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Long-term landscape – land use interactions as explaining factor for soil organic matter variability in Dutch agricultural landscapes

Catharina J.E. Schulp *, A. Veldkamp

Land Dynamics Chair Group, Department of Environmental Sciences, Wageningen University, P.O. Box 47, 6700 AA Wageningen, The Netherlands

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ABSTRACT

The present-day land use pattern is often used for estimating soil organic matter pools. Although the effect of historical land use on soil organic matter (SOM) pools is often recognized, this factor is never accounted for in large-scale SOM inventories. We assessed if an inventory of long-term landscape management can be used to improve estimates of landscape-scale SOM variability for a 60 km^2 case study in the northern Dutch sand area. We hypothesize that soil, present-day and historical land use and their interactions can explain the bulk of SOM variability at multiple scales. Actual SOM data from a 1:10.000 soil inventory of the study area were used to test this hypothesis. Land use history (1780-2000) was reconstructed using topographic maps and land use databases. Potential explaining factors for SOM contents were analysed. Linear models were used to characterize SOM variability at 50 m, 200 m and 500 m resolutions. Soil characteristics like loam content (R^2=0.25), median sand grain size (R^2=0.20) or soil classification (R^2=0.23) can partly explain total SOM variability. Present-day land use only explains 2% of SOM variability. Historical land use patterns explain a much larger part of the total SOM variability (R^2=0.14 for land use patterns in 1780 and R^2=0.20 for land use patterns in 1850). At 50 m resolution, SOM contents can be best explained with soil and land use history factors (R^2=0.28). At 200 m resolution, soil and groundwater factors yileld the best model (R^2=0.42) while at 500 m resolution a model including soil, groundwater and historical land use performs best (R^2=0.75). We conclude that land use history data can significantly improve SOM inventories at multiple scales. Especially at detailed scales it can improve insight in both SOM pool size and origin of SOM variability. As land use history of the Netherlands is relatively well documented, we expect that an improvement of national SOM pool estimates is feasible.

1. Introduction

The global soil organic carbon (SOC) pool is estimated to amount to 1200-1600 Pg carbon in the upper 1 m (Batjes, 1999), similar to 2.5 times the carbon pool in vegetation or two times the amount of carbon in the atmosphere. Hence, sequestration of carbon in soils is often recognized as an option for mitigation of climate change. To be able to estimate the potential CO_2 uptake of the soil, information on the potential and actual SOC pool is needed.

Spatial distribution of SOC pools is influenced by several factors. Climate and parent material characteristics define a range of SOC levels for an ecosystem (McLauchlan, 2006). At landscape level, the actual SOC pool size is to a large extent determined by human impact on the landscape, e.g. land use and management. These determine the input and output of organic matter (OM) to the soil organic matter (SOM) pool. Therefore, often a direct link between land use and SOM content is assumed (Smith et al., 2000; Jarecki and Lal, 2003; Lettens et al., 2005). SOM contents in croplands are generally lower than SOM contents in forests and grassland. Subsequently, conversion of grassland or forest to cropland is assumed to cause a decrease of SOM content whereas the opposite conversions are assumed to increase SOM contents (Degryze et al., 2004; Lettens et al., 2004a; Gerzabek et al., 2005).

At pedological timescales SOM is very dynamic (Richter, 2007): SOM contents can change within decades to centuries. At temporal scales up to a few decades, often clear SOM content changes are observed following land use conversions (Lettens et al., 2004b; Falloon et al., 2006). In due time after conversion, the rate of SOM content change decreases until the SOM content reaches a new quasi-equilibrium (Freibauer et al., 2004). These changes can last centuries after land use conversion. Therefore, not only present-day human impact but also land use history up to decades (Pulleman et al., 2000; Sonneveld et al., 2002) to centuries (Springob et al., 2001) or millennia (Verheyen et al., 1999; Kristiansen, 2001) ago can be assumed to still have an effect on present-day SOM variability.

Many countries have only a limited amount of detail in their spatial information on size and quality of SOM pools (Lindner and Karjalainen, 2007). In the Netherlands a country-wide SOM inventory

* Corresponding author. Tel.: +31 317 482004; fax: +31 317 482419.
E-mail address: nynke.schulp@wur.nl (C.J.E. Schulp).

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based on 1:50.000 soil and groundwater maps (Kuikman et al., 2003) represents the current state of knowledge on spatial distribution of SOM. For a national scale assessment, the relation between soil and groundwater and SOM pools can represent SOM pools correctly. At the landscape scale, other factors that influence SOM pools might dominate over the effect of soil and groundwater (Veldkamp et al., 2001). Spatial variability of SOM pools at landscape scale might be better represented by patterns of management (Dendoncker et al., 2004; Schulp et al., 2008b), land use or land use history.

