Respiration rate in some soils as affected by physical and chemical properties

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Abstract

The effects of soil physical and chemical properties on the respiration rate of some soils in the Western Region of Ghana were investigated. Soils were sampled from two standard depths, 0-20 cm and 20-40 cm, at the Agricultural Research Station (Aiyinasi) and Ntrentrenso (Sefwi Wiawso) both in the Western Region. The soils were either untreated or treated by addition of 0.4 g glucose, and respiration rate determined by measuring CO_2 evolution. Laboratory analysis was also carried out to determine *p*H, total nitrogen, particle size distribution, organic matter and exchangeable K, Na, Mg, Ca, H and Al. Atewa Series, a loam (Haplic Lixisol) produced more CO_2 than Tikobo Series (Haplic Acrisol). The higher the organic matter content, the higher the amount of CO_2 evolved and the amount of CO_2 evolved declined down the profile as organic matter content decreased. The rate of evolution of CO_2 increased considerably when 0.4 g glucose was added to Atewa and Tikobo series. However, in the midst of a low nitrogen content (< 0.10%) in the soil, especially in a loam, glucose-enriched substrate seems to be the underlying factor influencing a rise in CO_2 production. The rate of loss of C from soils correlated with the rate of CO_2 evolution. It is recommended that an inclusion rate 0.4 ± 0.1 g glucose 50 g^{-1} soil could be investigated to find the possible optimum rate for accelerated mineralization.

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Introduction

The soil pores that are not filled with water contain gases, and these gases constitute the soil atmosphere. Its composition differs from that of the free atmosphere since the plant roots and organisms living in the soil remove oxygen from it and respire carbon dioxide into it, so that it is richer in carbon dioxide and poorer in oxygen than the free atmosphere.

Respiration is a term that has been given a variety of definitions. Domsch (1962) and Drobikova & Drobrin (1965) defined respiration as means or process of taking up of oxygen and/or the release of carbon dioxide by living metabolizing entities in the soil. Respiration also is a term which is applied to soils as they are said to respire because of their ability to take up oxygen and release carbon dioxide.

Soil respiration is an indicator of the biological activity in soil and can be determined by measuring the flux of carbon dioxide from the soil surface. Measurements of soil respiration, in a sense, can be used to determine the soil's contribution to greenhouse gas production because respiration represents a direct input of carbon dioxide to the atmosphere. The rate of respiration also indicates how fast carbon is lost from soil. This information may be useful in determining the carbon storage capacity of soils under different management.

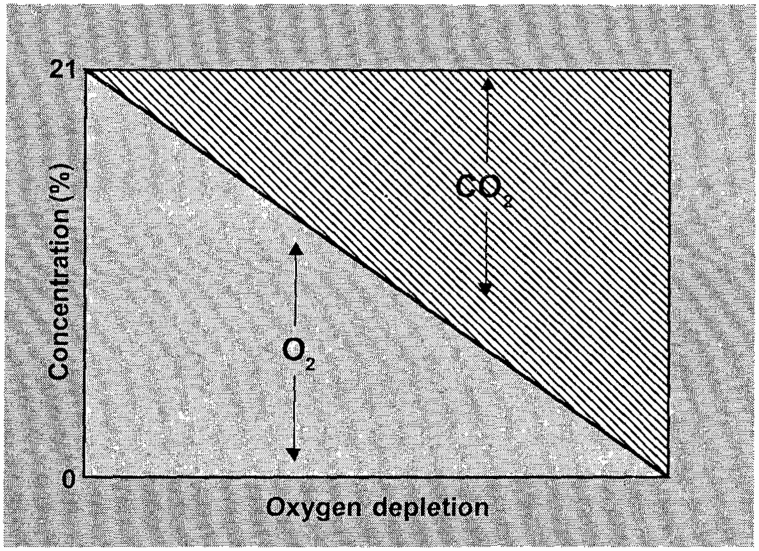
The mechanism of respiration can be summarised in the following equation for the oxidation of glucose (Fig. 1).

$$C_6H_{12}O_6 + 6O_2 \Leftrightarrow 6CO_2 + 6H_2O + \text{Energy}$$

The rate at which respiration occurs depends on many factors including the following:

