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Water Use Efficiency of Main Dominant Species in Steppes and Deserts of Mongolia

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Water use efficiency of main dominant species in steppes and deserts of Mongolia

N.I. Bobrovskaya & R.I. Nikulina

Abstract

An assessment of the water expense efficiency for producing phytomass by dominating species in true (dry) and desert steppes as well as in steppe, true and extremely arid deserts in Mongolia is given. It was revealed that both in steppe and desert plant communities their dominants are presented by species of different efficiency of water utilization. It is possible to state that water expense efficiency is only slightly correlated with type of area distribution of species and its zonal optimum as well with the life form. Different *Stipa* species are most effective in water utilization in all community types. The water expense by communities in different subzonal stripes of steppes and deserts was calculated and compared with the precipitation amount.

Key words: plant community, dominant species, steppes, deserts, transpiration coefficient, community water consumption

Introduction

It is well known that the water arriving to a given surface of the earth is distributed unevenly. Arid and semiarid territories with water deficiency occupy about 40 % of the earth's surface. Natural zones differ strongly with respect to water relations of plants, and the specific mechanisms of drought resistance have been a key research topic since long ago. Particularly prominent is the work by SCHIMPER (1898) who was the first to start publishing on the need to assess functional activity of plants of various zones. Since then, a lot of studies dealt with water relations of plants at different levels (population, organism, cellular), including some large-scale comparisons and important reviews (KOZLOVSKI 1964, HSIAO 1973, SVESHNIKOVA 1979, WALTER et al. 1983, HELMECKE & BUMŽAA 1985, RYCHNOVSKA 1988, BOBROVSKAYA 1991, and others). A high number of publications describe various types of plant adaptations to dry conditions in arid areas. However, published data are not always easily compared because the aims, approaches and methods of measuring water relations differ greatly.

Plant ecology of Central Asia arid regions has always been of considerable interest for botanists for a variety of reasons, including a general scarcity of data, specificity of the climatic conditions and the uniqueness of the flora and vegetation. Studies on water relations of plants in Mongolia were a key topic of ecological research of the Russian (formerly Soviet Union) Mongolian Complex Biological Expedition (1970–1987). Measurements were carried out at three field stations.

Huge territories of natural vegetation are still relatively intact in Mongolia where the natural zones are clearly distinct, especially in the central and eastern parts. The country is situated at the high upland plateau with mean elevation about 1500 m[1)] and with an elevation range from 532 to 4658 m.

Our earlier analyses revealed similarities and also key differences in the water relations of steppe and desert plants of Mongolia (BOBROVSKAYA 1991, BOBROVSKAYA & NIKULINA 2005). Data

[1] Here and below altitudes refer to meters above sea level.

on water use efficiency of dominant species of steppe and desert communities given in the present communication demonstrate the relationship of water exchange and above-ground productivity. The latter is a very important parameter to assess the adaptive capacity of plants, especially in arid regions. Data on water use efficiency of plants in arid and humid areas are available in earlier works of HENKEL (1968), KOZLOVSKY (1964) and others. However, data on the effectiveness of water use of plants of the Central Asian steppes and deserts are largely missing.

Material and metods

Comparative analyses of water relations of plants were carried out along the ecological profile: dry steppes → desert steppes[2)] → steppe deserts → true deserts → extreme arid deserts.

The *dry steppe* field station was located in Middle-Khalkha on the territory of Undzhul somon (village) in the Central administrative district. The dominant species of the ***Caragana stenophylla + C. pygmaea + C. microphylla – Cleistogenes squarrosa + Agropyron cristatum + Artemisia frigida + Stipa krylovii*** [3)] community, that is typical for dry steppes zone of Mongolia, were the objects of research (table 1).

Desert steppes and steppe deserts were studied at field stations in two regions, i.e. in Northern and Trans-Altai Gobi.

Northern Gobi

The *desert steppe* site at the territory of Bulgan somon in the Eastern Gobi administrative district with the ***Caragana leucophloea – Stipa gobica + Cleistogenes songorica + Artemisia frigida*** community is located on the inclined, denudated piedmont plain of the Gurvan-Saykhan ridge, representing the lowest altitudinal belt in that region. The steppe desert site covered by the ***Salsola passerina + Haloxylon ammodendron + Reaumuria songarica*** community is located in the vast Bayan-Dzag depression approximately 20 km away from the first one.

