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Photosynthetic pathway and morphological functional types in the steppe vegetation from Inner Mongolia, North China

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Abstract

Photosynthetic pathway (C_3, C_4, and CAM) and morphological functional types were identified for the forage species from steppe vegetation in Inner Mongolia, China, using the data from both field survey and references. Of the total 136 identified vascular species, in 29 families and 89 genera, 78 % were found with C_3 photosynthesis, including dominant herbs, *e.g. Stipa grandis* P. Smirn., *S. krylovii* Roshev., and *Leymus chinensis* (Trin.) Tzvel. These C_3 species covered about 90 % of the total herbage production in the steppe. 20 % were found with C_4 photosynthesis and 2 % with CAM photosynthesis. Photosynthetic pathway functional types were coarse and may not fit for the studies and land management in small scales, because of the high C_3 photosynthesis composition and the few families in which C_4 species occur. Morphological functional types (*e.g.* shrubs, high perennial grasses, short perennial graminaceous plants, annual grasses, annual forbs, perennial forbs, and succulents) may be practical for spatial and temporal descriptions of steppe ecosystems in local and region scales. Classification for plant functional types, especially morphological types, may contribute to studying the links between plant species and communities, ecosystems, and global changes, and for steppe management decisions in the region.

Additional key words: annual and perenial plants; C_3, C_4, and CAM photosynthesis; dry and wet soils; forbs; grasses; land cultivation.

Introduction

Plant functional types are referred to groups or types of species that share morphological and physiological attributes and play a similar role in ecosystems. They are popular means for studying the logical links between physiological and life-history strategies at plant level, and ecological process at ecosystem and global levels (Chapin 1993, Paruelo and Lauenroth 1996). Classifications of plant functional types were mainly based on plant photosynthetic pathway types (C_3, C_4, and CAM) or morphological attributes. Most of studies on plant functional types were focused on photosynthetic pathway identification (Williams and Markley 1973, Downton 1975, Raghavendra and Das 1978, Waller and Lewis 1979, Redmann *et al.* 1995, Wang 2002b), morphological functional type classifications (Smith *et al.* 1993, Aguiar *et al.* 1996, Paruelo and Lauenroth 1996, Pillar 1997, Scholes *et al.* 1997, Diaz *et al.* 1998, McIntyre *et al.* 1999, Duckworth *et al.* 2000), as well as the relationships between plant functional types and global changes (Teeri and Stowe 1976, Teeri *et al.*1980, Collins and Jones 1985, Takeda and Hakoyama 1985, Ueno and Takeda 1992, Box 1996, Cramer 1997, Diaz and Cabido 1997, Leemans 1997, Yin and Li 1997, Ehleringer *et al.* 1997, Keeley 1998, Collatz *et al.* 1998, Pyankov *et al.* 2000). These works provide strong evidence that the abundance of plant functional types correlates with different vegetation, land use, and climatic attributes in local, region, and global scales.

Inner Mongolian steppe, distributed at the eastern end of the Eurasian steppe zone, covers large continuous areas in Inner Mongolia. The usual growing condition for the steppe herbage is superior both in quality and quantity, so that this type of grassland is one of the best suited in northern China for the range land industry (Jiang *et al.* 1985, Li *et al.* 1988, Xiao *et al.* 1995). Studies on local flora, plant communities, plant biomass, and their responses to environmental changes have been conducted (Liu 1993, Jiang *et al.* 1985, Li *et al.* 1988, Zhao *et al.* 1988, Xiao *et al.* 1995), but plant functional type compositions in Inner Mongolian steppe remain unclear. Plant functional types are the important linkages between plant species and ecosystems, land use, as well as global changes.

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The objective of the present study was to investigate the photosynthetic pathway type and morphological functional type compositions in Inner Mongolian steppe. This study may contribute new information for better understanding the plant functional types in Inner Mongolian steppe and their relations with ecosystems, climate changes, and land use.

