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Assessment of the nitrogen and carbon budget of two managed temperate grassland fields

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ABSTRACT

Greenhouse gas budgets as well as the productivity of grassland systems are closely related to the carbon (C) and nitrogen (N) cycles. Within the framework of the CarboEurope and NitroEurope projects we have measured C and N exchange on the field scale at the grassland site Oensingen previously converted from arable rotation. The site is located on the Swiss Central Plateau and consists of two parallel fields of equal size. One field was subjected to intensive management with average nitrogen input of 230 kg-N ha^{-1} $year^{-1}$ and 4–5 cuts per year, and the other to an extensive management with no fertilisation and less frequent cutting. The total C budget of the fields was assessed by measuring the CO_2 exchange by eddy covariance and analysing the carbon import by manure application and export by harvest. The N budget of the managed grassland is more complex. Besides the management related import and export, it includes gaseous exchange in many different forms (NO, NO_2, HNO_3, N_2O, NH_3, N_2) needing different analytical techniques, as well as input by rain and leaching of N-compounds with the soil water. The main ("level-3") field sites in the NitroEurope project are supposed to measure 95% of the N fluxes at the field scale. For several of the N fluxes specific measurements have been performed for 1 year or longer at the site. Some of the remaining N budget components (dry and wet deposition) could be estimated from results of a national deposition network, while other components (NH_3 and N_2 emission) were estimated based on literature parameterisations. However, we found indications that the (systematic) uncertainties of these estimated N-fluxes are large and that it is important to make site-specific measurement for all relevant budget components. The suitability of corresponding experimental methods is discussed.

Analysis of the C budget over a 6-year period (2002–2007) showed a significant mean difference between the two newly established grassland fields with a likely net carbon loss for the extensive management and a net sequestration for the intensive management. Since the C/N ratio of the soil organic matter of the grassland is constrained in a rather narrow range around 9.3, the change in the soil carbon pool is supposed to be accompanied by a corresponding change in the N storage. This approach provided an alternative method to check the N budget of the two grassland fields derived from the individual N fluxes.

1. Introduction

Nitrogen (N) is an essential nutrient for all natural and managed ecosystems. Consequently, the import and loss of N will influence the vegetation growth and thus the carbon cycling and storage in the ecosystem. To produce the food for the growing human population, an increasing amount of reactive nitrogen is needed that has to be transformed from inert atmospheric molecular nitrogen (N_2) by fixation (Galloway et al., 2004). This has resulted in a significant increase of the N cycle in all ecosystems of the world contributing to various environmental problems like eutrophication, ozone formation, acidification, and greenhouse effect. In a steady-state world the formation of reactive nitrogen is balanced by complete denitrification, i.e. an equal amount of newly formed reactive nitrogen is returned to the atmosphere as N_2 and N_2O. Real ecosystems are likely to deviate from equilibrium and a net change of the storage of C and N in the soil (accumulation or loss) will occur. To mitigate the increase of greenhouse gases in the atmosphere, management options enhancing the storage of C in the vegetation and soil are implemented in the Kyoto protocol. Due to the rather constant characteristic C/N ratios of individual organic matter pools, especially in the soil, a change in the C stock is generally accompanied by a corresponding change in the N stock.

For a quantitative description of the carbon and nitrogen cycling of an ecosystem, all relevant import and export

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processes have to be determined. The sum of all imports and exports results in the total budget (= storage change) of the ecosystem. While for natural ecosystems the carbon and nitrogen exchange are dominated by gaseous uptake from or loss to the atmosphere, in managed agricultural ecosystems harvest biomass export and fertiliser application contribute significantly to the respective budgets. In addition, transport in dissolved forms through the hydrological cycle (in rain or soil drainage water) is also possible.

In recent years, field scale measurements of the total carbon budget have been performed for various ecosystems (e.g. Goulden et al., 1996; Aubinet et al., 2000; Soussana et al., 2007; Ammann et al., 2007). In contrast, the nitrogen budget is more difficult to assess on the field scale because it consists of a larger variety of different components with very different physical and chemical properties, particularly for the gaseous exchange with the atmosphere. Therefore the assessment of the full nitrogen budget of an ecosystem necessitates the simultaneous quantification of the fluxes of many different N compounds with different measurement techniques. Up to now, the various N fluxes were mostly investigated by different scientific communities with different objectives (focussing either on air pollution, greenhouse gases, water pollution, plant nutrition, etc.), while complete N budgets with all relevant import and export fluxes have rarely been measured on the ecosystem scale.

