三种利用类型羊草草地氮总矿化、硝化和无机氮消耗速率的比较研究

李玉中[1]，祝廷成[2]，R.E. Redmann[3]
(1.中国农业科学院农业气象研究所，北京 100081；2.东北师范大学草地研究所，长春 130024；3.Department of Crop Science and Plant Ecology, University of Saskatchewan, Canada)

摘要：采用同位素^{15}N库稀释技术研究了3种不同利用类型羊草草地土壤氮的总矿化、硝化速率以及无机氮总消耗速率，3种类型草地分别为：保护区(无人为扰动)、割草场、过度放牧地。结果表明：4月份过度放牧场的总矿化速率最高，为21.3μg N/(g土·d)，7月份割草场的值最高，为38.5μg N/(g土·d)，9月份保护区最高，值为15.6μg N/(g土·d)，总的来看，保护区的总矿化速率高于其它利用类型草地，这与土壤有机氮的含量较高有关，3种类型草地铵态氮的消耗速率与总矿化速率有类似的趋势。3种利用类型草地的氮总矿化速率均以7月份为最高，分别为36.5、38.5、29.8μg N/(g土·d)。总硝化速率放牧场最高，保护区、割草场、放牧场7月份的总硝化速率分别为18.6、21.45、35.45μg N/(g土·d)。3种利用类型草地中放牧场的硝态氮含量最高，其消耗的速率也高于其它两种利用类型草地。

关键词：草地；总矿化速率；总硝化速率

A Comparative Study on Soil Nitrogen (N) Gross Rate of Mineralization, Nitrification and Consumption Over Three Management Systems of *Leymus chinensis* Grasslands

LI Yu-Zhong[1], ZHU Ting-Cheng[2], R.E. Redmann[3] (1. *Agrometeorology Institute, Chinese Academy of Agricultural Sciences, Beijing* 100081, *China*; 2. *Grassland Institute, Northeast Normal University, Changchun* 130024, *China*; 3. *Department of Crop Science and Plant Ecology, University of Saskatchewan, Canada*). **Acta Ecologica Sinica, 2002, 22(5): 668～673.**

Abstract: This experiment was carried out in *L. chinensis* grasslands in northeast China. Grasslands that were 1) protected; 2) overgrazed and 3) mown were compared for gross rates of mineralization, nitrification and consumption during growth seasons.

The ^{15}N isotope pool dilution technique in intact cores was used to study differences in nitrogen transformation within three management systems of *L. chinensis* grasslands.

Sampling was carried out in the middle April, July and September respectively. In brief, Zincified iron cylinders (4cm diameter × 10cm deep) were driven into soil, and then larger cylinders (8cm diameter × 10cm deep) were driven into soil around the smaller ones in concentric form. The pair were removed and the soil between the two cylinders was placed in plastic bags, mixed, and subsampled for extraction with 2 mol/L KCl (about 30g dry soil to 150 ml KCl), the remaining soil was used for gravimetric moisture test. The inner cores were taking out, covered one end, solution of 95% ^{15}N enrichment 80μg ^{15}N/ml concentration of ether $(^{15}NH_4)_2SO_4$ or $K^{15}NO_3$ was injected in 6 times from both ends as even as possible, the proportion is about 1g dry soil to 2μgN, after the injection, covered the both ends, placed into soil for incubation 24 hours, and then placed

基金项目：国家自然科学基金国际合作资助项目(9389009-1)；国家高技术研究发展计划资助项目(2001AA242041)
收稿日期：2000-08-24；**修订日期**：2001-12-01
作者简介：李玉中(1964～)，男，内蒙古赤峰人，博士。主要从事生态学研究。

the soil in the core into a plastic bags, mixed, extracted with 2mol/L KCl. Filtrated the extraction, the filtrate then was used for NH_4^+ and NO_3^- content analysis, distillation methods were used for the analysis. After acidification and concentration of the distillation, the ^{15}N enrichment was analyzed.

