Postprint: Nitrogen Uptake Strategies of Ephemeral Plants in the Gurbantünggüt Desert

Authors: Zhuang Weiwei

Date: 2021-09-14T00:00:00+00:00

Abstract

Investigating whether niche separation exists in nitrogen utilization among plants of the same life form in desert ecosystems contributes to a deeper understanding of desert plant survival strategies and a better grasp of nitrogen's influence on desert plant survival. In the Gurbantunggut Desert, four ephemeral plants are widely distributed: Erodium oxyrrhynchum, Hyalea pulchella, Nonea caspica, and Lactuca undulata. This study investigated the absorption and utilization of different nitrogen forms by these four desert ephemeral herbaceous plants across different months and soil depths. The results demonstrated: (1) At various soil depths, nitrogen absorption rates of all four species were higher in May than in April; regarding absorption rates of different nitrogen forms, glycine was consistently lower than nitrate nitrogen and ammonium nitrogen. (2) In April, Nonea caspica exhibited the highest recovery rate for nitrate nitrogen, reaching 52.3%; in May, Nonea caspica showed the highest recovery rate for ammonium nitrogen, reaching 90.7%. (3) Hyalea pulchella exhibited lower 15N absorption compared to the other three plant species. (4) The four ephemeral plants could not only utilize soil inorganic nitrogen but also effectively utilize soil organic nitrogen, with Erodium oxyrrhynchum and Lactuca undulata demonstrating a clear absorption preference for nitrate nitrogen. (5) In the Gurbantunggut Desert ecosystem, plants of the ephemeral life form exhibit differential and diversified characteristics in nitrogen absorption capacity, and all can absorb soluble organic nitrogen sources from the soil.

Full Text

Abstract

Investigating whether ecological niche separation exists in nitrogen utilization among plants sharing the same life form in desert ecosystems can deepen our understanding of desert plant survival strategies and clarify how nitrogen influences plant persistence. In the Gurbantunggut Desert, four short-lived herbaceous species—*Erodium oxyrrhynchum*, *Hyalea pulchella*, *Nonea caspica*, and *Lactuca undulata*—are widely distributed. This study examined the uptake of different nitrogen forms by these species across different soil depths and months. Results showed that nitrogen uptake rates for all four species were higher in May than in April across soil depths. For different nitrogen forms, glycine uptake rates were consistently lower than those for nitrate and ammonium. *Nonea caspica* achieved the highest nitrate recovery in April (52.3%), while its ammonium recovery peaked in May (90.7%). *Hyalea pulchella* exhibited lower ^{15}N uptake than the other three species. These short-lived plants could effectively utilize both inorganic and organic soil nitrogen, with *E. oxyrrhynchum* and *L. undulata* showing marked preferences for nitrate. The findings demonstrate that short-lived plants in the Gurbantunggut Desert ecosystem possess differentiated and diversified nitrogen uptake capacities, and all can absorb soluble organic nitrogen sources from soil.

Keywords: eremophytes; isotopic labeling; nitrogen absorption; Gurbantunggut Desert

Introduction

Plant diversity maintenance represents a crucial mechanism in ecosystems, and a deeper understanding of species coexistence is based on plants' direct utilization of organic nitrogen. Resource niche separation among different plants constitutes the primary reason for species coexistence, encompassing differences in light, water, and nutrient allocation. Nitrogen (N) is a fundamental element in many terrestrial ecosystems but often limits plant maintenance, growth, and reproduction. Soil contains diverse chemical nitrogen forms, ranging from simple inorganic nitrogen (ammonium and nitrate) to organic nitrogen (free amino acids and short peptides), each with distinct properties such as solubility, mobility, and toxicity that affect plant uptake. Nitrogen limitation is ubiquitous in terrestrial ecosystems, necessitating explanations of plant coexistence in N-limited systems through temporal, spatial, and chemical form differentiation in nitrogen utilization.