Soil Respiration

$CH_2O + O_2 = CO_2 + H_2O$
soil microorganisms > plant roots > soil animals
Consumes O_2 and produces CO_2
Air = 79% N_2, 21% O_2, 0.035% CO_2 (350 p.p.m.)
O_2 and CO_2 will vary inversely: (%O_2 + CO_2) = 21%



Re-aeration from the surface
only means by which consumed O_2 can be replaced

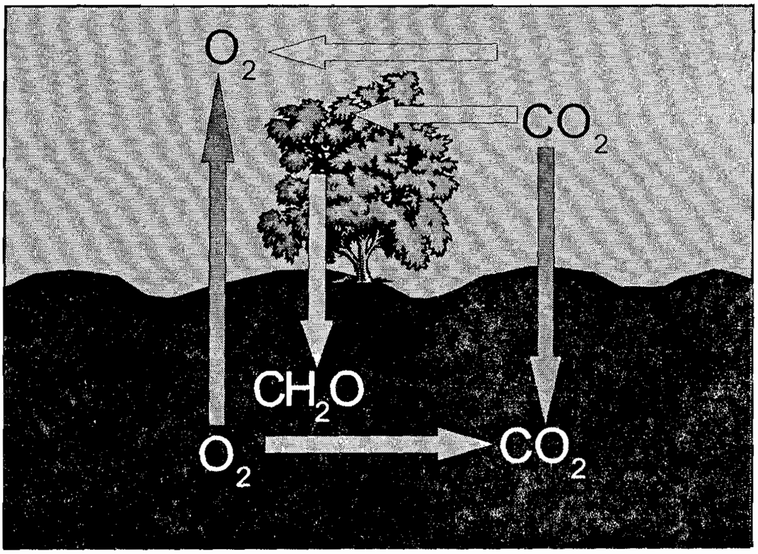


Fig. 1. Summary of the dynamics of soil respiration
(*Source*: Fuller, R., Centre for Environmental Science, State University of New York, Plattsburgh).

(1) the amount of organic matter available for oxidation which is the food supply and the general fertility of the soil; (2) the soil temperature, for the rate of respiration doubles for every 10 °C rise in temperature; (3) soil moisture, for the bacteria and roots need water; (4) the oxygen concentration in the soil air; (5) the activity of the roots of crops and its associated rhizosphere organisms; and (6) fluctuations in air pressure.

The most active respiration, therefore, occurs in organic-rich, moist aerated soils with a respiratory quotient (RQ) close to unity (RQ is the ratio of the volume of carbon dioxide produced to the volume of oxygen consumed). This ratio only rises above unity when there are aerobic pockets present in the soil (Rixon & Bridge, 1968). Organic matter, on which the rate of respiration depends, is the non-mineral portion of the soil solids. It comprises the residues and remains of higher plant and animal life, together with soil micro-organisms and the farmer's additions (Farmyard manure).

Benefits of organic matter are only realized when it undergoes decomposition on or in the soil by microbes. Where fresh organic residue is added to soil, there is a boost in microbial activity, with conducive environmental factors such as temperature, *p*H, moisture, oxygen availability and inorganic nutrients. Over the world, there is substantially more carbon in the top metre of soil than in the atmosphere most of which eventually decompose so that organic matter accounts for less than 5 per cent of the organic carbon (Jenkinson & Cadd, 1981). Therefore, selected soils of the Western Region were characterized for physical and chemical properties and their respiration rates measured. It was assessed if the variation in characteristics bore any relation to the rates of respiration.

Materials and methods

Soil sampling

Soils were collected from two locations; first, an experimental site situated at Aiyinasi Research Station near Menzezor. The field is gently undulating with 0-20 per cent slope and has a south-eastern-northwestern aspect. The site had been previously cropped to cassava. The area is perfectly drained and the vegetation is made up mainly of *Sporobulus pyramidalis, Aspilia africana and Chromolaena odorata.* The second location was at Ntrentrenso. The field is gently rolling with 2-4 per cent slope and a western aspect, with moderate to perfectly-drained sandy clay loams to clays. The site is a forest regrowth that had been cropped to cassava in the preceeding 2 years. Common plant species include *Euphorbia* sp., *Chromolaena odorata, Aspilia africana* and some grasses.

