

Flush of CO₂ as a Soil Biological Quality Indicator

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Abstract

Soil microbial biomass is an active part of soil organic matter that plays a key role in the decomposition of organic materials, nutrient cycling, and formation of soil structure. Measurement of soil microbial biomass has been proposed with a number of biochemical procedures, which vary in their sensitivity, procedural complications, and relationship to other active soil organic matter pools. Across a number of soils, the flush of CO₂ following rewetting of dried soil was closely related to (1) the flush of CO₂ following fumigation with chloroform, (2) potential C mineralization, and (3) potential N mineralization. Both chloroform fumigation-incubation and rewetting of dried soil utilize the activity of the surviving native soil microbial community to evaluate the soil microbial biomass. We describe how the flush of CO₂ can be used to discriminate changes in soil biological quality induced by various agricultural management practices under different soil conditions.

Keywords: Carbon mineralization; Microbial biomass C; Nitrogen mineralization; Soil biological activity; Soil quality

1. Introduction

Active fractions of soil organic matter are important to plant-available nutrient supply, decomposition of natural and synthetic organic amendments, and manipulation of soil structure as a result of microbial biomass and activity. Assessments of biological soil quality must estimate these important biogeochemical functions of soils.

Methodology for determining the traditional suite of soil biological properties can be laborious and lengthy and can require expensive analytical equipment. An alternative methodology was developed that measured the flush of CO₂ following rewetting of dried soil (Franzluebbbers et al., 2000). Measurement of the flush of CO₂ was found to have value for routine soil testing of biological soil quality because it:

- a) Is an incubation procedure patterned after natural occurrences in most soils,
- b) Exhibits strong overall relationships with active organic fractions,
- c) Shows relatively minor changes in relationships with active organic fractions that may be due to climatic variables,

- d) Has a simple setup with minimal equipment requirements, and
- e) Has rapid analysis time.

The flush of CO₂ has been procedurally defined with both 0-1 (C_{MIN}_{0-1 d}) and 0-3 d (C_{MIN}_{0-3 d}) periods (Franzluebbers et al., 2000). Both evaluation periods are strongly related within most soils (Fig. 1). Using C_{MIN}_{0-1 d}, Haney et al. (2001) observed strong relationships with bermudagrass forage N uptake receiving different levels of dairy manure as fertilizer.

Our objective was to summarize recently collected data illustrating the value of the method under different conditions.

2. Materials and methods

Soil analyses followed the procedures outlined in Franzluebbers et al. (2000). Briefly, C_{MIN} was determined from 15 to 120 g subsamples of soil that were oven-dried (55 °C, 48 h) and gently crushed to pass a 4.75-mm screen. Duplicate soil samples were moistened to 50% water-filled pore space and incubated at 25 ± 1 °C in 1-L canning jars containing vials with 10 mL of 1.0 M NaOH to absorb CO₂ and water to maintain humidity. Alkali traps were replaced at 3 and 10 d and removed at 24 d. Carbon dioxide evolved was determined by titration of alkali with 1.0 M HCl. At 10 d, one of the subsamples was removed, fumigated with chloroform, and incubated separately for a further 10 d under the same conditions to determine the flush of CO₂-C representing soil microbial biomass C using a k_C factor of 0.41. Net N mineralization was determined from inorganic N concentration at 0 and 24 d of incubation using Cd reduction and salicylate-nitroprusside autoanalyzer techniques from 2 M KCl extracts (Bundy and Meisinger, 1994). At 0 and 24 d, soil was oven-dried (55 °C, 48 h), sieved to pass a 2-mm screen, and a 10-g subsample shaken with 20 mL of 2 M KCl for 30 minutes. Soil organic C and N were determined either by dry combustion for soils with pH < 7 or dichromate oxidation with heating to 150 °C for 1 h and Kjeldahl digestion for soils with higher pH.

In Evaluation 1, 15 soils were collected in 2005 at a depth of 0-10 cm: ten of the soils were from wheat production systems in western Oklahoma, two of the soils were from a maize-wheat rotation in central Texas, two of the soils were from cereal production in Maine, and one soil was from potato production in Idaho. Soil pH ranged from 5.1 to 8.3.

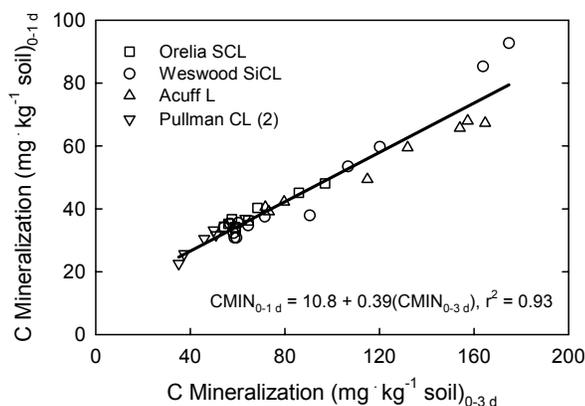


Figure 1. Relationship of C mineralization during 0-3 d with C mineralization during 0-1 d in four soils from Texas. From Franzluebbers et al. (2000).

