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The carbon budget of newly established temperate grassland depends on management intensity

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Abstract

The carbon exchange of managed temperate grassland, previously converted from arable rotation, was quantified for two levels of management intensities over a period of 3 years. The original field on the Swiss Central Plateau had been separated into two plots of equal size, one plot was subjected to intensive management with nitrogen inputs of 200 kg ha^{-1} $year^{-1}$ and frequent cutting, and the other to extensive management with no fertilization and less frequent cutting. For both plots, net CO_2 exchange (NEE) was monitored by the eddy covariance technique, and the flux data were submitted to extensive quality control and gap filling procedures. Cumulative NEE was combined with values for carbon export through biomass harvests and carbon import through application of liquid manure (intensive field only) to yield the annual net carbon balance of the grassland ecosystems. The intensive management was associated with an average net carbon sequestration of 147 (±130) g C m^{-2} $year^{-1}$, whereas the extensive management caused a non-significant net carbon loss of 57 (+130/−110) g C m^{-2} $year^{-1}$. Despite the large uncertainty ranges for the two individual systems, the special design of the paired experiment led to a reduced error of the differential effect, because very similar systematic errors for both parallel fields could be assumed. The mean difference in the carbon budget over the 3-year study period was determined to be significant with a value of 204 (±110) g C m^{-2} $year^{-1}$. The difference occurred in spite of similar aboveground productivities and root biomass. Additional measurements of soil respiration under standardized laboratory conditions indicated higher rates of soil organic carbon loss through mineralization under the extensive management. These data suggest that conversion of arable land to managed grassland has a positive effect on the carbon balance during the initial 3 years, but only if the system receives extra nitrogen inputs to avoid carbon losses through increased mineralization of soil organic matter.

Keywords: Carbon sequestration; Temperate grassland; Management intensity; CO_2; NEE; NBP; Fertiliser; Land-use change; Soil organic carbon

1. Introduction

In the wake of the Kyoto Protocol, terrestrial ecosystems have attracted considerable scientific and policy interest because of their potential role as sinks or sources for atmospheric CO_2 (IPCC, 2000). For agricultural ecosystems such as grassland or cropland, suitable management options may sequester carbon by a sustained increase in the soil organic carbon content (SOC) and thus contribute to the committed reduction of greenhouse gas emissions in many countries (Smith, 2004a). Conversion of arable land into permanent grassland is one measure that is believed to have a considerable carbon sequestration potential (IPCC, 2000; Soussana et al., 2004). Under similar site conditions, permanent grasslands typically have higher soil organic carbon (SOC) contents than arable crop rotations, because (i) they receive higher residue inputs, (ii) relatively more carbon is deposited belowground, and (iii) decomposition is slower due to the absence of tillage-induced aeration and due to stronger soil aggregation (Paustian et al., 1997). Calculated over a 50-year period, sequestration rates between 50 and 100 g C m^{-2} $year^{-1}$ have been estimated (IPCC, 2000) corresponding to a total increase of the carbon content of between 2.5 and 5 kg SOC m^{-2}. For temperate

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sites in Switzerland, Leifeld et al. (2003) estimated sequestration potentials of 2.0–2.2 kg SOC m^{-2}.

While positive effects of converting arable land to grassland are generally accepted (e.g. Follett, 2001), the influence of grassland management intensity after conversion is less clear. A review of global data sets revealed that intensively managed and fertilised grasslands had, on average, higher SOC stocks than natural or less intensively managed systems (Conant et al., 2001). Accordingly, Nyborg et al. (1997) found with increasing level of fertilisation larger SOC contents associated with higher productivity for Canadian grasslands. In contrast, no relationship between the intensity of management and SOC stocks was found for Alpine grasslands (Zeller et al., 1997; Bitterlich et al., 1999). Many of the European grasslands are currently cultivated for forage production and reach high productivity in temperate regions with sufficient rain. However, low-input systems are becoming more attractive in areas where the need or profitability of agricultural production declines. This latter trend may counteract efforts to improve the carbon balance of agricultural land, but data from direct comparisons of intensively and extensively managed systems are lacking.

The most direct approach to investigate carbon sequestration effects in soils is through monitoring SOC content over time. However, due to statistical limitations, this method requires a large number of samples and time scales longer than about 5 years (Smith, 2004b), and it yields no information about underlying processes, which would help to understand and interpret differences between ecosystems and management regimes. As an alternative, changes in the carbon balance can be determined from measured carbon imports and exports. This approach is more complex and requires sophisticated measuring systems, but it yields information about processes involved in carbon cycling and their temporal variability. In natural ecosystems, the carbon balance (corresponding to the net biome productivity NBP as described by Schulze et al., 2000) is mostly determined by the net CO_2 exchange with the atmosphere (NEE), and the carbon sequestration can be approximated by integration of the measured NEE over 1 year or more (see e.g. Goulden et al., 1996; Aubinet et al., 2000). For managed agricultural ecosystems, however, harvest biomass export (H_{export}) and carbon import through organic fertilisation (mainly as manure M_{import}) contribute to the carbon budget. Thus, the change in SOC with time (an increase corresponding to a carbon sequestration of the grassland ecosystem) can be expressed as:

$$\frac{\Delta \mathrm{SOC}}{\Delta t} = -\mathrm{NEE} - H_{\mathrm{export}} + M_{\mathrm{import}} \quad (1)$$

It has to be considered that NEE commonly follows the micrometeorological sign convention with positive values indicating an upward net flux of CO_2 and thus a loss of carbon to the atmosphere. Therefore NEE, like H_{export}, occur in Eq. (1) with a negative sign.

The present study was part of the EU project GREENGRASS that aimed at measuring the net global warming potential resulting from the exchange of CO_2, N_2O and CH_4 in managed European grasslands. The aims of our experiment were (i) to investigate the effect of management intensity on the carbon balance after conversion of arable land to grassland, (ii) to test the hypothesis that conversion to a low-input grassland system reduces or even reverses the carbon sequestration effect, and (iii) to establish a full greenhouse gas budget for newly established high- and low-input grassland fields. Here we report results related to the first two aims, while the greenhouse gas budget is treated in Flechard et al. (2005). To address these questions, an arable field on the Swiss Central Plateau was converted to grassland in 2001. The original field was separated into two plots, one subjected to intensive management (i.e. high nitrogen input and frequent cutting), and the other to extensive management (i.e. no fertilization and infrequent cutting). Carbon fluxes were monitored in parallel during a 3-year period starting in spring 2002 in order to obtain the carbon budget of the two grassland systems according to Eq. (1).

2. Methods

2.1. Site description

The experimental site is located on the Central Swiss 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 characterised 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 temperature of 9.5 °C. During wintertime, especially in January and February, a snow cover (mean depth 6 cm) is observed for 27 days per year, on average (see Table 2). Before the experiment, the field was under a ley-arable rotation management (common for the region) with a typical rotation period of 8 years including spring 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 parts (0.77 ha each) as shown in Fig. 1. 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 seven species. For the extensively managed field (referred to as extensive field or EXT) a more complex mixture of over 30 grass, clover and herb species was applied. During the measurement period the composition of the vegetation was surveyed by the visual estimation method of Braun-Blanquet (1964) twice each year. It yielded average relative cover values for grass, legume, and herb species of