The NitroEurope integrated project of the 6th European framework program (NEU) addresses the major question: what is the effect of reactive nitrogen supply on net greenhouse gas budgets for Europe? One of the important objectives is to establish a robust dataset of N fluxes in relation to C–N cycling of representative ecosystems. This includes the measurement of 95% of the N budget at a high temporal frequency over a period of 4.5 years at the main (level-3) sites distributed across the main ecosystems in Europe. Grassland is one of the dominant land uses, covering about 22% of the European land area (Soussana et al., 2007). Most grasslands in Europe are managed for feeding domestic herbivores, representing an important food source for milk and meat products. They typically have a high N turnover and are therefore key players in regional N budgets. The Oensingen site on the Swiss Central Plateau was chosen as a NitroEurope main site characterising managed sown grassland in a temperate climate.

The NitroEurope measurement activities at the Oensingen grassland site started in summer 2006. At the present stage in the first half of the project, a series of specific N component measurements have started less than a year ago. Consequently measurement derived values are not yet available. However, the carbon budget and some nitrogen budget components have already been measured since 2002 within the EU projects GreenGrass and CarboEurope-IP (see Flechard et al., 2005; Ammann et al., 2007). Besides the carbon budget for 2002–2007 we present here an *a priori* evaluation of the full nitrogen budget for this mostly pre-NitroEurope period. It is based on the available measurements of the management related N exchange, on routine N_2O flux measurements, on deposition fluxes derived from the Swiss air pollution network, and on commonly used parameterisation approaches for other N fluxes. The relative magnitude (with uncertainty range) and the relevance of the various N budget components are assessed and discussed in order to identify the most important data and knowledge gaps in the N budget of the managed ecosystems. For the parameterised budget components, available methods for a direct in situ flux measurement and their suitability for long-term observations are discussed. Finally, the import/export derived N budget is compared to an indirect estimation based on the C budget and the observed soil C/N ratio.

2. Methods

2.1. Field site description

The experimental site is located on the Swiss Central Plateau near the village of Oensingen in the north-western part of Switzerland (7°44′ E, 47°17′ N, 450 m a.s.l.). The region is characterized by a relatively small scale pattern of agricultural fields (grassland and arable crops). The climate is temperate with an average annual rainfall of about 1100 mm and a mean annual air temperature of 9.5 °C. Before the experiment, the field had been under a ley-arable rotation management (common for the region) with a typical rotation period of 8 years including summer- and winter-wheat, rape, maize and bi- or tri-annual grass-clover mixture. The nitrogen input depended on the crop type and followed the Swiss standard fertilisation practice (110 kg-N ha^{-1} $year^{-1}$ on average). In November 2000 the field was ploughed for the last time. The area was then divided into two equal rectangular parts (52 m × 146 m each). They were sown in May 2001 with two different grass-clover mixtures typical for permanent grassland under intensive and extensive management, respectively. The intensively managed field (referred to as intensive field or INT in the following) was sown with a grass-clover mixture of 7 species. For the extensively managed field (referred to as extensive field or EXT) a complex mixture of over 30 grass, clover and herb species was applied. The intensive field was cut typically 4 times per year and was fertilised with solid ammonium nitrate or liquid cattle manure at the beginning of each growing cycle (after the previous cut). In contrast, the extensive field received no fertiliser (besides atmospheric deposition) and was cut 3 times per year, the first time not before 1st June. Details of management activities are given below (Section 3.2).

The soil is classified as Eutri-Stagnic Cambisol (FAO, ISRIC and ISSS, 1998) developed on clayey alluvial deposits. Clay contents between 42% and 44% induce a total pore volume of 55% and a fine pore volume of 32% (permanent wilting point) as measured by means of the soil moisture release curve in the laboratory.

2.2. The ecosystem budget approach

The carbon and nitrogen budgets of the two grassland fields were assessed by measuring or estimating all relevant import and export fluxes to/from the ecosystems. In the case of carbon, the gaseous exchange by CO_2 as well as the export of organic matter by harvest and the import by organic fertiliser had to be considered (see Ammann et al., 2007). In addition, the leaching of dissolved organic or inorganic carbon to groundwater may possibly contribute to the budget (Siemens, 2003). The sum (balance) of all carbon import and export fluxes results in the respective storage change in the ecosystem. On an annual or longer term basis, the storage change in the grassland vegetation (living biomass) and in mineral forms in the soil are small and may be neglected, and only the storage change in soil organic matter has to be considered. Thus the carbon budget of the grassland fields can be described as:

$$\frac{\Delta SOC}{\Delta t} = \sum(\text{C exchange fluxes}) = FC_{CO_2} + FC_{\text{org. fertilizer}} + FC_{\text{harvest}} + FC_{\text{leaching}} \quad (1)$$

Throughout the manuscript, the ecological sign convention is used for carbon and nitrogen fluxes, i.e. all flux quantities on the right-hand side of Eq. (1) are formally defined as import fluxes to the ecosystem. In case of carbon export (loss) from the ecosystem, they get a negative value. Accordingly, the import flux FC_{CO_2} equals the net ecosystem productivity (NEP) but is opposite in sign