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Modelling C Turnover through the Microbial Biomass in Soil

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Summary

A simulation model was developed to describe the transformations of C and N in the soil. The aim of this study was to validate the concept of fractionating organic residues into pools of different decomposability in order to describe the residue quality. All the data obtained were compiled in the mathematical model and the simulated data were compared with measured data of C- and N-mineralization and soil microbial biomass. According to the different standard deviation values, the simulation was termed “perfect”, “adequate” or “poor” and in our experiment, all the curves of C-mineralization were “perfectly” fitted with the model used.

Résumé

Modélisation du renouvellement de carbone à travers la biomasse microbienne dans le sol

Un modèle de simulation a été développé pour décrire les transformations de C et de N dans le sol. Le but poursuivi dans cette étude était de valider le concept de fractionnement des résidus organiques en pools ayant différents taux de décomposition dans le souci de décrire leur qualité. Les données obtenues ont été compilées dans un modèle mathématique et une comparaison a été faite entre les résultats simulés et mesurés de la minéralisation de C et de N ainsi que de la biomasse microbienne du sol. Suivant les différentes valeurs des déviations standards, la simulation a été qualifiée de “parfaite”, “adéquate” ou “médiocre” et dans notre expérience, les courbes de minéralisation de C ont été “parfaitement” ajustées avec le modèle utilisé.

Introduction

Frissel and Van Veen (3) have classified soil N models according to their purpose, dynamics and concept. Two types of soil nitrogen models can be distinguished: “mechanistic” and “practical” models. The purpose of the mechanistic models is to gain a better understanding of the processes involved and their interactions. Practical models are developed for predictive and management purposes. Simulation models of the growth and activity of the soil microbial biomass in relation to its role in mineralization-immobilization processes range in their complexity and level of resolution (2, 4, 6). The soil microbial biomass is a transformation pool whereby organic materials are assimilated, converted into new products and subsequently released either actively or passively (10). All the processes occur simultaneously and are interdependent. Little is known about the mechanisms of microbial death and other processes by which organic substrates become available for decomposition or the predatory-prey relations. Furthermore, the soil microbial biomass consists of many taxa and an attempt to include them all would be impractical.

In this study, we will present the CO_2 simulated and measured of incubation experiment that was carried out on 2 sets of air-dried soils: (i) rewetted and (ii) pre-incubated for 7 days at 25 °C. The 2 sets were amended with four different alley cropping species: *Senna siamea*, *Leucaena leucocephala*, *Dactyladenia barteri* and *Flemingia macrophylla* and incubated for 140 days at 25 °C (5).

Objectives and methodology

Objectives

The aim of this study was to validate the importance of fractionating organic residues into pools of different decomposability in order to describe the residue quality. The organic fractions of the plant residues determined by Van Soest (8) and Van Soest and Wine (9) method and the other quality parameters obtained during the characterization of plant residues were compiled in the mathematical model and the output

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model was compared with measured data of C- and N-mineralization and soil microbial biomass.

Model development

Three main entities were considered in the used mechanistic model and each entity was subdivided into an “active”, a “resistant” and an “old” fraction. The three pools included in the model were: (i) the added organic material (AOM), (ii) the native soil organic matter (SOM) and (iii) the soil microbial biomass (BIO).

The model was written in TURBO PASCAL (version V) computer language (5) and was adapted from the original version which was written in FORTRAN language (2). The basic concepts concern the central position of microorganisms in the N-cycle, the interdependance of C- and N-cycles, the use of multiplicative reduction factors to account for the effect environmental factors on the several processes.

Processes

The main formulas used in the model to estimate the CO_2 production during 140 days of aerobic incubation were:

```
for i:= 1 to 140 do
Begin
itime [i]:= (itime [i-1] + 1);
day:= 1;
(* CO2 production *)
(* Added organic material *)
Aaco:= Aac [i-1] * (1 - exp (-Aakc * day));
Arco:= Arc [i-1] * (1 - exp (-Arkc * day));
Aoco:= Aoc [i-1] * (1 - exp (-Aokc * day));
Atco:= (Aaco + Arco + Aoco);
(* Soil organic material *)
Saco:= Sac [i-1] * (1 - exp (-Sakc * day));
Srco:= Src [i-1] * (1 - exp (-Srkc * day));
Soco:= Soc [i-1] * (1 - exp (-Sokc * day));
Stco:= (Saco + Srco + Soco);
(* Daily produced CO2 *)
co:= (Stco + Atco);
(* Cumulative produced CO2 *)
tAco [i]: (tAco [i-1] + Atco);
tSco [i]: (tSco [i-1] + Stco);
```

(with A= added; S= soil; a= active; r= resistant; o= old; c= carbon; k= constant; co= CO_2).

Methodology

The flexibility of the mechanistic model used remained the essential criterion in the improvement of agreement between the output model and the observed data. This flexibility could be obtained by handling specific parameters of the model such as the proportions of the active fractions especially in the beginning of incubation, the decay and death rate constants, the efficiencies and the C/N ratios of the soil microbial biomass.

The data simulation could be continued by steps until the absolute value of the difference between the measured and the simulated values ranged between reasoning limits. Therefore, the simulation was termed: (i) “perfect” when the standard deviation ranged between 0 and 10, (ii) “adequate” when it ranged between 10 and 20 and (iii) “poor” when the standard deviation was > 20.

Material and methods

In the mechanistic model, we used data of soil, plant residues and soil microbial biomass obtained from analytical standard methods (5). Other data were calculated or collected from the literature.

Results and discussion

CO_2 production

The results of simulation of C-mineralization in rewetted and pre-incubated soils are given in tables 1 and 2 respectively.