The initial pool sizes were calculated from the sum of the ambient pool and the amount of N injected. The ambient pool sizes were estimated from KCl extracts of soil collected between the two cores in concentric circles. The amount injected was calculated from the volume times the concentration of injecting solutions divided by the mass of soil sample in the core.

The equations of Kirkham and Bartholomew(1954) were used to calculate the gross rates of mineralization, nitrification, and consumption in the three management systems.

Overall results indicate that gross mineralization rates of all the three management system were higher in July compared to the other months of testing, this is close related to soil moisture and temperature. As the grasslands have more rainfall in summer than any other seasons, also temperature is higher, this is benefit for microbe 's activity. And rates of mineralization were highest in overgrazed *L. chinensis* grassland during the month of April at 21.3μg N/(g soil·d) while rates for mown grassland was highest in July at 38μg N/(g soil·d). The rate of protected *L. chinensis* grasslands was highest during September at 15.6μg N/(g soil·d). The gross rates of soil N mineralization are higher in protected *L. chinensis* grassland in average, the reason is that protect *L. chinensis* grassland have more organic N compared with the other two management systems.

The patterns of gross nitrification rates have some differences with gross mineralization rates in the three management systems, the gross nitrification rates are higher in September in general. The rates were significant high in the overgrazed system compared to mown or protected systems in April and July, and the difference is not significant compared with mown region in September, the difference between overgrazed system and protected system is not significant.

consumption of NH_4^+ includes the sum of immobilization, autotrophic nitrification, volatilization, and other possible fates. The pattern of NH_4^+ consumption rates has similar pattern with soil gross mineralization under the three management systems. The highest NH_4^+ consumption occurred in July.

Consumption of NO_3^- includes the sum of microbial denitrification, dissimilatory NO_3^- to NH_4^+, and microbial assimilation. The pattern of NO_3^- consumption rates has similar pattern with soil gross nitrification under the three management systems. The consumption rates of NO_3^- are higher in September in mown and overgrazed grasslands, and the differences of NO_3^- consumption between protected and overgrazed grasslands are significantly in different seasons.

NH_4^+ and NO_3^- concentrations are higher in July compared to the other months of testing in the each management system. NH_4^+ concentration of protected grasslands is higher than overgrazed and mown grasslands in July, NO_3^- concentration of overgrazed grasslands is significantly higher than protected and mown grasslands in different months.

In conclusion, the gross rates of soil N mineralization and nitrification are strongly influenced by grassland management, the influences are varied in different seasons.

Key words: ^{15}N isotope; N gross mineralization; nitrification; grasslands

文章编号:1000-0933(2002)05-0668-06 **中图分类号**:Q142,Q948,S543.9 **文献标识码**:A

氮矿化是指由微生物的活动将有机氮转变为铵态氮的过程。也有一些学者将硝化作用也并入到矿化作用过程[1]。硝化作用是指由微生物(硝化细菌)活动将有机氮或铵态氮转变为硝态氮的过程。本文中土壤氮总矿化(gross mineralization)是指由有机氮转化为 NH_4^+ 的过程,总硝化(gross nitrification)是指由有机

氮和 NH_4^+ 转化为 NO_3^- 的过程。

目前,国内外相关文献中,绝大多数研究是有关净矿化和净硝化的研究[2],总矿化、总硝化的研究限于方法的限制,文献还比较少。Davidson[3]介绍了野外测定总矿化、总硝化和微生物对铵态氮和硝态氮同化速率,并用^{15}N 库稀释法测定了草地与森林这三种速率。在氮矿化、硝化等相关领域里,Tisdale 等[4]研究了C、N 比与矿质和微生物同化作用之间的关系,认为当 C/N 大于 30:1 时,微生物同化是主要的;20:130:1,微生物的固持作用与矿化作用大体相等;当 C/N 小于 20:1 时,矿化作用占优势。土壤中的水分、温度、pH 值、基质对矿化和硝化作用均有影响。最适宜的矿化条件要求 pH 值在 4.8~5.2。而硝化最适宜的 pH 值为 7~9[5]。相对高的温度对于矿化和硝化作用均有利。湿润的土壤也有利于矿化和硝化作用,通气性差或水淹不利于这两个过程的进行[6]。

