TEMPERATURE AND GLUCOSE EFFECTS ON SOIL ORGANIC CARBON: CO_2 EVOLVED AND DECOMPOSITION RATE[1]

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ABSTRACT - A study was conducted to determine the effect of glucose on C mineralization from soils with different origins at elevated temperature. Soils from Northern Europe showed higher mineralization rate than Brazilian soils for recent energy source at 35°C. At 15°C as incubation temperature, there was no difference between soils. The addition of glucose to soil accelerated the turnover of native organic C. That acceleration was higher at 35°C and in soils from temperate regions. Only the pH and total soil organic carbon had significant influence on CO_2 mineralization parameters. No significance was found to C/N ratio and clay content.

Index terms: elevated temperature of soil, mineralization rate, energy source, incubation.

EFFEITO DA TEMPERATURA E DA GLUCOSE SOBRE O CARBONO ORGÂNICO DO SOLO: TAXA DE ENVOLVIMENTO E DE DECOMPOSIÇÃO DE CO_2

RESUMO - O trabalho foi conduzido com o objetivo de determinar o efeito da glucose na mineralização de carbono em solos de diferentes origens submetidos a elevadas temperaturas. Os solos do norte europeu demonstraram maior taxa de mineralização de carbono do que os solos brasileiros para fontes recentes de energia a 35°C. A 15°C, como temperatura de incubação, não se observaram diferenças entre solos. A adição de glucose acelerou o "turnover" do carbono nativo do solo. Esta aceleração foi maior a 35°C e em solos da região temperada. Somente o pH e o carbono orgânico total apresentaram influência significativa sobre os parâmetros de mineralização. Não se observaram diferenças para a relação C/N e para o teor de argila.

Termos para indexação: temperaturas elevadas do solo, mineralização, fontes de energia, incubação.

INTRODUCTION

The amount of organic carbon present in soil at a particular time is determined by decomposition rate, by annual C input, by temperature, moisture content, and by soil and microbial biomass characteristics.

Many studies have shown that addition of plant residues increase the decomposition of native soil organic matter. Hallam & Bartholomew (1953) showed that the effect of added residues persisted for more than a hundred days. In three soils and two plant materials, the native organic matter was more extensively decomposed following addition of plant materials. The native organic matter decomposition was called "priming effect" by Jenkinson (1966). Soil clay content has influenced on the decomposition of soil organic matter by stabilizing metabolic products. Sorensen (1972) showed that the addition of montmorillonite did not influence the carbohydrates decomposition rate but increased the stability of metabolic products formed during decomposition.

Crop residues are the primary substrates to renew the soil organic matter and, for good management practices, it is necessary to incorporate those residues into the soil; the CO_2 decomposition rates became fundamental, underlining the fact that organic matter can be kept at high levels. The temperature effect was shown by Joergensen et al. (1990). About 29% of the organic C initially in the soil was mineralized to CO_2 when the incubation temperature increased from 15°C to 35°C.

The objective of the present study was to compare the effect of incubations at different tempera-

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tures on the CO_2 evolution and organic matter stability of soil from Northern Europe (i.e. U.K.) and tropical (i.e. Brazilian) regions.

MATERIALS AND METHODS

Soils used and some selected characteristic are shown in Table 1. The Pegwell soil samples, collected with high moisture content, were slowly dried at room temperature to water contents ranging from ca. 30-45% (W/W). The Janaúba, Capinopólis and Woburn soils were collected in dry conditions. The soils were sampled to a depth of 15 cm.

The soils samples were hand-picked to remove discrete plant materials and visible soil fauna, sieved (< 2 mm) adjusted to 40% of full water holding capacity and stored until needed at + 5°C in sealed polythene bags. The water holding capacity (WHC) was measured as described by Shaw (1958).

