ABSTRACT: To assess nitrogen (N) resorption patterns in semi-arid sandy land, N concentrations in green leaves (Ng) and senesced leaves (Ns) of 35 species of shrubs and herbages were measured along habitats of decreasing soil total N (0.54 to 0.041 g g\(^{-1}\) d.w. of top soil level) in Horqin Sandy Land (Inner Mongolia, China). These habitats are following: inter-dune grassland (IDG), fixed sand dune (FD), semi-fixed sand dune (SFD), semi-mobile sand dune (SMD), and mobile sand dune (MD) were considered. Results showed that Ng and Ns (i.e. nitrogen resorption proficiency, NRP) increased and leaf nitrogen use efficiency (NUE) decreased significantly with increasing soil N status across the above habitats, but nitrogen resorption efficiency (NRE) was not affected. The levels of Ng, Ns and NUE experience two stages across habitats: first, there were low Ng and Ns and high NUE in MD and SMD; second, there were high Ng and Ns and low NUE in IDG, FD and SFD. Plants from IDG, FD and SFD had incomplete N resorption during foliar senescence, but plants from MD and SMD had complete N resorption. Leaf NRE was determined by life forms which had no significant effect on Ng but on Ns and NUE. For all plants in the five habitats, NRE and NUE decreased with the sequence of grass, herb, shrub, while Ns showed a contrary tendency. Plants from strong N limitation habitats did not show higher NRE, but showed higher NRP and leaf NUE, so NRP was a more sensitive indicator of changes in N status than NRE. In conclusion, Leaf N resorption patterns were mainly determined by soil N status across habitats, and there were some consistent patterns among life forms.

KEY WORDS: leaf nitrogen, nitrogen resorption efficiency and proficiency, nitrogen use efficiency, life form, Horqin Sandy Land

1. INTRODUCTION

Nitrogen (N) resorption from senescing leaves minimizes N losses, enabling plants to conserve and reuse this nutrient, so it is an important mechanism to increase plant nitrogen use efficiency (NUE) (Aerts 1996, Richardson et al. 2005). It may be quantified by nitrogen resorption efficiency (NRE, the proportion of N resorbed from senescing leaves) or by nitrogen resorption proficiency (NRP, the N concentration in senesced leaves) (Killingbeck 1996, Yuan et al. 2005a). The inverse of the N concentration in leaf litter has been used as an index of leaf nitrogen use efficiency (NUE) (Vitousek 1982). Higher NRE is an adaptation advantage for plants in infertile habitats (Aerts and Chapin 2000), so it is predicted that species adapted to nitrogen-poor environments have higher NRE (Pensa and Sellin 2003,
Pugnaire and Chapin III 1993, Yuan et al. 2005b) and lower N concentrations in senesced leaves (Killingbeck 1996, Richardson et al. 2005). However, this hypothesis remains controversial. Within species, NRE sometimes decreases (Huang et al. 2008, Yuan et al. 2005b), increases (Birk and Vitousek 1986), or does not respond to increasing nutrient (Knops and Köning 1997). Therefore this controversial topic needs further studies (Kobe et al. 2005).

Killingbeck (1996) argued that nutrient concentration of leaf litter decreases as soil nutrient availability decreases (Richardson et al. 2005, Yuan et al. 2005b). Compared with NRE, NRP seems to be more responsive to N availability (Killingbeck 1996, Rejmáková 2005, Yuan et al. 2005a). Several studies reported that N fertilization resulted in higher N concentrations in the litter of plants (Chapin III and Moilanen 1991, Huang et al. 2008), suggesting that N fertilization may lead to lower NRP. The relationship between NRP and N availability was also found along natural fertility gradients (Richardson et al. 2005, Wright and Westoby 2003). One approach to testing this hypothesis has been to compare NRP in species growing on soils of different N concentrations (Richardson et al. 2005) or among species of different life forms typical of fertile and infertile sites (Killingbeck 1996). However, such interspecific comparisons are potentially confounded if plant species typical of infertile soils are predisposed to have inherently low leaf and litter nutrient concentrations (Aerts and Chapin 2000, Richardson et al. 2005). Intraspecific variation in NRP along a soil fertility gradient would be a more direct test of the hypothesis that NRP changes with soil N availability (Eckstein et al. 1999). To date, such variation has been examined in either single species or small groups of similar species coexisted at different habitats along a soil fertility gradient (Richardson et al. 2005, Yuan et al. 2005b).

