Journal of Hydrology (2007) **333**, 100–108

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/jhydrol

Morphological and physico-chemical characteristics of soils in a steppe region of the Kherlen River basin, Mongolia

Asano Maki [a,*], Tamura Kenji [a], Kawada Kiyokazu [b], Higashi Teruo [a]

[a] *Graduate School of Life and Environmental Sciences, University of Tsukuba, 1-1-1 Tennoudai, Tsukuba, Ibaraki 305-8572, Japan*
[b] *National Institute for Agro-Environmental Sciences, 3-1-3 Kannondai, Tsukuba, Ibaraki 305-8604, Japan*

Received 31 August 2005; received in revised form 14 March 2006; accepted 24 July 2006

KEYWORDS
Kastanozems;
Soil properties;
Soil morphology;
Mongolia;
RAISE

Summary Morphological and physico-chemical characteristics of five soil profiles were studied at steppe sites in a vegetation transition zone of the Kherlen River basin, Mongolia. A vegetation survey showed differences in floristic compositions between southern and northern sites, and suggested a grazing effect and varying moisture conditions among the study locations. The presence of a mollic horizon and the accumulation of calcium carbonate ($CaCO_3$) characterized the profile morphologies. The depths of the $CaCO_3$ accumulation horizon differed among the study sites. The soils were classified as Calcic Kastanozems and Calcic Hyposodic Kastanozems, and soil physical properties showed high bulk density values and low hydraulic conductivity in the $CaCO_3$ accumulation horizons. Regarding chemical properties, the organic carbon content was high in the A horizon then decreased rapidly with soil depth. The pH and electrical conductivity (EC) of the A horizon ranged from 6.3 to 7.2 and 0.29 to 0.95 dS m^{-1}, respectively. The $CaCO_3$ accumulation horizons of the five study sites showed distinct differences in pH and EC ranging from 8.6 to 10.0 and 1.25 to 4.70 dS m^{-1}, respectively. Differences in the amounts of water soluble and exchangeable ions were remarkable, with sites in downstream areas of the Kherlen River basin tending to have higher Na^+, SO_4^{2-}, and Cl^- ion values.

Introduction

Human activities and climate changes have altered rangeland ecosystems in Mongolian over the past 40 years (Natsagdorji, 2000). Moreover, recent changes in livestock

---

[*] Corresponding author. Tel.: +81 29 853 4684; fax: +81 29 853 6878.
E-mail address: ma_oasisu@ybb.ne.jp (A. Maki).

0022-1694/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.jhydrol.2006.07.024

policies and economic factors have resulted in more intensive land use (Bayasgalan et al., 2000; Chuluun and Ojima, 2001). During the past 60 years, the annual mean air temperature has also increased by 1.56 °C (Natsagdorji, 2000), and along with overgrazing and other climate changes is likely to accelerate land degradation. Because Mongolia is located in a transition zone between the Siberian taiga and Central Asian desert regions, changes in the Mongolian environment will have an impact on forest, steppe, and/or desert ecosystems. In general, such transition zones (ecotones) are sensitive and susceptible to environmental changes (Pogue and Schnell, 2001; Miegroet et al., 2005); thus, the ability to predict and take precautions against land degradation is essential. However, knowledge about how this ecotone responds to environmental changes remains insufficient.

An integrated research project, RAISE (the rangelands atmosphere—hydrosphere—biosphere interaction study experiment in Northeastern Asia), was developed to evaluate the effects of environmental changes on rangeland ecosystems with emphasis on the role of the hydrologic cycle in Northeast Asia (Sugita et al., 2006). Since the effect of grazing and climate changes on soil degradation changes with location (Nemoto et al., 1992; Opp et al., 2000), it is necessary to ascertain the most suitable management method for the specific conditions of different locations (Takeuchi et al., 1995). Therefore, it is imperative to comprehend the actual soil characteristics and degree of soil degradation.

The rangelands of Mongolia are primarily a region of semiarid steppe, where the most prominent soil-forming process is the translocation of calcium carbonate ($CaCO_3$) from the surface horizon to an accumulation layer at varying depths. The depth and composition of salts in the carbonate accumulation horizon depend strongly on soil water flow and mean annual precipitation (Arkley, 1963; Marion et al., 1985; Matsumoto and Cho, 1985). Therefore, the depth of the carbonate accumulation horizon is a suitable index of the soil moisture environment.

In this study, we aim to clarify the morphological and physico-chemical characteristics of soil in the steppe region of the northeastern Mongolia ecotone. We primarily focus on the relationship between the floristic composition and $CaCO_3$ accumulation horizon, which is thought to reflect the moisture conditions at each location.

Materials and methods

Study sites

The study took place in a steppe area of the Kherlen River basin in northeastern Mongolia. All study sites were located within the ecotone area, where clear distinctions between forest steppe and steppe vegetation are observed. Individual study sites were located in the villages of Baganuur (BGN), Jargalthaan (JGH), Kherlenbayan-Ulaan (KBU), Underhaan (UDH), and Darhan (DH) in the Hentiy province of Mongolia (Fig. 1). BGN was located on mountain forest steppe, while JGH, KBU, UDH, and DH were located on steppe (Batima et al., 2000).

