Agriculture, Ecosystems and Environment 184 (2014) 158–167

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Revealing N management intensity on grassland farms based on natural $\delta^{15}N$ abundance

Melanie Kriszan[a], Jürgen Schellberg[a,*], Wulf Amelung[b], Thomas Gebbing[c], Erich M. Pötsch[d], Walter Kühbauch[a]

[a] Institute of Crop Science and Resource Conservation (INRES), Division of Plant Production, University Bonn, Katzenburgweg 5, 53115 Bonn, Germany
[b] Institute of Crop Science and Resource Conservation (INRES), Soil Science and Soil Ecology, University Bonn, Nussallee 13, 53115 Bonn, Germany
[c] Chamber of Agriculture North Rhine Westfalia, Siebengebirgsstraße 200, 53229 Bonn, Germany
[d] LFZ Raumberg-Gumpenstein, Raumberg 38, 8952 Irdning, Austria

ARTICLE INFO

Article history:
Received 2 April 2013
Received in revised form
15 November 2013
Accepted 28 November 2013
Available online 22 December 2013

Keywords:
$\delta^{15}N$
N balance
Management
Grassland

ABSTRACT

High application rates of farmyard manure on grasslands generally results in nitrogen (N) losses and a shift in N isotope composition. The aim of this study was to elucidate to which degree the ^{15}N signatures of miscellaneous N pools at two different levels of management intensity may be used to reproduce the N level of various grassland farms in practise, i.e. beyond the control of experimental plots. We hypothesized that (i) higher $\delta^{15}N$ values in soil, plant and animal samples can be found with intensified grassland farming and high N-input management, (ii) that the ^{15}N signature originating from manure application is influenced by application technique and (iii) that it declines with increasing distance from stable to field. To test these hypotheses, we monitored different N pools on nine different farms (dairy, suckler, beef production) in grassland dominated regions of North Rhine-Westphalia, Rheinland-Palatinate (Germany) and Styria (Austria). Samples were taken from 0 to 5 cm soil depth and aboveground biomass at each of five sub-sites on farm, as well as from feed components, fertilizers, and cattle product and tissue like milk, hair, faeces and urine.

The results indicated a considerable variation in $\delta^{15}N$ values of the top soil (1.47‰ to 7.91‰) and of harvested plant material (−2.18‰ to 6.79‰). On average, $\delta^{15}N$ values of samples from high N-input grasslands were elevated by 2.8 delta units relative to those of low N-input grasslands. For the soil and plant samples, the $\delta^{15}N$ values were thus closely correlated with the overall N balance as well as with stocking rate and fertilizer input ($r^2 = 0.71$ to 0.85). Respective trends for the isotopic signatures in milk, hair and faeces were also evident but less apparent. Furthermore, low emission application techniques of organic fertilizer and increasing distances from the stable to the field exhibited lower $\delta^{15}N$ values of top soils and plants, but only in the low input system. We conclude that high N-input on grassland farms systematically changes the $\delta^{15}N$ values of soils and above ground biomass and thus also the N signature in animal tissues. Application of N isotope technique to these N pools thus allows for tracing back intensity of fertilizer management regardless of high natural $\delta^{15}N$ variations in terrestrial environments.

1. Introduction

Intensive animal husbandry frequently leads to serious imbalances of major nutrients on farmland (Van Keulen et al., 2000). During the last decades, particularly increasing application rates of N fertilizer have resulted in unwanted side effects on water and air quality. In order to lower N surpluses and improve N budgets at larger scales, farmers benefit from increasing political support and subsidies when practising low N-input systems. However, it is still difficult to discover N imbalances at field and farm scale (OECD, 2001). Budgeting at farm-scale is a first simple comparison of nutrient inputs and outputs of a system over a defined period of time (Domburg et al., 2000; Jarvis, 1993; Oenema et al., 2003). The difference between N input and output is used as a measure for either nutrient surplus or deficit and allows an easy calculation of the overall N use efficiency (NUE) of the system (Cassman et al., 2002). Several methods for calculating N budgets are available, namely (i) farm-gate balance, (ii) soil-surface and (iii) soil-system balance. The accuracy of these approaches is increasing in the same order (Oenema et al., 2003). However, the underlying N cycle in grassland

* Corresponding author. Tel.: +49 228 73 2881.
E-mail address: j.schellberg@uni-bonn.de (J. Schellberg).

0167-8809/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agee.2013.11.028

systems is more complex because of, e.g. N return from ruminants, N leaching and volatilization, anthropogenic N deposition, and symbiotic N_2 fixation of plants (Jarvis, 1993).

In practice, N farm-gate balances are used to assist farmers with their nutrient management, but it is also used as a regulatory policy instrument. With a certain instructional intent, data on farm-gate balances are published in annual farm statistics. However, the resulting budgets do not consider the various environmental interactions that control N sinks and sources as well as redistribution at a spatial scale (Schnyder et al., 2010). In contrast, soil surface balances record all nutrients that enter and leave the soil though still ignoring N losses through volatilization (OECD, 2001). Only the soil system budget allows control over either net nutrient reduction or accumulation within the system (Oenema et al., 2003). However, respective long-term observations on farmland and in laboratory, which might allow tracking back changes in soil nutrient budget, are missing in most instances. To retrace nutrient imbalances in the soil–plant system, especially after prolonged high N-input (HNI) or low N-input (LNI) management, it would be worthwhile to have simple measures on farm that could be used to assess balance calculation.

