons and along the soil salinity gradient. The ratio of C_3:C_4 species was represented as 10:1, 10:2 and 10:9 for xero-, xerohalo-, haloxerophyte plant communities from non-saline to saline habitats, respectively. During summer season insignificantly increased values of C_4 species (in 1.5-3.7 times) were found for investigated plant communities. More than 90% of biomass proportion of xerophyte plant community is represented by C_3 species. The total productivity of xerohalophyte plant community is 1000 kg/ha of which 15% belongs to C_3 species and 85% to C_4 species. The productivity of haloxerophyte plant community is determined by C_4 species, which consists of 87% of total biomass. From spring to autumn a decreasing trend of biomass of C_3 and increasing of C_4 plants in the vegetation cover of desert rangelands was revealed. Optimal spatial combination of C_3/C_4 plants by considering their phenological rhythms and mechanisms of adaptation to drought cycles and soil salinity guarantees high plant survival and biomass accumulation on salt affected rangelands. Coexistence of C_3/C_4 species under wide range of salinization combined with limited content of water in the soil was considered as the essential factor in the elaboration of optimal landscape planning and rehabilitation techniques of degraded rangelands affected by salinity.

Key Words: Agroforestry, C_3/C_4 types, Kyzylkum desert ecosystems, Salinity gradient, Vegetation dynamics

1. Introduction

Drought and salinity can have great effect on food security in Central Asia. The inland Irano-Turanian cold desert ecosystem under currently ongoing climate changes are characterized by reduced species-richness, especially trees and shrubs and, thus, by having a low resistance to climate extinctions. Vegetation cover of sandy desert rangelands has a complicated spatial structure determined mostly by impact of heterogeneity of desert environment. Replacement of deep-rooted, perennial native vegetation by shallow-rooted, annual and invasive non palatable species induced salinization, waterlogging and decreasing of rangelands productivity. Frequency of climatic extremes (droughts) and changes in soil salinity alter the plant functional group composition, distribution and abundance of species, which significantly reduce productivity of arid ecosystems and loss of biodiversity. Considerable research has been done on soil-vegetation relationship in coastal salt marshes saline soils (Pop, 1984; Greaver and Sternberg, 2006). 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 (Akjigitova, 1982; Toderich *et al*., 2009). It is presumed that the virgin psammo- and xerophytic desert plant communities (with predominant of C_3 species) available for grazing of animals are replaced by halophytic plant communities (C_4 species predominant) with less nutritional values and palatability. As a rule C_4-plants have twice as much the water use efficiency (WUA) as C_3 ones (Farguhar *et al*., 1989). Meanwhile, the C_4-plants input to Central Asia desert flora are relatively low (Pyankov, 2001). Additionally, these species colonize marginal areas and are more competitive towards sensitive species (Toderich *et al*., 2007). However, many of Asiatic C_3/C_4 are at the edge of disappearance due to overgrazing and may become an irreversible loss of phytogenetic resources. Most of populations of the desert halophytes within flora of the Uzbekistan are local and small, sometimes fragmented. They frequently have incomplete life cycles with little ability to reproduce, low indices of renewal and replacement. The present study aims to describe the seasonal variation of distribution and density/productivity of C_3/C_4 species for different desert plant communities along the salinity gradient. The $\delta^{13}C$ data were used to assess the responses of native plants to climate change and the effect of

*Corresponding Author: evshuya@gmail.com
K.A. Timiryazev Institute of Plant Physiology RAS, Botanicheskaya st., 35, Moscow, 127276, Russia
1) K.A. Timiryazev Institute of Plant Physiology RAS 3) Graduate School of Bioresources, Mie University, Japan
2) Department of Desert Ecology and Water Resources Research, Samarkand Division of the Academy of Sciences of Uzbekistan. Uzbekistan 4)Arid Land Research Center, Tottori, Japan

salinization on natural vegetation in Central Asian dryland ecosystem.