Desert ecosystems are typical nitrogen-deficient systems with limited available nitrogen exhibiting high temporal and spatial heterogeneity, thereby constraining primary productivity. Consequently, desert plants must evolve successful nitrogen utilization strategies to ensure survival. In nitrogen-poor regions, plant utilization of organic nitrogen beyond inorganic forms becomes key to guaranteeing growth, reproduction, and species coexistence. Plants in arid and semi-arid regions have been confirmed to absorb amino acids through roots. In desert ecosystems, soluble organic nitrogen content may be higher than in other ecosystems, and soil nitrogen differences can significantly influence plant nitrogen uptake preferences.

The Gurbantunggut Desert represents a typical temperate desert ecosystem yet harbors abundant herbaceous vegetation. In spring, short-lived herbaceous plants alone account for 60% of all plant species in this desert. How do such numerous plant species complete their entire life cycles within brief periods? How do ephemeral plants absorb and utilize limited nitrogen during different growth stages? Can they absorb and utilize soil organic nitrogen for growth and development? Do they exhibit niche separation in nitrogen utilization? These questions motivated our research.

We selected four common desert ephemeral herbaceous plants—*Erodium oxyrrhynchum*, *Hyalea pulchella*, *Nonea caspica*, and *Lactuca undulata*—for ^{15}N-labeled field experiments to investigate how growing season and nitrogen application depth affect plant nitrogen uptake and utilization. We hypothesized that different plant species would utilize different nitrogen forms across temporal and spatial variations.

1.1 Study Area Description

The study area was located within a large permanent plot at the Fukang Desert Experimental Station of the Chinese Academy of Sciences in the Gurbantunggut Desert. The fenced plot prevents large-scale human activities and grazing, and complete meteorological data are available. In 2019, we selected flat terrain with consistent crust development type and uniform vegetation coverage within the permanent plot, establishing 10 m × 10 m quadrats spaced more than 10 m apart, equivalent to 15 replicates. Fukang Meteorological Station data showed no rainfall at the plot during the experimental period. Soil composition during the experimental period is shown in .

1.2 Plant Selection

Within the quadrats, we selected four common ephemeral herbaceous species: *Erodium oxyrrhynchum*, *Hyalea pulchella*, *Nonea caspica*, and *Lactuca undulata*. These four species begin germinating after snowmelt in late March, enter rapid growth in mid-April, reach maximum biomass in mid-May, and wither by early June.

1.3 Nitrogen Labeling Experiment

For each 10 m × 10 m quadrat, we established 50 cm × 50 cm sub-quadrats for biomass collection, distinguishing among species. Aboveground biomass was collected by clipping, while belowground biomass was obtained by excavating soil blocks of 50 cm × 50 cm × 5 cm for the 0–5 cm depth, then continuing to extract 5–10 cm soil blocks to collect deeper root biomass. Plant above- and belowground biomass was oven-dried at 65°C to constant weight and weighed.

In the nitrogen labeling experiment, each sub-quadrat received nitrogen addition at 0.6 $g \cdot m^{-2}$. The three nitrogen form treatments were: control (no labeled nitrogen), ^{15}N-NH_4Cl, ^{15}N-KNO_3, and ^{15}N-Glycine. Each nitrogen form had equal amounts ($0.2\ g \cdot m^{-2}$ each), but only glycine-N contained ^{15}N isotope. Isotopic nitrogen concentrations were 99.14% (^{15}N-KNO_3), 99.19% (^{15}N-NH_4Cl), and 99.13% (^{15}N-Glycine) (all from Institute of Botany, Chinese Academy of Sciences, Beijing). The nitrogen mixture was dissolved in distilled water.

The ^{15}N solution and control were randomly applied to sub-quadrats within each 10 m × 10 m quadrat. To ensure uniform distribution for plant uptake, each 50 cm × 50 cm sub-quadrat was divided into 49 grid cells (approximately 7.1 cm each). Equal solution aliquots were injected into the center of each grid cell using a syringe at 0.5 cm from plant bases to avoid direct contact. Injection depths were 2.5 cm for 0-5 cm soil and 7.5 cm for 5-10 cm soil. A funnel was used during injection to prevent contamination of aboveground plant parts. The nitrogen addition method followed reference [15].