The decrease in soil N status along different habitats in Horqin Sandy Land, Inner Mongolia (Zhao et al. 2009, Zhou et al. 2008) presents an opportunity to examine how resorption varies with N status. We measured leaf and litter N concentrations from 35 species of shrubs and herbage along a habitat gradient of inter-dune grassland (IDG), fixed sand dune (FD), semi-fixed sand dune (SFD), semi-mobile sand dune (SMD) and mobile sand dune (MD). We hypothesized that: (1) plants in habitats with strong N limitation (e.g. MD and SMD) will have higher N resorption; (2) NRP will respond more sensitively than NRE to changes in N status. In addition, the study was designed to assess the N resorption pattern (1) along a habitat gradient and (2) across life forms.

2. STUDY AREA

This study was conducted in the southwestern Horqin Sandy Land, Inner Mongolia, China (42°55′N, 120°42′E; elevation approx. 360 m). This area has a temperate, semi-arid and continental monsoonal climate. Annual mean precipitation is 360 mm, with 75% of it occurring between June and September. The annual mean latent evaporation is 1935 mm (Li et al. 2003). Annual mean temperature is around 6.4°C, with the minimum monthly mean temperature of −13.1°C in January and the maximum 23.7°C in July. The annual mean wind velocity is in the range of 3.2 to 4.1 m s⁻¹.

The topography is characterized by sand dunes and inter-dunes. The sandy soil is vulnerable to wind erosion, and the sandy grassland in Horqin Sandy Land is ecologically fragile and is subject to desertification. A number of psammophilous species were dominant, including Salix gordejevii Chang et Skv., Caragana microphylla Lam., Lespedeza davurica (Laxm.) Schindl., Mellissitus ruthenicus (L.) C.W.Chang, Artemisia halodendron Turcz. ex Bess., A. frigida Willd., A. scoparia Waldst. et Kit., A. sieversiana Ehnhart ex Willd., Salsola collina Pall., Agriophyllum squarrosum (L.) Moq., Corispermum macrocarpum Bunge, Bassia dasyphylla (Fisch. et Mey.) O. Kuntze, Cleistogenes squarrosa (Trin.) Keng, Setaria viridi (L.) Beauv., Phragmites australis (Cav.) Trin. ex Steud. and Pennisetum centrasiaticum Tzve1 et al.

In 2008, we chose five typical habitats (i.e. MD, SMD, SFD, FD and IDG) within a small range (approx. 1000 m by approx. 1000 m). The studied habitats are part of a nature reserve. We set up the sampling plots (40 × 40 m) within habitats. The five sampling plots
were so close to each other that they shared highly similar climate conditions.

3. METHODS

3.1. Plant sampling and nitrogen analysis

In total, 35 species of shrubs and herbages were studied in five habitats, as shown in Table 1. Twenty-five, 16, 14, five and three species were chosen in IDG, FD, SFD, SMD and MD sites, respectively, including all species enough for sampling. These species mainly consist of 4 families of leguminosae, gramineae, compositae and chenopodiac, and belong to 3 life form groups (i.e. herbs, grasses, and shrubs). The life forms were divided according to the definition by Kobe et al. (2005) and Yuan et al. (2005a).

Green and senesced leaves were collected from July to October 2008. Petioles and the rachides of compound leaves were generally shed as an integral component of the senesced leaves and therefore collected and processed as above (Yuan et al. 2005a). In late July (flourishing period), 5 g of fully expanded green leaves were randomly collected from 10–20 marked individuals of each species. In late September to early October, similar collections were carried out for senesced leaves. For species with shedding leaves, senesced leaves were collected as dead leaves that were ready to abscise. We considered leaves ready to abscise if they were completely dry and yellow or red without signs of deterioration (Norby et al. 2000, Wright and Westoby 2003). These leaves were removed by a gentle flicking of the branch or leaf. For species that retained dead leaves on the plants (all monocotyledons), leaves that were functionally disconnected from the shoot were cut off and collected (Yuan et al. 2005a). Senesced leaves were collected directly from plants rather than from leaf litter to avoid decomposition of leaf litter and leaching of leaf N that would lead to underestimates of N concentration in senesced leaves (Yuan et al. 2005a).