2. Material and Methods

2.1. Description of the study sites

The study area is located at north-east part of Karakata depression in the central part of Kyzylkum desert, Uzbekistan (mean annual temperature = 15.7°C, mean annual precipitation = 175 mm; Gintzburger *et al*., 2003). Geographically the rangeland plots are located between the coordinates of 41°06' 13.7''N; 064°50'55.5''E and 41°03'36.4''N; 064°53'52.6''E and elevation ranges of 100-130 m above the see level. The climate of Karakata depression is typical for the condition of Kyzylkum desert which is characterized by sharp fluctuations of daily and seasonal temperatures. The amount of precipitation is small and it is mostly occurred during the winter-spring seasons. Spatial distribution (zonation) of natural vegetation in relation to soil salinity was studied in a distance of about 4 km, located between two artesian hot springs. The most important factor for the zonation was soil salinity (calculated for total dissolved salts values) and the salt tolerance limits of species. Based on geobotanical descriptions of vegetation cover (ratio of xerophilous and halophilous species) and on level of soil salinization (EC values) 4 microlandscape sites were divided along the salinity and relief gradients. These selected plant communities belong to different vegetation types: xerophyte (1 site), xerohalophyte (2 sites), haloxerophyte (1 site). The wet salt depression was used as a benchmark of high soil salinization (according to total content of cations and anions) and specified as "Solonchak".

2.2. Calibration EM38

Electromagnetic conductivity devices were expressed at standardized reference temperature of 250°C. The reason for expressing at reference temperature is the fact that electrolytic conductivity increases at a rate of approximately 1.9% (Rhoades *et. al*.,1999). The formula provided in Sheets and Hendrickx (1995), who fit the curve to conversion table given in USDA (1954), we used as: $EC_{25} = EC_a * [0.4470 + 1.4034\exp(T/26.815)]$, where EC_{25} is standardized EC_a, EC_a - apparent electrical conductivity and T-soil temperature.

2.3. Plant samples

2.3.1. Vegetation surveys

Geobotanical descriptions were done using 2 m × 50 m transect (in semi shrub plant communities) and 5 m × 50 m transect (in shrub plant communities - Haloxylon aphyllum associated), in three replications. Total numbers of shrubs of each species within the 100 m^2 and 250 m^2 were counted in 3 size classes (big, medium, small) based on plant height and diameter. For each size class and each species one representative plant was harvested and separated into woody, green and dead parts. The total biomass for each subplot was determined by combining density data of each species present. Cover of individual shrub species was determined from a 50m-line intercept along one edge of the 2 m × 50 m and 5 m × 50 m plot.

2.3.2. Stable isotope analysis

Plant material for stable isotope analysis had been gathered at natural vegetation of typical desert plant communities. The leaves or photosynthetic shoots from 3-5 individuals of each plant species were collected at each site. The photosynthetic organ samples were oven-dried at 70°C for 48 h and finely grounded. 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 (Flash2000 & Delta S, Thermo Fisher Scientific) at Field Science Education and Research Center, Kyoto University. Carbon isotope ratios were expressed by the following equation: $\delta^{13}C$ value=((Rsam-Rstd)/Rstd)*1000 (‰), where Rsam and Rstd represent the $^{13}C/^{12}C$ of the samples and standard.

2.3.3. Estimation dry biomass

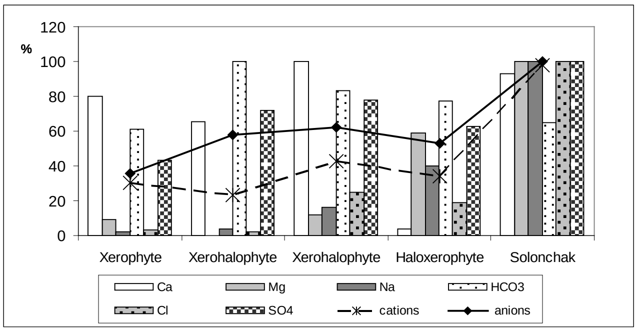
The harvested material was packed in paper bags in the field and then oven dried at 65°C for 72 hours in laboratory. The dry weight of all the species was then combined to get the total biomass estimates.

3. Results and Discussion

3.1. Soil and ground water salinity characteristics

Groundwater table fluctuates from 0.5 - 2.5 m (below soil surface) during May-July at the dry solonchaks and experimental agricultural plots and up to 8.0 - 20.0 m in the virgin desert Artemisia pastures. Ground water mineralization at shallow water table level taken under haloxerophyte and halophyte sites varies in the range of 2000 - 8200 mg l^{-1} (Asian Development Bank, 2008). Measurements of soil EC in early spring and at the end of vegetation season (late autumn) shown slight to medium salinity (30 - 150 mS m^{-1}), although at the upper 40 cm horizon at some points EC reached values of over 250 mS m^{-1}. Soil types of surveyed area are light sandy and silt-sandy loam with low organic matter (less than 1%) throughout the profile up to the depth of 60 cm and cation exchange capacity in the range of 5.0 mmol g^{-1} and 10.0 mmol g^{-1}. The soil lower layers are also saline due to the presence of high content of gypsum. Total nitrogen (N) and phosphorus (P) contents in salt affected soils are low, usually ranging between 0.7 - 5.5 mg kg^{-1}

a)