Mini sampling profiles were dug with spade, shovels and pick-axe. Samples were taken from two standard depths, 0-20 cm and 20-40 cm. Samples were put in clean polyethylene bags, sealed and labelled. The soils were air-dried in the laboratory, ground and sieved through a 2-mm mesh sieve to give the fine earth. Analytical determinations were carried out for *p*H (1:2.5 soil-water ratio and measured using a digital *p*H-meter); organic matter *via* determination of the organic carbon content using the Walkley-Black wet oxidation method (Walkley-Black, 1934). The measure was then multiplied by 1.72. Total nitrogen (by the micro-Kjeldahl procedure) (Bremner & Mulvaney, 1982); particle size distribution by the pipette method as described by Gee & Bauder (1986); exchangeable cations - calcium, magnesium, sodium, potassium, hydrogen and aluminium by displacing all exchangeable cations with NH_4^+ in 1 *N* NH_4OAc at *p*H 7.

Measurement of the respiration rate of the soils

The rate of respiration was measured using a simple respirator. The amount of CO_2 given out and the loss of carbon from the soils were calculated. For the treatment of the soils, 0.4 g of glucose was added to 50 g of moist soil. Moist sterile sand served as the control. Moist here refers to soil at about field capacity.

Fifty grams of untreated moist soil, moist-treated soil and moist-sterile sand were transferred into conical flasks. Small glass tubes were fastened onto rubber bungs by a length of nylon thread. Into each tube, 10 ml of 0.3 *M* NaOH was pipetted. Tubes were carefully placed into the flasks to hang at the side, with rubber bungs firmly sealing off the tops to prevent loss of gas during the experiment. Date and time of the setup, in six replicates, were recorded.

After 3 days, the bungs were removed from the flasks and the tubes containing NaOH were taken from the flasks. The NaOH solution in each tube was poured, completely rinsing with distilled water, into clean 250-ml flasks. Ten millilitres of 1 *M* $BaCl_2$ and six drops of phenolphthalein indicator were added. Solutions were well mixed and titrated against 0.1 *M* HCl solution. Values were recorded.

Among the variables that affect soil respiration, soil moisture and soil temperature are considered to be the more important ones (Lloyd & Taylor, 1994). In this study, the two factors were kept approximately constant by keeping the soils just moist and temperature at 25 (±1) °C.

Results and discussion

Physical and chemical characteristics for the two soils are presented in Table 1.

Tikobo series is developed under very heavy rainfall and high temperature conditions, and the soil is well-drained. High rainfall and intense weathering have caused continuous leaching of basic cations from the soil leading to a decrease in amount of exchangeable bases down the profile. This confirms observations by Webster & Wilson (1990) that the high temperatures and rainfall in tropical climate result in continuous leaching of basic cations. Since most of the nutrients are held by bonds produced by soil organic matter, the elements are detached as soil organic matter declines, and leached down together as cultivation continues. FitzPatrick (1983) observed that intense rainfall leads to a decrease in *p*H as a result of the depletion of basic cations. The soil reaction recorded for both horizons (Table 1) indicated that

TABLE 1

Soil physical and chemical characteristics of two depths of Tikobo and Atewa series

Property	*Tikobo series*		*Atewa series*	
	0-20 cm	*20-40 cm*	*0-20 cm*	*20-40 cm*
Sand (%)	90.0	90.0	56.0	57.5
Silt (%)	7.0	7.0	25.5	18.5
Clay (%)	3.0	3.0	18.5	24.0
Carbon (%)	1.08	0.97	1.53	0.64
Nitrogen (%)	0.11	0.10	0.17	0.08
Organic matter (%)	1.86	1.67	2.64	0.10
C/N	9.8	9.7	9.0	8.0
*p*H	4.6	4.8	4.8	4.5
*Calcium	1.28	0.72	ND	ND
*Magnisium	0.48	0.48	ND	ND
*Sodium	0.13	0.13	0.24	0.22
*Potassium	0.09	0.05	0.27	0.17
*Aluminium + Hydrogen	0.90	0.80	0.35	3.80
*Total base	2.88	2.18	0.86	4.19
Base saturation (%)	68.75	63.30	59.30	9.30
*Effective cation Exchange capacity	2.88	2.18	0.86	4.19

* = units in $cmol_c\ kg^{-1}$; ND = Not determined

Textural class: Tikobo = Sand; Atewa = Loam the soils were strongly acid (*p*H range 4.5-4.9).

