Climate Change Research: Evaluation and Policy Implications
S. Zwerver, R.S.A.R. van Rompaey, M.T.J. Kok and M.M. Berk, (Eds.)

Soil carbon turnover in subalpine systems and its dependence on climate

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Abstract

In the "Westallgäuer Hügelland" in southern Germany with a mean annual precipitation of 1400 mm and a mean temperature of 6.5°C, soil respiration has been monitored since spring 1993 by means of the modified Lundegardh-method. Air temperatures in the months june to august 1994 were by an average 5°C higher than summer 1993 and long-term monthly means. This enabled the authors to determine the response of soils different in soil type, carbon content and slope position to a temperature increase under field conditions.

1. INTRODUCTION

The worlds soils contain about twice the amount of carbon present in the atmosphere, mainly in the form of soil organic carbon. Mineralization of litter and humus materials returns CO_2 to the atmosphere. Since the pool of organic matter on land is large, small changes in its size yield large impacts on the atmosphere. It is critical to understand, whether and how this reservoir takes part in a possible feedback loop with climate. Of special interest are soils, which developed under a moist and cool climate regime. These soils usually are on a high soil organic carbon level, when in equilibrium. Their response to potential climate change needs to be thoroughly understood.

Field measurements of the flux of CO_2 from the soil surface provide an estimate of the total respiration in the soil, and an approach for estimating turnover of the humus pool. Unfortunately, the respiration of living roots makes it difficult to use estimates of CO_2 flux in calculations of turnover of the soil organic matter pool (*Schlesinger, 1991*). Up to date, only rough estimates (53-90% of total rhizosphere respiration; *Johansson 1992*) for root respiration are available. In spite of this uncertainty, soil respiration is regarded as an indicator for the overall physiological activity of a given soil. The CO_2 efflux rates presented here are considered as being equivalent to soil respiration, but it has to be emphasized, that soil-CO_2 efflux rates, not actual soil respiration, are measured. A major methodical constraint exists in this context: there is no technique capable of exposing intact soils and sites to controlled conditions to evaluate their response to changing climatic conditions. A possible solution lies in the long-term monitoriong of soil carbon turnover *on site*. This offers the chance to compare the behavior of soil and site under the influence of seasons of varying intensity, and it should render insight into the principal behavior of a soil at a given site in case of changing climatic conditions. At the Siggen research site, soil respiration has been monitored since May 1993. The fact, that summer 1994 was much warmer than summer 1993 will be regarded as an on site experiment concerning the response of the soil system to changing climate.

2. MATERIALS AND METHODS

2.1 Site and soils

The "Westallgäuer Hügelland" belongs to the humid and cool areas in southwest germany. Rainfall increases from 700 mm per year at Ulm to 2-3000 mm at the perimeters of the alps, with the Siggen area receiving 1400 mm. Mean annual temperature at Siggen is 6,5°C. The area is dominated by temperate grassland, that receives up to five slurry applications per year and is cut 4 to 5 times. Grazing occurs usually only for a few weeks in late autumn, when cutting the gras would not be efficient any more. The research site Siggen was set up in 1987 on the northwestern slope of a terminal moraine of the Würm-glaciation. Siggen is one of several sites contributing to a project investigating the effects of intensive agriculture on the environment. It was initially selected to determine the effects of slurry induced nitrate leaching on the little lake "Neuweiher".

The two soils regarded here are a non-fertilized histic gleysol (SR) close to the lake and a gleyic cambisol (HFV), which is situated about 200 m upslope and is elevated about 30 m. The cambisol (HFV) is treated with fertilizer (= slurry) and cut 4-5 times a year according to local practice, the histic gleysol is cut one time per year if soil stability permits operation of harvesting machines, but does not receive any fertilizer. Vegetation consists mainly of filipendula and phragmites at SR, and is a lolio-cynosuretum at HFV. The main properties of the soils are given in Table 1.

2.2 Soil respiration

The most commonly used methods for measuring respiration rates employ one of many alkali absorption techniques or infrared gas analysis. The simple soda-lime technique described here was very appealing because measurement of soil CO_2 efflux in several plots scattered over a large area and 200 km away from the University Hohenheim was to be achieved. The method was recommended and tested by Tesarova & Gloser (*1976*) and Edwards (*1982*). CO_2 is absorbed by granules of soda-lime weighed before and after a 7 days exposure in plastic dishes under a metal cylinder (diameter 23 cm, height 31 cm), covering a surface area of 415.5 cm^2. Prior to each determination, all green vegetation is clipped out inside the cylinders. The cylinders are pushed 2-3 cm into the ground and covered with a 50x50 cm PVC-sheet to prevent excessive heating through solar radiation. Each variant consists of 8 replications, and new patches within the plots are selected for each measurement. Plots within the research site are of uniform soil characteristics and span an area of 400 square meters. The amount of CO_2 absorbed in soda lime is calculated from its weight increment. Details to the procedure are given in Kleber et al. (*1994*).