Sub-samples of < 2 mm soil were air-dried at room temperature, and pH was measured in 1:2.5 soil: water ratio. Total soil organic C and total soil N were measured on milled sub-samples. Total organic C was determined as described by Kalembasa & Jenkinson (1973); total N, as Bremner (1965), after Kjeldahl digestion. For the carbon mineralization experiment, the soils were amended with C^{14} - labelled glucose (1 mg C/g soil; sp. act = 11. 1 K Bg/ mg C) and $(NH_4)_2 SO_4$, 67 mg N/g soil) giving a C: N ratio of 15:1. Two treatments, viz - soil alone (Treat. 1) and soil plus glucose (Treat. 2) were prepared using six replications and incubated at 15°C and 35°C. Portions of moist soil from +5°C room containing 20g of soil on an oven dry basis (105°C) were weighed into a glass vial.

The labelled glucose was added as 1 ml solution with a syringe at different soils depth. A corresponding volume of distilled water was added to bring the soils to 50% WHC. The soils were incubated in brown 1.5 l bottles stoppered with a rubber bung and 20 ml 1 M NaOH was added to another glass vial and 30 ml of distilled water in the botton of the bottle. The incubations were done at 15°C and the NaOH was replaced at four day intervals initially but at longer intervals thereafter. The amount of trapped CO_2 was determined at 4, 11, 18, 25, 34, 48, 65, 76, 94 and 110 days of incubations. After 25 days in the 15°C incubation room, three replicates were changed to a 35°C incubation room. The amount of trapped CO_2 was determined at 2, 9, 16, 28, 43, 57 and 70 days of incubation. The CO_2 evolved from these treatments was measured by back titration with 0.491 M HCl from pH 8.3 to 3.7 as described by Jenkinson & Powlson (1976).

TABLE 1. Selected chemical characteristics and clay content.

Soil[1]	pH	Organic Clay	Organic C	C/N	WHC[2]
		%	%		%
Janaúba	5.2	25.4	1.27	18	42
Capinópolis	5.0	18.0	2.02	14	50
Woburn	6.8	16.7	1.51	11	54
Pegwell	7.1	20.0	4.04	13.5	54

1. Janaúba and Capinópolis are from Minas Gerais State, Brazil. Woburn and Pegwell are from England.
2. WHC - Water Holding Capacity

For determination of $^{14}CO_2$, a 1 ml aliquot of NaOH - Na_2CO_3 solution was placed into a plastic scintillation vial with 10 ml of scintillation cocktail (ultra Gold TM, Packard Inst.), sealed and mixed until clear. The misture was directly counted in a liquid scintillation counter (2500 TR liquid Scintillation Analyser Pachard) allowing samples to count to a 2% Sigma values of 1.0 during 5 min. The count detected (cpm) were converted to disintegration per minute (DPM) using a quench curve in the program for ^{14}C counting. The amount of $^{14}CO_2$ evolved from the soils was calculed as:

$$^{14}CO_2\,(mgC/gsoil) = \frac{(Cs - Co) * 20}{Ws * (SA)S}$$

Where Cs and Co are the counts of C^{14} - DPM in 1 ml 1 N NaOH from the soil or the blank. (SA) is the specific activity of the C^{14} - labelled glucose.

The amount of unlabelled C-CO_2 from substrate amended soils were calculated from the difference between the amount of total CO_2 and $^{14}CO_2$ evolved. All the results were expressed on an oven-dry soil basis (105°C, 24 h).

The statistical analysis was made by **MSTAT PROGRAM** (1987).

RESULTS AND DISCUSSION

CO_2 evolved and differences

Total CO_2 evolution from unamended soil and soil with labelled glucose are shown in Fig. 1. In Tables 2 and 3 the experimental data to total CO_2 evolved up to 110 days at 15°C and total from 25--95 days incubation period at 35°C are shown.

