Pergamon

Soil Biol. Biochem. Vol. 30, No. 14, pp. 2017–2022, 1998

Printed in Great Britain

PII: S0038-0717(98)00076-5

0038-0717/98 $19.00 + 0.00

CARBON DIOXIDE EVOLUTION FROM TOP- AND SUBSOIL AS AFFECTED BY MOISTURE AND CONSTANT AND FLUCTUATING TEMPERATURE

ANJA LOMANDER,[1]* THOMAS KÄTTERER[2] and OLOF ANDRÉN[2]

[1]Department of Forest Soils, SLU, P.O. Box 7001, 750 07 Uppsala, Sweden and [2]Department of Soil Sciences, SLU, P.O. Box 7014, 750 07 Uppsala, Sweden

(Accepted 17 April 1998)

Summary—Topsoil (0–25 cm) and subsoil (30–55 cm) samples were taken from clay soil which had been cropped with reed canarygrass (*Phalaris arundinacea*). After crumbling the soil into fragments < 10 mm and removing visible organic debris, CO_2 evolution was measured in the laboratory at four moisture contents (17, 26, 36 and 50% H_2O for the topsoil and 16, 23, 31 and 41% for the subsoil) and at constant temperatures of −4, 0.3, 5, 15, 25, and temperatures fluctuating (weekly) between −4 and +5°C. Evolution of CO_2 after the addition of roots or stubble of *P. arundinacea* to the topsoil (25°C, 36% H_2O) was also studied. The CO_2 evolution increased significantly with temperature and moisture. The CO_2 evolution rate per unit of soil carbon was about two times higher for topsoil than for subsoil. Temperature fluctuation between −4 and +5°C did not enhance CO_2 evolution significantly compared with incubation at a constant 5°C and was even lower than or not significantly different from samples at 0.3°C.

INTRODUCTION

Temperature and moisture, along with chemical and physical composition of the substrate are the major controllers of decomposition rates of soil organic matter (Swift *et al*., 1979). The availability of oxygen (Nyhan, 1976; Naganawa *et al*., 1989), the type of microorganisms present (Wilson and Griffin, 1975) and faunal abundance and activity (Andrén *et al*., 1990a) are additional factors. However, to explain C mineralization dynamics and the associated release of nutrients, studies of temperature and moisture dependence, along with the generalizations that can be obtained from these results, are probably of highest priority.

Generally, C mineralization decreases with decreasing temperature (see, e.g. Waksman and Gerretsen, 1931; Jenny *et al*., 1949; Clark and Gilmour, 1983; Anderson, 1991; Kirschbaum, 1995) from an optimum temperature down to 0°C (Andrén *et al*., 1990a) or below (Flanagan and Veum, 1974; Clein and Schimel, 1995). Cycles of freezing–thawing can promote the decomposition of organic material through the alteration of substrate quality (Goodroad and Keeney, 1984; Coxon and Parkinson, 1987).

In most soils, C mineralization increases with increasing moisture content, in terms of tensions from about −5 to about −0.05 MPa, and then decreases again due to oxygen deficiency. Bacterial respiration begins to decrease at −0.3 MPa and is almost negligible below −2 MPa (Wilson and Griffin, 1975). Mineralization below the wilting point (−1.6 MPa) is thus considered to be carried out mainly by fungi (Wilson and Griffin, 1975; Swift *et al*., 1979).

Several laboratory studies of C mineralization rates in relation to moisture and temperature have been performed (Flanagan and Veum, 1974; Nyhan, 1976; Clark and Gilmour, 1983; Howard and Howard, 1993; Kirschbaum, 1995). However, there are few studies carried out on cold and heavy soils. Experimental data from these types of soils are therefore of special interest. There is also a need for improved theoretical analysis, i.e. mathematical modelling, of the laboratory incubation data (Lomander *et al*., 1998).

In this study, measurements of soil respiration, as CO_2 evolution rates, were made at different temperature and moisture regimes in the laboratory. The objectives were to quantify: (1) the influence of soil temperature and moisture on CO_2 evolution rates in a heavy clay soil, (2) the influence of freezing–thawing on CO_2 evolution, (3) differences of CO_2 evolution due to substrate quality differences between top- and subsoil and, (4) the dynamics of CO_2 evolution after addition of roots or stubble.

*Author for correspondence.
E-mail: anja.lomander@sml.slu.se

MATERIALS AND METHODS

Site description and sampling

Topsoil (0–25 cm) and subsoil (30–55 cm) were sampled on 29 October 1994 from conventionally fertilized plots (treatment C2; Kätterer *et al.*, in press) which were cropped with reed canarygrass (*Phalaris arundinacea* L.) in an experiment designed in four blocks at Ultuna, Sweden (59°48′N, 17°38′E), 10 m above sea level (Andrén *et al.*, 1996). Four subsamples of approximately 25 kg each, one from each block, were taken from top- and subsoil, placed in black plastic bags and stored at +4°C. During the sampling, the weather was cloudy with air temperature around +10°C.