有机氮的矿化和硝化速率也是土壤供氮能力的一个重要指标[7]。研究不同类型草地在不同季节的总矿化速率,对深入研究草地退化机理、合理管理利用及草地氮循环的深入研究等具有十分重要的意义。

1 研究地点概况与研究方法

1.1 研究地点

本研究在吉林省长岭腰井子羊草草原自然保护区内进行,地理位置为东经 123°44′123°47′,北纬 44°40′44°44′。海拔 140~160m,地形相对高差 5~20m。

1.2 气候特点

研究地区位于温带半湿润、半干旱季风气候区,其气候特点具有典型的大陆性气候,温差较大;春季干燥多风,夏季温热多雨,秋季温和凉爽,冬季寒冷少雪。根据长岭县气象站(E 123°58′,N44°15′)近 30a 的气象资料统计,该地区年平均降水量为 470.6mm,主要集中在夏季(6~8 月份降水量约占全年的 70%);年蒸发量 1600.2mm,年平均气温 4.9℃,其中 1 月份平均气温 -16.4℃,平均最低温度 -21.8℃,绝对最低气温 -37.8℃;≥10℃ 的活动积温在 2545.93374.9℃ 之间;无霜期 136~163d,太阳总辐射 90263.7kW·h/(m^2·a);年平均日照时数 2882.4h。

1.3 植被特征

所研究的样地为羊草单优势种群落,伴生种有十几种,单优势种羊草总盖度达 80% 左右,羊草地土生物量占群落总生物量的 90% 以上[8]。在保护区核心区外的放牧场,由于利用不当,草地已出现严重退化现象[8],盐碱化指示植物碱茅(*Puccinellia tenuifolia*)、碱蓬(*Suaeda glauca*)大量出现。同时也出现了大量的光碱斑。

1.4 土壤基本性质

羊草草地保护区,割草场和放牧场土壤的有关理化性质如表 1 所示。从此表可以看出,所研究地带的羊草草地偏碱性,放牧场由于过牧出现退化,致使 pH 值升高,土壤容重明显地高于保护区和割草场。全氮含量由于割草场和放牧场 N 过度输出,致使全氮含量下降。

表 1 保护区、割草场、放牧场土壤特性

Table 1 Soil properties of the protected, mown and overgrazed areas

土壤理化特性 Soil characteristics	保护区 (0~15cm) Protected grassland	割草场 (0~15cm) Mown grassland	过度放牧场 (0~15cm) Overgrazed grassland
pH 值①	8.6	8.7	9.0
有机质(g/kg)②	32.4	25.3	26.6
全氮(g/kg)③	1.5	1.2	1.0
C:N	21.6	21.1	20.5
容重(g/cm^3)④	1.41	1.39	1.55

① pH value, ② Organic matter, ③ Soil total N, ④ Bulk density

1.5 研究方法

本研究采用 Davidson 等[3,9]改进的^{15}N 库稀释技术研究了 3 种类型草地土壤的氮转化速率。

从 4 月到 10 月于每个月的中旬在羊草草地保护区典型地段每隔 50m 设一取样点,在每个取样点上将内径 4cm 高 10cm 的柱形镀锌铁管打入土壤内,将另一直径为 8cm 高 10cm 的柱形取样器以同心圆的形式套在前一个内径为 4cm 的取样器周围并打入土壤,两个取样器同时取出,将两个取样器之间的土壤取出并放在塑料袋内混匀,一部分土壤立即用 2mol/L 的 KCl 提取(土水比 1:5)。剩余的土