Trans-Altai Gobi

There were three field sites situated along a profile stretching from the south of Shine-Dzhinst ridge up to the piedmont plain of Tsagan-Bogdo ridge (Bayan-Khongor administrative district).

The *steppe deserts* site with an ***Anabasis brevifolia + Stipa glareosa + Allium polyrrhizum*** community, which are typical for the whole Gobi desert, are located on the piedmont plain of Shine-Dzhinst ridge (1750 m).

The *true deserts* begin further south at elevations from 1300 to 1500 m. Studies were carried out in 3 communities: ***Sympegma regelii + Reaumuria songarica; Nitraria sphaerocarpa + Reaumuria songarica; Haloxylon ammodendron.***

The *extreme arid deserts* occupy vast spaces on watersheds (gamada) at 700 – 800 m asl., where vascular plants are almost absent except for single (2–3 per 100 m^2) individuals of ***Iljinia regelii***. Denser plant cover is developed in wadis (the beds of short-time seasonal water flows) where we studied the ***Iljinia regelii + Haloxylon ammodendron*** community.

The water use efficiency was determined by means of the transpiration coefficient. This coefficient was firstly used in agriculture to test limits of irrigation, and was later adopted to assess resistance to arid conditions in wild native species. We estimated the transpiration coefficient as the amount of water necessary for production of 1 g of dry biomass.

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[2] Desert steppe is steppe with desert species, steppe desert is desert with steppe species (LAVRENKO & KARAMYSHEVA, 1993).

[3] Latin names of plants are given according to S.K. CHEREPANOV (1995).

Table 1: Names, life forms and distribution ranges of the studied species

Species	Life form	Distribution range
	Dry steppes (Middle Khalkha)	
Agropyron cristatum	Loose-bunch grass	Pontic-Old Mediterranean
Allium bidentatum	Firm bunch perennial plant	South Siberia-Dauro-Mongolian
Artemisia frigida	Semi-dwarf shrub	Ural-Kazakhstan-Siberia-Mongolian
Caragana stenophylla	Shrub	North Chinese-Dauro-Mongolian
Caragana microphylla	Shrub	South Siberia-Dauro-Mongolian
Cleistogenes squarrosa	Loose-bunch-grass	East Black Sea-Kazakhstan-Mongolian
Leymus chinensis	Long-rhizomatous grass	East Siberia-North Chinese-Dauro-Mongolian
Stipa krylovii	Firm-bunch grass	East Siberia-Central Asian
	Desert steppes (Northern Gobi)	
Artemisia frigida	Primitive dwarf semi-shrub	Ural-Kazakhstan-Siberia-Mongolian
Cleistogenes songorica	Loose-bunch grass	North Turano-Dzungar-Gbian
Stipa gobica	Firm-bunch grass	Gobi-Mongolian
Allium polyrrhizum	Firm-bunch plant	Dzungar-North Gobian
A. mongolicum	Firm-bunch plant	Gobi-Mongolian
	Steppe deserts (Trans-Altai Gobi)	
Allium mongolicum	Firm bunch plant	Gobi-Mongolian
A. polyrrhizum	Firm bunch plant	Dzungaria-Northern Gobian
Anabasis brevifolia	Semi dwarf shrub	Dzungaria-Northern Gobian
Cleistogenes songorica	Loose-bunch grass	North Turano-Dzungar-Gobian
Stipa glareosa	Small-bunch grass	Middle Asian-Central-Asian
	Steppe deserts (Northern Gobi)	
Brachanthemum gobicum	Tap root dwarf semi-shrub	Northeastern Gobian
Haloxylon ammodendron	Shrub, sometimes multi-stem tree	Turano-Gobian
Nitraria sibirica	Shrub	South Siberia-Mongolia-Gobi-mountain Middle Asian
Reaumuria soongorica	Dwarf semi-shrub	East Turano-Gobian
Salsola passerina	Dwarf semi-shrub	Central Gobi-Alashanian
Zygophyllum xanthoxylon	Shrub	Gobian
	True deserts (Trans Altai Gobi)	
Haloxylon ammodendron	Shrub, sometimes multi-stem tree	Turano-Gobian
Nitraria sphaerocarpa	Shrub	Gobian
Reaumuria songarica	Dwarf semi-shrub	Eastern Turano-Gobian
Sympegma regelii	Dwarf semi-shrub	Central Asian
	Extreme arid deserts (Trans-Altai Gobi).	
Haloxylon ammodendron	Shrub, sometimes multi-stem tree	Turano-Gobian
Iljinia regelii	Semi-shrub	Turano-Dzungarian-Gobian