Stable isotopic approaches are increasingly used to study the impact of environmental change and agricultural practices on ecosystems (Dittert et al., 1998; Kerley and Jarvis, 1996). The natural abundance of the stable isotope of ^{15}N ($\delta^{15}N$) provides insight into the main N transformation processes in the N-cycle of agricultural farms (Högberg, 1997; Robinson, 2001). This is attributed to the isotopic discrimination of heavy against light isotopes in biochemical processes due to their mass differences. Every process resulting in N losses thus discriminates against the heavier isotope ^{15}N. This causes a depletion of ^{15}N in products that are lost to the environment (NH_3, N_2, N_2O, NO_3^-) and an enrichment of ^{15}N in the residual substrate (NH_4^+, organic N).

Long-term forest fertilization trials showed elevated $\delta^{15}N$ isotope ratios in needles, grass and soil samples, mainly due to the greater losses of the lighter ^{14}N isotope through volatilization of ammonia (NH_3), leakage of NO_3^- and denitrification (Högberg and Johannisson, 1993; Johannisson and Högberg, 1994; Templer et al., 2007). These observations have been confirmed by investigations on cropland (Meints et al., 1975) and grassland (Frank et al., 2004; Watzka et al., 2006; Wrage et al., 2011). The degree of ^{15}N enrichment depends on type and amount of fertilizer used (Kriszan et al., 2009). Among them, organic amendments, such as animal manure, slurry or compost are enriched in ^{15}N (Kreitler, 1979; Wassenaar, 1995; Yoneyama, 1996), and so are soil and plants that receive these fertilizers (Watzka et al., 2006; Yuan et al., 2012). In contrast, N in chemical–synthetic fertilizers originates from atmospheric N synthesized in Haber–Bosch procedure. This is why the $\delta^{15}N$ signature of soil and plant material typically remains depleted or unaffected when these fertilizers are applied: their $\delta^{15}N$ values consistently range between −2‰ and +2‰. From these findings one can conclude that stable isotope analyses of ^{15}N can serve as a suitable indicator that allows distinguishing between conventionally and organically agricultural management, due to the exclusive use of farm manure in organic farming systems (Bateman et al., 2007; Flores et al., 2007; Schmidt et al., 2005). Thus, $\delta^{15}N$ should also be a suitable indicator for reconstructing the intensity of N management on practice farms.

It has been shown that the N signature of animal products, such as milk, is also influenced by the $\delta^{15}N$ values of the feed with different degrees of fractionation during digestion (DeNiro and Epstein, 1981; Knobbe et al., 2006; Kornexl et al., 1997). Samples like blood, fat and liver memorize the diet for weeks to months (Yanagi et al., 2012). Urine also provides conclusions on diets (Knobbe et al., 2006; Sponheimer et al., 2003).

In an earlier study, Schwertl et al. (2005) found that $\delta^{15}N$ in animal hair is suitable to detect differences in N management and N fluxes on farms and that the N signatures nicely integrates the dietary information across longer time scales due to low metabolic activity of the tissue. In this study, $\delta^{15}N$ was well correlated with stocking rate and N farm gate balance, which, if beyond a tolerable level, caused volatilization of excess N thereby leading to discrimination against the heavier N isotope. Based on these findings, similar studies published by Watzka et al. (2006) and our experimentation on changes in N isotopic signature on grassland plots (Kriszan et al., 2009), we learned that the $\delta^{15}N$ natural abundance can generally be used as an assessment indicator of NUE. One major advantage of the approach is that the sampling of milk, hair, urine, faeces and slurry and the preparation for stable isotopic analysis is simple, i.e. these materials could therefore additionally help to trace back the history of the underlying N management.

The objective of this study was, therefore, to relate $\delta^{15}N$ isotope ratios of several N pools of grassland farms to the underlying N management of the latter, and to test whether the isotopic signature of N pools reflects long-term N losses. Compared with previous work cited above we widened the scope from the individual animal to the farm in that we compared two levels of N intensity, integrated several pools and low and high emission N application techniques, and sampled the soil at different distances from the farmyard. This allowed us to integrate soil properties, application technique and distance to the farm into the evaluation of former N management intensity.

We hypothesized (i) that we find higher $\delta^{15}N$ values in soil, plant and animal samples on intensively managed farms and especially with high N-input, (ii) that the slurry application technique influences the ^{15}N signature in the above mentioned samples and (iii) that a spatial variation in $\delta^{15}N$ exists on farm such that it declines with increasing distance from stable to field.

2. Materials and methods

2.1. Study area

The study area was located between 50°13′N to 51°27′N and 6°12′E to 8°51′E in North Rhine Westphalia and Rhineland-Palatinate, Germany, and included sites between 260 and 520 m above sea level. Additionally, one site in Styria, Austria, was chosen (47°29′N and 14°09′E, 900–1100 m above sea level). Long-term mean annual air temperatures ranged between 7 and 10 °C. Long-term mean annual precipitation varied between 830 and 1200 mm. Soils were predominantly of sandy loamy texture and comprised mainly Cambisols and Stagnosols (WRB, 2006) with pH values ranging from 4.6 to 7.0 (data provided by farmers).

2.2. Farms selection

With the support of local agricultural services, nine typical livestock farms in the above-named regions were selected. Farms denoted as A, B, C, E, G, H and I were typical grassland farms with a proportion of grassland of more than 90%, whereas farm D cultivated arable crops on approximately 16% of its total farm land. Merely, the bull fattening farm (F) had a higher proportion of arable land (71%). Based on the production system we separated these farms into five conventional (A, B, C, E, F) and four organic farms (D, G, H, I). On four farms (F, G, H, I), some fields were managed following the nature conservation program (NPA—nature protection by agreement) funded by the government. Fertilizer application is generally not permitted on these NPA fields. Farm (I) was characterized by a very low N input, a low milk production rate and a more