Photosynthetic pathways and life form types for native plant species from Hulunbeier Rangelands, Inner Mongolia, North China

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Abstract

Photosynthetic pathway types (C_3, C_4, and CAM) and life forms of native species from Hulunbeier rangelands, north China were studied. Of the total 258 species, 216 species in 132 genera and 42 families had C_3 photosynthetic pathway, including dominant herbs, *e.g.* *Stipa baicalensis* Roshev. and *Leymus chinensis* (Trin.) Tzvel., *Filifolium sibiricum* Kitam. and *Arudinella hirta* (Thunb.) Koidz. 38 species in 28 genera and 10 families were found with C_4 photosynthesis, and 4 species in 2 genera and 1 family had CAM photosynthetic pathway. The occurrence of C_4 species was common in *Gramineae* and *Chenopodiaceae*, and the two families were leading ones within C_4 plants. More than 52 % of the total 258 species were in H form, 21 % in Th form, 19 % in G form; the other life form types, *e.g.* Ch, M, N, and HH, formed less than 3 %. 68 % of C_4 species were in Th form and 24 % in H form, indicating that these types were the dominant life forms for C_4 species in the rangeland region. The occurrence of C_4 species was closely related with plant habitats, disturbed lands had the highest C_4 abundance (55 % of the total C_4 species), followed by grasslands and sandy soil, and forests had the lowest C_4 abundance (8 %). Hence the occurrence of C_4 species could be efficient indicator for rangeland dynamics in Hulunbeier rangelands.

Additional key words: C_3, C_4 and CAM plants; meadow and steppe.

Introduction

Hulunbeier region (47°20'–50°12'N, 118°31'–121°03'E) covers an area of about 84 000 km^2 in the northeastern Inner Mongolia, China, about 85 % of which is rangelands. This type of rangelands has been grazed by nomadic herds for centuries. The high palatability of herbs with herbage production superior both in quality and quantity makes the rangelands ideal for grazing and forage in north China. More recently, sedentary agriculture has resulted in heavier grazing pressure and farm cultivation, which have led to increased soil erosion and desertification, an apparent deterioration in rangeland quality and productivity (Zhang and Liu 1992). Within the past 5 years there has been a move toward greater regulation of rangeland management in order to reduce rangeland deterioration and permit its sustainable utilization, as well as to improve the local environments. Such rangeland management regulation (*e.g.* warm season, cool season, and farm cultivation) must ultimately be based on scientific principles and will require more knowledge of the rangelands, *e.g.* rangeland vegetation types, dynamics, and photosynthetic pathway compositions. Previous researches on this type of rangelands mainly focused on rangeland classification (Pan 1992, Zhang and Liu 1992, Zhu 1993) and rangeland grazing (Li and Xiao 1965), but the photosynthetic pathway types, life forms, and their roles in rangeland management decision remain unclear.

Classification of photosynthetic pathway types and analysis of their relation to climatic patterns have been well documented for many vegetation types (Downton 1975, Teeri and Stowe 1976, Raghavendra 1978, Teeri *et al*. 1980, Takeda and Hakoyama 1985, Collins and Jones 1985, Ueno and Takeda 1992, Li 1993, Redmann *et al.* 1995, Collatz *et al*. 1998, Pyankov *et al.* 2000). Some studies deal with the relations between photosynthetic pathway types and land use (Williams and Markley 1973, Redmann *et al.* 1995, Wang 2002a,d), but only a few look at the relationships of the photosynthetic pathway types with life forms (Wang 2002b,c). Observations showed that photosynthetic pathway types combined with life forms could be efficient indicators for rangeland dynamics. The objective of the present study was to investigate the photosynthetic pathway types and life forms

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for the native plant species from Hulunbeier rangelands, north China. This study may bring new information for better understanding C_3 and C_4 plants in the region and their relations with rangeland ecosystems and land use.

Materials and methods

The study was conducted in Hulunbeier rangelands, a typical rangeland region distributed at the eastern end of the Eurasian steppe zone, with the main location in China being the eastern part of Inner Mongolia. The elevations of the rangelands vary from 600 m in the west to 1 000 m in the east. Local vegetation has been classified as temperate meadow and steppe, humid rangelands dominated by meso-xerophytes and associated mesophytes. Common dominant species in the rangelands are *Stipa baicalensis* Roshev. and *Leymus chinensis* (Trin.) Tzvel., and subdominants *Filifolium sibiricum* Kitam. and *Arudinella hirta* (Thunb.) Koidz. Most of the region has mountain dark brown chernozem and chestnut soils from the east to the west or from grassland–forest ecotone to typical steppe. The main characteristics of the climate of the region are cold, dry, and frequently windy spring; cool and short summer; early autumn frosts; and long cold winter with much snowfall. Mean air temperature varies from –26 °C in January to 19 °C in July. Moisture gradient is very steep, with annual precipitation varying from 450 mm in the east forests to 250 mm in the west steppes, of which 70–80 % falls between June and August (Zhang and Liu 1992).