Table 1
Simulated and measured cumulative CO_2 production in control and amended soils, rewetted and incubated at 25 °C

	CO_2 mg.kg^{-1}									
Time	*Dactyladenia*		*Flemingia*		*Senna*		*Leucaena*		Control	
(days)	Sim	Meas	Sim	Meas	Sim	Meas	Sim	Meas	Sim	Meas
2	60.0	60.0	66.6	66.6	120.0	120.0	120.0	120.0	37.5	37.5
7	120.0	140.0	166.7	266.7	364.0	364.0	440.0	440.0	50.0	75.0
14	180.0	200.0	270.0	366.7	560.0	560.0	680.0	680.0	87.5	100.0
28	260.0	280.0	433.3	533.3	760.0	780.0	840.0	840.0	150.0	156.0
56	380.0	400.0	666.7	703.3	880.0	940.0	1000.0	1080.0	225.0	200.0
84	470.0	480.0	800.0	833.3	960.0	1000.0	1100.0	1120.0	275.0	250.0
112	540.0	560.0	900.0	866.7	1040.0	1060.0	1140.0	1200.0	300.0	275.0
140	580.0	600.0	933.3	916.7	1080.0	1080.0	1180.0	1200.0	337.5	312.5

Legend: Sim= simulated. Meas= measured.

Table 2
Simulated and measured cumulative CO_2 production in control and amended soils, pre-incubated and incubated at 25 °C

Time	*Dactyladenia*		*Flemingia*		*Senna*		*Leucaena*		Control	
	CO_2 mg.kg^{-1}									
(days)	Sim	Meas	Sim	Meas	Sim	Meas	Sim	Meas	Sim	Meas
2	50.0	50.0	75.0	75.0	100.0	100.0	100.0	100.0	30.0	30.0
7	100.0	133.3	150.0	150.0	200.0	266.7	433.3	433.3	50.0	35.0
14	166.7	183.3	250.0	350.0	333.3	400.0	533.3	566.7	80.0	70.0
28	250.0	233.3	412.5	412.5	516.7	600.0	600.0	650.0	110.0	95.0
56	350.0	333.3	537.5	512.5	700.0	733.3	766.7	833.3	160.0	140.0
84	416.7	383.3	612.5	575.0	833.3	800.0	866.7	900.0	210.0	200.0
112	450.0	433.3	662.5	637.5	900.0	866.7	1000.0	966.7	240.0	250.0
140	450.0	466.7	700.0	675.0	933.3	916.7	1000.0	1000.0	260.0	275.0

Legend: Sim= simulated. Meas= measured.

The simulated and measured data of C-mineralization followed the trend: *Leucaena* > *Senna* > *Flemingia* > *Dactyladenia* > Control in the rewetted and pre-incubated soils. The decreasing order observed shows the relation between the "quality" of plant residues and the output model and validates the concept of "fractionation" (5). Furthermore, the simulated and measured data of C-mineralization followed the trend: "rewetted" > "pre-incubated". This is due to the soil pre-treatment which reduces the soil-drying effects. The data are steadily fitted in the mechanistic model for a short period (28-56 days). The discrepancies are due to: (i) the availability of soil nutrients, the complexity of mineralization – immobilization process, the effects of soil drying-rewetting processes, (ii) the nature and quality of plant residues applied, (iii) the soil microbial growth and death rates, the complexity of soil microbial taxa, their predator-prey relations and (iv) the environmental conditions of temperature, moisture stress.

According to our simulation definition, all the curves of C-mineralization were "perfectly" fitted by the model used. Among the parameters that we handled in order to reduce the discrepancies between measured and simulated data, the increase of both active fractions from the native soil organic matter and their decay rate constants revealed their effectiveness during the simulation. As mentioned by Van Veen *et al.* (10), any mathematical model is able to simulate the sudden variations e.g. following a high substrate input, or the effects of soil properties in influencing the proportions of organic residues accounted for in biomass. With *Leucaena* and *Senna*, a relative high flux of CO_2 was observed in the beginning of aerobic incubation due essentially to drying-rewetting effect and high relative active fractions. The enhancement of CO_2 evolution and of N mineralization following rewetting of dry soils has long been recognized as an important phenomenon in the process of C and N turnover (1). Underlying mechanisms are not well understood. The enhanced mechanisms are though to result from the increased availability of organic substrates due either to chemical reactions or to death of cells during drying. In our case, the effects of drying-rewetting during the simulation were compensated by the increase of active fractions from the native soil organic matter and their decay rates. In the pre-incubated soils, the drying-rewetting effects are less pronounced because the decomposition of organic materials occurs during the pre-incubation period.

Conclusion

All the curves of C-mineralization were perfectly fitted by the model used. In all cases, the concept of "fractionation" of organic residues used in the model was related to the "litter quality" as shown by the trends of simulated C-values which followed the decreasing order: *Leucaena* > *Senna* > *Flemingia* > *Dactyladenia*. The simulated and measured data of C-mineralization followed the trend: "rewetted" > "pre- incubated" due to the soil pre-treatment which reduces the soil-drying effects. The fitting solution of the mechanistic model includes the management of soil properties, the quality of plant residues, the dynamics of soil microbial biomass and environmental conditions. So, our work confirms that any mathematical model is able to simulate sudden variations due to complex biological transformations (10). To simulate the drying-rewetting effects, McGill *et al.* (6) considers that death rate is inversely related to moisture stress and death at extreme moisture stress is not considered while in Smith (7), an exponential relationship between moisture stress and death rate is used. On the other hand, Van Veen *et al.* (10) considers both a moisture effect on microbial death rate and a stochastic event of moistening a dry soil.

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