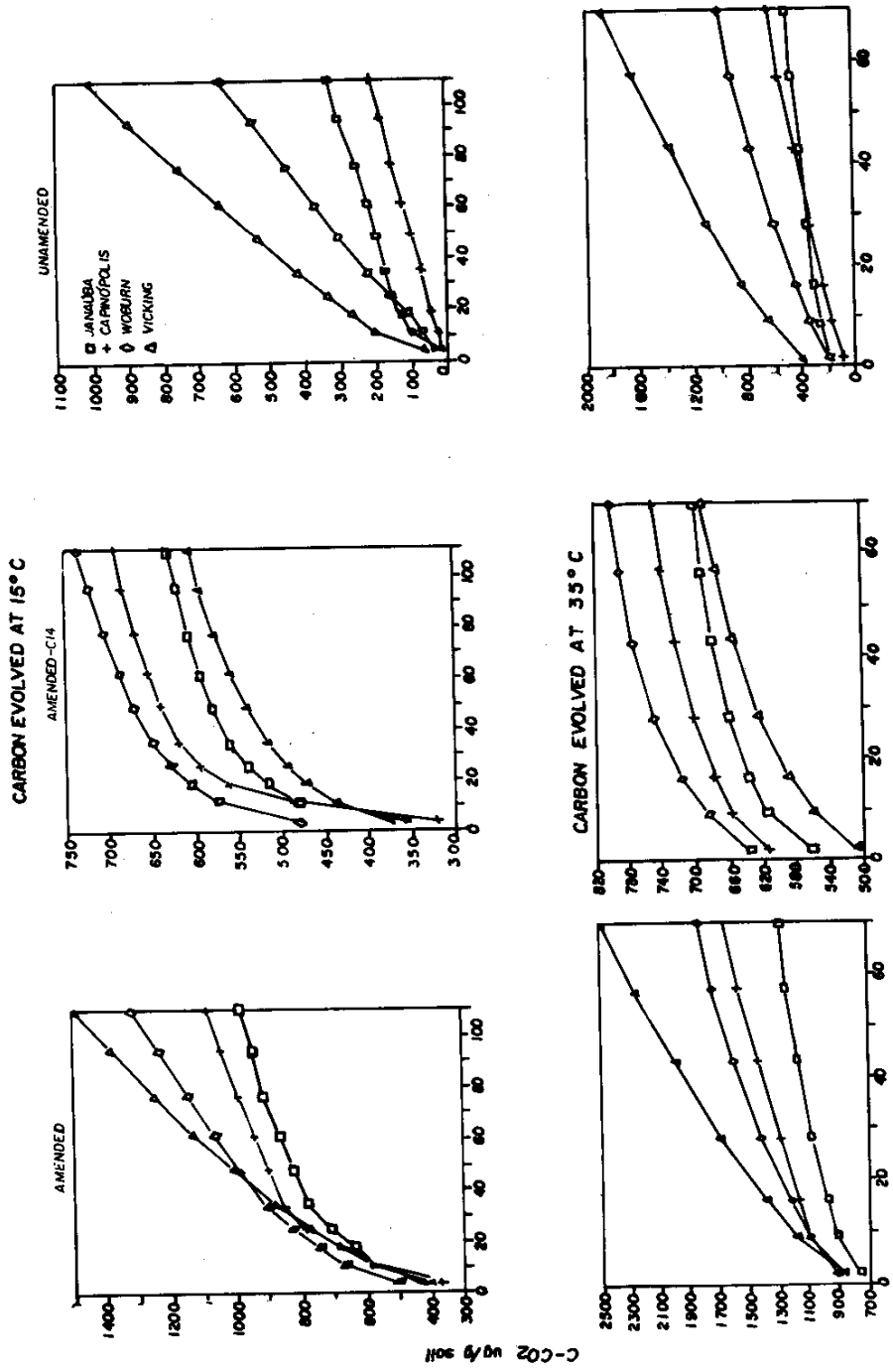

FIG. 1. Cumulative mineralization of C during incubation at 15°C and 35°C, amended and unamended with C^{14}-glucose.

TABLE 2. Total CO_2 evolved at 15°C, during a 110-day incubation.