Floristic species were obtained from both field survey and references published from 1980 to 2002 (Commissione Redactorum Flora Intramongolicae 1980, Pan 1992, Chen and Jia 2002). Photosynthetic pathway types for the plant species were determined by stable carbon isotope ratio ($\delta^{13}C$) and from the references published between 1985 and 2002 (*e.g.* Takeda and Hakoyama 1985, Pan 1992, Li 1993, Redmann *et al.* 1995, Yin and Li 1997, Pyankov *et al.* 2000, Wang 2002b,c). Plants with $\delta^{13}C$ values above –19 ‰ were considered to have the C_4 photosynthetic pathway, and those with $\delta^{13}C$ values less than –21 ‰ to have C_3 photosynthesis (Redmann *et al.* 1995, Yin and Li 1997). Plants identified in the region were classified into seven life form types: hemicryptophyte (H), geophyte (G), therophyte (Th), chamaephyte (Ch), macrophanerophyte (M), nanophanerophyte (N), and hydrogeophyte (HH) (Li 1979, Wang 2002b,c). Plant distribution habitats were classified into five main types: frost (FO), grassland (GL), disturbed land (DB), sandy soil (SS), and wetland (WL) (Table 1).

Results

Rangeland floristic composition: 258 vascular plant species, about 20 % of the total species identified in the Hulunbeier rangelands, in 155 genera and 46 families were selected into those having C_3, C_4, and CAM photosynthesis (Table 1). One species (*Ephedra sinica* Stapf.) was identified in *Gymnospermae*, the others in *Angiospermae*. Of the total 257 *Angiospermae* species, 182 species were found in *Dicotyledoneae*, *e.g.* *Compositae* (46 species), *Fabaceae* (21 species), *Chenopodiaceae* (17 species), *Rosaceae* (14 species), and *Ranunculaceae* (11 species). 75 species belang to *Monocotyledoneae*, *e.g.* *Gramineae* (50 species), *Cyperaceae* (9 species), and *Liliaceae* (9 species). As for photosynthetic pathway types, 216 species in 132 genera and 42 families were found with C_3 photosynthesis, 38 species in 28 genera and 10 families with C_4 photosynthesis, and 4 species in 2 genera and 1 family with CAM photosynthesis (Table 1). The number of C_4 species was no more than 3 % of the total plant species identified in local flora, even though it was about 15 % of those listed in Table 1. For the 182 *Dicotyledoneae* species listed in Table 1, 90 % was C_3 species, 8 % was C_4 species, and 2 % was CAM species. Of the 75 *Monocotyledoneae* species, however, 31 % were with C_4 photosynthesis, the other 69 % with C_3 photosynthesis. This indicated that the occurrence of C_4 species in *Monocotyledoneae* was as high as about 4 times that in *Dicotyledoneae* in the region.

The occurrence of C_4 species in the rangeland region was common in *Chenopodiaceae* (47 % of the total *Chenopodiaceae* species), *e.g.* *Kochia prostrata* (L.) Schrad., *K. scoparia* (L.) Schrad., *K. sieversiana* (Pall.) C.A. Mey., *Salsola collina* Pall., and *S. pestifer* A. Nelson, and in *Gramineae* (46 % of the total grasses), *e.g.* *Digitaria ciliaris* (Rotz.) Koel., *Eragrostis pilosa* (L.) P.B., *E. poaeoides* Beauv., *Eriochloa villosa* (Thunb.) Kunth L. Most of the C_4 species in these two families were annual species, some of them having great tolerance to arid environments. 74 % of the total C_4 species identified in Hulunbeier rangelands belong to *Gramineae* (53 % or 20 of 38) and *Chenopodiaceae* (21 % or 8 of 38), suggesting that these two families are the leading families with C_4 metabolism.

Plant life form types and distribution patterns: There were seven life form types for the plants from Hulunbeier rangelands (Fig. 1*A*). More than half (54 %) of the total 258 species were hemicryptophytes (H), and 6.5 % of H formed species with C_4 photosynthesis. In the rangeland region, therophyte (Th) was the second leading life form type, about 21 % of the total species in Table 1, but half of the Th form species were C_4 plants, which was about 68 % of the total C_4 species (Fig. 1*B*, Table 1). Of the total 258 species, 10 % was the Th form C_4 species, while for the H form it was only 3.5 %. Only one C_4 species

Table 1. Photosynthetic pathway types (C_3, C_4, and CAM), life forms, and habitats in the Hulunbeier rangelands, China. Life forms: H = hemicryptophyte, G = geophyte, Th = therophyte, Ch = chamaephyte, M = macrophanerophyte, N = nanophanerophyte, HH = hydrogeophyte. Habitat types: FO = frost, GL = grassland, DB = disturbed land, SS = sandy soil, WL = wet land.