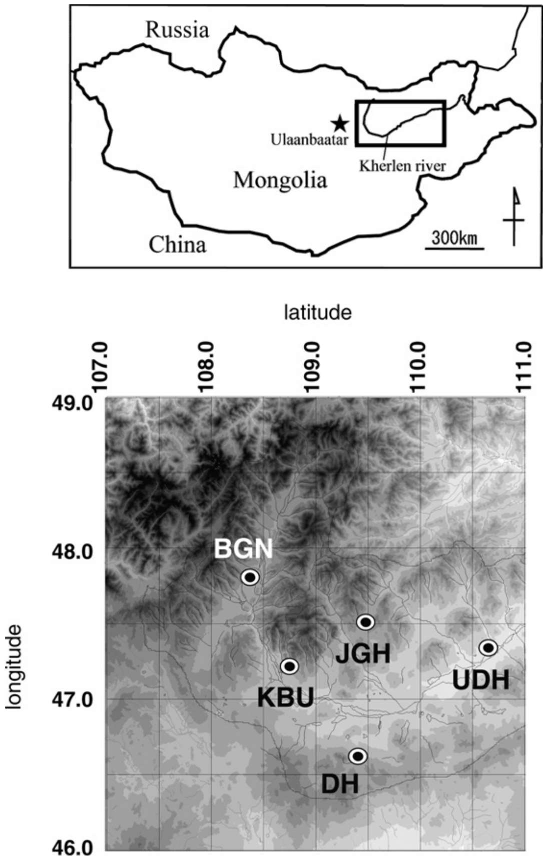

Figure 1 Location of the study sites. Circles denote the location of the studied sites. BGN: Baganuur, JGH: Jagalthaan, KBU: Kherlenbayan-Ulaan, UDH: Underhaan, DH: Darhan.

An automatic weather station (AWS) maintained by the RAISE project (Sugita et al., 2006) was located in each study site. The distribution of annual precipitation and the aridity index show that the southern and downstream areas of the Kherlen River basin are drier (Table 1). Here the amount of annual precipitation represents the average from 1993 through 2001, while the potential evaporation was calculated using the Penman method for 1988 (Sugita, 2003) with the ISLSCP Initiative I data set (Sellers et al., 1995). The annual precipitation at each site was obtained from an isohyet map produced from data obtained at the meteostation, a primary meteorology station maintained by the Institute of Meteorology and Hydrology (IMH) of Mongolia. Although precipitation data is actually measured at two stations, the above meteostation and the meteopost, a secondary station of the IMH, data from the latter were not used because Sugita et al. (2006) previously noted that the amount of annual precipitation measured by the meteopost stations tends to be less accurate than that obtained by the meteostation. The distribution of the aridity index agreed well with that reported by Araki and Kawada (2004).

Each study site was in rangeland located on flat land of the Kherlen River basin where soils are composed of granite, metamorphic rock, and loess. The study sites were thus relatively similar in terms of topography and geology, except for their vegetation zones. Therefore, the soil profile morphology and physico-chemical characteristics were expected to show variations within the vegetation zones and to reflect the hydrological environment of the soils. Soil

Table 1 General information of the sampling sites

Site designation	Latitude and longitude	Elevation (m)	Annual precipitation[a] (mm yr^{-1})	Potential evaporation[b] (mm yr^{-1})	Aridity index[c]
BGN	N47°47′02″ E108°21′37″	1361	221	508	0.43
JGH	N47°29′08″ E109°28′24″	1335	219	550	0.40
KBU	N47°12′36″ E108°43′59″	1170	209	511	0.41
UDH	N47°18′22″ E110°37′14″	1033	207	588	0.35
DH	N46°37′54″ E109°24′42″	1121	179	560	0.32

[a] The mean annual precipitation was obtained from isodose chart with the data from meteostation average for 1993–2001 observed by IMH.

[b] The potential evaporation is calculated with Penman method for 1988 (Sugita, 2003) with ISLSCP Initiative 1 date set (Sellers et al., 1995).

[c] Aridity index = precipitation/potential evaporation.

and vegetation surveys were conducted on 11 August 2002 at KBU, and from 21–26 June 2003 at the BGN, JGH, UDH, and DH sites.

Vegetation

For the vegetation investigation, five quadrats of 1 m × 1 m were established at each site, and the plant coverage (C; %) and height (H; cm) of each species in each site were measured using the modified Penfound–Howard method (Numata, 1987). Following this, the extended summed dominance ratio, E-SDR_2 (Yamamoto et al., 1995), was calculated to compare vegetation among communities. The E-SDR_2 was obtained using the following equation:

$$E - SDR_2 = (C' + H')/2 \tag{1}$$

where C' and H' are the relative coverage value and relative plant height of each species to the respective maximum values of all communities, respectively. Nomenclatures of the species were determined according to the Committee of flora of Inner Mongolia (1993).

Soil

Soil profiles were described according to the FAO (1990) and the soil classification by following the standards of the FAO/ISRIC/ISSS (1998). Soil samples were collected from each horizon of the five soil profiles. Undisturbed soil core samples for the physical measurements were sampled using a cylindrical 100-ml core sampler. Soil samples for chemical analyses were air dried and then sieved to 2 mm. The samples were subjected to the following physical measurements and chemical analyses (Committee of Soil Environment Analysis, 1997). The three-phase ratio was computed according to the actual volumetric method. Saturated hydraulic conductivity was determined by the falling-head permeability method. The organic carbon and total nitrogen contents were determined by the dry combustion method using an NC analyzer (Sumigraph NC-900, Sumika Chemical Analysis Service, Tokyo, Japan). The inorganic carbon content was determined by the wet combustion method (Clark and Ogg, 1942). The pH values of the samples were determined for a 1:2.5 air-dried soil/distilled water mixture using a glass electrode pH meter. The electric conductivity (EC) was determined for a 1:5 air-dried soil/distilled water mixture using a platinum electrode. Exchangeable bases were determined for 1 M CH_3COONH_4 (pH 7.0) extracts by atomic absorption spectrophotometry, and the cation exchangeable capacity (CEC) was determined with 1 M CH_3COONH_4 (pH 7.0) according to the semi-micro Schollenberger method (Committee of Soil Environment Analysis, 1997). Water-soluble ions were extracted in a 1:5 air-dried soil/distilled water mixture, and then cations of Ca^{2+}, Na^{+}, Mg^{2+}, and K^{+} were determined by atomic absorption spectrophotometry (AA-6200, Shimadzu Corp., Kyoto, Japan). Anions of SO_4^{2-}, Cl^{-}, PO_4^{3-}, and NO_3^{-} were determined by ion chromatography (7000 Series II, Yokogawa IC, Tokyo, Japan).