In Evaluation 2, two soils (clay loam subsoil and loamy sand overwash from a landscape dominated by Typic Kanhapludults in Georgia) were planted with tall fescue tillers to evaluate the effect of tall fescue – endophyte association on soil biogeochemical properties (Franzluebbers, 2006). Endophyte-free and endophyte-infected plants were grown for 8, 20, 36, and 60 weeks and soil sampled for soil C and N fractions.

In Evaluation 3, a Typic Kanhapludult from North Carolina was sampled yearly for five years from three cropping systems varying in maize silage intensity (Franzluebbers and Brock, 2006). Soil was collected at depths of 0-3, 3-6, 6-12, and 12-20 cm.

3. Results and discussion

From the 15 soils in OK, TX, ME, and ID, the flush of CO₂ during the first day following rewetting of dried soil (CMIN_{0-1 d}) was highly related to CMIN_{0-3 d}, CMIN_{0-30 d}, soil microbial biomass C, and water-soluble organic C (Fig. 2). These relationships confirmed previous findings and suggest that the flush of CO₂ was highly related to readily available sources of organic C (i.e., water-soluble organic C), biologically active organic C (i.e., potential C mineralization in 30 days), and soil microbial biomass C.

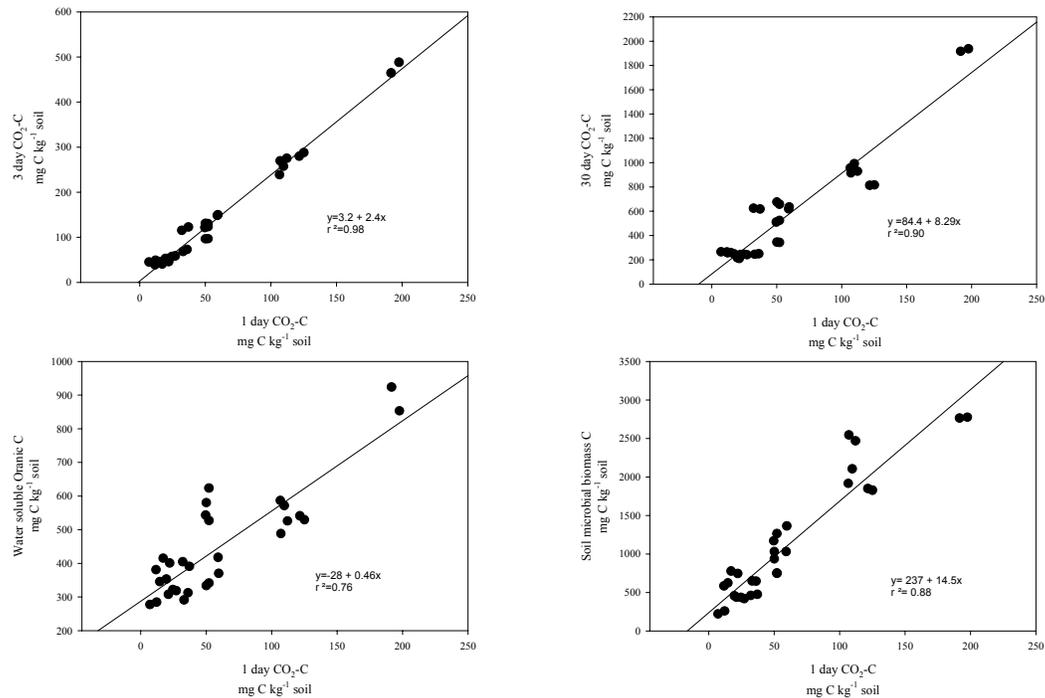


Figure 2. Relationship of the flush of CO₂ during the first day following rewetting of dried soil (CMIN_{0-1 d}) with CMIN_{0-3 d}, CMIN_{0-30 d}, soil microbial biomass C, and water-soluble organic C.

From the two soils under different lengths of time exposed to tall fescue endophyte association, the flush of CO₂ during the first 3 days following rewetting of dried soil was highly related to all measured soil C and N fractions, including potential C and N mineralization during 24 days, soil microbial biomass C, particulate organic C, and total organic C and N (Fig. 3). These relationships also confirmed previous findings and suggest that CMIN_{0-3 d} can be considered a robust soil biological indicator under a diversity of conditions, including during the active growth cycle of a perennial grass.

Slope coefficients for CMIN_{0-24 d}, soil microbial biomass C, particulate organic C, total organic C, and net N mineralization were mostly within the range of values previously reported for other soils and conditions (Franzluebbers et al., 2000). Some variations in mean slope coefficient occurred with respect to other soils from Georgia, but this may have been due to the actively growing tall fescue roots during the course of this study.