	Species	C_3 / C_4	Life form	Habitat
Gymnospermae				
Ephedraceae	*Ephedra sinica* Stapf.	C_3	Ch	GL
Angiospermae				
Dicotyledoneae				
Amaranthaceae	*Amaranthus ascendens* Loisel.	C_4	Th	DB
	A. retroflexus L.	C_4	Th	DB
Asclepiadaceae	*Cynanchum amplexicaule* Hemsl.	C_3	G	GL
	C. chinensis R. Br.	C_3	G	GL
	C. thesioides (Freyn) K. Schum.	C_3	G	GL FO
	Pycnostelma paniculatum K. Schum.	C_3	G	SS FO
Betulaceae	*Betula dahurica* Pall.	C_3	M	FO
Bignoniaceae	*Incarvillea sinensis* Lamark.	C_3	Th	SS DB
Boraginaceae	*Cynoglossum divaricatum* Steph.	C_3	G	SS DB FO
	Lappula myosotis Moench	C_3	H	SS DB FO
Campanulaceae	*Adenophora stenanthina* (Ledeb.) Kitag.	C_3	G	SS FO
	A. stenophylla Hemsl.	C_3	G	SS FO
	Platycodon grandiflorum DC.	C_3	G	FO
Caryophyllaceae	*Dianthus amurensis* Jacq.	C_4	H	GL
	D. chinensis L.	C_3	H	GL FO
	Silene repens Pall.	C_3	H	SS FO
Chenopodiaceae	*Agriophyllum arenarium* Bieb.	C_4	Th	SS DB
	Axyris amaranthoides L.	C_3	Th	DB SS
	Bassia dasyphylla (Fisch. *et* Mey.) Kuntze	C_4	Th	SS DB
	Chenopodium acuminatum Will.	C_3	Th	DB
	C. album L.	C_3	Th	DB
	C. album. L. var. *stenophyllum* Makono	C_3	Th	DB
	C. aristatum L.	C_3	Th	DB
	C. glaucum L.	C_3	Th	DB GL
	Corispermum mongolicum Iljin	C_3	Th	SS FO
	Kochia prostrata (L.) Schrad.	C_4	Ch	SS FO
	K. scoparia (L.) Schrad.	C_4	Th	GL
	K. sieversiana (Pall.) C.A. Mey.	C_4	Th	GL
	Salsola collina Pall.	C_4	Th	DB
	S. komarovii Iljin	C_4	Th	DB
	S. pestifer A. Nelson	C_4	Th	DB FO
	Suaeda corniculata (C.A. Mey.) Bunge	C_3	Th	GL
	S. glauca Bunge	C_3	Th	GL
Compositae	*Artemisia anethifolia* Weber	C_3	H	GL
	A. anethoides Mattf.	C_3	H	GL
	A, annua L.	C_3	H	DB
	A. argyi Levl. *et* Vant.	C_3	H	GL FO
	A. desertorum Spreng.	C_3	H	SS GL
	A. dracunculus L.	C_3	H	GL FO
	A. eriopoda Bunge	C_3	H	FO
	A. frigida Willd.	C_3	Ch	GL
	A. integrifolia L.	C_3	H	GL FO
	A. japonica Thunb. var. *manshurica* Kom.	C_3	H	GL SS
	A. laciniata Willd.	C_3	H	GL
	A. mongolica Fisch.	C_3	H	GL DB
	A. ordosica Krasch.	C_3	Ch	SS FO
	A. oxycephala Kitag.	C_3	Ch	SS FO
	A. pectinata Pall.	C_3	H	GL SS

Table 1 (continued)

	Species	C_3 / C_4	Life form	Habitat
Compositae (cont.)	*A. scoparia* Waldst. *et* Kit.	C_3	H	DB GL
	A. selengensis Turcz. *ex* Bess.	C_3	H	GL
	A. sieversiana Willd.	C_3	H	DB
	Aster alpinus L.	C_3	H	GL
	Cirsium pendulum Fisch.	C_3	H	DB
	Echinops gmelini Turcz.	C_3	G	SS GL
	E. latifolius Tausch.	C_3	G	SS GL
	Filifolium sibiricum Kitam.	C_3	H	GL
	Heteropappus altaicus (Willd.) Novopokr.	C_3	H	GL SS
	Inula britanica L.	C_3	H	GL WL
	I. japonica Thunb.	C_3	H	GL WL
	Ixeris chinensis Nakai subsp. *graminifolia* Kitag.	C_3	H	DB
	I. chinensis Nalai var. *intermedia* Kitag.	C_3	H	DB
	I. sonchifolia Hance	C_3	H	DB
	Lactuca indica L.	C_3	G	DB WL
	Leontopodium leontopodioides Reauv.	C_3	H	GL SS
	Ligularia jamesii (Hemsl.) Kom.	C_3	H	GL
	L. mongolica (Turcz.) DC.	C_3	H	GL
	Neopallasia pectinata (Pall.) Polijak	C_3	Th	GL
	Olgaea leucophylla (Turcz.) Iljin	C_3	H	SS WL GL
	Picris japonica Thunb.	C_3	H	GL
	Saussurea japonica (Thunb.) DC.	C_3	G	GL DB
	S. runcinata DC.	C_3	G	GL
	Scorzonera glabra Rupr.	C_3	H	GL SS
	Senecio ambracens Turcz.	C_3	H	GL DB
	S. integrifolius Claiville.	C_3	H	DB
	Serratula komarovii Iljin	C_3	G	GL SS
	Taraxacum mongolicum Hand.	C_3	H	GL DB
	T. ohwianum Kitam.	C_3	H	GL DB
	Xanthium strumarium L.	C_3	Th	DB
	Youngia tenuifolia (Willd.) Babc. *et* Stebb.		H	SS
Convolvulaceae	*Calystegia pellita* Ledeb.	C_3	G	GL WL
Crassulaceae	*Orostachys fimbriatus* (Turcz.) Berger	CAM	Th	SS
	O. malacophyllus (Pall.) Fisch.	CAM	Th	SS
	O. spinosus (L.) C.A. Mey.	CAM	Th	SS
	Sedum aizoon L.	CAM	H	GL WL
Cruciferae	*Dontostemon dentatus* Ldb.	C_3	H	SS DB
	D. micranthus C.A. Mey.	C_3	H	SS DB
	Lepidium apetalum Willd.	C_3	H	DB
	Ptilotrichum canescens (DC.) C.A. Mey.	C_3	N	SS
Dipsacaceae	*Scabiosa comosa* Fisch. *ex* Roem. *et* Schult.	C_3	H	GL SS
	S. tschiliensis Grunnin	C_3	H	GL SS
Euphorbiaceae	*Euphorbia esula* L.	C_3	G	GL
	E. humifusa Willd.	C_4	Th	GL
Fabaceae	*Astragalus adsurgens* Pall.	C_3	H	GL SS
	A. melilotoides Pall.	C_3	H	SS GL
	A. scaberrimus Bunge	C_3	H	GL
	Caragana microphylla Lam.	C_3	N	SS FO
	C. stenophylla Pojark.	C_3	N	SS FO
	Gueldensfaedtia stenophylla Bunge	C_3	H	GL
	Kummerowia stipulacea (Maxim.) Makino	C_3	Th	GL
	K. striata (Thunb.) Schindler	C_3	Th	GL
	Lespedeza davurica Schindler	C_3	Ch	GL SS
	Medicago falcate L.	C_3	H	GL
	Melilotus suaveolens Ledeb.	C_3	H	GL
	Melilotoides ruthenica (L.) Sojak	C_3	H	GL
	Oxytropis filiformis DC.	C_3	H	GL SS