Results and discussion

Vegetation

Table 2 shows the 10 most dominant plant species at each site determined by the E-SDR_2 method. *Leymus chinensis*, *Stipa krylovii*, and *Kochia prostara* dominated plant communities in BGN, while in JGH and KBU, *S. krylovii* and *Carex* sp. were dominant, and in UDH and DH, *L. chinensis* and *Carex* sp. dominated. *Arenaria capillaries*, *Pulsatilla turczaninovii*, and *Polgonum divaricatum* were also found in BGN. In JGH, KBU, UDH, and DH, annual species such as *Salsola collina* and *Artemisia adamsii* also ranked highly according to the E-SDR_2 method.

BGN had the highest total number of species (31), while JGH had the highest plant coverage (70%). UDH had both the lowest number of species and coverage (10 species and 44% coverage). BGN and JGH had the same number of semi-drought-resistant and drought-resistance species, whereas DH and UDH had fewer semi-drought-resistance species. This suggests that BGN and JGH were relatively humid, DH and UDH were relatively dry, and KBU had moderate conditions, and this tendency agreed well with the distribution of the aridity index (Sugita et al., 2006).

Gunin et al. (2001) showed that in eastern Mongolia, species that respond negatively to livestock grazing, such as *Stipa* spp., have decreased at sites with high grazing pressures, whereas grazing-tolerant species such as *Artemisia frigida* and *Caragana stenophylla* have increased. In addition, Sasaki et al. (2005) reported that annual or biennial herbs replaced perennial herbs as the grazing intensity rose in southern Mongolia. Previous studies in the Inner

Table 2 Major species of the study sites. Showing the top 10 species in each site based on E-SDR$_2$ value

Species	Life form	BGN	JGH	KBU	UDH	DH
Mean coverrage (%)		58	70	60	44	66
Number of species		31	19	16	10	18
Stipa krylovii	Per	55	63	90	53	21
Carex sp.	Per	36	65	58	62	62
Artemisia adamsii	Per		61	37	18	44
Salsola collina	Ann		58	22	24	53
Leymus chinensis	Per	67			85	74
Allium polyrhizum	Per	35			4	
Potentilla bifurca	Per		20		19	
Artemisia frigida	Per		21			17
Cleistogenes squarrosa	Per			48	49	52
Caragana stenophylla	Per			34	13	
Astragalus galactites	Per			24		28
Kochia prostrata	Per	55				
Arenaria capillaris	Per	44				
Pulsatilla turczaninovii	Per	42				
Polgonum divaricatum	Per	34				
Koeleria cristata	Per	24				
Saussurea salicifolia	Per	24				
Euphorbia esula	Per		47			
Serratula centauroides	Per		23			
Thymus serpyllum var. asiatic	Per		19			
Convolvulus ammannii	Per			30		
Lappula redowskii	Ann			28		
Haplophyllum dauricum	Per			19		
Allium mongolicum	Per				5	
Agropyron cristatum	Per					29
Chenopodium album	Ann					19

Life form Per; Perennial, Ann; annual.

Mongolian grasslands reported the same tendency, revealing the indicative species (Nakamura et al., 1998, 2000; Yiruhan et al., 2001). In this study, based on the indicator species of rangeland degradation stages in Mongolia (Gunin et al., 2001), the floristic compositions of each site indicated moderate to strong impacts of grazing.

Soil profile morphology and classification

Table 3 presents brief descriptions of the soil profile morphologies of the study sites. The most prominent differences in the soil profile morphologies were the depths of the $CaCO_3$ accumulation horizons and the existence of a mollic horizon. The $CaCO_3$ accumulation horizons appeared at shallower depths in the southern sites, indicating that the depth of soil water infiltration was shallower here.

The soil color of the A horizon was brownish black in BGN, dark brown to brown in JGH, KBU, and UDH, and dark reddish brown in DH. The field texture classes ranged from sandy clay loam to silty clay loam. The sand content was relatively high in KBU and JGH. The soil structure had a poorly developed $CaCO_3$ accumulation horizon that was compact and hard. The plant roots were distributed almost entirely in the A horizon.

The soils observed in UDH were classified as Hyposodic Calcic Kastanozems, and those in KBU, JGH, BGN, and DH as Calcic Kastanozems according to the WRB (FAO/ISRIC/ISSS, 1998). According to the classifications for Mongolia (Dordschgotov, 2003), the soils in all studied sites are typical Kastanozems.

Soil physico-chemical characteristics

Tables 4 and 5 list the physico-chemical characteristics of the soils. Three-phase ratio measurements of the soils showed a high solid phase and low liquid phase. The solids in the A horizon and $CaCO_3$ accumulation horizon ranged from 47.4% to 50.8% and 43.6% to 65.2%, respectively. Saturated hydraulic conductivity values were relatively high in the $CaCO_3$ accumulation horizons. Wuyunna et al. (2004) reported that grazing intensity increased the soil solids and hardness of the top horizon. Our soil analyses suggested that the top horizons of the studied sites had been impacted by grazing.

The organic carbon content ranged from 10.4 to 21.4 g kg^{-1}, with high values in the top soil horizon and rapid decreases with soil depth. The total nitrogen content showed a similar tendency. The organic carbon and total nitrogen contents were related to the results of vegetation coverage and the number of plant species.

