Abstract No: A-109

VULNERABILITY OF SOIL ORGANIC MATTER IN ANTHROPOGENICALLY DISTURBED ORGANIC SOILS

Annelie Säurich*, Bärbel Tiemeyer, Michel Bechtold, Axel Don and Annette Freibauer

Thünen-Institute of Climate-Smart Agriculture, Braunschweig, Germany

**Corresponding author: annelie.saeurich@ti.bund.de*

SUMMARY

Drained peatlands are hotspots of carbon dioxide (CO_2) emissions from agriculture. However, there is a high variability of the magnitude of CO_2 for disturbed peat soils and little is known about the soil properties and drivers causing these differences in CO_2 emissions. While the instantaneous driving factors for carbon cycling such as temperature and moisture are well studied for both genuine peat and mineral soil, there is a lack of information concerning the role of soil organic matter quality and in general for soil types at the boundary between organic and mineral soils. Our study aims to identify drivers for the vulnerability of soil organic matter to decomposition in anthropogenically disturbed organic soils, especially those near the boundary to mineral soils. Recently agricultural soils in Germany were sampled in an 8x8 km² grid following standardized protocols in the course of the German agricultural soil inventory. From this large sample pool, we selected 120 soil samples from more than 80 sites covering a broad range of soil and site characteristics. As reference sites, three anthropogenically undisturbed peatlands were sampled as well. All samples were sieved through 2 mm, incubated at standardized water content and examined in three replicates using an automated incubation device. CO_2 production was measured as basal respiration and to determine the microbial biomass via substrate induced respiration (SIR) after glucose addition. To determine the equilibrium values of the basal respiration, an exponential model was fitted to the measured data using the Differential Evolution Adaptive Metropolis (DREAM) algorithm. Surprisingly, preliminary results of basal respiration showed that rates of CO_2 production per unit soil organic carbon (SOC) are on average higher for soils at the boundary of mineral and organic soils than for SOC-rich peat soils, while presenting a high variability in the low SOC content range. Analysis of the metabolic coefficient indicated that soils with lower SOC content, higher pH and narrower C:N ratio seemed to have higher bioavailability and more efficient turnover of carbon, whereas the carbon pool of soils with wide C:N ratios seems to be more stable. We conclude that an increasing transformation of organic matter increases the vulnerability of organic matter but cannot explain the large variability in observed mineralization rates.

INTRODUCTION

A lot of former natural peatlands have been influenced and strongly altered by anthropogenic impacts like drainage and fertilization to use the soil for agricultural production. Employment of extensive drainage leads to aeration of the peat layer which optimizes conditions for microbial oxidation of soil organic carbon (SOC) and therefore increases emissions of carbon dioxide (CO_2) to the atmosphere (Kechavarzi *et al.*, 2010). However, the variability of CO_2 emissions is high for disturbed peat soils and little is known about the soil properties driving this variability. While the driving factors for carbon cycling are well studied for both genuine peat and mineral soil (e.g. Brake *et al.*, 1999; Ausec *et al.*, 2009; Kechavarzi *et al.*, 2010; Don *et al.*, 2013; Beare *et al.*, 2014), there is a lack of information about the influence of soil properties on SOM decomposition in soil with high SOC content, in particular in soils at the boundary between organic and mineral soils. Such soils can be of very contrasting origin and develop either from natural processes (e.g. Humic Gleysols) or due to anthropogenic management. The latter type of soils results from former SOC-rich peat layers that were strongly altered by intensive mineralization or by incorporation of mineral soil either by mixing with layers underlying the peat or by surface application of mineral soil.

The study examined 120 samples of soils under cropland and grassland use from all over Germany ranging from almost mineral soil (72 g kg^{-1}) to carbon rich peatlands (up to 560 g kg^{-1}). Our experiments aim to determine soil and peat characteristics that are drivers for soil respiration rates of anthropogenically disturbed organic soils. Furthermore, we would like to answer the question whether there are any critical thresholds of SOC concentrations beyond which the carbon-specific respiration rates or drivers of decomposition change. We hypothesize that basal respiration increases with SOC content but that CO_2 production rates per unit SOC are higher in peat samples than in samples with mineral particles on which SOC can be stabilized.