1.4 Plant Collection and Analysis

In each 10 m × 10 m quadrat, we selected 50 cm × 50 cm sub-quadrats for biomass collection by species. After 48 hours of nitrogen application, individual plants (or those with other species removed early) were collected from sub-quadrats. Plant aboveground parts with roots intact were extracted, and roots were rinsed under tap water to remove surface soil. Roots were soaked in 0.5 $mmol \cdot L^{-1}$ $CaCl_2$ solution for 30 minutes to remove adsorbed ^{15}N, then rinsed with distilled water. Above- and belowground parts were separated, oven-dried at 65°C, weighed, and ground in a ball mill [16]. Samples were analyzed for ^{15}N and ^{13}C using an elemental analyzer coupled with an isotope ratio mass spectrometer. Control samples served as natural abundance references.

1.5 Data Statistical Analysis

Total plant ^{15}N absorption (U b d, $g \cdot m^{-2}$) was calculated using:

$$U_{labeled} = \text{atom\%ex} \times N_{\text{content}} \times B$$

where atom%ex is atom percent excess, N_{content} is plant nitrogen concentration, and B is plant biomass [17].

Plant nitrogen uptake rate (V, $g \cdot g^{-1} \cdot h^{-1}$) was calculated using:

$$V = \frac{U_{labeled}}{t \times m_{root}}$$

where t is labeling time and m_{root} is root biomass.

Recovery rate (R, %) was calculated as:

$$R = \frac{U_{labeled}}{N_{added}} \times 100$$

Data entry and basic calculations were performed using Excel 2019. One-way ANOVA analyzed differences in biomass, nitrogen uptake rates, recovery rates, and nitrogen absorption among four plant species, two sampling months, and two soil depths. Origin 2019b software was used for statistical analysis and graphing.

2 Results and Analysis

2.1 Variation in Nitrogen Uptake Rates of Ephemeral Plants

As shown in [Figure 1: see original paper], nitrogen uptake rates differed significantly among the four ephemeral plant species for nitrate, ammonium, and glycine ($P < 0.05$). From the perspective of nitrogen forms, nitrate uptake rates were highest for all species: *E. oxyrrhynchum* ($1.700\ \mathrm{g \cdot g^{-1} \cdot h^{-1}}$), *H. pulchella* ($2.900\ \mathrm{g \cdot g^{-1} \cdot h^{-1}}$), *N. caspica* ($5.147\ \mathrm{g \cdot g^{-1} \cdot h^{-1}}$), and *L. undulata* ($2.940\ \mathrm{g \cdot g^{-1} \cdot h^{-1}}$). For *H. pulchella* and *N. caspica*, ammonium uptake rates were second highest and glycine lowest. For *E. oxyrrhynchum* and *L. undulata*, glycine uptake was lower than both nitrate and ammonium.

Across soil depths, the trend was consistent: ammonium > nitrate > glycine for *N. caspica*; nitrate > ammonium > glycine for *L. undulata*; nitrate > ammonium > glycine for *H. pulchella* at 0-5 cm (similar to *N. caspica* at 5-10 cm); and nitrate uptake rates were highest for *E. oxyrrhynchum* across both depths. Nitrogen uptake rates in May exceeded those in April across all species, soil depths, and nitrogen forms. Glycine uptake rates were consistently lower than nitrate and ammonium. Different species, months, and nitrogen forms significantly affected uptake rates ($P < 0.05$), while soil depth had relatively minor effects.

2.2 Variation in Nitrogen Recovery Rates of Ephemeral Plants

Recovery rates of ^{15}N-labeled nitrate, ammonium, and glycine for the four species are shown in [Figure 2: see original paper]. Across soil depths, maximum recovery rates for nitrate reached 64.3% for *N. caspica*, 48.3% for *H. pulchella*, 42.0% for *L. undulata*, and 34.0% for *E. oxyrrhynchum*, with shallow soil recovery consistently exceeding deep soil. Similar patterns occurred for ammonium and glycine.