Inorganic carbon was detected in the $CaCO_3$ accumulation horizons, but not the A horizons. The presence of

Table 3 Brief description of the soil profile morphology

	Holizon	Depth (cm)	Color	Texture	Structure[a]	Root distribution[b]	Carbonate[c]	Hardness[d] (kPa)
BGN	A1	0–10	10YR2/3	SiCL	MOMEGR	VFM, FM, MVF, CVF	N	617
	A2	10–29	10YR3/3	SL	WEVFGR	VFM, FM, MF, CVF	N	396
	AB	29–62	10YR4/4	LS	WEVFSA	VFC, FC, MF	SL	1156
	Bk	62–100	2.5YR6/3	SL	MA	FF	EX	4720
JGH	A1	0–9	10YR3/4	L	MOVF-MEGR	VFM, FM	N	342
	A2	9–28	10YR3/3	SiL	WEVFGR	VFM, FM, MVF, CVF	N	532
	AB	28–47	10YR4/6	SiL	WEVF-FI	VFC, FF, MF	N	982
	Bk1	47–70	10YR8/2	SC	MA	FF	EX	3700
	Bk2	70–100	10YR7/2	SC	MA	–	EX	4720
KBU	A1	0–7	7.5YR4/3	SCL	WEMESA	VFM, FM, MVF, CVF	N	1156
	A2	7–23	7.5YR4/3.5	SL	MOME-COSA, WEFIGR	VFM, FM, MF, CVF	N	1370
	AB	23–38	7.5YR4/2.5	SL	WEFI-COSA	VFC, FC, MF	N	1156
	Bw	38–68	10YR5/3	LS	WEME-COSA	FF	SL	838
	Bk1	68–93	10YR7/3	LS	MA	–	EX	1970
	Bk2	93–110	10YR6/3	LS	MA	–	EX	1970
UDH	Al	0–12	7.5YR4/4	SiCL	WEFIGR, WEMESA	VFM, FM	N	617
	A2	12–31	7.5YR3/4	SiCL	WEFISA	VFM, FM	M	617
	Bk1	31–48	10YR6/3	SiC	MA	VFF, FC	EX	2398
	Bk2	48–75	10YR7/3	SCL	MA	VFF, FF	EX	1970
	Bk3	75–100	7.5YR6/3	SL	MA	VFF, FF	EX	2956
DH	Al	0–8	5YR3/4	SiCL	WEFI-MESA	VFM, FC	N	532
	A2	8–28	7.5YR4/4	L	WEFI-MESA	VFC, FC	N	1970
	Bk1	28–58	10YR7/3	CL	MA	VFF, FF	EX	1636
	Bk2	58–81	10YR8/3	SCL	MA	FVF	EX	1370
	Bk3	91–100	10YR8/2	SL	MA	FVF	EX	1636

Description of soil profile morphology were according to FAO (1990).

[a] Description for structure: VW, WE, MO, ST, and VS grades of development stand for very weak, weak, moderate, strong, and very strong, respectively; sizes are designated as VF, VF-FI, VF-ME, FI, FI-ME, FI-CO, ME, ME-CO, CO, and VC for very fine, very fine to fine, very fine to medium, fine, fine to medium, fine to coarse, medium, medium to coarse, and coarse, very coarse, respectively, and the shapes are abbreviated as GR, SA, and MA for granuur, subangular, and massive structure, respectively.

[b] Description of root distribution' size is designated as VF, F, M and C for very fine, fine, medium, and coarse root, respectively, and the quantity is abbreviate as V, F, C and M for very few, few, common, and many, respectively.

[c] Description of carbonate: amount is estimated by the reactive to HCl as non-calcareous (N), slightly calcareous (SL), moderately calcareous (MO), strongly calcareous (ST), and extremely calcareous (EX).

[d] Hardness was measured by Yamanaka type penetrometer and converted to pressure resistance (kPa) (Committee of Soil Environment Analysis, 1997).

inorganic carbon reflects carbonate abundance. Dissolution of carbonate and subsequent accumulation in a $CaCO_3$ accumulation horizon are governed by two factors: the CO_2 pressure of the soil air and the concentration of dissolved ions in the soil water. The partial CO_2 pressure of the soil air is normally highest in the A horizon, where root activity and respiration by microorganisms cause CO_2 levels to be 10 to 100 times higher than in the atmospheric air. Thus, in the A horizon, carbonate dissolves and Ca^{2+} and HCO_3^- move downward with percolating soil moisture. In deeper parts of the soil profile, saturation soil moisture and precipitation of carbonate occur due to the evaporation of water and a decrease in partial CO_2 pressure; these factors lead to few plant roots, low soil organic matter, and fewer microorganisms (Driessen et al., 2001). Differences in the $CaCO_3$ accumulation horizon depths at each study site reflect the activities of vegetation and microorganisms and the depth of capillary water evaporation. These differences are also closely related to the thickness of the A horizon. KBU had the deepest $CaCO_3$ accumulation horizon. Field texture class observation showed that gravel and sand contents were significantly higher below the Bw horizon in KBU (Table 3). This texture may affect the flow of soil moisture, leading to a deeper $CaCO_3$ accumulation horizon in this profile.

The pH (H_2O) values of the A horizons ranged from 6.3 to 7.2; values for the $CaCO_3$ accumulation horizons were slightly higher, indicating alkalinity. The $CaCO_3$ accumulation horizons in UDH showed particularly strong alkalinity with pH (H_2O) values ranging from 8.6 to 10.0. A comparison of pH (H_2O) values at each site showed that the soil was more alkaline in areas downstream of the Kherlen River.

