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Nitrogen retention efficiency and nitrogen losses of a managed and phytodiverse temperate grassland

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Abstract

Maintaining nitrogen retention efficiency (NRE) is crucial in minimizing N losses when intensifying management of temperate grasslands. Our aim was to evaluate how grassland management practices and sward compositions affect NRE (1 − N losses/soil available N), defined as the efficiency with which soil available N is retained in an ecosystem. A three-factorial grassland management experiment was established with two fertilization treatments (without and combined N, phosphorus and potassium fertilization), two mowing frequencies (cut once and thrice per year) and three sward compositions (control, monocot- and dicot-enhanced swards). We measured N losses as leaching and nitrous oxide emissions, and soil available N as gross N mineralization rates. Fertilization increased N losses due to increased nitrification and decreased microbial N immobilization, and consequently decreased NRE. Intensive mowing partly dampened high N losses following fertilization. Sward compositions influenced NRE but not N losses: control swards that developed for decades under extensive management had the highest NRE, whereas monocot-enhanced sward had the lowest NRE. NRE was highly correlated with microbial NH_4^+ immobilization and microbial biomass and only marginally correlated with plant N uptake, underlining the importance of microbial N retention in the soil-plant system. Microbial N retention is reflected in NRE but not in indices commonly used to reflect plant response. NRE was able to capture the effects of sward composition and fertilization whereas N losses were only sensitive to fertilization; thus, NRE is a better index when evaluating environmental sustainability of sward compositions and management practices of grasslands.

Zusammenfassung

Im Rahmen der Intensivierung der landwirtschaftlichen Nutzung von temperatem Grünland ist die Stickstoffretentionseffizienz (NRE) essentiell für die Minimierung von Stickstoffverlusten. Ziel der vorliegenden Arbeit ist es, den Einfluss von Grünlandbewirtschaftung und Vegetationszusammensetzung auf die Stickstoffretentionseffizienz (1 - Stickstoffverluste ÷ verfügbarer Stickstoff im Boden), definiert als die Effizienz, mit der im Boden verfügbarer Stickstoff in einem Ökosystem zurückgehalten wird, zu erfassen. Es wurde ein dreifaktorielles Grünlandbewirtschaftungsexperiment mit zwei Düngeintensitäten (ohne Düngung und mit kombinierter Stickstoff-, Phosphor- und Kaliumdüngung), zwei Mahdfrequenzen (einmal und dreimal pro

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Jahr) und drei Vegetationszusammensetzungen (Kontrollvegetation, Monokotyl-angereicherte Vegetation und Dikotyl-angereicherte Vegetation) etabliert. Dabei wurden Stickstoffverluste als Summe aus Stickstoffauswaschung und Stickstoffoxidemissionen berechnet. Der im Boden verfügbare Stickstoff wurde anhand der Brutto-Stickstoffmineralisationsraten ermittelt. Düngung verstärkte die Stickstoffverluste durch einen Anstieg der Nitrifikation bei gleichzeitig verringerter mikrobieller Stickstoffimmobilisation und verringerte folglich die Stickstoffretentionseffezienz. Intensives Mähen konnte die durch Düngung hervorgerufenen Stickstoffverluste teilweise kompensieren. Die Vegetationszusammensetzung hatte keinen Einfluss auf die Stickstoffverluste, beeinflusste jedoch die Stickstoffretentionseffizienz: Die (unbehandelte) Kontrollvegetation, die sich im Laufe jahrzehntelanger extensiver Bewirtschaftung entwickelt hat, zeigte die höchste Stickstoffretentionseffizienz. Die niedrigste Stickstoffretentionseffizienz war für die Monokotyl-angereicherte Vegetation zu verzeichnen. Es bestand eine starke Korrelation zwischen der Sticksoffretentionseffizienz und der mikrobiellen Ammoniumimmobilisation sowie der mikrobiellen Biomasse. Die Korrelationen zwischen Stickstoffretentionseffizienz und der Stickstoffaufnahme durch Pflanzen war hingegen nur marginal-signifikant, was die Bedeutung des mikrobiellen Stickstoffrückhaltes im System Boden-Pflanze unterstreicht. Im Gegensatz zu anderen häufig verwendeten Indizes berücksichtigt die Stickstoffretentionseffizienz diesen Mechanismus. Zudem war die Stickstoffretentionseffizienz in der Lage, Unterschiede zwischen den Vegetationszusammensetzungen abzubilden, während die (absoluten) Stickstoffverluste nur durch die Düngung beeinflusst wurden. Die Stickstoffretentionseffizienz ist demnach ein geeigneter Indikator für die Evaluierung von Nachhaltigkeit in der Grünlandbewirtschaftung und der Vegetationszusammensetzung.