In April, *N. caspica* showed the highest nitrate recovery (52.3%), while in May, *N. caspica* achieved the highest ammonium recovery (90.7%). *E. oxyrrhynchum* and *L. undulata* showed higher nitrate recovery in April, while *H. pulchella* had higher ammonium recovery. Glycine recovery was lower than nitrate and ammonium across all species, months, and soil depths. Recovery rates in shallow soil (0-5 cm) exceeded those in deep soil (5-10 cm). Species, month, soil depth, and nitrogen form all significantly affected recovery rates ($P < 0.05$).

2.3 Total Plant ^{15}N Uptake in Gurbantunggut Desert Ephemeral Plants

Total ^{15}N uptake values for nitrate, ammonium, and glycine by the four species are shown in (April) and (May). Total nitrogen uptake was greater in shallow than deep soil across all months and species. From the perspective of nitrogen compounds, most species preferred nitrate recovery, with the highest total ^{15}N uptake in *N. caspica* (53.84 $\text{g} \cdot \text{m}^{-2}$), followed by *H. pulchella* (40.88 $\text{g} \cdot \text{m}^{-2}$), *L. undulata* (36.05 $\text{g} \cdot \text{m}^{-2}$), and *E. oxyrrhynchum* (12.99 $\text{g} \cdot \text{m}^{-2}$). Nitrate uptake was highest in *N. caspica* (20.37 $\text{g} \cdot \text{m}^{-2}$), followed by *H. pulchella*, *L. undulata*, and *E. oxyrrhynchum* (10.58-17.78 $\text{g} \cdot \text{m}^{-2}$). Ammonium uptake was also highest in *N. caspica* (15.73 $\text{g} \cdot \text{m}^{-2}$), with other species ranging 10.28-14.32 $\text{g} \cdot \text{m}^{-2}$.

Overall, *E. oxyrrhynchum* had the lowest ^{15}N uptake, indicating minimal dependence on soil nitrogen and better adaptation to low-nitrogen environments. All four species could utilize both inorganic and organic soil nitrogen, with *E. oxyrrhynchum* and *L. undulata* showing clear nitrate preferences. These results demonstrate that different species within the same growth form possess differentiated and diversified nitrogen uptake capacities, with some effectively utilizing soluble organic nitrogen sources.

3 Discussion

Using ^{15}N labeling, we investigated nitrogen uptake strategies for organic and inorganic forms in four Gurbantunggut Desert ephemeral plants. In this temperate desert, all four species absorbed substantial quantities of organic nitrogen, with organic N accounting for 24.13-28.52% of total nitrogen uptake. Therefore, short-lived plants in the Gurbantunggut Desert exhibit differentiated and diversified nitrogen uptake capacities, all capable of absorbing soluble organic nitrogen sources. This allows species to occupy different ecological niches, reducing competition while enhancing utilization of limited soil resources. These findings provide deeper insights into how plants efficiently exploit limited nitrogen resources in temperate desert habitats where available nitrogen is a limiting factor.

Generally, NO_3^- uptake consumes more energy than NH_4^+ uptake. Ammonium can be directly absorbed by roots and converted to glutamate for immediate use, whereas nitrate must be reduced through an energy-intensive pathway before utilization [24]. Consequently, plants typically prefer ammonium over nitrate [25]. However, our results show that *E. oxyrrhynchum*, *H. pulchella*, and *L. undulata* all displayed preferences for NO_3^-. Across different growth seasons, all four species showed higher nitrogen uptake rates in May than in April. In the Gurbantunggut Desert, studying plant nitrogen uptake strategies is crucial for nutritional assessment of desert ecosystems under environmental change and for nutritional management during restoration. This research can serve as a reference for nitrogen input quantities during desert ecological restoration.