METHODS

Sites

The German agricultural soil inventory represented the sample basis for our study. Following standardized protocols the soil inventory has sampled agricultural soils in Germany in an 8x8 km^2 grid. From this pool of more than 3000 sites we selected 120 samples of soil horizons from 81 sites. The basic criteria were i) SOC of at least 72 g kg^{-1} (equals 15 % soil organic matter), ii) representing the whole range of basic soil properties (Tab. 1) and iii) sampling depth > 10 cm to avoid disturbance caused by living roots. The final selection was based on cluster analysis to optimally cover the parameter range in Table 1, as well as land use, peat type and geographical position. Land use of our final set of samples comprised croplands (20 %) and grasslands (80 %). Additionally three anthropogenically undisturbed peatlands were sampled as reference sites. These were bog peat, transition bog peat and fen peat.

Table 1: Range of soil properties of selected soil samples

parameter	min	max
SOC (g kg^{-1})	72	568
total nitrogen (g kg^{-1})	2	29
C:N-ratio (-)	10	80
bulk density (g cm^{-3})	0.06	1.41
pH (-)	2.5	7.4
sand content (%)*	0	95
clay content (%)*	2	70

*Only determined for samples with SOC < 190 g kg^{-1}

Incubation

The soil samples were incubated aerobically under optimum moisture and constant temperature conditions to determine basal and substrate-induced respiration (SIR), the latter being converted to microbial biomass.

Preliminary experiments showed that dried samples (40°C) are reusable for measuring soil respiration after a reasonable pre-incubation time as follows: dried, 2 mm sieved soil samples were moistened to a standardized water content of 60 % water-filled pore space and afterwards stored in darkness under aerobic conditions for 7 days at 6°C, following 7 days at 23°C. After 14 days the soil samples were prepared for the incubation in the „Heinemeyer" device (Heinemeyer *et al.*, 1989). Divided in three 20 g dry wt. replicates each sample was put loosely in an acrylic glass tube (25 x 4 cm ID) and enclosed at both ends with polystyrene foam stoppers. Inside the automated incubation device, humidified outside air flew through 24 independent lines, containing the soil samples, at flow rates between 160 and 180 ml min^{-1}. An infrared CO_2 gas analyzer (ADC, UK) measured CO_2 concentrations in differential mode, comparing the concentration in the sample line to the outside air. Each replicate sample was measured hourly for an incubation time of at least 40 h or until stable basal respiration was reached.

For estimation of the active microbial biomass using the SIR method of Anderson and Domsch (1978), the soil samples were amended with a mixture of 100 mg glucose and 100 mg talcum using an electronic stir for 30 s. The addition of inert talcum improved handling and distribution of the glucose. The mixture was then incubated again in the Heinemeyer device for 6 hours to obtain the maximal initial respiratory response of the microbial biomass (Anderson *et al.*, 1995). SIR was transcribed to microbial biomass as follows: SIR-C_{mic} (µg g^{-1} soil) = µl CO_2 g^{-1} soil h^{-1} x 30 (Kaiser *et al.*,1992). To quantify the efficiency of microbial respiration per unit biomass the metabolic or respiratory quotient qCO_2 (mg CO_2-C h^{-1} g^{-1} biomass SIR-C_{mic}) was calculated (Brake *et al.*, 1999). This metabolic quotient describes whether microorganisms use the carbon substrate for their energy metabolism or for growth.