Materials and methods

The study was conducted in Xilingol steppe (41°35'~46°46' N, 111°09'~119°58' E), a typical steppe in the Mid-Inner Mongolia (Fig. 1). The steppe is part of Mongolian Plateau, which covers about 200 000 km^2 area, on average 1 200 m above sea level, varying from 900 m in the north-east to 1 300 m in the south-west. Most of the region has chestnut, chernozem, and sandy soils. The main determinants of the climate in the region are the Mongolian anticyclone and moist Pacific air mass. In winter, north-east China is dominated by an intense Mongolian anticyclone. The steep pressure gradient between this high- and the Aleutian low-pressure system produces a strong westerly flow of cold, dry continental air, at the surface, over north China. As the anticyclone breaks down in spring, the region comes increasingly under the influence of moist Pacific air mass, reaching a climax in the summer monsoon, which lasts two months. The mean annual air temperature ranges from 0 to 3 °C, varying from –21 °C in January to 21 °C in July. Moisture gradient is very steep, with annual precipitation varying from 100 mm in the west to 400 mm in the east. Precipitation is not distributed evenly over growing season, of which 70 % falls between June and August in this region.

Floristic species were obtained from 11 references published from 1980 to 2002 (Commissione Redactorum Flora Intramongolicae 1980, Li *et al.* 1988, Liu 1993, Zhang and Liu 1992, Wang 2002b,c,d), as well as from the sampling data conducted from 2000 to 2002 (Wang 2002c,d). The data on photosynthetic pathway types and morphological functional types were compiled from 9 references published between 1985 and 2002 (*e.g.* Takeda and Hakoyama 1985, Li *et al.* 1988, Zhao *et al.* 1988, Li 1993, Redmann *et al.* 1995, Yin and Li 1997, Pyankov *et al.* 2000, Wang 2002c,d). Plants identified in the region were classified into three photosynthetic pathway types (C_4, C_3, and CAM) by physiological attributes and morphological functional types: shrubs (SHR), high perennial grasses (HPG), short perennial grasses (SPG), annual grasses (ANG), annual forbs (ANF), perennial forbs (PEF), and succulents (SUC), by morphological attributes (Table 1).

Results

Floristic composition of photosynthetic pathway types: 136 vascular plant species, in 89 genera and 29 families, and about 25 % of the total species in Xilingol steppe were identified with C_3, C_4, and CAM photosynthesis (Table 1). Of these species, 71 % (96 of 136) were found in *Dicotyledoneae*, *e.g. Compositae* (30 species), *Chenopodiaceae* (13 species), *Fabaceae* (9 species), *Rosaceae* (8 species). 29 % (40 of 136) were in *Monocotyledoneae*, e.g. *Gramineae* (31 species), *Cyperaceae* (4 species), *Liliaceae* (3 species), and *Iridaceae* (2 species). As for photosynthetic pathway types, 106 species (78 %) in 66 genera and 25 families were found with C_3 photosynthesis, 27 species (20 %) in 22 genera and 9 families with C_4 photosynthesis, and 3 species (2 %) in 2 genera and 1 family with CAM photosynthesis. For the 96 *Dicotyledoneae* species, 83 % (80 of 96) were C_3 species, 14 % were C_4 species, and 3 % (3 of 96) were CAM species. 35 % *Monocotyledoneae* species, however, were C_4 species, the others (65 %) were C_3 species. This indicated that the occurrence of C_4 species in *Monocotyledoneae* was as high as 2 times than in *Dicotyledoneae* in Xilingol steppe region. But the occurrence of C_4 species was common in *Chenopodiaceae*, 54 % (7 of 13) identified *Chenopodiaceae* were C_4 species. Most of *Chenopodiaceae* species were annual and succulent, and occurred in arid environments, *e.g. Kochia sieversiana* (Pall.) C.A. Mey., *K. prostrata* Schrad., *Salsola collina* Pall., *S. pestifer* A. Nelson, *Suaeda corniculata* (C.A. Mey.) Bunge, and *S. glauca* Bunge. 3 CAM species were identified in the steppe region, *e.g. Orostachys fimbriatus* (Turcz.) Berger, *O. malacophyllus* (Pall.) Fisch., and *Sedum aizoon* L. Succulent and annual attributes were advantage for resistance to ecological stress and conditions in arid steppe.