We observed higher glycine uptake rates than expected, indicating substantial plant capacity for organic nitrogen absorption per unit time. This contrasts with most previous studies suggesting plant preference for inorganic nitrogen. We hypothesize this discrepancy relates to high soil NH_4^+ content at our experimental site. Previous research shows soil NH_4^+ content can influence plant uptake preferences, and plants adjust their nitrogen absorption preferences when the availability of different nitrogen forms changes [26]. Additionally, NO_3^- moves more readily in soil, potentially contributing to observed preferences [27]. We also found that most roots of these four ephemeral plants distributed within the 0–5 cm soil layer, which likely contributed to higher nitrogen uptake rates, recovery rates, and total ^{15}N absorption in shallow versus deep soil.

However, the factors and regulatory mechanisms influencing plant preference for organic nitrogen absorption and utilization across different ecosystems remain unclear. Further research combining soil temperature, moisture, and other environmental factors is needed to address how nitrogen nutrition supports rapid growth of numerous herbaceous plants in the Gurbantunggut Desert.

The four species showed substantial differences in nitrogen uptake. Overall, uptake rates followed: *L. undulata* > *N. caspica* > *H. pulchella* > *E. oxyrrhynchum*. However, maximum nitrogen uptake capacity showed a different pattern: *N. caspica* > *L. undulata* > *H. pulchella* > *E. oxyrrhynchum*, with inorganic nitrogen maximum uptake capacity exceeding organic nitrogen capacity. This suggests that in the nitrogen-poor Gurbantunggut Desert, plants exhibit dependence on inorganic nitrogen but must utilize available organic nitrogen to supplement their growth and reproductive needs, adjusting nitrogen preferences according to soil nitrogen composition [28]. These results align with Min et al. [29].

4 Conclusion

Across soil depths, all four species showed higher nitrogen uptake rates in shallow versus deep soil. For different nitrogen forms, glycine uptake rates were lower than nitrate and ammonium. The four ephemeral plants in the Gurbantunggut Desert can utilize both inorganic and organic soil nitrogen, with *E. oxyrrhynchum* and *L. undulata* showing clear nitrate preferences. Short-lived plants exhibit differentiated and diversified nitrogen uptake capacities, with some species effectively utilizing soluble organic nitrogen sources from soil.

References

[1] Zhu Q, Zhuang Q. Modeling the effects of organic nitrogen uptake by plants on the carbon cycling of boreal forest and tundra ecosystems[J]. Biogeosciences, 2013, 10(12): 7943-7955.

[2] Liu Q, Ren T, Liao S, et al. Effect of different nitrogen application on seedling growth and allocation of carbon and nitrogen in oil seed rape[J]. Chinese Journal

of Oil Crop Sciences, 2019, 41(1): 92-100.

[3] Schoener T W. Resource partitioning in ecological communities[J]. Science, 1974, 185(4145): 27-39.

[4] Gough L, Osenberg C W, Gross K L, et al. Fertilization effects on species density and primary productivity in herbaceous plant communities[J]. Oikos, 2000, 89(3): 428-439.

[5] Yang J, Shan L, Bai Y, et al. Effects of nitrogen addition and precipitation on physiological indices of *Reaumuria soongorica*[J]. Arid Zone Research, 2021, 38(2): 460-468.

[6] Yao F, Zhu B, Du E. Use of natural abundance in nitrogen cycling of terrestrial ecosystems[J]. Chinese Journal of Plant Ecology, 2012, 36(4): 346-352.

[7] Mechthild T, Celine M D. Source and sink mechanisms of nitrogen transport and use[J]. New Phytologist, 2018, 217(1): 35-42.

[8] Chen J, Carrillo Y, Pendall E, et al. Soil microbes compete strongly with plants for soil inorganic and amino acid nitrogen in a semi-arid grassland exposed to elevated CO_2 and warming[J]. Ecosystems, 2015, 18(5): 867-880.

[9] Yao X, Hu W, Ma Y, et al. Nitrogen uptake preference of *Schima superba* and its root foraging strategies[J]. Acta Ecologica Sinica, 2020, 56(2): 1-11.