DREAM algorithm

To determine proper equilibrium values of the basal respiration, we fitted an exponential model to the measured data, instead of using the less accurate traditional method of determining a mean value of the last ten measured data points. In this analysis, all three replicates were simultaneously fitted. The uncertainty of the basal respiration rates was inferred as well in a statistically sound manner. For fitting, we used the iterative Markov Chain Monte Carlo (MCMC) method. This method is basically a Markov chain that generates a random walk through the high-probability-density region in the parameter space, separating behavioral from non-behavioral solutions following the probability distribution (Vrugt *et al.*, 2009). The Differential Evolution Adaptive Metropolis (DREAM) algorithm is an efficient MCMC sampler that runs multiple Markov chains simultaneously for global exploration of the parameter space. Thereby DREAM uses a differential algorithm for population evolution and a metropolis selection rule to decide whether a population of candidate points is accepted or not. After the burn-in period the convergence of individual chains is checked using the Gelman and Rubin (1992) diagnostic R-statistics, that examine the variance between and within chains (Vrugt *et al.*, 2008; Vrugt *et al.*, 2009a).

RESULTS & DISCUSSION

As expected CO_2 production rates increased with SOC content (not shown). However, the relation was only weak, indicating that SOC alone is not sufficient to explain basal respiration rates. Surprisingly, CO_2 production rates per unit SOC were highest and most variable for soils with low SOC content (Fig. 1a). These high respiration rates at low SOC content, contradict our hypothesis of carbon stabilization on mineral surfaces. Figure 1b shows the dependence of basal respiration on the C:N ratio and indicates that wide ratios seem to prevent high respiration rates while maximum CO_2 production rates per unit SOC occur at C:N ratios of 10 to 20. These differences are possibly originating from different peat substrates or fertilization. Low C:N ratios also occur in highly humified SOC. However CO_2 production rates per unit SOC were not correlated with other soil properties like total nitrogen, pH or dry bulk density (Tab. 2).

Our data further shows a positive correlation between microbial biomass and total nitrogen content which, as expected, indicates the important nutrition function of nitrogen (Fig. 1c). As observed for the CO_2 production rates per unit SOC, the relation of microbial biomass and C:N ratio (not shown) shows the highest scatter for narrow C:N ratios. In addition to these two soil properties, the results of the microbial biomass indicated significant dependence on SOC, dry bulk density and pH (Tab. 2). Furthermore, the relation between CO_2 production rates per unit SOC and microbial biomass (Fig. 1d) reveals a strong correlation and gives an idea about magnitude and variability of the metabolic quotient.

Overall, it can be noted that the CO_2 production rates per unit SOC of the reference samples fit surprisingly well into the results of their disturbed counterparts. Few exceptions are samples of very young, hardly degraded top layers of undisturbed peatlands that have noticeable higher values of microbial biomass and hence increased production of CO_2. However, samples from increasingly degraded and deeper (> 50 cm) peat layers present results that are similar to the samples from organic soils under agricultural use. The metabolic quotient of the samples from undisturbed peatlands was almost constant (11.8 ± 2.13 mg CO_2-C h^{-1} g^{-1} biomass SIR-C_{mic}) despite the highly varying peat properties. This suggests that the metabolic quotient may represent a relatively stable ecosystem property as the only common feature of these peat samples was the permanent water saturation of the soils. This has to be further studied in a larger ensemble of samples.

Table 2: Matrix of Pearson correlation coefficients between soil and microbial properties without reference sites

	Basal respiration	**Microbial biomass**	**Metabolic quotient**
SOC	-0.31**	0.28**	-0.45*
total nitrogen	-0.04	0.53*	-0.44*
C:N-ratio	-0.35*	-0.19	-0.07
bulk density	0.05	-0.33*	0.34*
pH	0.16	0.29**	-0.08