The soil was classified by Andrén *et al.* (1990b) as a Fluventic Eutrochrept (Limenthic; Soil Survey Staff, 1975), with a mean clay content of approximately 53% between 0–55 cm. The total silt content, dominated by finer fractions, is approximately 35% and the sand content is about 5%. The wilting point corresponds to approximately 25 vol.% of water and remains fairly constant down to 100 cm (Johansson *et al.*, 1985).

Sample preparation and treatments

In January 1995, the four subsamples were bulked into one top- and one subsoil sample. The soil was crumbled into fragments (dia < 10 mm) and roots and other visible organic material were removed by hand-picking. Organic C concentrations were analyzed in the separated seed- and crown-roots, and in the lower 10 cm of the straw of *Phalaris arundinacea*, which corresponded to stubble. The latter was harvested on 22 October 1994 in the plots from which the soil samples had been taken, and dried at 70°C for 48 h. The stubble was added (0.3 g per 79.97 g dry soil) to two treatments (see below).

Soil cation exchange capacity (CEC) and base saturation (BS) were analyzed by extraction with ammonium acetate. Organic and total C were determined on one bulked sample of both top- and subsoil, respectively, before incubation. Total C was measured as CO_2 using infrared gas analysis (IRGA) after combustion at 1300°C, while organic C was determined after combustion at 500°C. Initial amounts of total N were determined by oxidation of organic nitrogen to nitrogen oxides, which was measured using IRGA. Loss on ignition (LOI) was estimated by heating the soil to 600°C, and pH was measured in distilled water.

Top- and subsoil were carefully mixed separately, and samples were put into vessels (466 ml) of standard styrene–acryl nitril plastic (SAN) as described in detail by Persson *et al.* (1989). Lids containing rubber septa and rubber seals were used to close off the vessels periodically in order to accumulate CO_2 for the respiration measurements. Each sample that was placed in the vessels had a fresh mass of 100.00 g, which corresponded to a dry mass of 79.97 g for the topsoil and 83.02 g for the subsoil, as determined by drying 100 g soil at 105°C for 2 d in three replicates.

The pore volume of the soil in the vessels was generally much higher than that in the field. To estimate the water holding capacity (WHC), 100.00 g of the crumbled and mixed soil was placed on a fine mesh (530 μm). Water was added over several days until the samples were saturated, and the mass was then measured.

Before incubation of the samples at six temperatures (–4, 0.3, 5, 15, 25 and fluctuating –4/5°C) the water content was adjusted to four values between 100% WHC and the wilting point (17, 26, 36, 50 and 16, 23, 31, 41 g H_2O 100 g^{-1} dry soil for top- and subsoil, respectively). These moisture contents were based on the tension curves by Johansson *et al.* (1985). For one of the topsoil moisture–temperature combinations (25°C, 36 g H_2O), two additional treatments were introduced. In the first, 300 mg of dry roots which were removed from the other treatments were added to the soil before incubation, while in the second, 300 mg of stubble of *P. arundinacea* were added. The treatments (50 total; i.e., 4 water contents × 6 temperatures × topsoil and subsoil = 48, plus "root" and "stubble" treatments) were replicated three times. All soil samples were stored at 4°C until they had reached the desired water content and on 25 January 1995 (day zero) they were placed in constant temperature rooms.

In the following text, topsoil samples (T) with added stubble (S) and roots (R) will be referred to as, i.e., TS 25/36 and TR 25/36, respectively, where the first value indicates the incubation temperature (°C) and the second indicates water content (%H_2O 100, dry soil mass basis). Correspondingly, subsoil samples will be referred to as A (from alv, the Swedish name for subsoil).

CO_2 measurements

Soil respiration was measured as CO_2 evolution at increasing time intervals, i.e., from 1-week intervals at the beginning of the experiment to 4-week intervals after six months. The containers were closed with an airtight lid and a background value was obtained by taking a gas sample after about 15 min with a 100 μl syringe (Unimetric Corporation TP 5100R) and injecting it into a gas chromatograph (Hewlett Packard 6890A) equipped with a hot wire detector. Helium with a pressure of 138 kPa was used as carrier gas and the temperature of the column was 100°C.

CO_2 was allowed to accumulate in the headspace for about 24 h for top- and subsoil samples incubated at 0.3°C, 22 h for top- and subsoil samples at 5°C, 20 h for subsoil samples at 15 and 25°C and 5 h for topsoil samples at 15 and 25°C. The gas