Table 1 (continued)

	Species	C_3 / C_4	Life form	Habitat
Fabaceae (cont.)	*O. hirta* Bunge	C_3	H	GL SS
	O. myriophylla DC.	C_3	H	GL SS
	Thermopsis lanceolata R.Br.	C_4	H	SS
	Trifolium lupinaster L.	C_3	H	GL
	T. pratense L.	C_3	H	GL
	T. repens L.	C_3	H	GL
	Vicia multicaulis Ledeb.	C_3	H	GL WL
	V. unijuga R.Br.	C_3	H	GL WL
Geraniaceae	*Erodium stephanianum* Willd.	C_3	G	DB SS
Labiatae	*Elsholtzia ciliata* (Thunb.) Hyland.	C_3	H	GL FO
	Phlomis tuberosa L.	C_3	H	GL
	P. umbrosa Turcz.	C_3	H	GL
	Prunella asiatica Nakai	C_3	H	GL
	Schizonepeta multifida (L.) Briq.	C_3	Th	SS
	Scutellaria baicalensis Georgi	C_3	G	GL SS
	S. ikonnikovii Juz.	C_3	G	GL SS
	S. scordifolia Fisch.	C_3	G	SS
	Thymus serphyllum L.	C_3	Ch	SS DB
Linaceae	*Linum stelleroides* Planchon	C_3	Th	SS GL
Moraceae	*Cannabis sativa* L. f. *ruderalis* Chu	C_3	Th	DB
Orobanchaceae	*Orobanche caerulescens* Stephan	C_3	Th	SS
Papaveraceae	*Papaver nudicaule* L.	C_3	H	SS FO
Plantaginaceae	*Plantago asiatica* L.	C_3	H	GL DB
	P. depressa Willd.	C_3	H	GL DB
Plumbaginaceae	*Limonium bicolor* O. Kuntze	C_3	H	GL DB
Polygalaceae	*Polygala tenuifolia* Willd.	C_3	H	GL SS
Polygonaceae	*Polygonum aviculare* L.	C_3	Th	DB WL
	P. divaricatum L.	C_3	H	GL DB
	P. sibiricum Laxm.	C_3	G	GL
Portulacaceae	*Portulaca oleracea* L.	C_4	Th	DB
Primulaceae	*Glaux maritima* L.	C_3	Th	WL
Ranunculaceae	*Clematis hexapetala* Pall.	C_3	G	SS GL
	C. mandshurica Ruor.	C_3	G	SS FO
	Delphinium grandiflorum L.	C_3	G	SS FO
	Paeonia lactiflora Pall.	C_3	G	FO
	P. obovata Maxim.	C_3	G	FO
	Pulsatilla tuczaninovii Kryl. *et* Setg.	C_3	G	GL SS
	P. koreana Nakai	C_3	G	GL SS
	Ranunculus japonicus Thumb.	C_3	G	GL
	Thalictrum minus L.	C_3	G	GL FO SS
	Th. simplex L.	C_3	G	GL FO SS
	Th. squarrosum Steph. *ex* Willd.	C_3	G	SS FO
Rosaceae	*Geum aleppicum* Jacq.	C_3	H	GL WL
	Potentilla acaulis L.	C_3	H	GL
	P. anserina L.	C_3	H	GL
	P. betonicaefolia Poiret	C_3	H	GL
	P. chinensis Seringe	C_3	H	GL
	P. confetta Bunge	C_3	H	GL
	P. discolor Bunge	C_3	H	GL
	P. filipendula Willd.	C_3	H	GL
	P. flagellaris Willd.	C_3	H	GL
	P. verticillaris Steph.	C_3	H	GL
	Prunus sibirica (L.) Lam.	C_3	N	SS FO