Additional to SOM pool size, management, land use and land use history may influence SOM quality as well (Springob and Kirchmann, 2002). SOM pool size and quality together determine the potential amount and rate of carbon uptake or emission of the landscape. Therefore, insight in variability of SOM quality and quantity is required to be able to quantify the greenhouse gas mitigation potential of the landscape.

The effect of present-day land use on SOM pools is often used for stratification in inventories (Arrouays et al., 2001; Rodriguez-Murillo, 2001; Lettens et al., 2005) or to predict C pool changes (Falloon et al., 2006; Schulp et al., 2008a). Although the effect of historical land use on SOM pools is more and more recognized, this knowledge is as yet never used in SOM inventories.

In this paper we assess if inventory of long-term landscape management can be used to improve insight in present-day spatial variability of SOM pools in the Dutch sand area. This area is modified by humans for centuries and is dominated by man-made soils and recent heath reclamations. We hypothesize that soil, present-day and historical land use and their interactions can explain the bulk of SOM variability at multiple scales.

2. Materials and Methods

2.1. Case study area

In large parts of the north-west European sand area, the so-called plaggen agricultural system dominated the landscape since the early middle ages. In this agricultural system, heather and grass sods were used for animal bedding in stables. The sods together with animal excrements were used as manure on fields near the stables. This allowed for repeatedly growing of rye, oats and other crops on marginal grounds (Blume and Leinweber, 2004). At the manured fields, deep humiferous topsoils were formed that were elevated due to sand addition. On the other hand, sod cutting caused land degradation, leading to expansion of heathlands and drift sands. On areas that were too marginal for the plaggen system, often buckwheat was grown. On soils with a peat cover, the topsoil was burned before sowing of buckwheat (Bieleman, 1992). The Dutch sand area is assumed to be completely influenced by plaggen management (Blume and Leinweber, 2004). Since the second half of the 19th century, the plaggen system and the buckwheat system were abolished, succeeded by reclamation of wasteland (a collective term for heath, dunes, drift sands and peat). In the Netherlands, the wasteland area decreased from 3600 km^2 in 1900 to 285 km^2 in 2000 (Fig. 1). The majority of wastelands were converted to agricultural land.

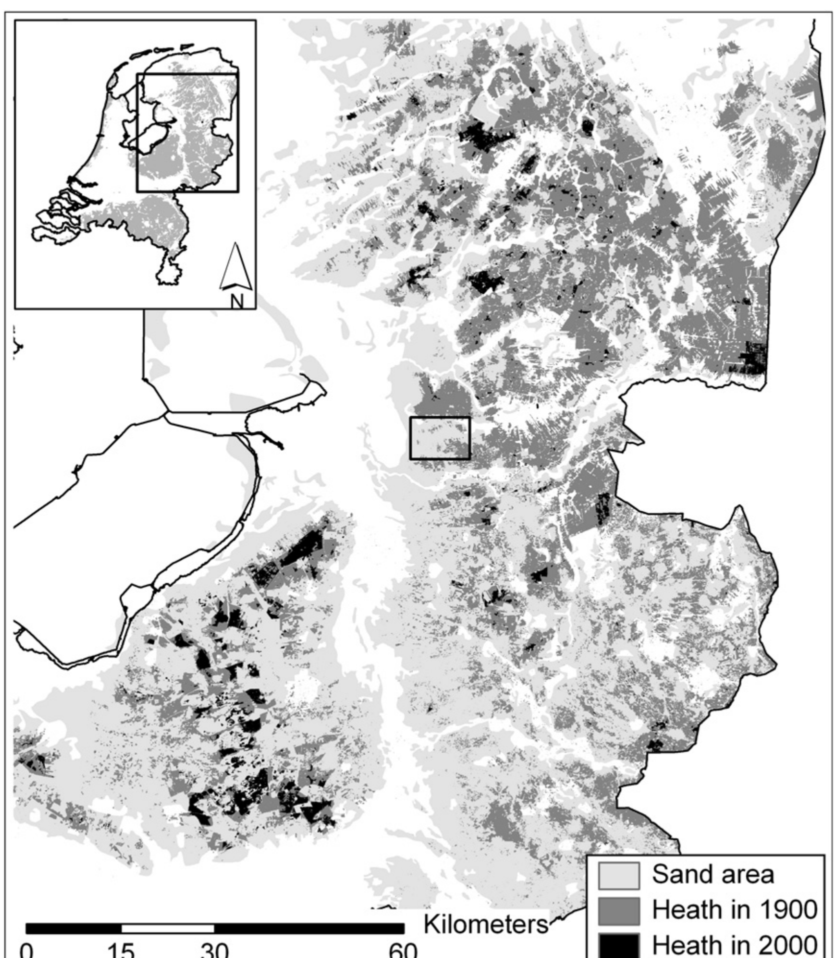

Fig. 1. The extent of heathlands in 1900 and 2000 in the northern and central Dutch sand area. The rectangle indicates the case study area. The insert top-left shows the extent of sandy soils in the Netherlands.