Soil	CO_2 evolved		
	Unamended	Amended	
	----------µg C / g soil----------		
	C^{12}	C^{14}	$C^{14} + C^{12}$
Janaúba	330c	631c	986c
Capinópolis	211c	693b	1088c
Woburn	639b	736a	1319b
Pegwell	1007a	606c	1491a
CV%	11	7.5	5.8
dms	127	26	149

Values for each individual soil followed by a different letter are significantly different ($p < 0.05$ Duncan's Multiple Range Test).

TABLE 3. Total CO_2 evolved at 35°C, during a 25-95-day incubation.

Soil	CO_2 evolved		
	Unamended	Amended	
	----------µg C / g soil----------		
	C^{12}	C^{14}	$C^{12} + C^{14}$
Janaúba	371d	160b	567bc
Capinópolis	601c	156b	794b
Woburn	865b	173a	1003b
Pegwell	1578a	200a	1720a
CV%	5.1	7.5	12.8
dms	92	27	274

Values for each individual soil followed by a different letter are significantly different ($p < 0.05$ Duncan's Multiple Range Test).

Glucose addition increased the CO_2 evolution during the incubation period. It was higher during the initial 10 days and decreased during the incubation period.

From unamended and amended soil, at 15°C and at 35°C, the total CO_2 evolved was higher in soils from temperate regions (Woburn and Pegwell) than in the ones from tropical regions (Janaúba and Capinópolis) (Tables 2 and 3).

In soils with little actively decomposition substrates, the biomass is dormant or resting with low respiration and turnover rates. The addition of glucose to soil increased the decomposition rate and apparently caused accelerated decomposition of native organic matter from tropical soils. It did not appear to happen to temperature soils. It means that microbial activities of soils with low fertility can be stimulated by glucose amendment.

Jenkinson (1966) considered four mechanims for explaining the priming effect: 1) changes in the rate of native soil organic matter decomposition and 2) nonuniformly substrate, 3) changes in soil pH and 4) changes in microbial activity (numbers of microorganisms, metabolic capacity and metabolities products). Brookes et al. (1987) found evidence that humified organic matter could provide at least some of the energy required from soil biomass.

Joergensen et al. (1990), working with a silty clay loam soil, pH 4.5, showed that the sum of the organic C remaining at the end of incubation was between 99% and 103% of that originally present without significant losses.

In relation to the C^{14} evolved at 15°C, there was not a large difference between soils from tropical and temperate regions. The U.K. Woburn soil has evolved more than the others; it was evolved 63.1%, 69,3%, 73,6% and 60,6% of total labelled glucose from Janaúba, Capinópolis, Woburn and Peqwell soil respectivlely (Table 2).

At 35°C, between the incubation days 25-95, the soils from temperate regions evolved more $C^{14}O_2$; it was evolved 67.2%, 70,0%, 78.4% and 68.4% of C^{14} of initialy added from Janaúba, Capinópolis, Woburn and Pegwell soil, respectively, (from 0-25 days, at 15 C was evolved, for Janaúba soil, CE = 377 + 27 * 5 + 160 mg C^{14}: 10 = 67,2%). The predicted cumulative amounts of organic C evolved (CE) during the incubation time was closely related by the expression.

$$CE = a + b\sqrt{t},$$

were t is the incubation time (days) as shown in Tables 4, 5 and 6. A statistical analysis was made using Regression Analysis Test for differences between level regression shows singificant difference for slopes and intercepts for unamended and amended soil at 15°C and 35°C incubation temperature.

The regression analysis for C^{14}-CO_2 evolved (Table 6) at 15°C shows no difference for slopes

TABLE 4. Regression between cumulative C evolved and $\sqrt{t}$ (t=incubation time) at 15°C and 35°C for unamended soil.