Table 1 (continued)

	Species	C_3 / C_4	Life form	Habitat
Rosaceae (cont.)	*Sanguisorba officinalis* L.	C_3	H	GL WL
	S. tenuifolia Fisch	C_3	H	GL WL
	Spiraea aquilegifolia Pall.	C_3	N	FO
Rubiaceae	*Galium verum* L.	C_3	H	GL
Rutaceae	*Haphophyllum dauricum* Juss	C_3	H	GL
Saxifragaceae	*Ribes diacantha* Pall.	C_3	N	FO
Scrophulariaceae	*Cymbaria dahurica* L.	C_3	H	SS GL DB
	Linaria vulgaris Mill.	C_3	H	GL
	Pedicularis rubens Steph. *ex* Willd.	C_3	H	DB WL
	Veronica incana L.	C_3	H	SS DB
	V. linearifolia Pall.	C_3	H	SS DB
Solanaceae	*Datura stramonium* L.	C_3	Th	DB
	Solanum nigrum L.	C_3	Th	DB
Thymelaeaceae	*Diarthron linifolium* Turcz.	C_3	Th	SS
	Stellera chamaijasme L.	C_3	H	SS GL
Umbelliferae	*Bupleurum chinense* DC.	C_3	H	GL FO
	B. scorzonerifolium Willd.	C_3	H	SS GL FO
	Carlesia sinensis Dunn	C_3	H	SS
	Heracleum moellendorffii Hance	C_3	H	SS
	Sphallerocarpus gracilis (Bess.) K.	C_3	H	GL SS
	Siler divaricatum Benth. *et* Hook	C_3	G	GL SS
Urticaceae	*Urtica cannabina* L.	C_3	H	DB WL
Violaceae	*Viola dissecta* Ledeb.	C_3	H	GL
Zygophyllaceae	*Tribulus terrestris* L.	C_4	Th	DB
Monocotyledoneae				
Commelinaceae	*Commelina communis* L.	C_4	Th	DB
Cyperaceae	*Bolboschoenus compactus* Heffm.	C_3	HH	WL
	Carex duriuscula C.A.M.	C_3	H	GL WL
	C. lanceolata Boott	C_3	H	GL
	C. pediformis C.A.M.	C_4	H	GL
	Cyperus difformis L.	C_3	H	GL WL
	C. fuscus L.	C_3	H	GL WL
	C. glomeratus L.	C_4	Th	WL GL
	C. orthostachyus Franch. *et* Sav.	C_3	H	GL WL
	Scirpus tabernaemontani Gmel.	C_3	HH	WL
Gramineae	*Achnatherum sibiricum* (L.) Keng	C_3	H	GL
	A. splendens (Trin.) Nevski	C_4	H	GL
	Agropyron cristatum (L.) Gaertner	C_3	H	GL SS
	A. desertorum (Fisch.) Schult.	C_3	H	SS GL
	Agrostis alba L.	C_3	H	GL DB
	Alopecurus pratensis L.	C_3	Th	DB
	Arthraxon hispidus (Thunb.) Makino	C_4	H	DB WL
	Arundinella hirta (Thunb.) Tanaka	C_4	H	GL WL
	Avena fatua L.	C_3	Th	DB
	Beckmannia syzigachne (Steud.) Fern.	C_3	Th	GL
	Bromus inermis Leyss.	C_3	H	GL
	Calamagrostis epigeios (L.) Roth	C_3	H	GL WL
	C. macrolepis Litv.	C_3	H	GL
	Chloris virgata Sw.	C_4	Th	GL WL
	Cleistogenes chinensis (Maxim.) Keng	C_4	H	GL
	C. squarrosa (Trin.) Keng	C_4	H	GL
	Clinelymus sibiricus (L.) Nevski	C_3	H	GL
	Deschampsia caespitosa (L.) Beauv.	C_3	H	GL

Table 1 (continued)