Photosynthetic pathway type compositions were consistent with habitat conditions in Xilingol steppe region (Fig. 2*A,B*). Total species numbers dropped significantly from dry steppe (DS) to wet soil (WS), the species numbers in WS was only 8 % of that in DS. This was mostly due to the high composition of xerophytes (*e.g. Stipa grandis* P. Smirn., *S. gobica* Roshev., *S. krylovii* Roshev., *Artemisia intramongolica* H.C. Fu.) in the steppe region. Disturbed and cultivated lands (DB) had the highest number of C_4 species (10 species), which was about 32 % of the total species in this habitat type (Fig. 2*B*), and most of these species were annual forbs (*e.g. Salsola collina* Pall., *Amaranthus retroflexus* L., *Portulaca oleracea* L.), annual grasses [*e.g. Setaria arenaria* Kitag., *S. glauca* (L.) Beauv., *S. viridis* (L.) Beauv.]. Sandy soil habitats (SS) and meadow steppe (MS) also had relatively more

Table 1. Photosynthetic pathways (C_3, C_4, and CAM) and plant functional types in Inner Mongolian steppe, North China. Nomenclature follows Kitagawa (1979) and Yin and Wang (1997). Habitat types: DB = disturbed and cultivated land, DS = dry steppe, MS = meadow steppe, SM = saline meadow, SS = sandy soil, WS = wet soils (Wang 2002a). Plant functional types: SHR = shrubs, HPG = high perennial grasses, SPG = short perennial graminaceous plants (grasses and sedge), ANG = annual grasses, ANF = annual forbs, PEF = perennial forbs, SUC = succulents.

	Species	C_3/C_4	Habitat	Plant functional type
Dicotyledoneae				
Polygonaceae	*Polygonum aviculare* L.	C_3	DB	ANF
	P. sibiricum Laxm.	C_3	SM	ANF
Chenopodiaceae	*Agriophyllum pungens* (Vahl) Link A. Dietr.	C_4	SS	ANF
	Atriplex sibirica L.	C_4	SM SS	ANF
	Axyris amaranthoides L.	C_3	DB	ANF
	Bassia dasyphylla O. Kuntze	C_4	SS	SUC
	Chenopodium album L.	C_3	DB	ANF
	Ch. acuminatum Willd.	C_3	DB	ANF
	Ch. glaucum L.	C_3	DB SM	ANF
	Kochia prostrata Schrad.	C_4	DB SS	SHR
	K. sieversiana (Pall.) C.A. Mey.	C_4	SS	SUC
	Salsola collina Pall.	C_4	DB	SUC
	S. pestifer A. Nelson	C_4	SS	SUC
	Suaeda corniculata (C.A. Mey.) Bunge	C_3	SS	SUC
	S. glauca Bunge	C_3	SS	SUC
Amaranthaceae	*Amaranthus retroflexus* L.	C_4	DB	ANF
Portulacaceae	*Portulaca oleracea* L.	C_4	DB	ANF
Ranunculaceae	*Clematis hexapetala* Pall.	C_3	SS DS MS	PEF
	Ranunculus japonicus Thumb.	C_3	MS	PEF
	Thalictrum petaloedeum L. var. *supr.* (Nakai) Kitag.	C_3	DS	PEF
	Th. simplex L.	C_3	MS	PEF
	Th. squarrosum Steph.	C_3	SS DS	PEF
Cruciferae	*Lepidium apetalum* Willd.	C_3	DB SM	ANF
Crassulaceae	*Orostachys fimbriatus* (Turcz.) Berger	CAM	SS	SUC
	O. malacophyllus (Pall.) Fisch.	CAM	SS	SUC
	Sedum aizoon L.	CAM	DS	SUC
Rosaceae	*Armeniaca sibirica* (L.) Lam.	C_3	SS	SHR
	Geum aleppicum Jacq.	C_3	MS	PEF
	Potentilla acaulis L.	C_3	DS	PEF
	P. anserina L.	C_3	MS	PEF
	P. bifurca L.	C_3	DS	PEF
	P. flagellaris Willd.	C_3	MS	PEF
	P. fragaricides L.	C_3	DS	PEF
	Sanguisorba officinalis L.	C_3	MS	PEF
Fabaceae	*Caragana microphylla* Lam.	C_3	DS SS	SHR
	C. stenophylla Pojark.	C_3	DS SS	SHR
	Gueldensfaedtia stenophylla Bunge	C_3	MS	PEF
	Lespedeza davurica Schindler	C_3	DS	SHR
	Melilotus suaveolens Ledeb.	C_3	MS	ANF
	Melilotoides ruthenica (L.) Sojak	C_3	DS SS	PEF
	Oxytropis hirta Bunge	C_3	SS	PEF
	O. filiformis D.C.	C_3	DS SS	PEF
	O. myriophylla D.C.	C_3	MS DS SS	PEF
	Thermopsis lanceolata R. Br.	C_4	MS DS	PEF
Geraniaceae	*Erodium stephanianum* Willd.	C_3	DS SS	ANF
Zygophyllaceae	*Tribulus terrestris* L.	C_4	SS	ANF
Rutaceae	*Haphophyllum dauricum* Juss	C_3	DS	PEF
	Polygala tenuifolia Willd.	C_3	DS MS	PEF