Soil	Equation	R^2 %
	15°C (0-110 days)	
Janaúba	CE = -19 + 32.7 (±1.8) $\sqrt{t}$	*** 98
Capinópolis	CE = -46 + 22.8 (±1.5) $\sqrt{t}$	*** 98
Woburn	CE = -171 + 72.4 (±4.3) $\sqrt{t}$	*** 99
Pegwell	CE = -187 + 109 (±4.1) $\sqrt{t}$	*** 99
	35°C (25-95 days)	
Janaúba	CE = 40 + 47.8 (±1.7) $\sqrt{t}$	*** 99
Capinópolis	CE = -127 + 83.4 (±5.0) $\sqrt{t}$	*** 98
Woburn	CE = -180 + 123.4 (±5.0) $\sqrt{t}$	*** 99
Pegwell	CE = 131 + 219.2 (±10) $\sqrt{t}$	*** 99

*** significant level (1%)

TABLE 5. Regression between cumulative C evolved and $\sqrt{t}$ (t=incubation time) at 15°C and 35°C for amended soil (C^{14}+C^{12}).

Soil	Equation	R^2 %
	15°C (0-110 days)	
Janaúba	CE = 356 + 64 (±4.8) $\sqrt{t}$	*** 98
Capinópolis	CE = 314 + 79 (±7.6) $\sqrt{t}$	*** 98
Woburn	CE = 347 + 93 (±1.9) $\sqrt{t}$	*** 99
Pegwell	CE = 164 + 125 (±1.8) $\sqrt{t}$	*** 99
	35°C (25-95 days)	
Janaúba	CE = -41 + 75 (±2.7) $\sqrt{t}$	*** 100
Capinópolis	CE = -100 + 105 (±2.9) $\sqrt{t}$	*** 100
Woburn	CE = -158 + 140 (±1.6) $\sqrt{t}$	*** 100
Pegwell	CE = -293 + 235 (±7.2) $\sqrt{t}$	*** 100

*** significant level (P < 0.01%)

among soils. At 35°C there was difference only between tropical and temperate soils. It means that soils from a temperate region had higher mineralization rate then tropical soils for recent energy source at 35°C. It is necessary to explain the difference between C-CO_2 evolved from new (glucose) and old (native organic matter) energy source. The data in Table 7 calculated from equations in Tables 4, 5 and 6, show that the percentages of $^{14}CO_2$ evolved from glucose source, at 15°C, were higher for Woburn and Capinópolis soils. At 35°C Woburn and Pegwell show higher mineralization rate than tropical soils.

TABLE 6. Regression between cumulative C^{14} evolved and $\sqrt{t}$ (t=incubation time) at 15°C and 35°C for amended soil.

Soil	Equation	R^2 %
	15°C (0-110 days)	
Janaúba	CE = 377 + 27 (±4.1) $\sqrt{t}$	*** 92
Capinópolis	CE = 363 + 36 (±6.4) $\sqrt{t}$	*** 89
Woburn	CE = 481 + 26 (±2.6) $\sqrt{t}$	*** 96
Pegwell	CE = 354 + 26 (±1.8) $\sqrt{t}$	*** 98
	35°C (25-95 days)	
Janaúba	CE = 13 + 19 (±1.8) $\sqrt{t}$	*** 98
Capinópolis	CE = 3.5 + 19 (±1.0) $\sqrt{t}$	*** 99
Woburn	CE = -11 + 23 (±1.6) $\sqrt{t}$	*** 99
Pegwell	CE = -13 + 26 (±1.0) $\sqrt{t}$	*** 100

*** significant level (P < 0.01)

According to Van't Hoff's rule an increase in 10°C of incubation temperature doubles the rate of decomposition. However it depends on the soil. The amount of organic C mineralized during the incubation was roughly doubled by increasing the temperature from 15 to 35°C for Janaúba soil; roughly triplied by doing the same to Woburn and Pegwell soils and quadruplied for Capinópolis soil. The Co_2 evolved from recent energy source as shown by C^{14} - CO_2, smaller changing pattern between temperatures. It is necessary to notice that Capinópolis does not change the C^{14} evolved. Then the main source of most of the CO_2 evolved during the incubation must have been from native soil organic matter.