In soil from North Carolina under different silage cropping intensity, the flush of CO₂ during the first 3 days following rewetting of dried soil was highly related to net N mineralization and soil microbial biomass C (Fig. 4). This study also confirmed the strong quantitative capability of CMIN_{0-3 d} to predict biologically active soil C and N fractions.

Other studies have also found strong relationships between CMIN_{0-3 d} and various biologically active soil C and N fractions. In a semi-arid region in Wyoming, CMIN_{0-3 d} was highly related to CMIN_{0-21 d}, soil microbial biomass C, net N mineralization during

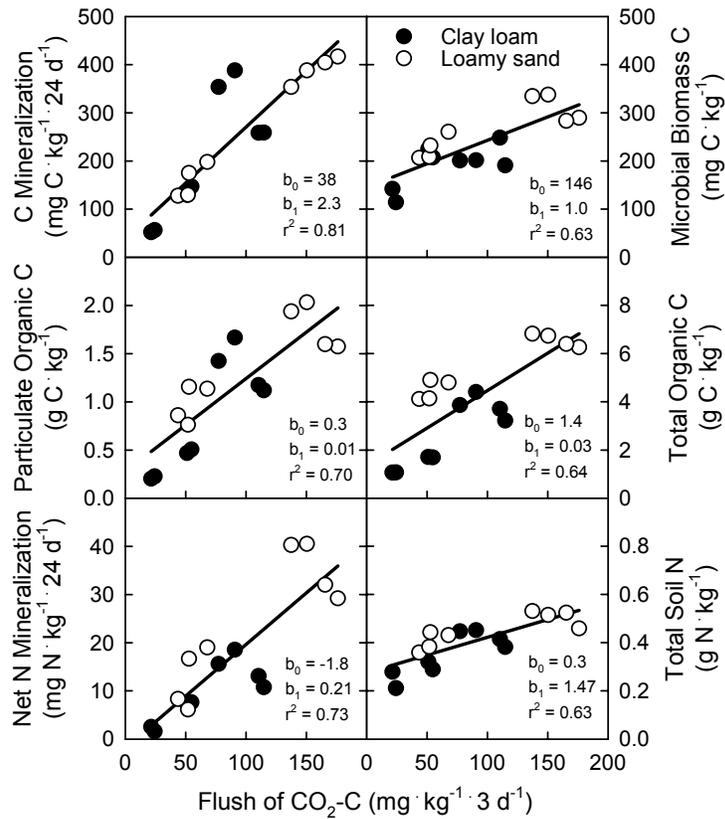


Figure 3. Relationship of the flush of CO₂ during the first 3 days following rewetting of dried soil (CMIN_{0-3 d}) with CMIN_{0-24 d}, soil microbial biomass C, particulate organic C, total organic C, net N mineralization during 24 d, and total soil N. Data from Franzluebbers (2006).

21 d, total organic C, and total soil N (Ingram et al., 2005). Relationships were strong in native rangeland, on reclaimed mine land, and on mine spoil material. These authors found great potential in using $CMIN_{0-3d}$ to assess the recovery of reclaimed, coal mine soils.

On an Oxisol in the Cerrado region of Brazil, $CMIN_{0-3d}$ was also highly related to $CMIN_{0-24d}$, net N mineralization, total soil N, and several enzyme activities, including β -glucosidase, acid phosphatase, arylamidase, and fluorescein diacetate hydrolysis (Green et al., 2006). The results of this study in the tropics have verified the strength of relationships outside of the temperate region, where the method was originally developed.

4. Conclusions

The flush of CO_2 following rewetting of dried soil exhibited strong relationships with biologically active soil C and N fractions, including water soluble organic C, potential C mineralization, net N mineralization, and soil microbial biomass C. Strong relationships were derived in a diversity of soils and under different management conditions. The relatively simple, rapid, and reliable methodology makes the flush of CO_2 a viable test for soil testing of biological soil quality.

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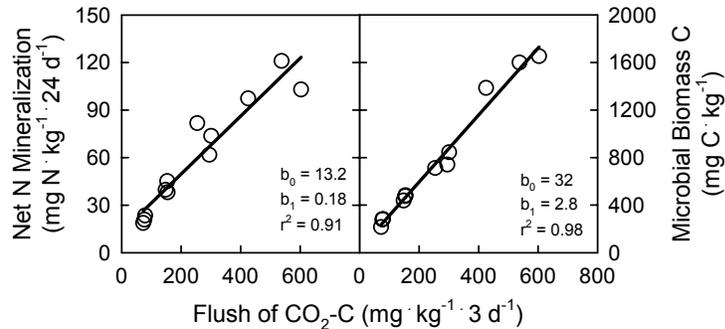


Figure 4. Relationships of the flush of CO_2 during the first 3 days following rewetting of dried soil ($CMIN_{0-3d}$) with net N mineralization during 24 d and soil microbial biomass C. Data from Franzluebbers and Brock (2006).

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