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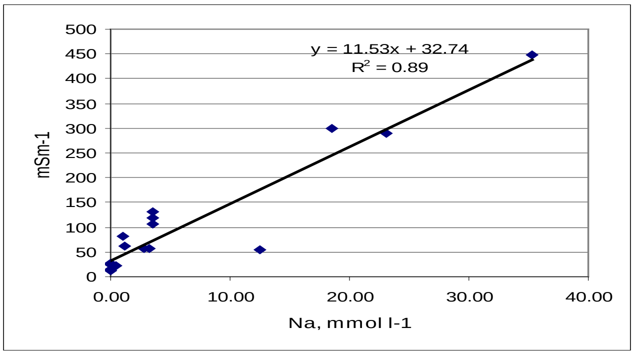


Fig. 1. a) Relative content of different cations and anions in soils among studied zones (where the maximum content of ions was taken as 100%); b) Linear regression between estimated of soluble salts from electrical conductivity (EM38) and Na^+ content across salinity gradient.

and 10.0 -18.26 mg kg^{-1}, respectively. Available potassium (K^+) content is classified as low or moderate. Chemical analysis of soil showed that main type of mineralization is calcium-sodium and hydrocarbonate-sulfate. The virgin Artemisia pasture and gray brown stabilized sands (under xherophyte site) with the least content of salinity and soil moisture is characterized by significantly amount of Ca^{2+}, HCO_3^{2-} ions and the least content of Na^+, Mg^{2+}, Cl^- compare with other tested sites.

As shown on **Figure 1** a,b, 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 rising accordingly to spatial changes in floristic composition within investigated rangelands sites. Electric conductivity values and Na^+ content were graphed and a high positive ($R^2 = 0.89$) linear regression was observed as increasing the level of soil salinization, which mostly occurs on lowland saline depression (less than 100 m above sea level) across desert relief (Perelman *et al.*, 2001). i.e. electric conductivity value reflects the salinity characteristics at microrelief level.

3.2. Plant communities structure

The seasonal dynamics of vegetation is related to inter-specific and intra-specific plant species competition, carrying capacity of rangeland and land use management. Desert topographical features and salinity gradient are of primary importance in determining the contribution of various plant taxons with different photosynthetic pathways to comprise core ecological plant associations or vegetation units. The main criteria of differentiation of vegetation communities were the abundance of the individual species. Three types of ecological plant associations on desert rangelands were allocated and their botanical composition was identified: 1. aboriginal xerohytes on sandy and grey-brown desert soils represented by *Ferula assa-foetida, Aellenia subaphylla, Ammothamnus Lehmannii, Astragalus villosissimus, Artemisia diffusa, Salsola praecox, Heliotropium* sp., *Calligonum leucocladum, Stipa* sp., *Convolvulus hamadae, Mausolea eriocarpa*; 2. xerohalophytes plant communities consists of *Artemisia diffusa, Haloxylon aphyllum, Ammothamnus Lehmannii, Peganum harmala, Alhagi pseudoalhagi*; 3. haloxerophytes on saline prone sandy soils dominated by annuals species of *Salsola* sp., *Climacoptera* sp., *Suaeda* sp., *Halocharis hispida*, and perennials *Halimocnemum strobilacea*; *Halostachys belangeriana*; *Aeluropus littoralis*; *Limonium suffruticosa* and others.

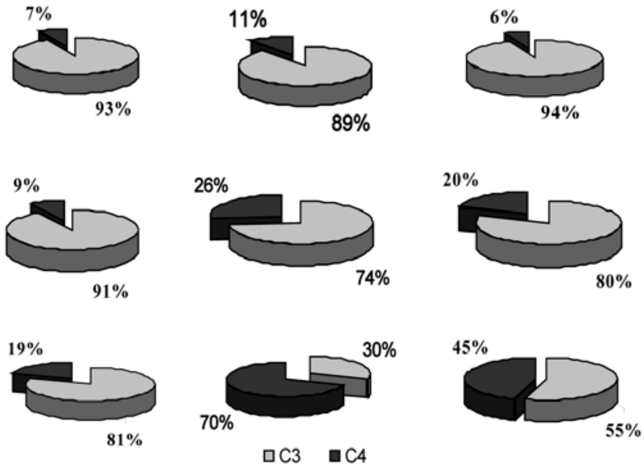


Fig. 2. Ratio of species with C_3 and C_4 types of photosynthesis in different plant associations (a – xerophyte, b - xerohalophytes, c – haloxerophyte) during vegetation season.