Thus data on intensity of transpiration and productivity of each species were used for the calculation of the transpiration coefficient. The transpiration intensity was measured by the method of rapid weighing (IVANOV et al. 1950). Measurements during daylight hours and daily were made over 3–5 (in the Trans-Altai Gobi 5) growing seasons yielding about 500 measurements for each species. Most data shown in fig. 1, given in table 2 and in the text refer to mean values. Figure 1 also shows data on maximum values of transpiration.

The productivity of the entire plant community (fig. 2) and that of certain species were determined on the same experimental sites where water relations have been studied (GORDEEVA et al. 1981, KAZANTSEVA 1988). In addition, the water consumption of entire communities was calculated and compared to the amount of precipitation.

Results

Effectiveness of water use by dominant species

Dry steppes

According to the transpiration coefficient, dominant species of the dry steppe community ***Caragana stenophylla + C. pygmaea + C. microphylla – Cleistogenes squarrosa + Agropyron cristatum + Artemisia frigida + Stipa krylovii*** differ considerably in their water use efficiency. Among these *Artemisia frigida* and *Caragana stenophylla* are least effective and consume almost 2 times more water than, for example, *Stipa krylovii* (table 2). On average, the dominant species of dry steppes consume slightly more than 2 liters (2130 g) of water per g. dry matter produced.

Desert steppes

On average, dominant species in the ***Caragana leucophloea – Stipa gobica + Cleistogenes songorica + Artemisia frigida*** community use 2440 g of water. It is not surprising that in the southern regions with their lower precipitation and higher temperatures the water use efficiency decreases. However, we may have expected considerably higher differences between dry steppe and desert steppe plants, because the climatic differences are so pronounced. According to BUDYKO (1984) steppes are generally confined to areas where the aridity radiation index varies from 1 to 2, while semi-deserts show values from 2 to 3. In Mongolia, even dry steppes occur at a radiation index of about 2.8, while in the in Northern Gobi the desert steppes exist under the incredibly high value of 7.8 (BERESNEVA 1981).

The transpiration coefficient of *Artemisia frigida* in desert steppes of the Northern Gobi (table 2) was lower than in dry steppes of Middle Khalkha. This implies that water use efficiency of a given species was higher in more xeric conditions. This may be related to a potentially higher resistance of, e.g. photosynthesis of *Artemisia frigid*, where stress becomes higher due to increasing water deficit in the soil (SLEMNEV 1988). It has been shown (ZAVADSKAYA & DENKO 1988) that under dehydration drought-resistant plants often increase thermo-resistance.

Steppe deserts

The dominant species in the ***Salsola passerina + Haloxylon ammodendron + Reaumuria songarica*** community (*Northern Gobi*) consume on average 1730 g of water. Therefore their efficiency of water use is higher than that of desert steppe species. This can be largely explained by the lower intensity of transpiration of desert plants (fig. 1) compared to steppe species. For example, *Salsola passerina* and *Reaumuria songarica* use almost 2 times less water than *Haloxylon ammodendron* and *Brachanthemum gobicum* (table 2).

In the ***Anabasis brevifolia + Stipa glareosa + Allium polyrrhizum*** community (Trans-Altai Gobi) the most effective species in terms of water use is *Stipa glareosa* while the dominant species *Anabasis brevifolia* is slightly inferior (table 2). *Allium* species, especially *A. mongolicum,*