	Species	C_3 / C_4	Life form	Habitat
Gramineae (cont.)	*Digitaria ciliaris* (Rotz.) Koel	C_4	Th	DB
	D. ischaemum (Schreb.) Schreb. *ex* Muhl.	C_4	Th	DB
	Echinochloa crusgalli (L.) Beauv.	C_4	Th	DB WL
	E. crusgalli (L.) Beauv. var. *caudata* Kitag.	C_4	Th	DB WL
	Eragrostis pilosa (L.) P.B.	C_4	Th	DB
	E. poaeoides Beauv.	C_4	Th	DB GL
	Eriochloa villosa (Thunb.) Kunth L.	C_4	Th	DB
	Festuca ovina L.	C_3	H	GL
	Hemarthria compressa R.Br. var. *fasciculata* Keng	C_4	HH	WL
	Hierochloe glabra Trin.	C_3	H	GL
	Hordeum brevisubulatum (Trin.) Link	C_3	H	GL
	Koeleria cristata (L.) Pers.	C_3	H	GL
	Leymus chinensis (Trin.) Tzvel	C_3	H	GL
	L. dasystachys (Trin.) Nevski	C_3	H	GL
	Miscanthus sacchariflorus (Maxim.) Hack.	C_4	H	GL SS
	Panicum ruderale (Kitag.) Cheng	C_4	Th	DB
	Pennisetum flaccidum Griseb.	C_4	G	SS DB
	Phleum phleoides (L.) Simk.	C_3	H	GL
	Phragmites communis Trin.	C_3	HH	WL
	Poa pratensis L.	C_3	H	GL
	Puccinellia chinampoensis Ohwi.	C_3	H	GL
	P. jeholensis Kitag.	C_3	H	GL
	P. tenuiflora (Turcz.) Scrib. *et* Merr.	C_3	H	GL WL
	Roegneria ciliaris (Trin.) Nevski	C_3	H	GL
	R. kamoji Ohwi	C_3	H	GL
	Setaria lutescens (Weigel) F.T. Hubb.	C_4	Th	DB
	S. viridis (L.) Beauv.	C_4	Th	DB
	Spodiopogon sibiricus Trin.	C_4	Th	GL FO
	Stipa baicalensis Roshev.	C_3	H	GL
	S. grandis P. Smirn.	C_3	H	GL
	S. krylovii Roshev.	C_3	H	GL SS
	Tripogon chinensis (Fr.) Hack.	C_3	H	GL SS
Iridaceae	*Iris dichotoma* Pall.	C_3	G	GL DB
	I. pallasii Fisch.	C_3	G	GL
	I. ruthenica Ker-Gawl.	C_3	G	GL
	I. tenuifolia Pall.	C_3	G	GL SS
	I. ventricosa Pall.	C_3	G	GL
Liliaceae	*Allium condensatum* Turcz.	C_3	G	GL
	A. macrostemon Bunge	C_3	G	DB
	A. polyrrhizum Turcz.	C_3	G	GL DB
	A. senescens L.	C_3	G	GL
	A. tenuissimum L.	C_3	G	GL
	Anemarrhena asphodeloides Bunge	C_3	G	GL SS
	Asparagus davurica Fisch.	C_3	G	SS
	Lilium tenuifolium Fisch.	C_3	G	GL
	Scilla thunbergii Miyabe *et* Kudo	C_3	G	GL WL
Typhaceae	*Typha minima* Funk	C_3	HH	WL

was found in each of the geophyte (G), chamaephyte (Ch), and hydrogeophyte (HH) forms, even though there were generally 48 species in the G form. No C_4 species was found in macrophanerophyte (M) and nanophanerophyte (N) forms in the Hulunbeier rangelands.

Photosynthetic pathway type compositions were consistent with habitat conditions in Hulunbeier rangelands (Fig. 2). Of the total 258 species, 162 species (63 %) were found distributed in grasslands, *e.g.* meadow and steppe, 9 % of the grassland species were C_4 plants. 79 species were distributed in sandy soil, *e.g.* in fixed dunes and mobile dunes, and only 8 % were C_4 species. However, 30 and 20 % of the species distributed in disturbed land (69 species) and wetland (35) were found with C_4 photosynthesis, respectively. The occurrence of C_4 species in forest habitats was less than 9 % in the region.

Relatively more C_4 species in disturbed land suggested that this type plants have greater tolerance to environmental stress, because the disturbed land may be characterized by a lower soil moisture, poor nutrition, and higher evaporation.

Discussion

Hulunbeier rangeland region is one of the important rangeland regions in north China, due to its large and high quality pastures (Zhang and Liu 1992). Scientific studies on the rangelands, however, were much less common than those on the Xilingol steppes and the Songnen grasslands. This might lead to blindness in making rangeland management decisions. The identification of photosynthetic pathway and plant life form types may bring new information for better understanding the rangelands and rangeland management decisions. Complicated relief (elevation range of 600–1 000 m) and vegetation types (*e.g.* forests, meadows, and steppes) in the region may result in relatively large species abundance: 1 380 vascular plant species in 570 genera and 108 families were identified in the rangeland region. The total number of native plant species in Hulunbeier rangelands was 1.8 and 2.2 times higher than that in the Songnen grasslands and Xilingol steppes, respectively. High species abundance may result in relative large abundance of C_4 species (38 species), which was much greater (52 %) than in the Xilingol steppes and Hunshandake desert (Wang 2002c,d), but 12 % less than in the Songnen grasslands (Wang 2002c). In general, the occurrence and the relatively large species abundance of C_4 plants was common, identified in 10 families and 28 genera, in the Hulunbeier rangelands. This was mainly due to greater tolerance of C_4 species to environmental stress and greater ability to maintain intense photosynthesis during dry season (Redmann *et al.* 1995, Wang 2002b). 74 % of the total identified C_4 species was found in *Gramineae* and *Chenopodiaceae*, indicating that C_4 species occurred mainly in few families in the region. *Gramineae* was the leading family with C_4 photosynthesis and *Chenopodiaceae* ranked the second, this is much consistent with researches conducted in Xilingol steppes and Hunshandake desert (Wang 2002a,d). No endemic C_4 species was identified in Hulunbeier rangelands, but more than 200 species in the genera with C_4 plants have not been determined yet.