The organic matter content of the A1 horizon was 1.86 per cent (Table 1). This is low as compared to the range of 2.0-6.7 per cent quoted for tropical top-soils of moist evergreen forest zones (Nye & Greenland, 1960). Organic matter makes up 3-5 per cent of the total soil mass and is found within 15 cm depth from the topsoil surface in the tropical region. Physically, it is responsible for most desirable qualities of the soil, such as improved structure, increased soil porosity, improved water retention and aeration, and reduction in erosion by facilitating infiltration and reducing surface water run-off. Chemically, it is the source of nearly all nitrogen, 5-60 per cent of P, up to 80 per cent sulphur, and a large part of boron and molybdenum. Naturally, there was very little vegetation cover, and associated with this will be a low release of nutrients down the profile as the litter decomposes. The A2 horizon thus recorded a lower organic matter content of 1.67 per cent.

Nitrogen content from above is wholly dependent on the organic matter content of the soil. Generally, it was low and decreased slightly from 0.11 per cent in A1 down to 0.10 per cent in A2. (Table 1). Nye & Greenland (1960) observed the range for nitrogen content in moist evergreen forest zones and moist semi-deciduous forest zones to be between 0.12-0.33 per cent and 0.13-0.30 per cent, respectively. Organic carbon in the soil decreased down the profile. Organic matter is primarily made up of carbon, about 58 per cent by weight, with lesser amounts of hydrogen, oxygen and other elements. Nye & Greenland (1960) observed that percentage carbon in the top layers of tropical soils usually ranged between 1.35-4.0 per cent. Organic matter was generally low and percent organic carbon, therefore, had corresponding values of 1.08 and 0.97 for A1 and A2, respectively.

Atewa series is also developed under high temperature and rainfall conditions. The soil has undergone weathering and leaching giving rise to low exchangeable bases which decrease down the profile (Table 1). This confirms studies done by Webster & Wilson (1990). The organic matter of the top soil was 2.64 per cent, which falls within the range of 2.0-6.7 per cent quoted by Nye & Greenland (1960) and 2-4 per cent by Ahn (1970) for tropical forest soils. The organic matter content of the topsoil is relatively higher than in tikobo series and declines down the profile. The relatively higher organic matter content observed for the topsoil might be attributed to excessive leaf fall from the predominance of *Chromolaena odorata*. This plant species had occupied virtually the whole site, and it is also known to give copious leaf fall. The nitrogen content was 0.17 per cent at the topsoil but declined down the profile. The *p*H of Atewa series decreased down the profile (*p*H 4.8-4.5). The soil is strongly acid for both horizons (*p*H range 4.5-4.9). This might be due to large amounts of organic matter which might have induced acidity (Brady, 1990).

Brady (1990) reported that C:N ratio of organic matter of arable soils community ranged from 8:1 to 15:1, the median lying between 10:1-12:1, where the soil is fairly stabilized. It is to be noted that the quantity and quality of soil organic matter accumulation depend upon the type of organic matter used. For example, application of easily degradable materials (i.e. C/N ratio < 30) would increase the labile nitrogen pool. The application of plant materials with a high C/N (i.e. > 100) favours humus formation and, therefore, benefits soil structural development. C/N ratios are important. Plant and animal residues that have C/N of 30:1 and over have too little N to allow for rapid decomposition. Therefore, the micro-organisms will take ammonium and nitrate out of the soil to fuel decomposition. This depletes the soil of nitrate and ammonium. On the other hand, residues with low ratios have sufficient N for the micro-organisms to decompose the residues without taking from the soil. Table 1 shows C/N ratios for both the A1 and A2 horizons of Tikobo and Atewa series. The ratios indicate that organic matter should be readily decomposable in these soils. Atewa series, by virtue of the dominance of the non-lignified *Chromolaena odorata,* showed slightly lower ratios than Tikobo series.