壤作土壤含水量分析(105℃,24h 烘干)。内径 4cm 的土壤取样器取出,上部加盖密封、倒置,将丰度为 95%浓度为 80μg ^{15}N/ml 的(^{15}NH)$_2$ SO$_4$或 K^{15}NO$_3$分 6 次,按每克土 2μgN 的比例均匀注入取样器内的土壤中。注射完成后将底部的盖子也盖好,竖过来,放在原取样处培养 24h 后取出,将取样器内的土壤取出、混匀,用 2mol/L 的 KCl 提取,Whatman 1 号滤纸过滤。取滤液 40ml,用蒸馏法测定滤液内铵态氮或硝态氮的含量,馏出液经酸化处理、浓缩,进行^{15}N 光谱分析。氮的总矿化速率和硝化速率按以下公式计算:

$$m = \frac{M_0 - M_1}{t} \times \frac{\log(H_0 M_1 / H_1 M_0)}{\log(M_0 / M_1)}$$

$$c = \frac{M_0 - M_1}{t} \times \frac{\log(H_0 / H_1)}{\log(M_0 / M_1)}$$

此公式是 Kirkham 和 Bartholomew[10]得出的,M_0:$^{14+15}$N 初始的库浓度(μg N/g 土);M_1:$^{14+15}$N 培养后库浓度(μg N/g 土);H_0:^{15}N 初始的库浓度(μg N/g 土);H_1:^{15}N 培养后的库浓度(μg N/g 土);m:矿化速率(μg N/(g 土·d));c:N 消耗速率(μg N/(g 土·d)),是指生物与非生物过程对无机氮的固定,其中,NH_4^+ 的消耗包括 NH_4^+ 的生物固持和硝化作用等,NO_3^- 的消耗包括微生物的吸收利用、NO_3^- 还原为 NH_4^+、反硝化作用等;t 培养时间(此处为 1);注入同位素$^{15}NH_4^+$ 的 NH_4^+ 库用 M 和 H 表示,如注入的是$^{15}NO_3^-$,NO_3^- 库浓度也用 M 和 H 表示,但公式中的 m 要换成 n,它表示的是硝化速率。本实验设 3 次重复。

2　结果与分析

2.1　保护区、割草场、放牧场不同季节土壤氮总矿化、硝化和无机氮消耗速率的比较

3 种利用类型的草地氮总矿化和硝化作用的速率如图 1、图 2 所示,4 月份过度放牧场的土壤氮总矿化速率高于其它两种利用类型草地,为 21.3μg N/(g 土·d);7 月份保护区、割草场、过度放牧场氮总矿化速率分别为 36.5、38.5、29.8μg N/(g 土·d),割草场最高;九月份保护区氮总矿化速率最高,为 15.6μg N/(g 土·d)。3 种利用类型草地氮总矿化速率均以 7 月份最高,这说明温度和土壤湿度的增加对土壤氮的矿化作用有着十分重要的促进作用,因为在雨热同期的 7 月份,降水和温度均比较高。在这几种利用类型的草地中,保护区氮矿化作用强度总的来看比较高,其次是放牧场,而割草场除在 7 月份较高外,4、9 月份均较低。不同利用类型草地氮总矿化速率与土壤中 N 矿化基质多少有关,从表 1 可以看到 3 种类型草地有机质含量以保护区为最高,其次是放牧场,最后是割草场,草地利用方式是产生这一结果的原因,保护区多年不利用,凋落物积累,使土壤有机质增加,放牧场由于牲畜践踏,使部分牧草茎叶直接归还于土壤,加之牲畜粪便的归还,其有机质含量不是很低,而割草场由于连年打草,植物地上部分几乎全部被带出该生态系统,致使土壤有机质较低。

