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The impact of sieving on heterotrophic respiration response to water content in loamy and sandy topsoils

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ABSTRACT

Understanding the relation between soil heterotrophic respiration and water content is important for the prediction of climate change effects on soil CO_2 emissions. In order to quantify the influence of air-drying and sieving with 2 mm meshes on the heterotrophic respiration response to soil water content we incubated intact cores and sieved samples of two loamy and two sandy soils for six levels of effective soil water saturation. We further determined soil textural properties and the soil water retention curves of the soils with the intent to identify links between soil physical characteristics and moisture sensitivity functions of heterotrophic respiration. The incubation of sieved and intact soils revealed distinct differences in the response of heterotrophic respiration to soil water content. The sieved soils exposed a threshold-type behaviour, whereas the undisturbed soils exposed a quadratic increase of heterotrophic respiration with increasing effective soil water saturation. Further, we detected significant correlations between the moisture response functions of the undisturbed soils and soil texture. From the comparison of sieved and intact soil incubations we conclude that the destruction of soil structure by sieving hampers the transferability of measured soil moisture response of heterotrophic respiration to real-world conditions. For modelling purposes we suggest the use of a quadratic function between relative respiration and effective saturation for soils with a clay fraction < 20%.

1. Introduction

Soil respiration causes one of the largest terrestrial carbon fluxes and its accurate quantification is still a matter of on-going research (Reichstein and Beer, 2008; Wang et al., 2014). Heterotrophic soil respiration is produced by the degradation of soil organic material, which is known to depend on soil temperature and moisture. The impact of soil temperature on the carbon decomposition is pronounced (Davidson and Janssens, 2006; Exbrayat et al., 2013). At a global perspective the second most relevant driver of heterotrophic respiration is soil water content (Bauer et al., 2008; Moyano et al., 2012). This becomes even more relevant against the background of global climate change (Falloon et al., 2011; Wang et al., 2014) since the predicted climate changes include altered precipitation regimes (IPCC, 2013). Dryer soils potentially counteract the effect of increased soil temperatures because a decrease in soil water content is generally expected to reduce soil heterotrophic respiration in terrestrial soils. Thus a precise mathematical description of the relation between soil water content and soil heterotrophic respiration is required (Blagodatsky and Smith, 2012).

In contrast to the temperature sensitivity function of respiration, for which basically only two types of functions, Arrhenius and Q_{10}, are widely applied, there is a large diversity of functions used to model the soil water content influence on respiration (Falloon et al., 2011; Exbrayat et al., 2013). The effect of soil water content on heterotrophic respiration is manifold, however, there are two main influences: First, low water contents reduce the diffusion of nutrients towards microorganisms and microbial motility (Manzoni et al., 2014). Secondly, they may isolate the microbial habitats and thus inhibit microbial competition (Monga et al., 2008). Additional effects like e.g. water repellency (Lamparter et al., 2009), soil aeration (Schjonning et al., 1999; Ball, 2013), osmotic stress (Moyano et al., 2013), or substrate availability may also affect the soil water content response of heterotrophic respiration.

Even more striking, the soil moisture dependencies of respiration derived from field data (Davidson et al., 1998; Epron et al., 1999; Koizumi et al., 1999; Borken et al., 2003; Petersen et al., 2008; Wang et al., 2014) deviate from the functions derived from laboratory incubation experiments. One explanation for the consistent differences between field study and incubation derived functions may be the influence of other abiotic drivers. First of all, soil temperature obscures the intrinsic sensitivity of respiration towards soil water content under field conditions (Davidson et al., 1998; Borken et al., 2003). Further, diffusion limited transport of CO_2 or oxygen deficits limiting the production of CO_2 might also play a role under field conditions. Further complexity under field situations arises from the 'Birch effect' (Birch, 1958). Large peaks of respiration were observed due to precipitation pulses following extended drought periods, which could be explained

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by the rapid mineralization of dead microbial biomass and osmoregulatory compounds (Unger et al., 2010).

In contrast to field data, the soil water sensitivity function derived from incubation experiments tends to show a plateau or optimum-type behaviour. Various functions, like exponential, sinusoidal or Gaussian-type, are applied to describe this relation below this threshold (Moyano et al., 2013). A lot of process-based models apply this threshold-type approach (Bauer et al., 2008; Falloon et al., 2011; Exbrayat et al., 2013). The threshold-type function might partly result from the incubation procedure itself. The dependence of the accessibility of carbon to the decomposers on soil structure is documented in several studies (Six et al., 2000; Strong et al., 2004; Navarro-Garcia et al., 2012). During almost all of the incubation procedures documented in literature, the soil was sieved and homogenized (Manzoni et al., 2012; Moyano et al., 2012) prior to incubation, which clearly causes the destruction of the original soil structure. Lamparter et al. (2009) observed differences in the heterotrophic respiration response between disturbed and structural intact cores incubated at 3 soil water potentials and concluded that soil structure had a significant influence on respiration activity. Lomander et al. (1998) detected that respiration of disturbed soils was high, compared to field results, and stated that the transfer of results from the lab to field scale may be questionable. They expected an improvement by using intact soil cores for incubation experiments.