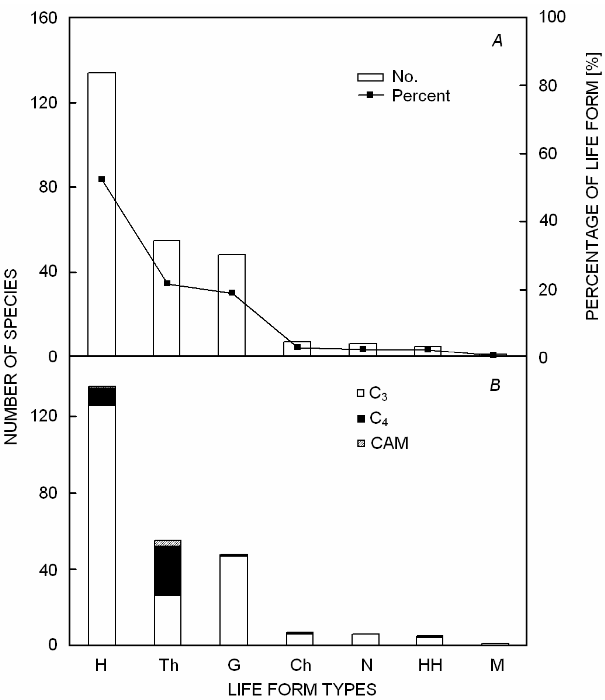

Fig. 1. The life form types (H = hemicryptophyte, G = geophyte, Th = therophyte, Ch = chamaephyte, M = macrophanerophyte, N = nanophanerophyte, HH = hydrogeophyte) (*A*) and photosynthetic pathway compositions in each life form type (*B*) in Hulunbeier rangelands, Inner Mongolia, China.

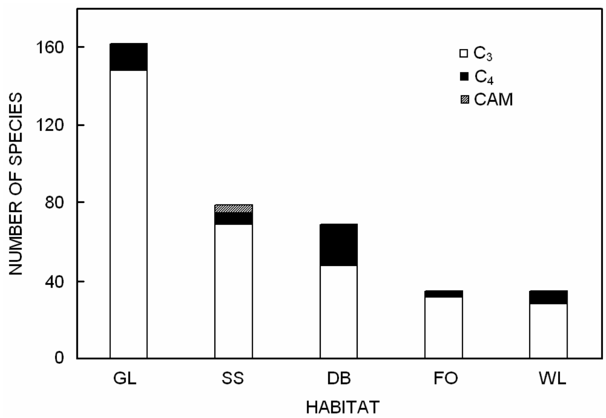

Fig. 2. The variations of photosynthetic pathway types in different habitats (GL = grassland, SS = sandy soil, DB = disturbed land, FO = frost, WL = wet land) in Hulunbeier rangelands, Inner Mongolia, China.

Plant life form composition was consistent with climate, floristic composition, and habitats (Li 1979, Wang 2002c,d). Of the total 258 species identified in Hulunbeier rangelands, 54 % was in the H form. This was mainly due to the moist climate, high composition of graminaceous plants (grass and sedge) for grassland and forest vegetation types, because more than 60 % of the total plants were of the H form in grasslands and grassland-forest ecotones (Li 1979, Wang 2002a,b). 21 % of the total species in Table 1 was in the Th form, which was somewhat less than in the Xilingol steppes and the Songnen grassland, but a half of the Th form species had C_4 photosynthesis. Relatively greater abundance of Th form C_4 species in the region may be mainly due to their greater ability to survive the harsh environment, *e.g.* drought and cold, and higher capacity to maintain intense photosynthesis (Wang 2002a,b,c). The proportion of geophyte (G) form (17 %) in the Hulunbeier rangelands was much greater than in the other rangelands of north China. This may also be consistent with the cold climate of the region because the G form represents an advantage for plants to survive the long and cold winter (Li 1979). Few macrophanerophyte (M) and nanophanerophyte (N) form species, *e.g.* *Betula dahurica* Pall., *Caragana microphylla* Lam., *C. stenophylla* Pojark., and *Spiraea aquilegifolia* Pall., were found widely distributed in the rangelands, and most of these species were shrubs, with small leaves and great tolerance to dryness or seasonal dryness (Li 1979, Pan 1992, Wang 2002b). Unlike in the steppe region in Inner Mongolia (Wang 2003), there were some hydrogeophyte (HH) form plants in Hulunbeier rangelands, due to the relatively more precipitation in the east or the grassland-forest ecotones. This suggests that the moisture condition in this type of rangelands was better than in the steppes or deserts in Inner Mongolia.

