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Soil ecology and ecosystem services of dairy and semi-natural grasslands on peat

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ABSTRACT

Peat wetlands are of major importance for ecosystem services such as carbon storage, water regulation and maintenance of biodiversity. However, peat drainage for farming leads to CO_2 emission, soil subsidence and biodiversity losses. In the peat areas in the Netherlands, solutions are sought in reducing drainage, adapting farming to wetter soils, and converting productive dairy grasslands to less intensively managed semi-natural grasslands. Our objective was to compare the soil ecology and related ecosystem services of dairy and semi-natural grasslands on peat soils (Terric Histosols). Soil biotic and abiotic parameters were measured in twenty dairy and twenty semi-natural sites, with particular focus on (i) soil faunal diversity (ecosystem service "maintenance of biodiversity"), (ii) CO_2 emission ("climate regulation"), (iii) water infiltration ("water regulation") and (iv) soil fertility ("grass production"). Mean soil faunal taxonomic richness per site (alpha diversity) was higher in dairy grasslands compared to semi-natural grasslands. However, the total observed number of taxa (gamma diversity) in dairy grassland was 13% lower for soil fauna and 21% lower when including plant species. Potential C mineralization rate in the topsoil – used as a proxy for CO_2 emission – was not influenced by land use but was limited by drought. Additionally, potential C mineralization depended on different C sources and microbial groups in the two grassland types. Water infiltration rate differed by a factor of five between land use types (dairy > semi-natural), and correlated with soil porosity. As expected, soil fertility was higher in dairy than in semi-natural grasslands. However, potential N mineralization was similar in dairy and semi-natural grasslands and was correlated negatively with bacterial biomass apparently indicating N immobilization, and positively with bacterial growth that depended on labile C and N in soil. Our study on peat soils shows that dairy versus semi-natural grassland use influences biodiversity, climate regulation, water regulation and (potential for) grassland production. We conclude with recommendations for land management to optimize the delivery of those ecosystem services.

1. Introduction

Peat wetlands worldwide deliver important ecosystem services such as carbon (C) storage, maintenance of biodiversity and water regulation (Maltby and Immirzi, 1993; Verhoeven and Setter, 2010). In the river deltas of the Netherlands, land reclamation for agriculture by peat drainage and peat harvesting for fuel was carried out from the Middle Ages onwards (Van de Ven, 1993) and caused soil subsidence, resulting in a decline of peat-covered land area. At present, 8% of the surface of the Netherlands is covered by peat soil and is in use for grassland based dairy farming (82%), semi-natural grasslands (7%), nature (5%), and infrastructure, buildings and surface water (De Vries, 2004; Van den Born et al., 2016). For productive dairy grasslands, the ground water level is kept well below the soil surface (generally 30–70 cm) by drainage. A major drawback of this land use is net decomposition of organic matter in the oxic topsoil, resulting in carbon dioxide (CO_2) emission (Kasimir-Klemedtsson et al., 1997; Van den Akker et al., 2008), soil subsidence (Schothorst, 1977) and high infrastructural costs (Van den

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Born et al., 2016). Moreover, additional issues related to dairy grasslands on drained peat have been reported: loss of floral and faunal aboveground biodiversity, including meadow birds (Beintema, 1986; Lamers et al., 2002), and eutrophication (Bobbink et al., 1998).

These observations, together with (inter)national agendas on biodiversity and climate, lead to increasing pressure from society on agricultural peat areas to maintain biodiversity, reduce CO_2 emission and provide water storage capacity (Van den Born et al., 2016). Thus, peatlands are challenged to deliver not only provisioning but also regulating and supporting ecosystem services (MEA, 2005). Solutions are seen in increasing the area of (semi-) natural grasslands and natural peat vegetation at higher ground water level, or in "nature-inclusive" agriculture with reduced drainage intensity, use of submerged tile drains and adaptation to wetter soils (Erisman et al., 2016; Van den Akker et al., 2008; Van den Born et al., 2016). Such changes should result in delivery of ecosystem services closer to the societal needs. For policy choices on land management in accordance with these needs, it is necessary to know how the delivery of ecosystem services changes following land use and land management changes. Dutch peatland has been drained intensively for centuries, and hence, the implications constitute a valuable case study for the development of sustainable use of peat soils in both the Netherlands and other countries.

Differences between peat grasslands managed for dairy production or for nature restoration have been studied in the Netherlands in relation to specific ecosystem components or processes, such as floral diversity (Berendse et al., 1992; Van Dijk et al., 2007), meadow birds (Schekkerman and Beintema, 2007; Verhulst et al., 2007), or soil biology, soil chemistry and peat decomposition (Brouns et al., 2016; Van de Riet et al., 2013; Van Dijk et al., 2009). However, because of the variety in delivery of ecosystem services with possible trade-offs, there is a need for integral knowledge across different land uses (Breure et al., 2005). Within the peat area, the monitoring programme of the Dutch Soil Quality Network covered only the land use "dairy farming", and did not include comparisons with other land use types (Rutgers et al., 2009). The objective of this paper is therefore to provide a comparison of the soil ecology and the related provision of ecosystem services of peat grasslands either used for grass production ("dairy grasslands") or for nature restoration and conservation ("semi-natural grasslands").