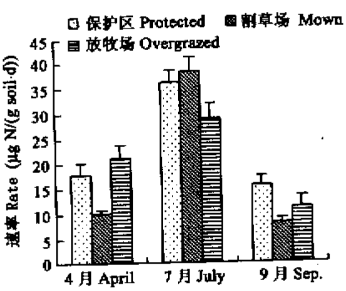

图 1　3 种类型草地不同季节氮总矿化速率比较

Fig.1　The comparison of soil N gross mineralization rates of three type grasslands in different seasons

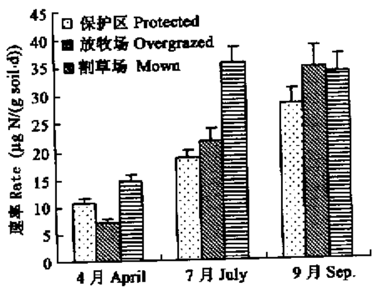

图 2　3 种类型草地不同季节氮总硝化速率比较

Fig.2　The comparison of soil N gross nitrification rates of three type grasslands in different seasons

3 种类型草地的总硝化速率 4 月份以放牧场为最高，其次是割草场，保护区的硝化作用强度最低，7 月份氮总硝化速率放牧场最高，其次是割草场，保护区最低，分别为 18.6、21.45、35.45μg N/(g 土·d)。9 月份保护区的总硝化速率最高，其次是过度放牧场，保护区最低。过度放牧场总硝化速率始终比较高的主要原因是放牧场由于放牧不当(如雨后放牧或过牧)致使其严重退化，牧草生长矮小，对土壤中矿化的铵态氮和硝态氮吸收减少，使放牧场硝化作用的主要基质 NH_4^+ 有一定的积累(图 3～图 5)，因而土壤硝化作用强度较高，产生的硝态氮由于植物利用的较少，使的硝态氮有一定的积累(见图 6)；另一方面割草场连年割草，也出现退化，pH 值也在升高，因而硝化作用强度也较高。3 种类型草地氮矿化强度与土壤 NH_4^+ 含量的分布、硝化作用强度与 NO_3^- 含量关系是密切的。氮矿化作用越强，土壤 NH_4^+ 含量越高，硝化作用强度越高，NO_3^- 含量也较高。

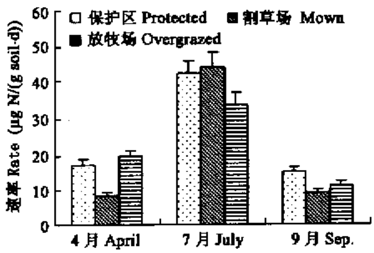

图 3 3 种类型草地不同季节铵态氮消耗速率比较

Fig.3 The comparison of soil NH_4^+ consumption rates of three type grasslands in different seasons

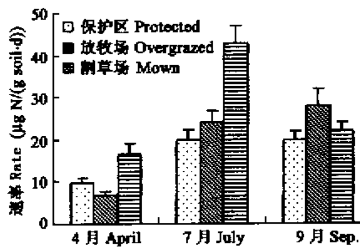

图 4 3 种类型草地不同季节硝态氮消耗速率比较

Fig.4 The comparison of soil NO_3^- consumption rates of three type grasslands in different seasons

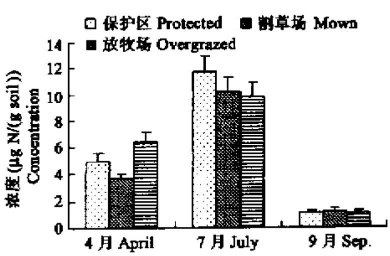

图 5 3 种类型草地不同季节铵态氮浓度比较

Fig.5 The comparison of soil NH_4^+ concentration of three type grasslands in different seasons

图 6 3 种类型草地不同季节硝态氮浓度比较

Fig.6 The comparison of soil NO_3^- concentration of three type grasslands in different seasons