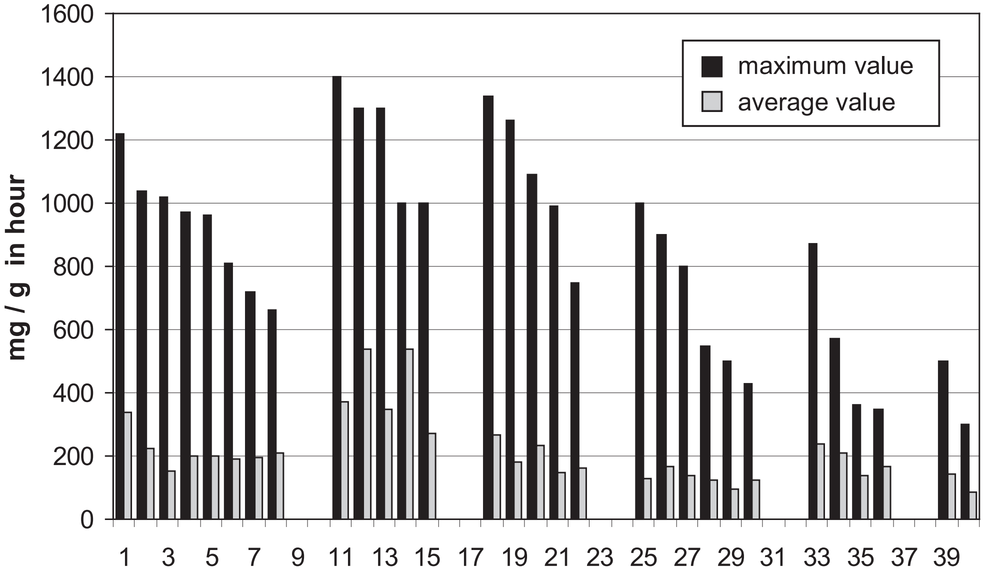

Fig. 1: Transpiration intensity of steppe and desert plants.

Numbers refer to species names: Middle Khalkha (true steppe): 1 – *Artemisia frigida*, 2 – *Caragana stenophylla*, 3 – *Leymus chinensis*, 4 – *Allium bidentatum*, 5 – *Agropyron cristatum*, 6 – *Cleistogenes squarrosa*, 7 – *Caragana microphylla*, 8 – *Stipa krylovii*; Northern Gobi (desert steppes): 11 – *Artemisia frigida*, 12 – *Cleistogenes songorica*, 13 – *Stipa gobica*, 14 - *Allium polyrrhizum* -, 15 – *Allium mongolicum*; Northern Gobi (steppe deserts): 17 – *Brachanthemum gobicum*, 18 – *Nitraria sibirica* -, 19 – *Reaumuria songarica*, 20 – *Zygophyllum xanthoxylon*, 21 – *Salsola passerina*, 22 – *Haloxylon ammodendron*; Trans-Altai Gobi (steppe deserts): 25 – *Stipa glareosa* -, 26 – *Allium mongolicum*, 27 – *Cleistogenes songorica*, 28 – *Allium polyrrhizum*, 29 – *Anabasis brevifolia*; Trans-Altai Gobi (true deserts): 33 – *Sympegma regelii*, 34 – *Reaumuria songarica*, 35 – *Haloxylon ammodendron*, 36 – *Nitraria sphaerocarpa*; Trans-Altai Gobi (extreme arid deserts): 39 – *Haloxylon ammodendron* (wadi), 41 – *Iljinia regelii* (watershed).