Table 1 (continued)

	Species	C_3/C_4	Habitat	Plant functional type
Euphorbiaceae	*Euphorbia esula* L.	C_3	SS	PEF
	E. humifusa Willd.	C_4	SS DB	ANF
Violaceae	*Viola dissecta* Ledeb.	C_3	SS DB DS	PEF
Thymelaeaceae	*Diarthron linifolium* Turcz.	C_3	SS	ANF
	Stellera chamaijasme L.	C_3	SS	PEF
Umbelliferae	*Bupleurum scorzonerifolium* Willd.	C_3	DS	PEF
	Saposhnikovia divaricatum (Turcz.) Schischk.	C_3	DS SS	PEF
Primulaceae	*Glaux maritima* L.	C_3	SM	ANF
Plumbaginaceae	*Limonium bicolor* O. Kuntze	C_3	SM	PEF
Asclepiadaceae	*Cynanchum amplexicaule* Hemsl.	C_3	MS	PEF
Boraginaceae	*Cynoglossum divaricatum* Steph.	C_3	SS	ANF
Labiatae	*Scutellaria baicalensis* Georgi	C_3	MS	PEF
	S. ikonnikovii Juz.	C_3	MS	PEF
	Thymus serphyllum L.	C_3	DS	PEF
Solanaceae	*Solanum nigrum* L.	C_3	DB	ANF
Plantaginaceae	*Plantago asiatica* L.	C_3	DB	PEF
	P. depressa Willd.	C_3	DB	PEF
Rubiaceae	*Galium verum* L.	C_3	MS	PEF
Compositae	*Artemisia anethifolia* Weber	C_3	SM	ANF
	A. annua L.	C_3	SS	ANF
	A. argyi Levl. *et* Vant.	C_3	MS	PEF
	A. desertorum Spreng.	C_3	SS	SHR
	A. dracunculus L.	C_3	DB DS	ANF
	A. frigida Willd.	C_3	DS SS	SHR
	A. japonica Thunb. var. *manshurica* Kom.	C_3	MS SS	ANF
	A. pectinata Pall. (*Neopallasia pectinata*) Polsak.	C_3	DS SS	ANP
	A .pubescens Ledeb.	C_3	SS	ANF
	A. scoparia Waldst. *et* Kit.	C_3	DB DS	ANF
	A. selengensis Turcz. *ex* Bess.	C_3	MS	ANF
	A. sieversiana Willd.	C_3	DB	ANF
	Aster alpinus L.	C_3	DS	ANF
	Filifolium sibiricum Kitam.	C_3	DS SS	FEF
	Heteropappus altaicus (Willd.) Novopokr.	C_3	DS SS	PEF
	H. altaicus (Willd.) Novopokr. var. *millefolium*	C_3	DS	PEF
	Hypochaeris grandiflora Ledeb.	C_4	MS WS	PEF
	Inula britanica L. var. *sublanata* Kom.	C_3	MS	PEF
	I. japonica Thunb.	C_3	MS	PEF
	Ixeris chinensis Nakai subsp. *graminifolia* Kitag.	C_3	DB	PEF
	I. sonchifolia Bunge	C_3	DB	PEF
	Leontopodium leontopodioides Reauv.	C_3	MS DS SS	PEF
	Picris japonica Thunb.	C_3	MS DS DB	ANF
	Saussurea japonica (Thunb.) D.C.	C_3	MS SS	PEF
	S. runcinata D.C.	C_3	SM	PEF
	Scorzonera austriaca Willd.	C_3	DS	PEF
	Serratula yamasutana Kitag.	C_3	DS	PEF
	Taraxacum mongolicum Hand.	C_3	MS DB	PEF
	T. ohwianum Kitam.	C_3	MS DB	PEF
	Xanthium strumarium L.	C_3	DB	ANF
Monocotyledoneae				
Cyperaceae	*Carex dahurica* Kukenth.	C_3	DS	SPG
	C. duriuscula C.A.M.	C_3	DS	SPG
	C. enervis C.A.M.	C_4	DS	SPG
	C. pediformis C.A.M.	C_4	DS SS	SPG