3 种类型草地 NH_4^+ 和 NO_3^- 的消耗速率分别与氮的总矿化和硝化作用趋势大致相同，见图 3、4，NH_4^+ 的消耗以保护区的强度为最高；NO_3^- 的消耗以放牧场为最高，说明放牧场由于过度放牧，造成土壤板结、通气性差(容重为 1.55)，pH 值高，有利于反硝化作用，因而也使得 NO_3^- 消耗量增加。

2.2 保护区、割草场、放牧场不同季节 NH_4^+ 和 NO_3^- 的动态比较

过度放牧场 4 月份 NH_4^+ 和 NO_3^- 的含量均显著地高于其它两种利用类型草地，保护区的 NH_4^+ 含量显著地高于割草场，NO_3^- 的含量略低于割草草场。7 月份保护区的 NH_4^+ 含量显著高于其它两种类型草地，割草场略高于过度放牧地，NO_3^- 含量放牧场最高，其次是割草场，保护区最低。9 月份 3 种利用类型草地

NH_4^+ 含量均很低,差异不显著,NO_3^- 含量差异比较大,放牧场最高,其次是割草场,保护区最低。

3　小结

保护区、割草场,放牧场这 3 种利用类型相比,保护区的总矿化总的来看高于其它类型草地,这与土壤有机氮的含量较高有关,铵态氮的消耗速率也高于其它两种类型草地,这是由于保护区牧草生长茂密、植物根系发达,吸收利用的铵态氮较多。总硝化速率以放牧场为最高,这与放牧场利用不当,牧草生长矮小,造成对土壤中铵态氮吸收量降低,致使土壤中的硝化作用基质铵态氮有一定积累等原因有关。3 种利用类型草地中放牧场的硝态氮含量最高,其消耗的速率也高于其它两种类型草地,这与放牧场容重增加,反硝化作用氮损失比较高有关。

由以上研究结果看,过度放牧的羊草草地、割草场土壤中氮的转化规律及含量与保护区有一定的差异,但这些差异不是造成草地退化根本原因,该类型草地退化的更主要原因是由于不适当的管理与利用。

参考文献

[1] Raison R J. Methodology for studying fluxes of soil mineral-N in situ. *Soil Biol. Biochem.*, 1987, **19**(5):521530.

[2] McDuff J H and White R E. Net mineralization and nitrification rates in a clay soil measured and predicted in permanent grassland from soil temperature and moisture content. *Plant and Soil*, 1985, **86**(2):151~172.

[3] Davidson E A, Hart S C, Shanks C A, *et al*. Measuring gross nitrogen mineralization, immobilization, and nitrification by 15N isotopic pool dilution in intact soil cores, *Journal of soil science*, 1991, **42**, 335349.

[4] Tisdale S L. *Soil fertility and fertilizers* (Fourth edition), Macmillan Publishing Company, New York, 1985.

[5] Zhu Z X(朱祖祥). Soil Science(in Chinese)(土壤学), Beijing: Agricultural Publishing Press, 1983. 268273.

[6] Donahue R L, Miller R W and Shickluna J C. *Soil-An introduction to soil and plant growth*, Prentice-Hall, Inc., Englewood, Cliffs, New Jersey, 1983. 216217.

[7] Mazzarino M J. Nitrogen mineralization and soil fertility in the dry Chaco ecosystem. *Soil Sci. Am. J.*, 1991, **55**: 515522.

[8] Li J D(李建东). The grassland types and their ecological distribution patterns near Zhongmachang in Jilin province. *Jilin Agri. Sci.* (in Chinese), 1981, **3**:7980.

[9] Davidson E A, Hart S C and Firestone M K. Internal cycling of nitrate in soils of a mature coniferous forest. *Ecology*, 1992, **73**:11481156.

[10] Kirkham D and Bartholomew W V. Equations for following nutrient transformation in soil, utilizing tracer data. *Soil Science Society of America Proceedings*, 1954, **18**:3334.