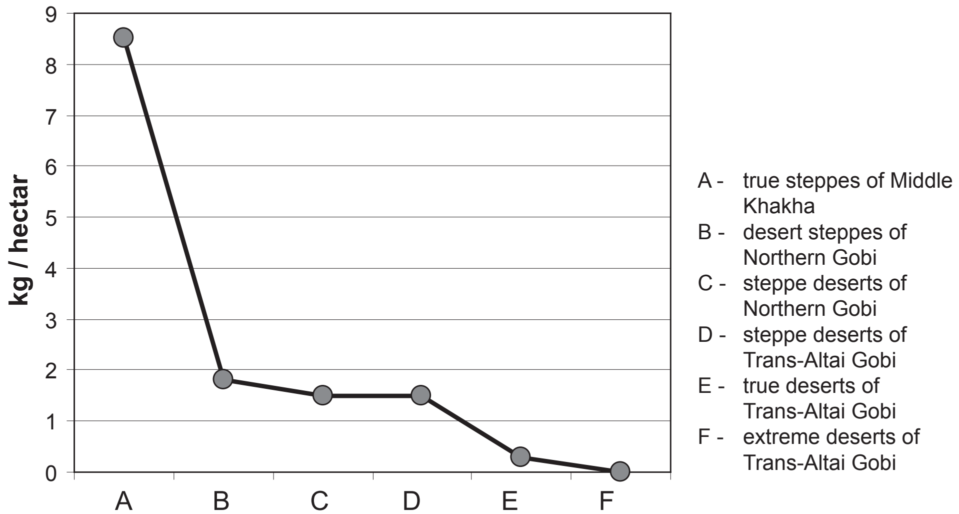

Fig. 2: Productivity of communities along the ecological profile (kg /ha).

Table 2: Transpiration coefficients by species, and water consumption by community

Species	Transpiration coefficient, water g/1 g of dry mass	Water consumption by community, mm
Dry steppes (Middle Khalkha)		
Artemisia frigida	2790	198
Caragana stenophylla	2630	
Leymus chinensis	2270	
Allium bidentatum	2240	
Agropyron cristatum	2010	
Cleistogenes squarrosa	1980	
Caragana microphylla	1730	
Stipa krylovii	1400	
Desert steppes (Northern Gobi)		
Allium mongolicum	3580	114
Cleistogenes songorica	2850	
Allium polyrrhizum	2290	
Artemisia frigida	2020	
Stipa gobica	1440	
Steppe deserts (Trans-Altai Gobi)		
Allium mongolicum	4450	112
A. polyrrhizum	3960	
Cleistogenes songorica	3570	
Anabasis brevifolia	2990	
Stipa glareosa	2430	
Steppe deserts (Northern Gobi)		
Nitraria sibirica	2550	112
Brachanthemum gobicum	2540	
Haloxylon ammodendron	2170	
Zygophyllum xanthoxylon	2000	
Reaumuria songarica	1330	
Salsola passerina	1250	
True deserts (Trans-Altai Gobi)		
Sympegma regelii	3410	34
Nitraria sphaerocarpa	3320	
Reaumuria songarica	2690	
Haloxylon ammodendron	2460	
Extreme arid deserts (Trans-Altai Gobi).		
Haloxylon ammodendron	2280	25
Iljinia regelii	1750	

have the least effective water use. The latter species had a mean water use efficiency of 4450 g, and in 1984 when high temperatures in Trans-Altai Gobi coincided with a large amount of a precipitation, it consumed about 7000 g of water. Data on such an irrationally high use of water are not known from the literature.

True deserts

In ***Sympegma regelii + Reaumuria songarica, Nitraria sphaerocarpa + Reaumuria songarica*** and ***Haloxylon ammodendron*** communities, *Sympegma regelii* and *Nitraria sphaerocarpa* were less productive with respect to water consumption compared to *Haloxylon ammodendron* and *Reaumuria songarica* (table 2). The dominant species of that community thus showed a wide variation in efficiency.

Extreme arid deserts. The only species that is able to survive in the extreme hot and dry conditions on the Trans-Altai Gobi watersheds, *Iljinia regelii*, uses water rather economically consuming less than 2 liters of water (table 2).

Community water consumption

In *dry steppes* of Middle Khalkha where the mean amount of precipitation is 235 mm, the ***Caragana stenophylla + C. pygmaea + C. microphylla – Cleistogenes squarrosa + Agropyron cristatum + Artemisia frigida + Stipa krylovii*** community consumes 198 mm per growing season (fig. 2).

Communities of *desert steppes* and *steppe deserts* of the Northern Gobi, despite of differences in composition and structure, consume almost equal amounts of water which are approximately similar to the precipitation values (fig. 2). Until now there are no reliable data on amount of water absorbed by soil from the atmosphere. As the studied desert steppe ***Caragana leucophloea – Stipa gobica + Cleistogenes songorica + Artemisia frigida*** community is located on a piedmont plain, surface water may inflow from slopes of the Gurvan-Saykhan ridge and provide additional water supply.

The ***Anabasis brevifolia + Stipa glareosa + Allium polyrrhizum*** community in *steppe deserts* of Trans Altai Gobi consumes about 160 mm per growth season. That exceeds the amount of a precipitation (fig. 3). This community is located on the piedmont plain of Shine-Dzhinst ridge at approximately 1.5 km distance from the mountain foot zone allowing to use the water flowing down from their slopes.