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The samples were immediately taken to the laboratory, oven dried at 70°C for 48 h, and then finely ground in a mill to pass a 60-mesh screen for later analysis. N concentration was analyzed by Kjeldahl procedure (UDK 140 Automatic Steam Distilling Unit, Automatic Titroline 96, Italy) (ISSCAS, 1978).

Nitrogen concentrations in green (N_g) and (N_s) senesced leaves were used to calculate leaf nitrogen resorption efficiency (NRE) on a mass basis (Killingbeck 1996), from which leaf nitrogen use efficiency (NUE) was also derived (Yuan et al. 2005a, Li et al. 2009):

\[
NRE(\%) = \frac{(N_g - N_s)}{N_g} \times 100\% \tag{1}
\]

\[
NUE(g g^{-1}) = \frac{1}{(N \times (1 - NRE))} = \frac{1}{N_s^2} \tag{2}
\]

where \(N_g\) and \(N_s\) are the N concentrations in green and senesced leaves, respectively. Nitrogen concentration in senesced leaves was used directly as an indicator of the nitrogen resorption proficiency (NRP) (Killingbeck 1996). Nitrogen resorption proficiency can be viewed as a measure of the completeness of N resorption in terms of proximity to the theoretical lower limit of the N concentration in senesced leaves (Yuan et al. 2005a).

3.2. Soil sampling and analysis

In each plot, a 40 m sampling transect was established from dune top to bottom, along the northwest (prevailing wind) direction. In each transect, eight quadrates of 1 × 1 m² were sampled at a 5 m interval. In each quadrate, a soil sample was obtained by mixing three sub-samples taken at the 0–10 cm depth and 10–20 cm depth, respectively. Soil samples were hand-sieved through a 2-mm screen to remove roots and other debris. Soil organic carbon was measured by the dichromate oxidation method of Walkey and Black (Nelson and Sommers 1982) and soil total N was determined by Kjeldahl procedure (UDK 140 Automatic Steam Distilling Unit, Automatic Titroline 96, Italy) (ISSCAS 1978). Soil total N was used, rather than available N forms. However, soil total N represents a long-term potentially available N pool (Rejmáneková 2005) and reflects soil nutrient.

3.3. Statistical analysis

Statistical procedures were carried out with SPSS (13.0) software. The data were log-transformed before analysis if necessary. The General linear models (GLM) with Tukey
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Post hoc comparison tests were used to examine the fixed effects of habitats, life forms (herb, grass and shrub) and their interactions (Richardson et al. 2005). For all species in the five sites, the effect of habitat on leaf N resorption traits was tested with one-way ANOVA. Extensive data set was available for this study in the five habitats was a large range of soil total N and green leaf N concentrations, allowing relationships between soil N status and various leaf N resorption traits (Rejmánková 2005). Therefore, linear regression analysis was performed to analyze their relationships (Yuan et al. 2005a).

**4. RESULTS**

4.1. Soil organic carbon and soil total N in different habitats

As shown in Table 2, soil organic carbon and total N decreased significantly with the sequence of IDG, FD, SFD, SMD and MD sites (Table 2). From IDG to FD, SFD, SMD and MD, organic carbon decreased by 57%, 71%, 89% and 92% at the depth of 0–10 cm, and 58%, 71%, 89% and 91% at the depth of 10–20 cm, respectively. Total nitrogen decreased by 59%, 72%, 90% and 92% at the depth of 0–10 cm, and 65%, 78%, 89% and 91% at the depth of 10–20 cm, respectively.

4.2. Leaf nitrogen resorption traits responses to habitats with different nitrogen status

Nitrogen concentrations in both green leaves (N_g) and senesced leaves (N_s) differed significantly across the five habitats (Table 3). Averaged N_g was highest in IDG and decreased in the order of SFD, FD, MD and SMD sites (Table 3). Averaged N_s decreased in the sequence of IDG, SFD, FD, SMD and MD sites (Table 3). However, there were no significant differences in N_g and N_s between FD and SFD sites, and between MD and SMD sites (Table 3).