In order to estimate the parameters of the respiration response function to soil moisture, various soil properties such as porosity, texture, and bulk density were evaluated (Franzluebbers, 1999a; Thomsen et al., 1999). Moyano et al. (2012) established regression equations based on organic carbon content, clay content and bulk density to predict the normalized respiration response to moisture for a comprehensive data set on sieved soils. However, the predictive capability of soil hydraulic properties for the respiration response to moisture was not investigated in the abovementioned studies. As the soil water retention parameters largely depend on the pore structure, it might be expected that this also affects the response of carbon decomposition to various levels of soil water saturation.

The experiments presented in this study were intended to elucidate the following hypotheses:

a) The heterotrophic respiration response function to soil moisture differs for disturbed and intact soils.
b) The respiration response functions determined within this study for disturbed and intact soils can be validated with literature data on incubation and field experiments, respectively.
c) The soil moisture sensitivity function of heterotrophic respiration is related to soil water retention parameters.

2. Material and methods

In order to test these hypotheses we incubated sieved soil samples and intact soil cores at various soil water contents. We further determined basic soil properties and soil hydraulic parameters, which were subsequently related to parameters of the fitted moisture response functions.

Disturbed and intact soil samples of the plough horizon were taken at four agricultural fields in the lower Rhine embayment, Germany, at a depth of 5 to 10 cm. The sites in Merzenhausen (50°55′47″ N, 6°17′49″ E) and Selhausen (50°52′9″ N, 6°27′0″ E) are characterized by Luvisols classified as silt loam, with the latter showing slightly higher amounts of sand (Table 1). The soils near Pulheim (51°2′22″ N, 6°49′12″ E) and Kaldenkirchen (51°19′13 N, 6°11′47 E) are classified as Cambisols with a sandy texture. The soils were sampled during spring, with the exception of the Pulheim soil, which was sampled during autumn, just before harvest. The four soils have a soil organic carbon (SOC) content varying at about 1% of mass, with a slightly lower SOC content for the sandy soils (Table 1). We further refer to the loamy soils of Selhausen and Merzenhausen as LS and LM, respectively. The sandy soils of Pulheim and Kaldenkirchen are referred to as SP and SK, respectively. A more detailed site description is given in the references listed in Table 1. At the sampling, the LM and LS soil had crumb structures and a moderate subangular blocky structure. Numerous earth worm burrows were detected for both loamy soils. For the SP and the SK soils only a crumb structure was recorded. The disturbed samples were air-dried and sieved with 2 mm meshes.

2.1. Soil hydraulic properties

The soil water retention curves of the four undisturbed soils were experimentally determined following the standard soil physical procedures documented by Klute (1986) to obtain paired data points of pressure head and water content for the 5 replicates. The soil cores in Kopecki cylinders with a volume of 100 cm^3 were equilibrated on a sand bed or on porous plates in high pressure cells. Gravimetric water content was determined by consecutive weighting and was converted to volumetric water content via bulk density.

The soil water retention data of the sieved soils was measured by a laboratory evaporation method. The HYPROP-device (UMS, Munich, Germany) was applied to measure soil water retention down to a pressure head of ~ -900 cm. For the very dry range, additional retention data was acquired using the WP4 dewpoint potentiameter (Decagon Devices, Pullman WA, USA) for pressure heads of $\sim -10^{4.2}$, $\sim -10^{5.4}$ and $\sim -10^{6.2}$ cm.

Soil water retention data was fitted with the commonly applied approach according to Van Genuchten (1980):

$$\Theta_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \left[1 + (\alpha_1 |h|)^{n_1}\right]^{-m_1} \tag{1}$$

where Θ_e is the effective saturation, θ is the water content, θ_s is the saturated water content, θ_r is the residual water content, α_1 is the inverse air entry pressure, n_1 is the slope parameter, m_1 is equal to $1 - 1/n_1$ and h is the pressure head. To account for the presence of multi-modal pore systems, observed for some of the undisturbed soils, Eq. (1) was extended by Durner (1994):

$$\Theta_e = \sum\nolimits_{i=1}^{k} \omega_i \left[\frac{1}{1 + (\alpha_i |h|)^{n_i}}\right]^{-m_i} \tag{2}$$

with $m_i = 1 - 1/n_i$, and the index i looping over the number of pore systems. In this study this approach was used to account for macroporous soils, resulting in a bimodal retention curve with $\omega_2 = 1 - \omega_1$. In fitting

Table 1
Soil classification and properties, d_g represents the mean grain diameter according to Shirazi et al. (1988) and SOC is soil organic carbon.

Soil/site	Soil type	Depth cm	Clay %	Silt %	Sand %	d_g μm	SOC g 100 g^{-1}	Bulk density g cm^{-3}	Reference
LM Merzenhausen	Orthic Luvisol	35	18	79	3	19.3	1.04	1.356	Kasteel et al. (2007)
LS Selhausen	Haplic Luvisol	33	18	67	15	29.6	1.13	1.365	Herbst et al. (2009)
SP Pulheim	Fluvic Cambisol	39	4	21	75	390.4	0.83	1.430	–
SK Kaldenkirchen	Gleyic Cambisol	30	2	8	90	681.2	0.84	1.455	Weihermüller et al. (2009)