Table 1:
Soil properties for the *first horizon*, all soils non-calcareous. Parameters determined according to Schlichting & Blume (*1966*). Soils are classified according to Spaargaren (*1994*).

	SR	HMV
soil type	histic Gleysol	gleyic Cambisol
C in fine earth (%)	19.99	3.94
bulk density (g cm^{-3})	0.31	0.9
stone content (%vol)	0	1.0
depth (cm)	10	10
stock of C (kg m^{-2})	6.24	3.49
pH	6.0	5.0
sand/silt/clay (%)	13/43/44	25/46/29
total pore space (%)	84	64

2.3 Soil temperature and moisture measurements

Soil temperature (at the depth of 5 cm) is measured with SKTS 200-Sensors of UP Umweltanalytische Produkte GmbH at two continuously recording weather stations. One weather station is located at the lakeside in the vicinity of site SR, the other uphill close to HMV. Soil moisture is determined gravimetrically from samples taken weekly from the upper soil layer, it is expressed as % of maximum water retention capacity (WRC), which was determined for each plot with ten replications according to Schlichting & Blume (*1966*).

3. RESULTS

As illustrated by Table 2, summer 1994 was unusually warm. Both 1993 and 1994 show precipitation values below yearly mean values. In 1994 air temperature was far above long-term monthly means. Air temperatures are generally higher in the basin than uphill. Depending on the month, air temperature in 1994 exceeded values of 1993 by 3-8°C uphill and 1-6° at the lakeside, with absolute values highest at the lakeside. On a global scale, soil respiration rates correlate significantly with mean annual air temperatures, mean annual precipitation and with the interaction of these two variables (*Raich & Schlesinger, 1992*). If smaller temporal and spatial scales are investigated, interactions of these factors are not quite as easy to be identified.

Figure 1 shows soil respiration in 1993 and 1994 at the site HMV. Soil temperature in 1994 noticeably exceeds the values of the previous year, but soil respiration remains at about the same level (Table 3). Obviously the lower soil moisture content in 1994 hampers respiration.

Table 2
Mean air temperature and precipitation at Wangen/Allgäu from 1951 to 1980; together with corresponding values at Siggen (about 10 km away from Wangen) for 1993 and 1994. (SR) denotes weather station at lakeside, (HMV) weather station uphill.

	temperature (°C) / precipitation (mm)			
	1951 - 1980 Wangen °C / mm		1993 Siggen °C / mm	1994 Siggen °C / mm
June	14.1 / 150	HMV	12.1 / 90	15.9 / 52
		SR	16.2 / -"-	17.3 / -"-
July	15.8 / 156	HMV	12.1 / 117	20.2 / 94
		SR	15.9 / -"-	21.8 / -"-
August	15.1 / 149	HMV	13.2 / 43	18.3 / 127
		SR	16.7 / -"-	19.5 / -"-

A rather different situation can be observed at the lakeside (Figure 2). Temperatures in 1994 exceed the 1993-values not as far as at site HMV. Respiration however increased by 50%. Again, soil moisture has to be held responsible for an explanation. While soil moisture at HMV was stable at or below 50% WRC (maximum water retention capacity), it varied between 50 and 70% WRC at SR. This soil moisture condition is usually regarded as optimal for soil carbon turnover and therefore recommended for incubation experiments (*Isermeyer, 1952*). It can be concluded, that at site SR the combined effects of a warm summer (increased soil temperature and lowered soil moisture) shifted the soil ecosystem to a state optimal for soil respiration.

Table 3
Cumulated soil respiration (g C m^2) for period from june - august in absolute values and as fraction of annual turnover (%).