Table 1 (continued)

	Species	C_3/C_4	Habitat	Plant functional type
Gramineae	*Achnatherum splendens* (Trin.) Nevski	C_4	MS SM	HPG
	Agropyron cristatum (L.) Gaertner	C_3	MS DS SS	HPG
	Avena fatua L.	C_3	MS DB DS	ANG
	Beckmannia syzigachne (Steud.) Fernald	C_3	MS	ANG
	Bromus inermis Leyss.	C_3	MS	HPG
	Calamagrostis epigeios (L.) Roth	C_3	MS WS	HPG
	Chloris virgata Sw.	C_4	SM WS	ANG
	Cleistogenes squarrosa (Trin.) Keng	C_4	MS	SPG
	Digitaria ischaemum (Schreb.) Schreb. *ex* Muhl.	C_4	DB	ANG
	Echinochloa crus galli (L.) Beauv.	C_4	MS WS	ANG
	Elymus dahuricus Turcz.	C_3	MS DS	HPG
	Enneapogon borealis (Griseb.) Honda	C_4	DS	ANG
	Eragrostis minor Host.	C_4	MS	ANG
	Festuca ovina L.	C_3	DS	HPG
	F. rubra L.	C_3	SS DS	HPG
	Hierochloe glabra Trin.	C_4	MS	SPG
	Hordeum brevisubulatum (Trin.) Link	C_3	SM	HPG
	Koeleria cristata (L.) Pers.	C_3	DS MS	HPG
	Leymus chinensis (Trin.) Tzvel.	C_3	SM DS	HPG
	Pennisetum centrasiaticum Tzvel.	C_4	DB	HPG
	Phragmites communis Trin.	C_3	MS	HPG
	Poa pratensis L.	C_3	MS	SPG
	Puccinellia tenuiflora (Turcz.) Scrib. *et* Merr.	C_3	SM	HPG
	Roegneria turczaninovii (Drob.) Nevski.	C_3	MS	HPG
	Setaria arenaria Kitag.	C_4	DB	ANG
	S. glauca (L.) Beauv.	C_4	DB	ANG
	S. viridis (L.) Beauv.	C_4	DB	ANG
	Stipa baicalensis Roshev.	C_3	DS	HPG
	S. gobica Roshev.	C_3	DS	HPG
	S. grandis P. Smirn.	C_3	DS	HPG
	S. krylovii Roshev.	C_3	DS SS	HPG
Liliaceae	*Allium polyrrhizum* Turcz.	C_3	SM	PEF
	A. senescens L.	C_3	DS MS	PEF
	A. tenuissimum L.	C_3	DS SS	PEF
Iridaceae	*Iris dichotoma* Pall.	C_3	DB DS	PEF
	I. ruthenica Ker. Gawl.	C_3	DB	PEF

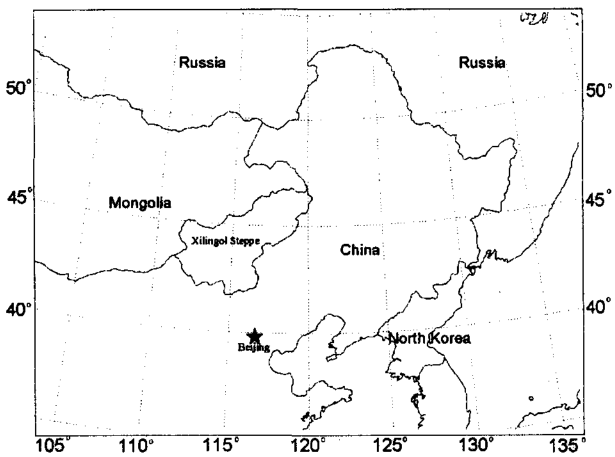

Fig. 1. Location of the Xilingol steppe in north China.

C_4 species (9 and 7 species, respectively). Saline meadow (SM) and wet soil habitats (WS) had the lowest number of C_4 species (3 species), but WS had the highest percentage of C_4 species, due to the low C_3 species composition in the habitat. Hence the photosynthetic pathway type compositions were not only related with climate changes in region and global scales, but also responded to habitats in small scale.