**Fig. 1 Relationships among soil total N with (a) nitrogen concentrations in green leaves, N_g (b) nitrogen concentrations in senesced leaves, N_s (c) nitrogen resorption efficiency (NRE) and (d) nitrogen use efficiency (NUE) (formula 2).** Soil total N was the values at 0–20 cm depth based on the average values of 0–10 cm and 10–20 cm presented in Table 2. Five columns showed N resorption traits in five habitats of MD, SMD, SFD, FD and IDG, respectively (two columns for soil total N in MD and SMD was too close to distinct). Each point represents measurements for all plants in their habitats (n = 189). Different stages of N resorption across habitats are separated by dotted line. The left of line represent the first stage: N_g and N_s is low, but NUE is high (in SMD and MD); second stage: N_g and N_s is high, but NUE is low (in IDG, FD and SFD). Symbols: × herb; Δ grass; ○ shrub.
Leaf nitrogen resorption pattern along a habitat gradient

Leaf NUE differed significantly across habitats (Tables 3). Leaf NUE decreased in the sequence of SMD, MD, FD, SFD and IDG sites. But there were no significant differences among IDG, FSD and SFD sites, and between MSD and SMD sites (Tables 3). Leaf NRE did not differ across habitats (Fig. 1).

As shown in Fig. 2, N concentration in green leaves in 35 species showed a positive correlation with N\textsubscript{s}, and a negative correlation with leaf NUE, but had no significant correlation with NRE.

4.3. Leaf nitrogen resorption traits responses to life forms

Life form had no significant effect on N\textsubscript{s}, but it had significant effect on N\textsubscript{s}, NRE and NUE (Tables 3, 4). For all species in five habitats, NRE decreased with the sequence of grass, herb and shrub. NUE showed a trend similar to NRE, while N\textsubscript{s} showed a tendency contrary to NRE (Table 3).

5. DISCUSSION AND CONCLUSIONS

Nitrogen concentrations in leaf and litter (i.e. NRP), and leaf NUE differed significantly, but NRE did not differ across the five habitats of decreasing N content—IDG, FD, SFD, SMD and MD (Tables 3, 4). Above results agree with our hypothesis that NRP was
a more sensitive indicator of changes in N status than NRE (Killingbeck 1996), consistent with previous results (Huang et al. 2008, Rejmánková 2005, Yuan et al. 2005b).

Although assessing the N limitation from soil total N is not very straightforward (Rejmánková 2005), and Bridgham et al. (2001) reported that plant nutrients do not correlate with soil total N. However, our results showed that Nₛ and Nₑ increased, and leaf NUE decreased with increasing soil total Nₑ (Fig. 1). The lowest N (9.2 mg g⁻¹) was found in C. macrocarpum in MSD site and highest (44.0 mg g⁻¹) in B. dasyphylla in IDG site, and the lowest Nₑ (5.2 mg g⁻¹) was found in S. viridis in SMD site and highest (25.0 mg g⁻¹) in A. sieversiana in IDG site (Table 3).

The differences in Nₑ and Nₛ were fourfold higher among all species at the species level, and averaged Nₑ and Nₛ were twofold higher among five sites (Table 3). Above results clearly demonstrate that plants adapt to soil N status through adjustment of N concentrations in foliar and senesced leaves (i.e. NRP) (Aerts 1996, Wright and Westoby 2003).

Nitrogen resorption proficiency can be used as an index of the loss of leaf N during senescence (Killingbeck 1996), with a higher NRP corresponding to a lower final N concentration in senesced leaves (Richardson

![Fig. 2 Relationships among nitrogen concentrations in green leaves, Nₑ with (a) nitrogen concentrations in senesced leaves, Nₛ (b) nitrogen resorption efficiency (NRE) and (c) nitrogen use efficiency (NUE). Each point represents measurements for all plants in their habitats (n = 189).](image-url)
Leaf nitrogen resorption pattern along a habitat gradient

Plants that occupied MD and SMD sites with lower N status had higher NRP compared to that occupied SFD, FD and IDG sites (Table 3, Fig. 1), consistent with previous documents (Killingbeck 1996, Richardsson et al. 2005, Yuan et al. 2005). According to the criterion proposed by Killingbeck (1996), most plants in IDG, FD and SFD sites can be categorized as low N-proficient plants, indicating their N resorption is incomplete; while most species in SMD and MD sites can be categorized as high N-proficient plants, indicating plants are more likely to reach complete N resorption there (Rejmánková 2005, Yuan et al. 2005b). These data strongly support our hypothesis that plants from habitats with strong N limitation (e.g. MD and SMD) will have higher NRP.