Effect of pH *on the respiration rates of the two soils*

Sorensen (1975) indicated that carbon mineralization is most rapid in neutral to slightly alkaline soil conditions and enhanced CO_2 production. Also, *p*H governs the type of micro-organisms present in any habitat. Since Tikobo and Atewa series are strongly acidic (Table 1), it is possible that fungi may constitute a larger percentage of the microbial community and, therefore, may be responsible for a considerable portion of the biochemical transformation in these acid habitats. During decomposition by fungi, about 30-40 per of the carbon metabolized is used to form cell carbon and release less CO_2. Fungi are more efficient in their metabolism as compared to aerobic bacteria which assimilate 5-10 per cent of the carbon metabolized. Thus, the low rate of CO_2 production in untreated soils of Tikobo and Atewa series (Table 2) could be attributed to the efficiency of fungi in converting substrate carbon into cell carbon. Decomposition typically proceeds more readily in neutral than in acid soils.

TABLE 2

Rate of carbon dioxide evolution in Tekobo and Atewa series

Tikobo series *Soil type*	*Soil layer 0-20 cm*		*Soil layer 20-40 cm*	
	Untreated	*Treated*	*Untreated*	*Treated*
G CO_2	6.8×10^{-3}	31.0×10^{-3}	5.1×10^{-3}	27.3×10^{-3}
G CO_2 g^{-1} dry soil	1.6×10^{-4}	7.6×10^{-4}	1.2×10^{-4}	6.5×10^{-4}
G CO_2 g^{-1} s^{-1}	6.2×10^{-10}	29.3×10^{-10}	4.6×10^{-10}	25×10^{-10}
Atewa series *Soil type*	*Untreated*	*Treated*	*Untreated*	*Treated*
G CO_2	8.8×10^{-3}	35.2×10^{-3}	6.6×10^{-3}	30.8×10^{-3}
G CO_2 g^{-1} dry soil	2.1×10^{-4}	8.4×10^{-4}	1.5×10^{-4}	7.5×10^{-4}
G CO_2 g^{-1} s^{-1}	8.1×10^{-10}	32.4×10^{-10}	6.0×10^{-10}	28.9×10^{-10}

Effect of nitrogen content on rates of respiration in the two soils

Nitrogen is a key nutrient substance for microbial growth and hence has tremendous effect on organic matter breakdown. If the nitrogen content of the substrate is low (< 0.10% N), decomposition is slow. Thus, carbon mineralization will be stimulated by supplemental nitrogen. Nitrogen-rich materials such as legume tissues are metabolized very rapidly and the micro-flora responds little to supplemental nitrogen. This could account for the differences in the level of nitrogen content in topsoils of Tikobo series (0.11%) and Atewa series (0.17%) because Atewa series might have received on the surface more leaf fall from the predominance of *Chromolaena odorata* than Tikobo series.

The higher amount of CO_2 produced in the topsoil of untreated Atewa series (8.8×10^{-3} g CO_2) as compared to the untreated topsoil of the Tikobo series (Table 2) can, therefore, be justified by the levels of nitrogen observed in the soils. Within each soil series, it can be observed that as nitrogen content decreased down the profile, the amount of CO_2 produced also decreased (Table 2). This was, however, not the case between the soils. Tikobo series at 0.1 per cent N recorded 27.3 g CO_2 in the A2 horizon whereas Atewa series yielded 30.8 g CO_2 for a much lower nitrogen content of 0.08 per cent in A2 (Table 2). The difference seems to have resulted from the addition of glucose. The effect of glucose was significant in the midst of low nitrogen contents. It is also possible that this significance was made possible by the nature of Atewa series (a loam).