The EC value of the A horizons ranged from 0.29 to 0.67 $dS\,m^{-1}$ in BGN, JGH, and KBU and was higher in UDH and DH, ranging from 0.45 to 0.95 $dS\,m^{-1}$. In the $CaCO_3$

Table 4 Some physical characteristics of undisturbed soil core samples from the five soil profiles

	Bulk density (Mg m^{-3})	Solid phase (%)	Liquid phase (%)	Gaseous phase (%)	Hydraulic conductivity ($k_{15} \times 10^{-3}$ cms^{-1})
BGN					
A1	1.27	47.4	21.3	31.4	2.4
A2	1.42	52.6	6.9	40.5	18.0
AB	1.48	54.4	7.1	38.5	6.0
Bk	1.55	56.9	5.3	37.8	1.2
JGH					
A1	1.31	49.8	11.3	38.9	1.2
A2	1.50	53.4	10.6	36.0	9.6
AB	1.51	54.9	6.2	38.9	6.1
Bk1	1.46	57.0	5.2	37.8	4.4
Bk2	1.42	51.5	11.0	37.5	5.3
KBU					
A1	1.26	48.3	3.6	48.1	0.8
A2	1.48	55.1	4.8	40.1	4.0
AB	1.62	60.1	3.7	36.2	7.8
Bw	1.64	59.5	3.1	37.4	7.7
Bk1	1.73	65.2	3.4	31.3	4.3
Bk2	1.62	62.7	4.7	34.7	5.2
UDH					
A1	1.27	47.7	6.8	45.5	2.3
A2	1.52	56.4	4.5	39.1	7.4
Bk1	1.28	46.8	7.9	45.3	6.7
Bk2	1.39	51.6	8.3	40.1	2.5
Bk3	1.37	50.3	8.5	41.0	1.8
DH					
A1	1.44	50.8	4.4	44.8	1.8
A2	1.46	53.7	6.3	40.1	5.5
Bk1	1.13	43.6	20.6	37.1	2.8
Bk2	1.47	51.7	9.7	38.7	4.1
Bk3	1.44	52.7	9.3	38.0	3.2

accumulation horizons, the EC values showed a sharp increase, ranging from 1.25 to 4.70 dS m^{-1}. Particularly high EC values of 3.68–4.70 dS m^{-1} were observed in UDH. At the southern sites and downstream of Kherlen River, the aridity index tended to increase, and high EC values were recorded in the A and $CaCO_3$ accumulation horizons. This feature was particularly pronounced in UDH and DH.

The amount of exchangeable bases showed no remarkable difference between the A horizons of each site but increased sharply in the $CaCO_3$ accumulation horizons in southern sites. The amount of exchangeable bases other than calcium also increased in the southern sites. The exchangeable bases were mostly composed of Ca^{2+}, although parts of Ca^{2+} in the $CaCO_3$ accumulation horizons could be derived from the dissolution of $CaCO_3$ by CH_3COONH_4 (pH 7.0) extraction. In the Bk2 and Bk3 horizons in UDH, the exchangeable Na^+ value was the highest at 3.53 and 5.09 cmol (+) kg^{-1}, respectively.

The total water-soluble ion content in the soil solutions increased at sites with a high aridity index. Moreover, the water soluble ion compositions in the $CaCO_3$ accumulation horizons differed slightly depending on the location. The Na^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-} values in the $CaCO_3$ accumulation horizons increased in DH and UDH. The existence of Na^+ and Mg^{2+} contribute to a pH increase beyond 8.5 (Bolt and Bruggenwert, 1976), leading to the high pH (H_2O) values in UDH (in the Bk2 and Bk3 horizons).

Differences in the depth and salt contents of soils in arid and semiarid regions are closely related to soil moisture, as indicated by the amount of precipitation or evaporation (Matsumoto and Cho, 1985). The salts in the Bk horizons in DH and UDH accumulated not only by leaching from the surface horizon but also by capillary rise from the groundwater. In this study, the exchangeable and water soluble salt composition agreed with the findings of Matsumoto and Cho (1985). However, the high solubility salts in the $CaCO_3$ accumulation horizons in the UDH and DH sites cannot be explained by differences in the amounts of precipitation, evapotranspiration, and water table height. Tsujimura et al. (2006) suggested that the composition of water-soluble salts in the groundwater differs according to study site location. Shallow groundwater in the Kherlen River basin does not receive contributions from the regional groundwater flow system, and groundwater in the flat plain area is mainly a local groundwater flow system affected by small topographical relief. Stable isotope analysis of groundwater

Table 5 Chemical characteristics of the horizons from six representative soil profiles