3.3. Plant density of C_3- and C_4 species

The highest density of xerophyte and xerohalophyte plant communities belongs to C_3 species consisting of 89-94% and 74-91%, respectively (**Fig. 2**). 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 term of the ratio of C_3 and C_4 plants. In spite of the dominancy character of C_3 species in haloxerophyte

a)

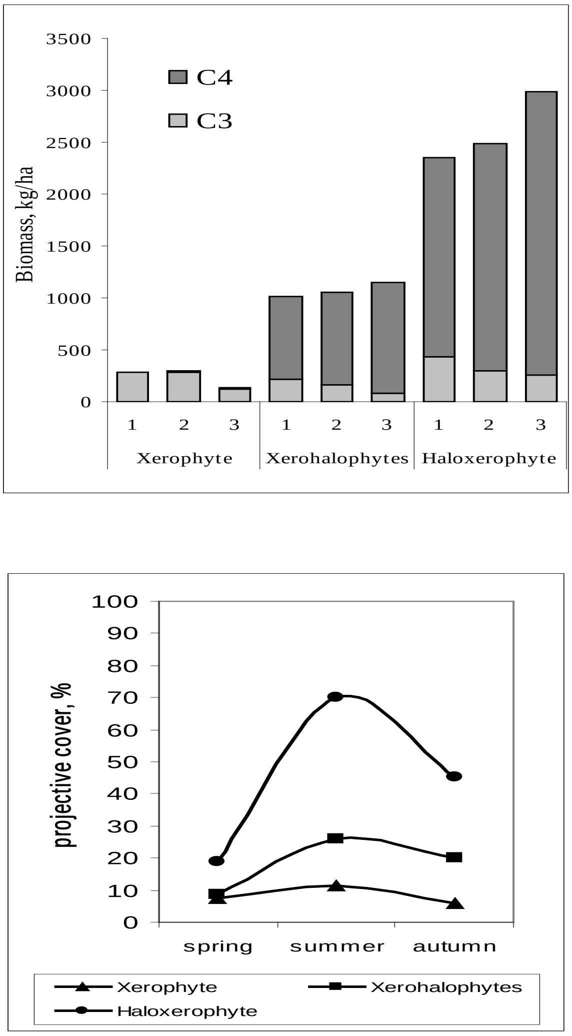


Fig. 3. Biomass production of C_3 and C_4 species (a) and seasonal projective cover of C_4 species (b) in plant communities (where 1, 2 and 3 corresponds to spring, summer and autumn seasons).

community, the proportion of C_4 species is noticeably increased than in other plant communities. The contribution of C_4 species in haloxerophyte community showed 19%, 70% and 45% during spring, summer and autumn seasons, respectively. However, during the summer season relatively increased values of C_4 species were observed for all plant communities.

3.4. Plant biomass of natural rangelands along the salinity gradient

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 (**Fig. 3**a). The total productivity of all plants in xerohalophyte plant communities is 1000 kg/ha 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 haloxeropyte 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 - 2600 kg/ha.

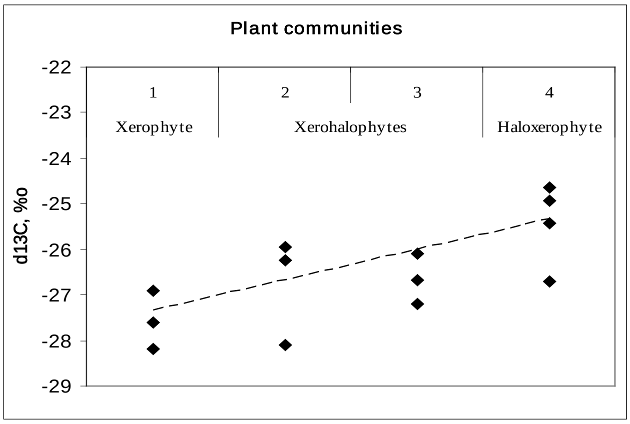
Seasonal dynamics of total biomass production of vegetation communities is characterized by increased trend during the vegetation period reaching the highest values in autumn season for the amount of C_4 species (Fig. 3b). However, there is opposite dynamics of biomass depending on the photosynthesis type plants: decreased trend for C_3 and increased trend for C_4 species during the seasons.