Effect of organic matter level on respiration rates of the two soils

The magnitude of carbon mineralization is directly related to the organic carbon content of the soil, i.e. the release of CO_2 is proportional to the organic matter level. Also, the production of CO_2 is enhanced by the addition of organic materials (Smith, 1966). The quality of organic inputs affects their decomposability. Inputs with 'high quality', a low lignin : nitrogen (L/N) ratio decay rapidly and yield proportionally small quantities of humified material. Conversely, 'low quality' inputs are high in lignin and decompose slowly. Other factors, such as polyphenolic and nutrient concentrations, can also affect the quality or decomposability of the plant material (Swift *et al.*, 1979). Phenolic polymers found in both organic inputs and soil organic matter are an important group of materials that inhibit micro-organisms and enzymes, and are often involved in protecting other materials from biological degradation by a tanning process. Thus, with organic matter at 1.08 per cent, 6.8×10^{-3} g CO_2 was produced in the A1 horizon of the untreated topsoil of Tikobo series and the amount decreased down the profile (Tables 1 and 2). The same trend was observed in the untreated topsoil of Atewa series (Tables 1 and 2). However, as the organic matter level in the topsoil of Atewa series was higher (2.64%) than that of Tikobo series, the amount of CO_2 produced in Atewa series was also higher (8.8×10^{-3} g CO_2) than in Tikobo series (6.8×10^{-3} g CO_2).

The amount of CO_2 produced decreased (6.6×10^{-3} g CO_2) with a reduction in organic matter level to 1.1 per cent, but yet still higher than in Tikobo series (5.1×10^{-3} g CO_2) which had a reduction in organic matter to 1.67 per cent. Smith (1966), in his work with the use of isotopes in soil organic matter, proposed that addition of glucose to soil generally accelerated, but sometimes reduced the mineralization process. This was confirmed, for instance, in the treated soils of Atewa series in which the addition of glucose increased production of CO_2 from 8.8×10^{-3} g CO_2 (untreated soil) to 35.2×10^{-3} g CO_2 (treated soil). A similar trend was observed in Tikobo series.

Rate of loss of carbon from the two soils

Loss of carbon in soils is associated with the evolution of CO_2. Thus, with the production of 6.2×10^{-10} g CO_2 g^{-1} dry soil s^{-1} in untreated soil of Tikobo series (Table 2), 1.67×10^{-10}g Cg^{-1} dry soil S^{-1} was lost from the A1 horizon probably due to the lower amount of organic matter (Table 3). The amount of carbon lost declined down the profile (Table 3) consistent with a reduction in organic matter level. Once the amount of CO_2 produced had gone down there will be a corresponding

TABLE 3

Rate of loss of carbon from Tikobo and Atewa series

Tikobo series *Soil type*	*Soil Layer 0-20 cm* *Untreated*	*Soil Layer 20-40 cm* *Untreated*
G C g^{-1} dry soil s^{-1}	1.67×10^{-10}	1.24×10^{-10}
G C g^{-1} dry soil d^{-1}	1.45×10^{-5}	1.07×10^{-5}
Atewa series *Soil type*	*Untreated*	*Untreated*
G C g^{-1} dry soil s^{-1}	2.19×10^{-10}	1.62×10^{-10}
G C g^{-1} dry soil d^{-1}	1.89×10^{-5}	1.39×10^{-5}

decline in the amount of carbon also lost from the soil. In the untreated soil of the Atewa series, an amount of 8.1×10^{-10} g CO_2 g^{-1} dry soil sec^{-1} was produced and this resulted in a much higher loss of carbon from the A1 horizon (Table 3). It can be inferred that the reduction in organic matter had shown a reduction in the amount of carbon dioxide and carbon, respectively (6.0×10^{-10} and 1.39×10^{-10}).

Conclusion

The rate at which CO_2 is released during mineralization varies substantially with soil types. Atewa series produced more CO_2 than Tikobo series, at both top and subsoils. It was also observed that the higher the organic matter content of the soil, the higher the amount of CO_2 evolved. When the levels of organic matter declined from topsoils to subsoils, CO_2 evolution rate also declined and the rate of loss of carbon also correspondingly reduced. However, in the midst of a low nitrogen content (< 0.10%) in the soil, especially in a loam, glucose-enriched substrate seems to be the underlying factor influencing a rise in CO_2 production. Adding glucose to soil at an inclusion rate of 0.4 g per 50 g soil in this experiment considerably accelerated the rate of mineralization.

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