The most typical communities of the *true deserts* of the Trans-Altai Gobi differ in water consumption: ***Sympegma regelii + Reaumuria songarica*** - 72.1 mm, ***Nitraria sphaerocarpa + Reaumuria songarica*** - 12.3 mm, ***Haloxylon ammodendron*** - 18.5 mm.

The very open ***Iljinia regelii*** community of *extreme arid deserts* consumes about 9 mm of water per growing season that is 5 times lower the than precipitation amount (fig. 3).

Discussion

As is well known (see GENKEL 1962), in humid regions the transpiration coefficient of different species varies from 400 to 1000 g of water/g dry mass while in semiarid and arid ones regions these values are more often at 2000-3000 g (KOZLOVSKI 1964). It has been suggested that up to 5000 g could be used by plants in semi-desert (KOZLOVSKI 1964). However, according to data from YAGOVTSEVA (1975) for the Kara-Kum, the transpiration coefficient of dominant species in deserts ranges from 500 to 4000 g. Mean values in our study along the latitudinal profile from dry steppes up to extreme arid deserts were in the range from 1250 to 4450 g, and the highest mean value (*Allium mongolicum*) found in a specific growing season was 7000 g.

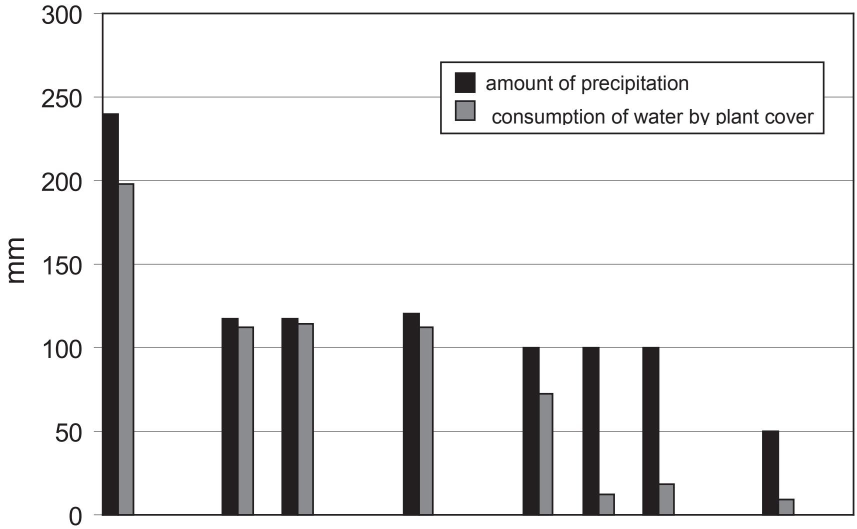

Fig. 3: Consumption of water by communities of steppes and deserts (mm), for letters see legend fig. 2.

The mean value of the transpiration coefficient of steppe species from different vegetation zones (from dominants in dry steppes up to co-dominants in steppe deserts) is only slightly higher than in desert plants (2570 g and 2360 g respectively). Southwards, these values increase for steppe species (2131 → 2436 → 3602), while in desert species the tendency is not obvious (2990 → 1973 → 2970 → 1750).

It would seem logical that with progressively drier conditions species with a more rational water use gain advantage. We found even in dry steppes of Middle Khalkha that plants of widely varying water use efficiency (2790 g and 1400 g) are present among the dominant species in one and the same stand. In steppes and deserts of Northern Gobi the transpiration coefficient of five species varied from 3580 g to 1440 g, in Trans-Altai Gobi four species of true deserts showed values between 4450 g and 2430 g (table 2).

The dry steppe communities with the richest species composition, the highest plant cover and the largest above-ground phytomass consume 80 % of the local precipitations (fig. 2). Less species-rich and less densely covered steppes and desert communities in the Northern Gobi with a low productivity and phytomass use about 100 % of the precipitation. Closely associated true desert plant communities show a wide range of values for water use efficiency (from 20 % to 80 %) and the sparsest stand with single plants of *Iljinia regelii* in the extreme arid deserts uses only 10 %.