* $p < 0.001$, ** $p < 0.01$

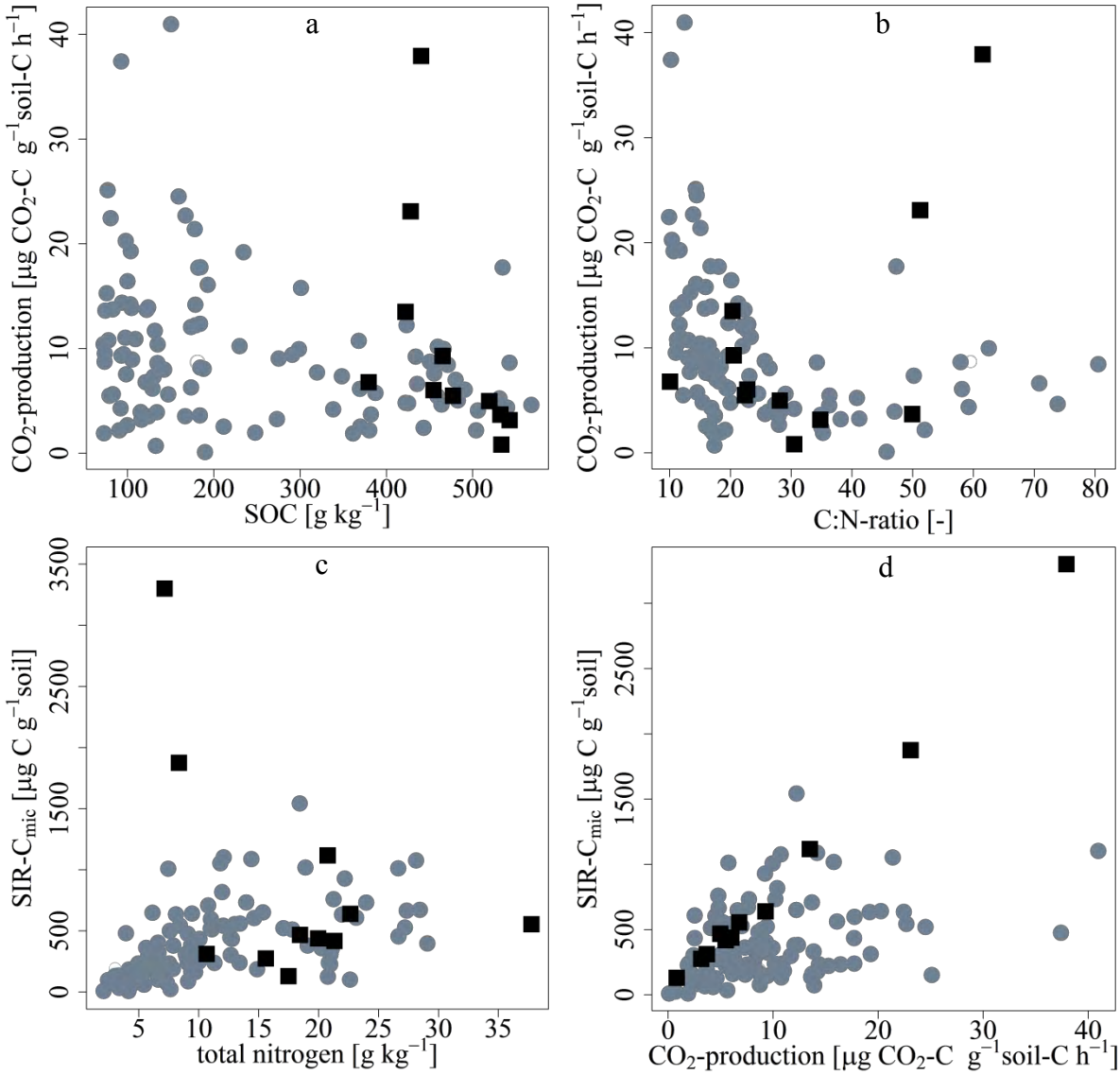

Figure 1: Relations between a) CO_2 production rate per unit SOC and soil organic carbon (SOC) b) CO_2 production rate per unit SOC and C:N-ratio c) substrate induced microbial biomass and total nitrogen and d) substrate induced microbial biomass and CO_2 production rate per unit SOC for the samples of the German agricultural soil inventory (grey circles) and anthropogenically undisturbed peatlands as references (black squares)