We selected dairy and semi-natural grasslands on peat (27–65% organic matter) and measured soil biotic and abiotic parameters, and botanical composition. To limit the influence of site-specific properties twenty replicates (grasslands) per land use type were sampled. Also, to minimize short-term effects of nutrient and C inputs to the soil, measurements were carried out during spring, before application of manure. In the interpretation we focus on the following parameters and ecosystem services: (i) soil faunal diversity (ecosystem service "maintenance of biodiversity"), (ii) CO_2 emission ("climate regulation"), (iii) water infiltration ("water regulation") and (iv) soil fertility ("grass production"). We hypothesize that the higher nutrient input in dairy grasslands leads to soil faunal communities with a lower taxonomic richness. In addition, we hypothesize that dairy grassland soils have higher microbial activity and CO_2 emission due to higher C inputs (plant residues, cattle manure) and more oxic conditions, but have less crumb structures and lower water infiltration rates than semi-natural grasslands due to compaction by machinery and livestock. Finally, we expect dairy grassland soils to have higher pH, contain more plant available nutrients and have higher potential N mineralization than semi-natural grasslands.

2. Materials and methods

2.1. Study sites

In the western peat district of the Netherlands, we selected twenty replicates for each grassland type studied: on commercial dairy farms ("dairy grasslands") and in areas owned and managed by nature conservation organizations ("semi-natural grasslands"). Selection criteria were: (i) situated on peat soil (Terric Histosol; FAO, 2015) (ii) minimum sward age of ten years, (iii) summer ditch water level within the range of 20–60 cm below soil surface and (iv) no major changes in management (drainage, fertilization, stocking) in the past five years. At each site, an experimental plot (6 m × 9 m) was laid out. During the experimental year, the plots remained unfertilized, ungrazed and unmown until soil sampling.

Table 1
Management and plant parameters of dairy (n = 20) and semi-natural (n = 20) grasslands on peat (means, standard deviations, *P*-values). Plant species in Supplementary Table S1.

		Dairy		Semi-natural		*P*-value
Parameter	Unit	mean	s.d.	mean	s.d.	
Historical management						
Ditch water level (summer)	cm below soil surface	49	8	40	14	0.009
N from organic manure	kg N ha^{-1} yr^{-1}	216	55	43	50	< 0.001
N from mineral fertilizer	kg N ha^{-1} yr^{-1}	140	91	0	0	< 0.001
Number of grass cuts	n yr^{-1}	2.7	0.8	1.1	0.5	< 0.001
Botanical composition						
Monocotyledon soil cover	%	82.5	10.6	55.1	21.1	< 0.001
Dicotyledon soil cover	%	8.8	10.0	22.6	16.2	0.002
Number of plant species	n	15.2	3.2	14.8	5.3	0.104

The dairy grasslands had an average ditch water level (summer) of 49 cm below soil surface (Table 1), ranging from 30 to 60 cm, and a conventional management with a history of mixed grazing and cutting. The year before the measurements, the dairy grasslands received on average 140 kg N ha^{-1} as inorganic fertilizer and 216 kg N-total ha^{-1} as cattle manure (mainly slurry manure; excluding excretion during grazing).

In the semi-natural grasslands, mean ditch water level was 40 cm below soil surface (range 20–60 cm), significantly higher than in dairy grasslands ($P < 0.01$; Table 1). Most of the semi-natural grasslands were extensively grazed by sheep or young cattle, cut once or twice a year after the chick season of meadow birds and had a low manure input of on average 43 kg N-total ha^{-1} yr^{-1}, mainly as solid cattle manure (excluding excretion during grazing). Three grasslands were not manured nor grazed, but mown once a year to keep the vegetation open and to export nutrients.

2.2. Vegetation survey

Botanical composition was measured in June 2010 according to the Braun-Blanquet cover-abundance method (Westhoff and van der Maarel, 1978). Before statistical analyses, Braun-Blanquet scores were replaced with a fully numerical 1–9 scale (Van der Maarel, 1979).

2.3. Soil measurements

All soil sampling and *in situ* measurements were carried out between 20 and 28 April 2010. In each plot, a bulk sample consisting of c. 50 randomly taken soil cores (0–10 cm, ø 2.3 cm) was collected. This sample was sieved through 1 cm mesh, homogenized and split into subsamples for biotic (nematodes, microbes and microbial processes) and abiotic (chemical composition, particle size distribution and gravimetric water content) analysis. Separate samples were taken for soil meso- and macrofauna and additional soil physical and chemical measurements.