	Carbon ($g\ kg^{-1}$)		N ($g\ kg^{-1}$)	pH H_2O	EC ($dS\ m^{-1}$)	Exchangeable bases (cmol (+) kg^{-1})					CEC (cmol (+) kg^{-1})	Water soluble cations (cmol (+) kg^{-1})				Water soluble anions (cmol (−) kg^{-1})			
	OC	IOC				Na^+	K^+	Mg^{2+}	Ca^{2+}	total		Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	NO_3^-	SO_4^{2-}	PO_4^{3-}
BGN																			
A1	21.4	n.d.	2.0	6.6	0.47	0.53	0.56	1.84	11.41	14.34	12.67	0.03	0.03	0.05	0.17	0.01	0.06	0.02	n.d.
A2	7.6	n.d.	0.7	6.7	0.29	0.04	0.14	1.13	7.04	8.34	6.38	0.03	0.02	0.05	0.10	0.01	0.03	0.02	n.d.
AB	5.1	4.7	0.5	8.5	1.15	0.07	0.13	0.73	12.05	12.99	11.55	0.04	0.01	0.07	0.51	0.02	0.02	0.02	n.d.
Bk	3.0	6.3	0.2	8.9	1.48	0.24	0.26	1.18	40.24	41.93	6.27	0.06	0.01	0.08	0.77	0.02	0.00	0.06	n.d.
JGH																			
A1	18.2	n.d.	1.8	6.3	0.43	0.12	0.35	0.40	8.07	8.95	10.74	0.02	0.03	0.06	0.16	0.01	0.05	0.02	n.d.
A2	11.6	n.d.	1.2	6.4	0.67	0.06	0.13	0.52	8.38	9.09	9.48	0.05	0.01	0.08	0.24	0.03	0.15	0.04	n.d.
AB	6.5	n.d.	0.7	6.8	0.65	0.13	0.12	0.56	10.23	11.03	10.75	0.05	0.01	0.08	0.27	0.01	0.16	0.02	n.d.
Bk1	3.0	14.7	0.3	8.8	1.39	0.32	0.14	2.94	42.65	46.04	7.20	0.12	0.01	0.12	0.59	0.02	0.01	0.08	n.d.
Bk2	3.0	18.5	0.2	9.1	1.25	0.24	0.08	2.88	42.98	46.18	6.91	0.11	0.01	0.11	0.48	0.01	0.00	0.01	n.d.
KBU																			
A1	14.2	n.d.	1.5	6.8	0.37	0.12	0.28	1.91	10.33	12.64	11.05	0.03	0.02	0.06	0.14	0.01	0.01	0.01	n.d.
A2	27.5	n.d.	2.7	6.4	0.40	0.08	0.61	2.03	10.50	13.22	11.95	0.03	0.04	0.04	0.12	0.01	0.01	0.02	n.d.
AB	9.4	n.d.	1.0	7.5	0.58	0.14	0.34	1.70	8.91	11.09	9.31	0.03	0.02	0.08	0.26	0.01	0.01	0.02	n.d.
Bw	4.2	n.d.	0.4	7.8	0.39	0.17	1.69	1.46	6.84	10.16	7.24	0.03	0.02	0.07	0.22	0.01	0.01	0.00	n.d.
Bk1	3.0	14.0	0.2	8.8	1.73	0.39	0.19	3.30	42.98	46.86	9.07	0.17	0.01	0.14	0.61	0.02	0.01	0.12	n.d.
Bk2	3.0	8.2	0.3	9.1	1.69	0.43	0.14	2.76	37.72	41.05	6.10	0.20	0.01	0.14	0.73	0.01	0.01	0.05	n.d.
UDH																			
A1	16.4	n.d.	1.3	6.6	0.69	0.27	0.96	0.68	10.14	12.05	12.81	0.03	0.09	0.10	0.23	0.01	0.01	0.01	n.d.
A2	9.9	n.d.	0.8	6.8	0.45	0.27	0.43	0.55	10.64	11.89	13.10	0.03	0.02	0.08	0.17	0.02	0.00	0.01	n.d.
Bk1	3.0	21.8	1.0	8.6	3.68	1.79	0.41	6.54	45.24	53.98	9.20	0.83	0.01	0.30	0.75	0.32	0.01	0.81	n.d.
Bk2	3.0	16.5	0.3	9.4	4.28	3.53	0.39	3.74	42.24	49.91	8.59	1.80	0.01	0.17	0.40	0.17	0.00	0.74	n.d.
Bk3	3.0	8.1	0.2	10.0	4.70	5.09	0.18	2.84	38.47	46.58	10.71	2.23	0.01	0.13	0.22	0.09	0.00	0.44	n.d.
DH																			
A1	10.4	n.d.	0.9	7.2	0.63	0.34	0.55	1.70	9.72	12.31	10.06	0.02	0.06	0.07	0.23	0.03	0.01	0.01	n.d.
A2	9.4	n.d.	0.8	7.0	0.95	0.28	0.35	1.91	13.62	16.16	14.17	0.03	0.01	0.10	0.35	0.25	0.00	0.01	n.d.
Bk1	3.0	22.5	0.7	8.7	1.34	0.31	0.30	3.08	47.72	51.42	14.86	0.06	0.04	0.25	0.79	0.01	0.02	0.02	n.d.
Bk2	3.0	18.2	0.1	9.0	2.33	1.94	0.17	11.90	49.25	63.26	16.42	0.71	0.01	0.39	0.38	0.07	0.01	0.32	n.d.
Bk3	3.0	3.8	0.0	9.1	2.09	2.14	0.17	13.27	45.64	61.22	19.74	0.72	0.00	0.31	0.31	0.02	0.00	0.18	n.d.

n.d., not detected.