Keywords: Nitrate leaching; Dissolved organic nitrogen; Nitrous oxide emissions; Gross N mineralization; Microbial immobilization; ^{15}N pool dilution; Functional group diversity

Introduction

Nitrogen (N) is an essential plant nutrient that limits primary production in many ecosystems, making the use of N fertilizers widespread in agricultural ecosystems (e.g. Vitousek & Howarth 1991). As a result of the growing global population, a more intensive agricultural production and hence an increase in the use of N fertilizers can be expected in the near future (e.g. Galloway et al. 2008). Agricultural intensification is, however, accompanied by negative environmental impacts: considerable amounts of applied fertilizer N can be lost through nitrate (NO_3^-) leaching or gaseous emissions, e.g. in the form of nitrous oxide (N_2O). Leaching of NO_3^- can be a threat to ground- and surface-water quality (e.g. Di & Cameron 2002), whereas N_2O is an important greenhouse gas that also contributes to the depletion of stratospheric ozone (e.g. Schlesinger 2009).

A N-efficient grassland system is characterized by closely coupled soil N production and retention processes, resulting in small N losses (e.g. Corre, Schnabel & Stout 2002). In agricultural systems, maintaining soil quality and high yields while minimizing N losses can only be achieved through efficient retention of N in the plant-soil system, i.e. available mineral N should be taken up by plants and immobilized by the microbial community before it is potentially lost through the microbial processes of nitrification and denitrification. N retention efficiency, defined as the efficiency with which available N is retained in an ecosystem, is thus an important parameter to evaluate the sustainability of a land use system.

Temperate grasslands have been subject to agricultural intensification in the last decades (i.e. increasing use of N fertilizers and increasing mowing frequencies), which had a strong impact on grassland biodiversity (e.g. Isselstein, Jeangros & Pavlu 2005). In temperate grasslands, N retention efficiency may be influenced by management practices and plant diversity (Christian & Riche 1998; Flechard, Neftel, Jocher, Ammann & Fuhrer 2005; Jones, Rees, Skiba & Ball 2005). Application of N fertilizer typically increases N losses (e.g. Christian & Riche 1998; Jones et al. 2005), whereas mowing can lead to a more efficient plant N uptake caused by overcompensatory regrowth of plants (Ferraro & Oesterheld 2002) or by a denser root system (Kammann, Grunhage, Muller, Jacobi & Jager 1998). A more diverse grassland community may have a higher N retention through complementary resource use, e.g. due to different rooting depths or root structures of various plant communities, uptake of different forms of N, or N uptake at different times of the year (e.g. Hooper & Vitousek 1998).

It has been reported that increasing plant species diversity reduces the amount of extractable soil mineral N (e.g. Ewel, Mazzarino & Berish 1991; Tilman, Wedin & Knops 1996). However, most of these studies have been carried out in artificial and intensively weeded grassland plots, making it difficult to compare with permanent, managed grassland. Furthermore, soil extractable NO_3^- concentrations are not directly related to NO_3^- leaching, complicating their interpretation (Scherer-Lorenzen, Palmborg, Prinz & Schulze 2003). To our knowledge, there are only three studies that directly quantified NO_3^- leaching losses as a function of plant diversity (Hooper & Vitousek 1997; Scherer-Lorenzen et al. 2003; Oelmann et al. 2007) and only one study investigated biodiversity effects on leaching of dissolved organic