Conclusion

The assessment of the amount of water consumed by plant communities along the aridity gradient from dry steppes up to the extreme arid deserts in Mongolia showed that desert steppes and steppe deserts use almost all water coming in as precipitation, while both south and north of these zones consumption is lower.

The average water use efficiency estimated as the transpiration coefficient of dominant species was rather similar among steppes and deserts. The efficiency of water consumption for production of 1 g of dry mass decreases at the southern limit of steppes. That of desert plants in southern direction increases but not as strong as it would be expected.

There are both high and low productive species among the dominants in desert and steppes communities. We failed to reveal links between the water consumption efficiency and taxonomy, life forms and distribution area of the studied dominant species. Even endemic species such as *Allium polyrrhizum*, *A. mongolicum* and *Brachanthemum gobicum* have rather low water use efficiency. Only several *Stipa* species dominant of various vegetation types such as dry and desert steppes as well as steppe deserts were consistently quite effective in this. This has probably allowed them to achieve dominance in a vast range of steppe types. Perhaps, evolutionary history should be taken into account in order supplement work on ecological and phytosociological factors.

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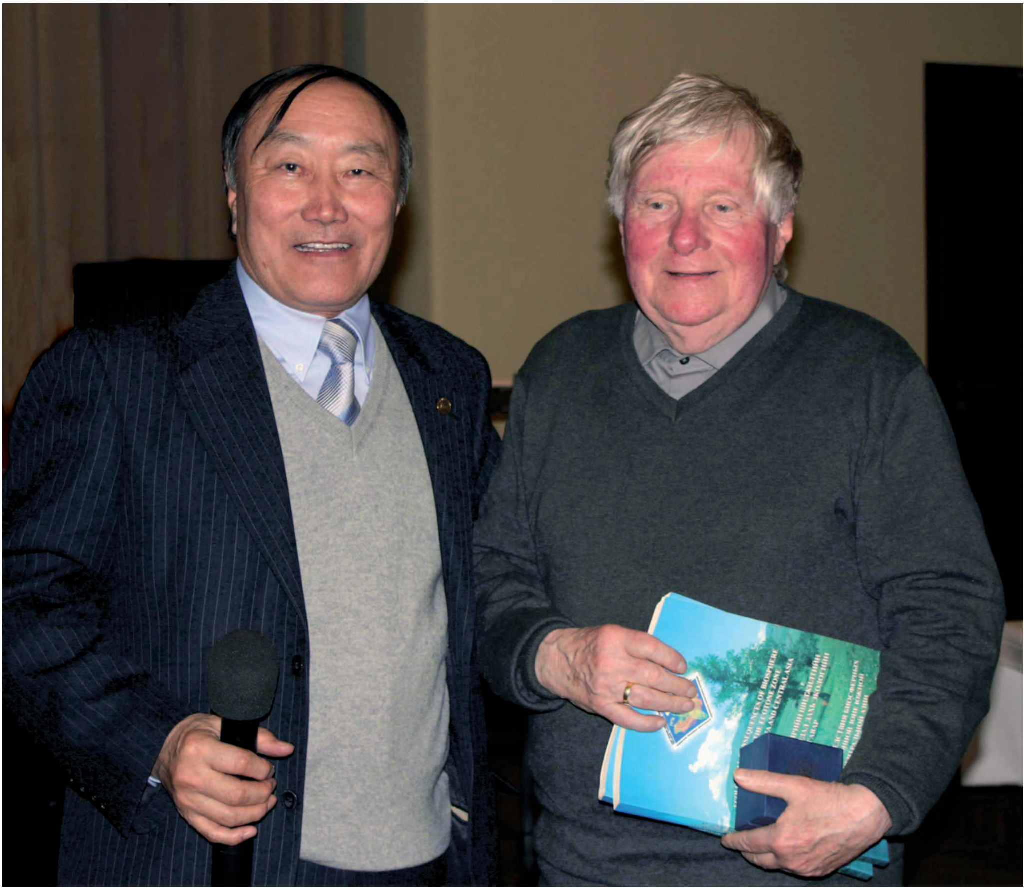

Prof. Dr. Chultem Dugarjav (Mongolian Academy of Sciences) and Dr. Peter Hanelt (IPK Gatersleben) during the evening session in the old cafeteria of the Martin-Luther-University Halle.