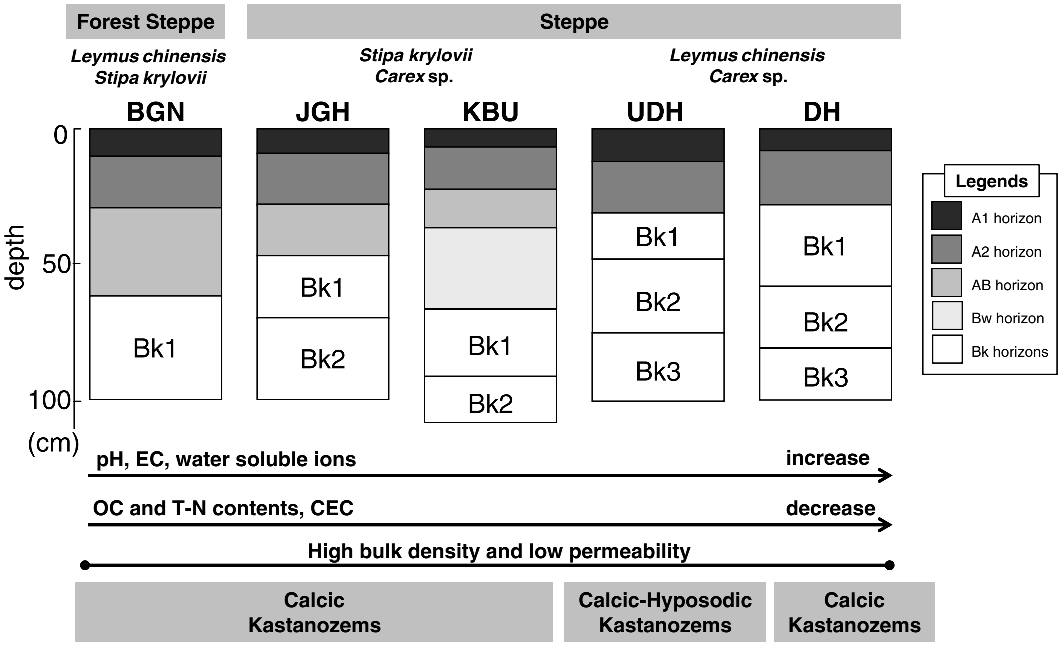

Figure 2 Schematic diagram of the morphology and physico-chemical characteristics of the studied soils.

has also suggested the possibility that groundwater in the BGN region is recharged by soil water affected by evaporation (Tsujimura et al., 2006). However, in the DH region, the groundwater is preferentially recharged by precipitation exceeding a certain amount.

Fig. 2 summarizes the morphology and physico-chemical characteristics of the studied soils. At drier sites, soil degradation caused by grazing is more advanced due to low precipitation, thin vegetation cover, and soil compaction (Opp et al., 2000). The present morphology and physico-chemical characteristics suggest that even if the same soil degradation were to occur throughout this river basin, the grassland ecosystems in UDH and DH would be more heavily damaged and require more time for reclamation than soils in BGN, JGH, and KBU, although the five soils were classified as Kastanozems, essentially in the same soil group. These differences reflect differences in the thickness of the A horizon and the depth of the $CaCO_3$ accumulation horizon, which is characterized by an alkaline and high salt content.

Conclusion

The floristic compositions showed differences in moisture conditions among the study sites and the effect of grazing. The profile morphologies characterized the presence of a mollic horizon and $CaCO_3$ accumulation horizon. The depth of the $CaCO_3$ accumulation horizon appeared shallower with a high aridity index. The soils were classified as Calcic Kastanozems and Calcic Hyposodic Kastanozems. Although the physico-chemical properties of the A horizons were not very different, there was a significant difference in the inorganic carbon content, pH, EC, exchangeable bases, and water soluble ions in the $CaCO_3$ accumulation horizons. The amount of exchangeable bases and water soluble ions tended to increase with Na^+, SO_4^-, and Cl^- in the $CaCO_3$ accumulation horizon at sites with a higher aridity index. These differences reflect the amount of precipitation and potential evapotranspiration at each study site.

Acknowledgements

We thank M. Sugita and M. Tsujimura of the Graduate School of Life and Environmental Sciences, University of Tsukuba, Japan; S. Li, T. Sato and Y. Sawaguchi of the Japan Science and Technology Agency; and all members of the RAISE project for their helpful suggestions and support during the field survey. We also thank G. Davaa, D. Oyunbaater and P. Gambold of the Institute of Meteorology and Hydrology, Mongolia, for their help in the field survey and collecting the soil samples in Mongolia, and K. Morisada of the Forestry and Forestry Products Research Institute for providing variable suggestions. We also thank Mr. M. Fukano and all members of the Laboratory of Environmental Soil Science, University of Tsukuba, for supporting the collection of soil samples and the experiments. This study was supported by the Japan Science and Technology Agency through a grant under the Core Research for Evolutional Science and Technology (CREST) program funded by the RAISE project. Partial support also came from the Global Environment Research Fund of the Ministry of the Environment, Japan.

References

Araki, M., Kawada, K., 2004. Detailed regionalization of aridity in an Inner Mongolia Autonomous Region. Jpn. J. Environ. 46, 103—109 (in Japanese).

Arkley, R.J., 1963. Calculation of carbonate and water movement in soil from climatic data. Soil Sci. 96, 239—248.

Batima, P., Bolortsetseg, B., Mijiddorj, P., Tumerbaatar, D., Ulziisaihan, V., 2000. Impact on natural resource base. In: Batima, P., Dagvadorj, D. (Eds.), Climate Change and Its Impact in Mongolia. JEMR Publishing, Ulaanbaatar, pp. 46—93.

Bayasgalan, Sh., Bolortsetseg, B., Dorj, B., Natsagdorj, L., Tuvaansuren, G., 2000. Impact on agriculture. In: Batima, P., Dagvadorj, D. (Eds.), Climate Change and Its Impact in Mongolia. JEMR Publishing, Ulaanbaatar, pp. 96—199.

Bolt, G.H., Bruggenwert, M.G.M., 1976. Soil Chemistry A. Basic Elements, second ed. Elsevier, Amsterdum, 281 pp.

Chuluun, T., Ojima, D., 2001. Sustainability of Pastoral Systems in Mongolia. In: Proceedings of the Symposium on Change and Sustainability of Pastoral Land Use Systems in Temperate and Central Asia. Interpress, Ulaanbaatar, pp. 52—57.

Clark, N.A., Ogg, C.L., 1942. A wet combustion method for determining total carbon in soils. Soil Sci. 53, 27—35.

Committee of flora of Inner Mongolian, 1989-1998. Flora of Inner Mongolia, vol. 5, second ed., Inner Mongolian popular Press. Huhhot, (in Chinese).

Committee of Soil Environment Analysis, 1997. Methods for Soil Environment Analysis. Hakuyu-sya, Tokyo, 427 pp. (in Japanese).