The addition of glucose to soil accelerated the turnover of native organic C. At 15°C, for example, Janaúba soil evolved 304 μg CO_2/g soil. From that, 128 μg/ g were from glucose and 176 μg C/g from native organic C. The unamended samples had evolved only 155 μg C/g. It means that the glucose increased the native organic C mineral-

TABLE 7. Soil CO_2 evolved at 15 and 35°C as incubation temperatures

Soil	C^{14}		$C^{12}+C^{14}$		C^{14}	
	15°C	35°C	15°C	35°C	15°C	35°C
	(1)		(2)		(3)	
	µg/g soil					
Janaúba	128	171	304	586	155	360
	(26%)	(35%)	(2.2%)	(4.3%)	(1.2%)	(2.8%)
Capinópol.	171	162	375	776	108	571
	(37%)	(35%)	(1.8%)	(3.7%)	(0.5%)	(2.8%)
Woburn	123	184	441	1016	343	852
	(32%)	(47%)	(2.7%)	(6.3%)	(2.3%)	(5.6%)
Pegwell	123	207	592	1673	517	1503
	(24%)	(40%)	(1.9%)	(4.0%)	(1.4%)	(3.7%)

(1) Carbon evolved from Glucose C^{14} source.
(2) Total carbon evolved.
(3) Carbon evolved from unamended soil.
(4) Values in parentheses represent the percentage of each source.

ization in 12%. Table 8 shows the glucose effects on the other soils.

At 15°C the Woburn soil did not decrease the native organic C in the glucose amended soil. To the other cases, the mineralization rate of native organic C was increased.

Tables 2 and 3 show that total C evolved, including the stabilization period, only tropical soils lost native organic C in the amended treatment, which indicates the initial high mineralization of C^{14}. Without glucose, Capinópolis soil at 15°C showed the smallest mineralization rate (Table 4). At 35°C this effect was increased.

The pool of potentially mineralizable carbon Co (mg C/g soil) and the mineralization rate coefficient K (1/day) were estimated by a first order reaction:

$$^{14}CR = Bo + Co * e^{-kt}$$

where CR (mg C/g soil) is the carbon amount from glucose remaining in the soil minus the cumulative C mineralized in time t (days). Co will be the pool and Bo, the nonmineralizable amount. The model was fitted to date on C mineralization by nonlinear regression. The half-life t1/2 was calculated from t (1/2) = ln2/k. The equation was listed as follows:

		R^2(%)	t1/2(days)
Janaúba:	15°C $CR = 362.5 + 92.7\,e^{-0.025t}$,	*** 97	28
	35°C $CR = 302.1 + 152.7e^{-0.06t}$,	*** 99	12
Capinópolis	15°C $CR = 300 + 100.2e^{-0.026t}$	*** 97	27
	35°C $CR = 248.2 + 151e^{-0.045t}$	*** 99	15
Woburn	15°C $CR = 234.7 + 130.7e^{-0.021t}$	*** 97	33
	35°C $CR = 192 + 180\,e^{-0.043t}$	*** 99	16
Pegwell	15°C $CR = 375.6 + 126.3\,e^{-0.021t}$	*** 98	33
	35°C $CR = 294 + 208\,e^{-0.036t}$	*** 99	19

The amount of the added carbon remaining in the soil (Bo) after a period of decomposition was consistently smaller at 35°C. In contrast, the pool of mineralizable carbon was consistently higher at 35°C and in Woburn and Pegwell. It means that soils from temperate regions have preferential exploitation for recent C amendment.

C-CO_2 evolved and the pH, total carbon, clay content and natural C/N ratio were correlated with CO_2 parameters as Bo (C^{14} remaining the soil) Co-

TABLE 8. Glucose effect on native organic C mineralization

Soil	Percent	
	15°C	35°C
Janaúba	+12	+27
Capinópolis	+47	+39
Woburn	-8	+47
Pegwell	+22	+47

pool of $C^{14}CO_2$ evolved, total carbon evolved in the amended and unamended soils and with b values from "$b\sqrt{t}$" fitted equations.

Only the pH and total carbon had significant influence on those parameters (Table 9). No significance was found to C/N ratio and clay contend on CO_2 evolution rate.