CONCLUSION AND OUTLOOK

The results of basal respiration and microbial biomass showed that soils with lower SOC contents, higher pH (6-7) and narrower C:N ratio have a lower metabolic quotient, which may indicate a better availability and more efficient use of carbon. Basal respiration rates per g SOC of soils at the boundary between mineral and organic soils showed to be at least as high as respiration rates of SOC-rich peat soils while presenting a high variability in the low SOC content range. Furthermore, our results indicated that the carbon pool of soils with wide C:N ratios seem to be more stable.

Given the first analysis of the preliminary results presented here, we consider it important to try to distinguish between two causes of decreased SOC content in organic soils: transformation and mineralization or anthropogenic mix with mineral soil, e.g. with deep ploughing. Additionally, it is planned to investigate the potential influence of land use change at the sites, and to analyze $\delta^{13}C$, $\delta^{15}N$ and the H/C and O/C ratio of the samples to get further information about the transformation stage of the soil organic matter.

REFERENCES

1. Anderson, J.P.E. & Domsch, K.H., 1978. A physiological method for the quantitative measurement of microbial biomass in soils. *Soil Biology & Biochemistry*, 10, pp.215–221.
2. Anderson, T.-H. *et al.* 1995. Methoden zur quantitativen Bestimmung und Charakterisierung der mikrobiellen Biomasse des Bodens. *Landbauforschung Voelkenrode. Sonderheft*
3. Ausec, L., Kraigher, B. & Mandic-Mulec, I., 2009. Differences in the activity and bacterial community structure of drained grassland and forest peat soils. *Soil Biology and Biochemistry*, 41(9), pp.1874–1881.
4. Beare, M.H. *et al.* 2014. Estimating the organic carbon stabilisation capacity and saturation deficit of soils: a New Zealand case study. *Biogeochemistry*, 120(1-3), pp.71–87.
5. Brake, M., Höper, H. & Joergensen, R.G., 1999. Land use-induced changes in activity and biomass of microorganisms in raised bog peats at different depths. *Soil Biology and Biochemistry*, 31(11), pp.1489–1497.
6. Don, A., Rödenbeck, C. & Gleixner, G., 2013. Unexpected control of soil carbon turnover by soil carbon concentration. *Environmental Chemistry Letters*, 11(4), pp.407–413.
7. Gelman, A. & Rubin, D.B., 1992. Inference from Iterative Simulation Using Multiple Sequences. *Statistical Science*, 7(4), pp.457–511.
8. Heinemeyer, O. *et al.* 1989. Soil microbial biomass and respiration measurements: An automated technique based on infra-red gas analysis. *Plant and Soil*, 116, pp.191–195.
9. Kaiser, E.A. *et al.* 1992. Evaluation of methods to estimate the soil microbial biomass and the relationship with soil texture and organic matter. *Soil Biology and Biochemistry*, 24(7), pp.675–683.
10. Kechavarzi, C. *et al.* 2010. The role of soil moisture, temperature and nutrient amendment on CO_2 efflux from agricultural peat soil microcosms. *Geoderma*, 154(3–4), pp.203–210.
11. Vrugt, J. a. *et al.* 2009. Accelerating Markov Chain Monte Carlo Simulation by Differential Evolution with Self-Adaptive Randomized Subspace Sampling. *International Journal of Nonlinear Sciences and Numerical Simulation*, 10(3), pp.273–290.
12. Vrugt, J. a. *et al.* 2009a. Equifinality of formal (DREAM) and informal (GLUE) Bayesian approaches in hydrologic modeling? *Stochastic Environmental Research and Risk Assessment*, 23(7), pp.1011–1026.
13. Vrugt, J. a. *et al.* 2008. Treatment of input uncertainty in hydrologic modeling: Doing hydrology backward with Markov chain Monte Carlo simulation. *Water Resources Research*, 44, pp.1–52.