Photosynthetic pathway types, especially the occurrence of C_4 species, could be efficient indicators for rangeland dynamics (Wang 2002c). In Hulunbeier rangelands more than 55 % of the total C_4 species can be found in disturbed lands, and all CAM species in sandy soils. These C_4 plants are the succession pioneers because of their greater tolerance to dry, saline, and poor soils (Yin and Li 1997) and high capacity for seed production and diffusion (Wang 2002a,b). CAM plants, *e.g.* *Orostachys fimbriatus* (Turcz.) Berger, *O. malacophyllus* (Pall.) Fisch., and *O. malacophyllus* (Pall.) Fisch., could tolerate extreme drought in sandy soil conditions, *e.g.* fixed dunes and mobile dunes. These two types of plants are useful indicators for rangeland successions and management evaluations in Hulunbeier rangelands.

References

Chen, M.J., Jia, S.X. (ed.): [Forage Plants in China.] – China Agriculture Press, Beijing 2002. [In Chin.]

Collatz, G.J., Berry, J.A., Clark, J.S.: Effects of climate and atmospheric CO_2 partial pressure on the global distribution of C_4 grasses: present, past, and future. – Oecologia **114**: 441-454, 1998.

Collins, R.P., Jones, M.B.: The influence of climatic factors on the distribution of C_4 species in Europe. – Vegetatio **64**: 121-129, 1985.

Commissione Redactorum Flora Intramongolicae: Flora Intramongolica. Vol. 1-5. – Inner Mongolian Press, Huhehaote 1980. [In Chin.]

Downton, W.J.S.: The occurrence of C_4 photosynthesis among plants. – Photosynthetica **9**: 96-105, 1975.

Li, J.D.: [Basic plant life form in the Northeastern grasslands in China.] – J. Jilin normal Univ. **2**: 143-155, 1979. [In Chin.]

Li, M.: [List of plants with C_4 photosynthesis.] – Plant physiol. Commun. **29**: 148-159, 221-240, 1993. [In Chin.]

Li, S.Y., Xiao, Y.F.: [Primary dividing of grazing stages in *Leymus chinensis* grassland in Muodamuji, Hulunbeier, Inner Mongolia.] – Acta phytoecol. geobot. sin. **3**: 200-207, 1965. [In Chin.]

Pan, X.Q. (ed.): [Hulunbeier Grassland in China.] – Jilin Science and Technology Press, Changchun 1992. [In Chin.]

Pyankov, V.I., Gunin, P.D., Tsoog, S., Black, C.C.: C_4 plants in the vegetation of Mongolia: their natural occurrence and geographical distribution in relation to climate. – Oecologia **123**: 15-31, 2000.

Raghavendra, A.S., Das, V.S.R.: The occurrence of C_4-photosynthesis: A supplementary list of C_4 plants reported during late 1974-mid 1977. – Photosynthetica **12**: 200-208, 1978.

Redmann, R.E., Yin, L., Wang, P.: Photosynthetic pathway types in grassland plant species from Northeast China. – Photosynthetica **31**: 251-255, 1995.

Takeda, T., Hakoyama, S.: Studies on the ecology and geographical distribution of C_3 and C_4 grasses. 2. Geographical distribution of C_3 and C_4 grasses in far east and south east Asia. – Jap. J. Crop Sci. **54**: 65-71, 1985.

Teeri, J.A., Stowe, L.G.: Climatic patterns and the distribution of C_4 grasses in North America. – Oecologia **23**: 1-12, 1976.

Teeri, J.A., Stowe, L.G., Livingstone, D.A.: The distribution of C_4 species of the *Cyperaceae* in North America in relation to climate. – Oecologia **47**: 307-310, 1980.

Ueno, O., Takeda, T.: Photosynthetic pathways, ecological characteristics, and the geographical distribution of the *Cyperaceae* in Japan. – Oecologia **89**: 195-203, 1992.

Wang, R.Z.: Photosynthetic pathway types of forage species along grazing gradient from the Songnen grassland, Northeastern China. – Photosynthetica **40**: 57-61, 2002a.

Wang, R.Z.: The C_4 photosynthetic pathway and life forms in grassland species from North China. – Photosynthetica **40**: 97-102, 2002b.

Wang, R.Z.: Photosynthetic pathways and life forms in different grassland types from North China. – Photosynthetica **40**: 243-250, 2002c.

Wang, R.Z.: Photosynthetic pathways, life forms and reproductive types for forage species along the desertification gradient on Hunshandake desert, North China. – Photosynthetica **40**: 321-329, 2002d.

Wang, R.Z.: Photosynthetic pathway and morphological functional types in the steppe vegetation from Inner Mongolia, North China. – Photosynthetica **41**: 143-150, 2003.

Williams, G.J., III, Markley, J.L.: The photosynthetic pathway type of North America shortgrass prairie species and some ecological implications. – Photosynthetica **7**: 262-270, 1973.

Yin, L., Li, M.: [A study on the geographic distribution and ecology of C_4 plants in China. C_4 plant distribution in China and their relation with regional climatic condition.] – Acta ecol. sin. **17**: 350-363, 1997. [In Chin.]

Zhang, Z.T., Liu, Q.: [Rangeland Resources of the Main Pasture Areas in China and Their Development and Utilization.] – China Science and Technology Press, Beijing 1992. [In Chin.]

Zhu, T.C.: Grasslands of China. – In: Coupland, R.T. (ed.): Natural Grasslands – Eastern Hemisphere and Resume. Vol. 8B. Pp. 61-82. Elsevier, Amsterdam 1993.