Morphological functional types: According to plant morphological attributes and life-span, the identified plant species were classified into 7 functional types, *e.g.* perennial forbs (PEF), annual forbs (ANF), high perennial grasses (HPG), short perennial graminaceous plants (grasses and sedge) (SPG), annual grasses (ANG), shrubs (SHR), and succulents (SUC) (Table 1 and Fig. 3*A*). Of the 7 functional types in Xilingol steppe, PEF type had the greatest number of species (40 % of the total species), followed by ANF type (23 %), HPG type (15 %), SUC (7 %), ANG type (6 %), SPG type (5 %), and SHR type (5 %), respectively. Of the total 136 species, 63 % were found in PEF and AEF, 26 % in HPG, ANG, and SPG, 5 % in SHR, and 7 % in SUC. This suggested that forbs were the leading plant functional type in this steppe region, but most of these forbs were companion species, few could be dominant in specific habitats, *e.g. Agriophyllum pungens* (Vahl) Link A. Dietr. and *Artemisia desertorum* Spreng. in mobile dunes, and *Suaeda corniculata* (C.A. Mey.) Bunge and *S. glauca* Bunge in saline meadows. Graminaceous plants were the common dominants, producing 70 % of the total herbage in the steppe region, *e.g. Leymus chinensis* (Trin.) Tzvel., *Stipa grandis* P. Smirn., and *S. krylovii* Roshev. This indicated that the plant functional type with most species may not be the key type in the steppe region.

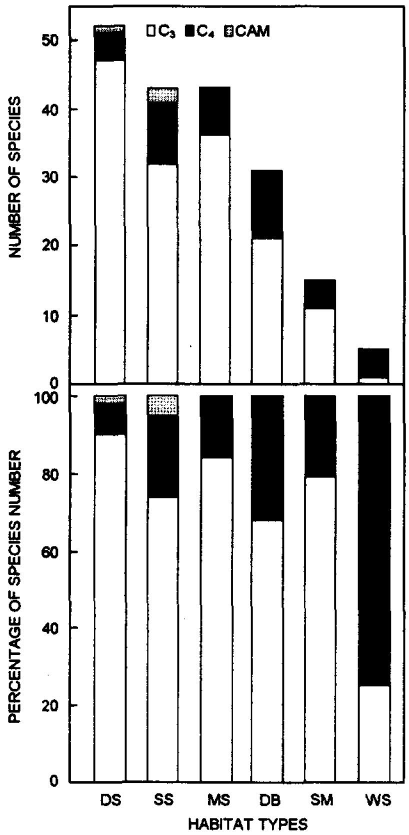

Fig. 2. The numbers of photosynthetic pathway types (C_3, C_4, and CAM) (*top*) and their percentages (*bottom*) in different habitats in Inner Mongolian Steppe, China. Habitat types: DB = disturbed and cultivated land, DS = dry steppe, MS = meadow steppe, SM = saline meadow, SS = sandy soil, WS = wet soils.

Photosynthetic pathway type compositions varied in each morphological functional types in Xilingol steppe (Fig. 3*A,B*). ANF and ANG types had greatest number of C_4 species (6 species in each), followed by SPG and SUC (4 species in each), HPG and PEF (2 species in each), and SHR (1 species). Relatively more C_4 species in ANF, ANG, and SPG types suggested these three functional types were more fit for the dry steppe conditions, because C_4 species have greater ability to tolerate the drought and to maintain high water use efficiency and intense photosynthesis. The occurrence of C_4 species in PEF, HPG,

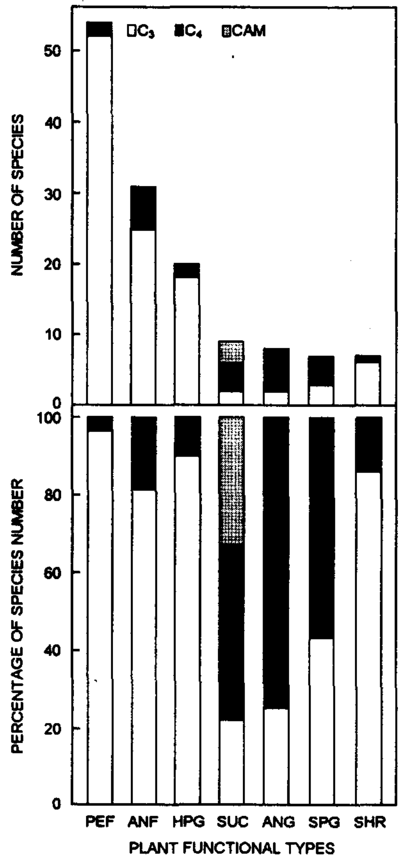

Fig. 3. The morphological functional types for the species from Inner Mongolian steppe (*top*) and their photosynthetic pathway compositions (*bottom*). Plant functional types: SHR = shrubs, HPG = high perennial grasses, SPG = short perennial grasses, ANG = annual grasses, ANF = annual forbs, PEF = perennial forbs, SUC = succulents.