The changes of NRP depend on $N_g$ and NRE according to formula 1 (Enoki and Kawaguchi 1999, Yuan et al. 2005b). In the present study, $N_g$ and $N_s$ (i.e. NRP) increased with increasing soil total N across habitats, but NRE was not affected (Table 3, Fig. 1). Additionally, $N_s$ correlated positively with $N_g$ (Fig. 2a). Therefore, NRP was determined by $N_g$ rather than NRE across species and habitats, consistent with a previous study (Kobe et al. 2005). At the leaf level, $N_g$ is positively related to the maximum photosynthetic rate, dark respiration, specific leaf area (Kobe et al. 2005, Reich et al. 1997), it is the most important factor affecting N resorption (Nordell and Karlsson 1995, Rejmánková 2005).

The lower $N_g$ and the greater NRE could have contributed jointly to leaf NUE

Table 3. Nitrogen concentrations in green leaves ($N_g$) and senesced leaves ($N_s$), nitrogen resorption efficiency (NRE), and nitrogen use efficiency (NUE) of 3 life-form groups in five habitats. Habitats and life forms – see Table 1. Values are mean ± SD (the number of species for each habitats and each life form were presented in Table 1; and three replicates for each species). Values with the same letters or no letter within columns are not significantly different among habitats or life forms at $P\geq 0.05$. Different letters indicates significant differences among habitats or life forms at $P < 0.05$.

<table>
<thead>
<tr>
<th>Nitrogen trait</th>
<th>Habitat</th>
<th>Total</th>
<th>Life forms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Min.</td>
<td>Max.</td>
</tr>
<tr>
<td>$N_g$ (mg g$^{-1}$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IDG</td>
<td>32.0 ± 5.5a</td>
<td>22.2</td>
<td>44.0</td>
</tr>
<tr>
<td>FD</td>
<td>29.0 ± 5.2b</td>
<td>21.8</td>
<td>39.9</td>
</tr>
<tr>
<td>SFD</td>
<td>29.8 ± 5.1b</td>
<td>22.7</td>
<td>39.8</td>
</tr>
<tr>
<td>SMD</td>
<td>14.3 ± 2.9c</td>
<td>9.2</td>
<td>19.7</td>
</tr>
<tr>
<td>MD</td>
<td>15.3 ± 3.6c</td>
<td>12.7</td>
<td>20.7</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$N_s$ (mg g$^{-1}$)</td>
<td></td>
<td>7.6</td>
<td>25.0</td>
</tr>
<tr>
<td>IDG</td>
<td>15.5 ± 5.0a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FD</td>
<td>13.1 ± 3.3b</td>
<td>8.3</td>
<td>20.0</td>
</tr>
<tr>
<td>SFD</td>
<td>14.5 ± 4.1ab</td>
<td>8.9</td>
<td>21.1</td>
</tr>
<tr>
<td>SMD</td>
<td>7.3 ± 2.5c</td>
<td>5.2</td>
<td>12.1</td>
</tr>
<tr>
<td>MD</td>
<td>7.2 ± 1.5c</td>
<td>5.3</td>
<td>8.4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NRE (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IDG</td>
<td>52 ± 13</td>
<td>39.9</td>
<td>131.6</td>
</tr>
<tr>
<td>FD</td>
<td>54 ± 11</td>
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<td>120.5</td>
</tr>
<tr>
<td>SFD</td>
<td>51 ± 13</td>
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</tr>
<tr>
<td>SMD</td>
<td>48 ± 12</td>
<td>31.7</td>
<td>91.5</td>
</tr>
<tr>
<td>MD</td>
<td>52 ± 10</td>
<td>39</td>
<td>59</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NUE (g g$^{-1}$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IDG</td>
<td>81.3 ± 20.3b</td>
<td>50.1</td>
<td>120.5</td>
</tr>
<tr>
<td>FD</td>
<td>75.4 ± 23.0b</td>
<td>47.4</td>
<td>113.0</td>
</tr>
<tr>
<td>SFD</td>
<td>148.7 ± 39.8a</td>
<td>83.0</td>
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</tr>
<tr>
<td>SMD</td>
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<td>119.85</td>
<td>190.40</td>
</tr>
<tr>
<td>MD</td>
<td></td>
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</table>
In addition, there were no or less significant relationships between species' resorption efficiency and their fertility gradients are inconsistent (Kob et al. 2005). However, NRE was not affected by soil total N (Fig. 1c), consistent with some studies (Aerts 1996, Cartaxana and Catarino 2002, Wright and Westoby 2003), but inconsistent with other studies (Enoki and Kawaguchi 1999, Yuan et al. 2005). Thus results about the relationships between species' resorption efficiency and their fertility gradients are inconsistent (Kobe et al. 2005). In addition, NRE did not correlate with soil total N among habitats (Fig. 2b), consistent with the report of Aerts (1996). However, Li et al. (2009) and Yuan et al. (2005a) reported that NRE positively correlated with soil total N, but Kobe et al. (2005) reported that NRE decreased with increasing soil total N in a global data set.