Gregorich et al. (1991), working with ten soils with the same type of clay and different amounts, indicated that the glucose was decomposed more quickly and the CO_2 was evolved more rapidly from relatively greater amounts of clay.

As Pinck & Allison (1951) noticed, the decomposition is determined primarily by the composition of the materials added. The correlations showed the importance of pH and the composition of native organic C on mineralization of added substance.

TABLE 9. Correlation coefficients.

Variables	Correlated with soil organic	
	pH	Carbon
	Ŷ values	
C^{14} pool		
at 15°C	0.950**	n.s.
at 35°C	0.947**	n.s.
Unamended - Total C evolved		
at 15°C	0.946**	n.s.
at 35°C	0.853*	0.920*
b values		
b at 15°C	962**	n.s.
b at 35°C	0.863**	0.909*
Amended - Total C evolved		
b at 15°C	0.862*	n.s.
b at 35°C	0.855*	0.935*
b values		
b at 15°C	0.862*	0.901**
b at 35°C	0.855*	0.919**

CONCLUSIONS

1. Soils from temperate regions (Woburn and Pegwell) showed higher mineralization rate than Brazilian ones, Capinópolis and Janaúba, for recent energy source at 35°C. At 15°C, as incubation temperature, there was no difference between soils.

2. The addition of glucose to soil accelerated the turnover of native organic C. That acceleration was higher at 35°C and on soils from temperate regions.

3. Only the pH and total soil organic carbon had significant influence on CO_2 mineralization parameters. No significance was found to C/N ratio and clay content.

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REFERENCES

BROOKES, P. C.; NEWCOMBE, A. D.; JENKINSON, D. S. Adenylate energy charge measurements in soil. **Soil Biology & Biochemistry**, London, v.19, p.211-217, 1987.

BREMNER, J. M. Total Nitrogen. In: BLACK, C. A. **Methods of soil analysis**. Madison: American Society of Agronomy, 1965. p.1149-1179.

GREGORICH, E. G.; VORONEY, R. P.; KACHANOSKI, R. G. Turnover of carbon through the microbial biomass in soils with different textures. **Soils Biology & Biochemistry**, London, v.23, p.799-805, 1991.

HALLAM, M. J.; BARTHOLOMEW, W. V. Influence of rate of plant residue addition in accelarating the decomposition of soil organic matter. **Soil Science Society America Proceedings**, v.17, p.365-368, 1953.

JENKINSON, D. S. The priming action. In: THE USE of isotopes in soil organic matter studies. Brunswick-Volkenrode: FAO/IAEA, 1966. p. 199--207.

JENKINSON, D. S.; POWLSON, D. S. The effects of biocidal treatments on metabolism in soil - IV. A method for measuring soil biomass. **Soil Biology & Biochemistry**, London, v.8, p.209-313, 1976.

JOERGENSEN, R. G.; BROOKES, P. C.; JENKINSON, D. S. Survival of soil microbial bi-

omass at elevated temperatures. **Soil Biology & Biochemistry**, London, v.22, p.1129-1136, 1990.

KALEMBASA, S. J.; JENKINSON, D. S. A comparative study of titrametric and gravimetric methods for the determination of organic carbon in soil. **Journal of the Science of Food and Agriculture**, v.24, p.1085-1090, 1973.

MSTAT. **A microcomputer program for the design, management, and analyses of agronomic research experiments**. [S.l.]: Michigan State University and Agricultural University of Norway, 1987.

PINCK, L. A.; ALLISON, F. E. Maintenance of soil organic matter: III. Influence of green manures on the release of native soil carbon. **Soil Science**, Baltimore, v.71, p.67-76, 1951.

SHAW, K. **Studies of nitrogen and carbon transformation in soils**. London: University of London, 1958. Tese de Doutorado.

SORENSEN, L. H. Stabilization of newly formed amino-acid metabolites in soil by clay minerals. **Soil Science**, Baltimore, v.114, p.5-11, 1972.