Result of this study 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-, haloxerophyte plant communities, respectively (Fig. 2). 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).

Nevertheless, proportion of C_4 species is increased along the salinity gradient and in haloxerophyte plant community its amount becomes comparable to the proportion of C_3 species. C_4 species occurs mostly on salt affected soils because Na^+ is essential for C_4 species (for the translocation of pyruvate across the chloroplast envelope) where sodium ion 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) Additionally, 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 also 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 ($\delta^{13}C$ value) of studied C_3 species along the salinity gradient (from -27.39‰ to -24.79‰) (**Fig. 4**a). A 2‰ differences in $\delta^{13}C$ value of C_3 plants indicates a difference in water-use efficiency of about 30% (Ehleringer and Cooper, 1988; Dawson, 1993). In this case, C_4 species demonstrates independence of $\delta^{13}C$ value along the salinity gradient (Fig. 4b).

A positive correlation of total productivity of main plant communities along the gradient of salinity with vegetative cover of C_4 species, especially due to the perennial C_4 tree and shrubs like *Haloxylon aphyllum* and *Calligonum leucocladum* was identified. The dominance of C_3 species in spring and early summer seasons in the studied areas is determined by abundance of short-live species of ephemers and ephemeroids. The high ratio of C_4 species in summer is stipulated by annuals

a)



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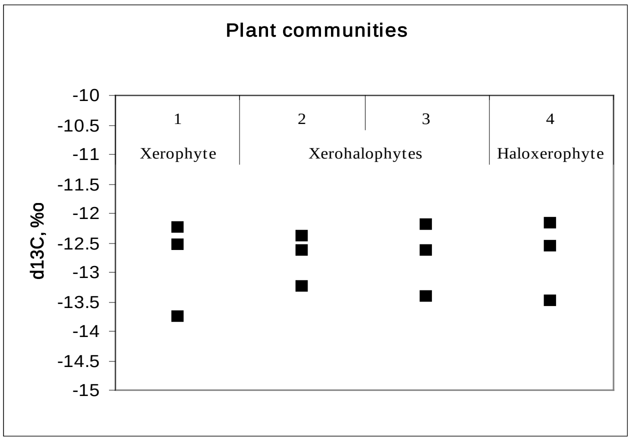

Fig. 4. Leaf carbon isotope ratio of (a) C_3 and (b) C_4 species along salinity gradient.

halophytes from genus *Salsola*, *Halocharis*, *Gamanthus*, *Climacoptera*, *Suaeda* etc. (more than 40% among total C_4 species of haloxerophytic plant community). The vegetation of majority of mentioned species is over at the end of summer-early autumn (Fig. 3b). Species with C_4 type of photosynthesis with high transpiration efficiency are better adapted to soil water deficit or physiological drought that is strongly expressed in summer period, thus, the productivity of C_4 species within different desert plant communities do not much dependent on the regime of rainfall. There is not linear relation between the biomass of plant communities and seasonal projective cover of C_4 species due to the occurrence of increased values of these plant parameters in different seasons: high biomass in autumn and high projective cover in summer.

3.5. Landscape planning and Rehabilitation Technique for salt affected Lands

A number of native and exotic halophytes both C_3 and C_4 plants suitable for reclamation of arid and semi-arid, salt/affected and waterlogging areas have been proven very useful in demonstration trials. Mixture of C_3/C_4 desert fodder species planted within the inter-spaces of salt-tolerant trees/shrubs plantations improves productivity of rangelands degraded affected by soil salinization. Application of such approach solves the animal feed gaps in the lands degraded both by overgrazing and salinity, and promotes to increase the income for farmers. Agro-silvi-pastoral trials used for landscape planning and rehabilitation of saline soils represent a model of ecosystem function/services for agropastoral communities as adaptation measures to climate change. The coexistence of C_3 and C_4 species is facilitated because C_3 species can colonize nutrient rich microsites, while C_4 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 of forage biomass than perennial species. The selection for trees with low $\delta^{13}C$ and, therefore, high transpiration efficiency, has the potential to increase total tree biomass growth in water-limited arid saline environments. Results obtained in this study showed that the successful performance of drylands afforestation technique is based on partial overlapping of natural niches of C_3/C_4 species. Therefore the optimal rehabilitation technique of saline prone rangelands consists from 12% of tree cover, 20% wild xerohalophytes, 38% of biannual and 30% annual forage crops, which in mixture planting significantly increase the productivity of rangelands by providing a satisfactory drainage - control and preventing accumulation of salts at the root zone area.

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