Although N resorption in the data set analyzed was mainly determined by habitats with different nutrients (Fig. 1; Tables 3, 4), there were also some consistent patterns among life forms (Tables 3, 4) (Rejmánková 2005). Life form had no significant effect on NRE among habitats (Table 4). Averaged NRE of herbs (14.5 mg g^-1) and shrubs (15.9 mg g^-1) were higher than that of grasses (9.4 mg g^-1) in the five habitats (Table 3), consistent with previous studies (Bertiller et al. 2005; Yuan et al. 2005a), suggesting that grasses may be more proficient at resorbing N than shrubs and herbs (Killingbeck 1996, Yuan et al. 2005a). There are considerable differences in NRE among species and life forms (Tables 3, 4), consistent with earlier reports (Aerts and Chapin 2000, Wright and Westoby 2003, Rejmánková 2005, Yuan et al. 2005a). As we known, the amount of N returned to the soil is largely determined by the leaf litter N quantity, so litter with higher NRP in grasses than herbs and shrubs may be associated with low leaf litter decomposition and N releasing rates. However, through the accumulation lignin and other secondary chemicals, shrubs and herbs could slow down litter decomposition and nutrient cycling (Bertiller et al. 2005). These differential patterns suggest that each life form has a different role in the decomposition pathway and N cycling (Bertiller et al. 2005). Therefore, changes in the dominance of different life forms could influence soil N cycling along a habitat gradient with different N status (Yuan et al. 2005a).

Large differences in NRE were observed among species and life forms (Table 3, 4). In the present study, shrubs (45%) exhibited the lowest NRE while grasses (62%) showed the highest NRE, herbs (51%) were in between (Tables 3). However, Yuan et al. (2005a) reported that NRE increased with the sequence of grasses (42%), shrubs (53%) and herbs (55%), presumably due to the differences of species composition: First, N fixers were included in shrubs and herbs in this study but not in grasses (42%). Second, shrubs (53%) and herbs (55%) had low NRE in our study (data not shown). In addition, we found wider variation of NRE among herb (Table 3), e.g. chenopodiaceae species often exhibit higher NRE than composite species (data not shown). These results indicate that species in the same family may
show the similar N strategy. Killingbeck and Whitford (2001) suggested that evolutional history and habitat specificity may be among the factors influencing resorption. Differences in the N strategy could help to explain the variations in NRRE (Yuan et al. 2005a), which is the objective of further study.

In conclusion, we have demonstrated that leaf Ng, Ns (i.e., NRP) and NUE differed significantly across habitats with a gradient of soil N status. Increasing dependence on Ns and Na along the habitat gradient suggests that N uptake become progressively limited, especially in MD and SMD. The levels of Ns, Na and NUE experience two stages across habitats: first, there were low Ns and Na and high NUE in MD and SMD sites; second, there were high Ns and Na and low NUE in IDG, FD and SFD sites. In addition, NRE was determined by life form rather than by habitat. Grasses have much more efficient and proficient resorption for N than herbs and shrubs. The large differences in NRP among habitats and life forms may strongly influence N cycling in Horqin Sandy Land, Inner Mongolia, China.

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Table 4. F values for the fixed effect of habitat and life form (herb, grass and shrub) on leaf N traits based on the data for all species in the five habitats. All symbols explanations see Table 1, 2. The effects of habitat and life form are presented using Type III F statistics from General linear models (GLM) analyses. * P< 0.05; ** P< 0.01; *** P< 0.001; NS P≥ 0.05.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Life form</th>
<th>Habitat×Life form</th>
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6. REFERENCES


Received after revision March 2010