[10] Stoelken G, Simon J, Ehlting B, et al. The presence of amino acids affects inorganic N uptake in non-mycorrhizal seedlings of European beech (*Fagus sylvatica*)[J]. Tree Physiology, 2010, 30(9): 1118-1128.

[11] Wang L, Macko S A. Constrained preferences in nitrogen uptake across plant species and environments[J]. Plant, Cell & Environment, 2011, 34(3): 525-534.

[12] Templer P H, Dawson T E. Nitrogen uptake by four tree species of the Catskill Mountains, New York: Implications for forest N dynamics[J]. Plant and Soil, 2004, 262(1-2): 251-261.

[13] Zhang L, Chen C. On the general characteristics of plant diversity of Gurbantunggut Sandy Desert[J]. Acta Ecologica Sinica, 2002, 22(11): 1923-1930.

[14] Wang R, Tian Y, Ou Y, et al. Nitrogen acquisition strategies used by *Leymus chinensis* and *Stipa grandis* in temperate steppes[J]. Biology and Fertility of Soils, 2016, 52(7): 951-961.

[15] Le J, Su Y, Peng Q, et al. Effects of nitrogen addition on soil enzyme activities and ecoenzymatic stoichiometry in alpine grassland of the Tianshan Mountains[J]. Arid Zone Research, 2020, 37(2): 382-389.

[16] Tao Y, Wu G, Liu Y, et al. Soil stoichiometry and their influencing factors in typical shrub communities in the Gurbantunggut Desert[J]. China Journal of Desert Research, 2017, 37(2): 305-314.

[17] Mckane R B, Johnson L C, Shaver G R, et al. Resource based niches provide a basis for plant species diversity and dominance in arctic tundra[J]. Nature, 2002, 415(6867): 68-71.

[18] Jacob A, Leuschner C. Complementarity in the use of nitrogen forms in a temperate broad-leaved mixed forest[J]. Plant Ecology & Diversity, 2015, 8(2): 243-258.

[19] Karina E C, Pernille L S, Anders M, et al. Site dependent N uptake from N form mixtures by arctic plants, soil microbes and ectomycorrhizal fungi[J]. Oecologia, 2008, 155(4): 771-783.

[20] Emily E S, David E R. Amino acid uptake by temperate tree species characteristic of low and high fertility habitats[J]. Oecologia, 2011, 167(2): 547-557.

[21] Adrien C F, Sean T B. The uptake of amino acids by microbes and trees in three cold temperate forests[J]. Ecology, 2005, 86(12): 3345-3353.

[22] Wang S, Nie J, Li Q, et al. Effects of nitrogen application rate on nitrogen absorption and utilization, and fate of nitrogen in soil-cotton system[J]. Journal of Plant Nutrition and Fertilizer, 2020, 26(4): 738-745.

[23] Li Y, Sun D, Li D, et al. Effects of warming on ectomycorrhizal colonization and nitrogen nutrition of *Picea asperata* seedlings grown in two contrasting forest ecosystems[J]. Scientific Reports, 2015, 5: 17546.

[24] Luo X, Zhang G, Wang S, et al. Nitrogen isotope ratios in leaves from degraded plant communities in a yellow soil region of the Karst Plateau[J]. Earth and Environment, 2019, 47(2): 113-120.

[25] Meng S. Nitrogen Dynamic Uptake and Genetic Expression of Translocator of Tree Species in Fine Roots[D]. Yangling: Northwest Agriculture & Forestry University, 2016.

[26] Min X, Ma J, Zan Y. Effects of water and salinity stress on carbon and nitrogen isotopic compositions in leaves of *Tamarix elongata* and *Haloxylon ammodendron*[J]. Arid Zone Research, 2017, 34(5): 1109-1116.

[27] Chen J, et al. [Additional citation details would be needed for complete formatting]

[28] Additional references would be needed to complete this citation properly.

[29] Min X, et al. [Additional citation details would be needed for complete formatting]

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv —Machine translation. Verify with original.