Dordschgotov, D., 2003. Soils of Mongolia. Admon, Ulaanbaatar, 287 pp. (in Mongolia).

Driessen, P., Deckers, J., Spaargaren, O., 2001. Lecture notes on the major soils of the world. World Soil Reports 94, FAO, Rome, 334 pp.

FAO, 1990. Guideline for Soil Description third ed. FAO, Rome, 70 pp.

FAO, ISRIC, ISSS, 1998. World reference base for soil resources. World Soil References Reports 84, FAO, Rome, 88 pp.

Gunin, P.D., Miklyaeva, I.M., Bazha, S.N., Severtsov, A.N., 2001. Succession dynamics of rangeland ecosystems of Mongolia. In: Chuluun, D., Ojima, D. (Eds.), Fundamental Issues Affecting Sustainability of the Mongolian Steppe. Interpress, Ulaanbaatar, pp. 122—140.

Marion, G.M., Schlesinger, W.H., Fonteyn, P.J., 1985. Caldep: a regional model for soil $CaCO_3$ (caliche) deposition in southwestern deserts. Soil Sci. 139, 468—479.

Matsumoto, S., Cho, T., 1985. Field investigations on the agricultural development of arid region in Iran. III. Soil profile investigations of salt accumulation related to the depth of groundwater level. J. Fac. Agric. Tottori Univ. 20, 86—97.

Miegroet, H.V., Boettinger, J.L., Baker, M.A., Nielsen, J., Evans, D., Stum, A., 2005. Soil carbon distribution and quality in a montane rangeland-forest mosaic in northern Utah. Forest Ecol. Manag. 220, 284—299.

Nakamura, T., Go, T., Li, Y., Hayashi, I., 1998. Experimental study on the effects of grazing pressure on the floristic composition of a grassland of Baiyinxile, Xilingol, Inner Mongolia. Veg. Sci. 15, 139—145.

Nakamura, T., Go, T., Wuyunna, Hayashi, I., 2000. Effects of grazing on the floristic composition of grassland in Baiyinxile, Xilingole, Inner Mongolia. Grassland Sci. 45, 342—350.

Natsagdorji, L., 2000. Climate Change. In: Batima, P., Dagvadorj, D. (Eds.), Climate Change and its impact in Mongolia. JEMR Publishing, Ulaanbaatar, pp. 14—43.

Nemoto, M., Lu, X., Li, S., Jiang, M., Liu, X., 1992. Influence of live stock grazing on vegetation at sand dunes in semi-arid Eastern Inner Mongolia, China. J. Jpn. Grassl. Sci. 38, 44—52 (in Japanese with English abstr.).

Numata, M., 1987. Papers on plant ecology. Tokai Univ. Press, Tokyo, pp. 50—167, (in Japanese).

Opp, C., Haase, D., Khakimov, V., 2000. Soils and soil processes in the Tyvinian part of the Uvs-noor basin. Pol. J. Soil Sci. xxxIII/2, 71—80.

Pogue, D.W., Schnell, G.D., 2001. Effects of agriculture on habitat complexity in a prairie-forest ecotone in the Southern Great Plains of North America. Agricul. Ecosyst. Environ. 87, 287—298.

Sasaki, T., Okayasu, T., Takeuchi, K., Undarmaa, J., Sanjid, J., 2005. Patterns of floristic composition under different grazing intensities in Blugan, South Govi, Mongolia. Grassland Sci. 51, 235—242.

Sellers, P.J., Meeson, B.W., Closs, J., Collatz, J., Corprew, F., Hall, F.G., Kerr, Y., Koster, R., Kos, S., Mitchell, K., McManus, J., Myers, D., Sun, K.-J., Try, P., 1995An overview of the ISLSCP Initiative I Global Data Sets ISLSCP Initiative I Global Data Sets for Land-Atmosphere Models, 1—5. NASA, CD-ROM.

Sugita, M., 2003. Interaction between hydrologic cycle and ecological system. Sci. J. Kagaku 73, 559—562, in Japanese.

Sugita, M., Asanuma, J., Tsujimura, M., Mariko, S., Lu, M., Kimura, F., Azzaya, D., Adyasuren, Ts., 2006. An overview of the rangelands atmosphere—hydrosphere interaction study experiment in Northeastern Asia (RAISE). J. Hydrol., doi:10.1016/j.jhydrol.2006.07.032.

Takeuchi, K., Katoh, K., Nan, Y., Kou, Z., 1995. Vegetation cover change in desertified Kerqin sandy lands, Inner Mongolia. Geogr. Rep. Tokyo Metropolitan University 30, 1—24.

Tsujimura, M., Tanak, T., Abe, Y., Shimada, J., Higuchi, S., Yamanaka, T., Sato, T., 2006. Stable istropic and geochemical characteristics of groundwater in Kherlen River basin, a semi-arid region in eastern Mongolia. J. Hydrol., doi: 10.1016/j.jhydrol.2006.07.026.

Wuyunna, Cheng, Y., Okamoto, K., Taniyama, I., 2004. Structural change in steppe vegetation community according to grazing gradient in semiarid regions of Inner Mongolia, China. J. Jpn. Agric. Syst. Soc. 20, 160—167 (in Japanese with English abstr.).

Yamamoto, Y., Kirita, H., Ohga, N., Saito, Y., 1995. Extended summed dominance ratio. E-SDR. For comparison of grassland vegetation. Grass. Sci. 41, 37—41 (in Japanese with English abstr.).

Yiruhan, Hayashi, I., Nakamura, T., Shiyomi, M., 2001. Changes in floristic composition of grasslands according to grazing intensity in Inner Mongolia, China. Grass. Sci. 47, 362—369.