	1993		1994	
	g C m^2	%	g C m^2	%
HMV	494	44	478	42
SR	311	45	467	**68**

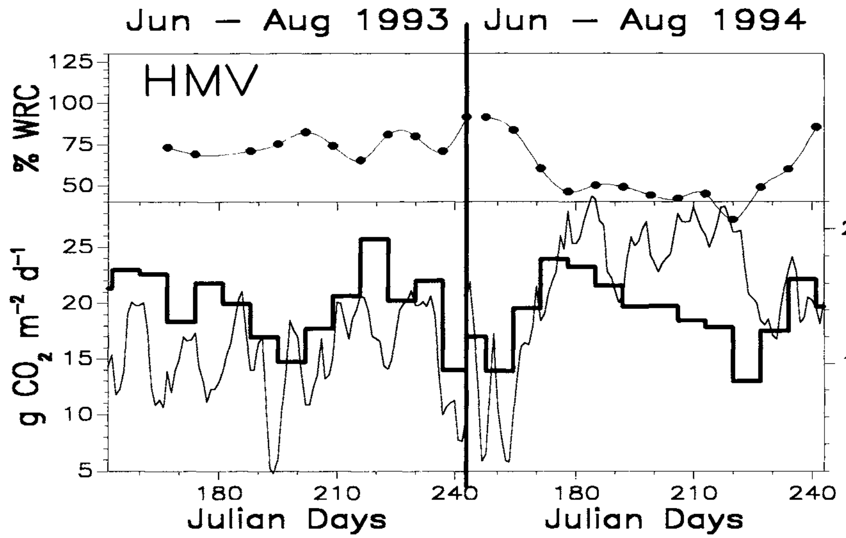

Figure 1. Respiration rates (heavy line), soil temperature in 5 cm depth (thin line) and soil moisture (dotted line) expressed as fraction of max. water retention capacity (100% max. WRC = pF 0.6) at site HMV.

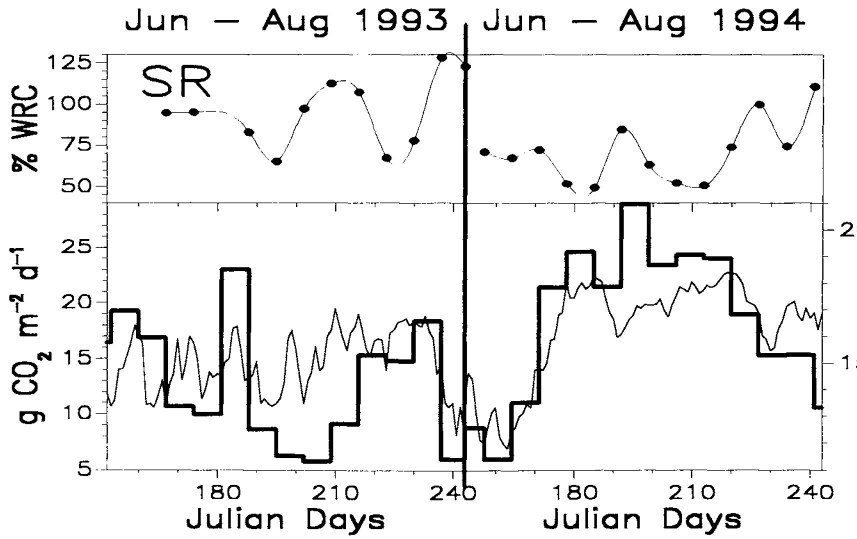

Figure 2. Respiration rates (heavy line), soil temperature in 5 cm depth (thin line) and soil moisture (dotted line) expressed as fraction of max. water retention capacity (100% max. WRC = pF 0.6) at site SR.

4. CONCLUSIONS

Soil respiration on the northwestern slope of the terminal moraine of the Würmian glaciation in a temperate grassland area in southwestern germany has been monitored since May 1993. A comparison of soil CO_2 efflux between the "standard" summer of 1993 and the warm summer of 1994 showed no difference in CO_2 - efflux at the site HMV on the upper slope of the moraine. At the site SR on the basis of the moraine, cumulated respiration was increased by 50% and reached 68% of the annual carbon turnover in 1994 versus 45% in 1993. Lower soil moisture contents at both sites during summer 1994 led to a moisture deficit uphill, but shifted soil moisture content in the basin into the optimum range for carbon turnover. Therefore, the following can be stated: 1. Carbon-rich soils do not necessarily respond to higher temperatures with higher respiratory activity. 2. Increased physiologic activity of a soil requires not only higher temperatures, but also adequate water supply. 3. Soil respiration will increase dramatically (50% over a three month period) if both soil temperature and soil moisture are shifted to optimum conditions. 4. Within a distance of 200 meters, soils differed considerably in their sensitivity to climate. Attempts to model carbon turnover on a large (global) scale have to take this into account.

5. REFERENCES

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