and SHR was not as common as that in ANF, ANG, and SPG, and percentages of C_4 species in these types varied from 4 to 15 %. In succulent type, 4 C_4 species, 2 C_3 species, and 3 CAM species were identified. Relatively more C_4 species, succulents and annuals occurred in sandy soil and dry steppe in the region indicated that the moisture stress, especially seasonal dry, in the steppe region was relative severe.

Discussion

Photosynthetic pathway and morphological types were the common means for plant functional type classification. The occurrence of C_4 species was most common in the Xilingol steppe, North China, likely due to the their greater tolerance to environmental stresses (drought, salinity, desertification) and capacities to maintain higher water use efficiency and intense photosynthesis (Wang 2002a,d). But the number of families (9 families) with C_4 photosynthesis in the steppe region was much less than that in Mongolia (16 families), where there are more types of large landscapes, *e.g.* forests, steppes, and gobi deserts (Pyankov *et al.* 2000). Of the total 27 C_4 species identified in the steppe region, 70 % were found in *Chenopodiaceae* (7 species) and *Gramineae* (12 species), indicating that C_4 species occurred mainly in these two families. 39 % of grasses and 54 % of *Chenopodiaceae* species identified in the steppe were found with C_4 photosynthesis. Few species were found with CAM photosynthesis (Table 1). The plants with C_3 photosynthesis, however, were the dominants [*e.g. Stipa grandis* P. Smirn., *S. gobica* Roshev., *S. krylovii* Roshev., *Leymus chinensis* (Trin.) Tzvel.], about 80 % of the total identified species and 90 % of the total herbage production in the steppe. Classification for plant functional types by photosynthetic attributes (C_3, C_4, and CAM) was coarse. It may not fit for the studies (*e.g.* community classification and community structure analysis) and land management (*e.g.* grazing and mowing) in plant community, landscape, and local scales in the steppe region, because of the high C_3 photosynthesis composition and the few families in which C_4 species occur.

Morphological functional types, however, did not only bring more details for studying the linkage between species, communities, and ecosystems (Smith *et al.* 1993, Aguiar *et al.* 1996, Diaz and Cabido 1997), but also for steppe management decisions (warm season and cool season). Relative complex geo-relief and landscape in Xilingol steppe resulted in vegetation complexes, *e.g.* dry steppes, shrubwoods, meadows, saline meadows, wetlands, and forests (Li *et al.* 1988, Zhao *et al.* 1988, Xiao *et al.* 1995). Morphological functional types may more fit for depicting the differences between these vegetations (Li *et al.* 1988, Zhao *et al.* 1988), and reflect their seasonal dynamics in the steppe. These may be supported by the previous observations that species number and biomass in both PEF and HPG types dropped significantly in the dry seasons and dry years, while that for SPG and SUC types remarkably increased (Li *et al.* 1988, Bai and Chen 2000). Species in ANF, ANG, and SUC types were the main plant components in the dry steppes and sandylands, likely because these types of species can use the limited water resource in rainy seasons and survive the dry seasons in the form of dormant seeds (Wang 2002d). This suggests that morphological functional types in the steppe region can indicate both spatial and temporal changes in steppe ecosystems in local and region scales.

Photosynthetic pathway type compositions in each morphological type differed significantly in Xilingol steppe (Fig. 3*B*). More than a half of the total species in each of SUC, ANG, and SPG types was C_4 species, while that in the other types was less than 25 %. Relatively more C_4 species in SUC, ANG, and SPG suggested these types are more fit the dry steppe conditions, because these C_4 species have great capacity to tolerate dry stress and maintain higher water use efficiency and intense photosynthesis. Pyankov *et al.* (2000) proved that the combination of C_4 species with succulence allows plants to occupy very arid conditions (Pyankov *et al.* 2000). This and previous studies (Box 1996, McIntyre *et al.* 1999, Pillar 1999) suggest that the identification of optimal plant functional types depends on the selection of plant attributes and study scales.

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