OPTIMISATION OF THE ROTHC MODEL POOLS TO SIMULATE C DYNAMICS AFTER APPLICATION OF EXOGENOUS ORGANIC MATTERS IN SOILS

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1 INTRODUCTION

The use of exogenous organic matters (EOM) in croplands can contribute to carbon sequestration by increasing soil organic matter content and to soil fertility improvement by recycling organic matter. Multi-compartments C dynamic models such as RothC (Coleman and Jenkinson, 1999) or CENTURY (Parton et al., 1987) are useful tools to evaluate the long-term potential C sequestration in croplands after EOM applications. These models need to be parameterized to account for the diversity of EOM types.

In the RothC model, organic C from EOM is split into the labile pool (DPM, turnover time of 1.2 month), the resistant pool (RPM, turnover time of 3.3 years) and possibly the humified pool (HUM, turnover time of 50 years). Then at each time-step of the model, a fraction of each pool (RPM, DPM and HUM) is decomposed and either mineralized into CO_2 or transferred into the humified (HUM) or the microbial biomass pools (BIO).

The objectives of the study were:

- To determine the distribution of EOM into the RothC entry pools (DPM_{EOM}, RPM_{EOM}, HUM_{EOM}) using mid to long terms field data, with the hypothesis that the decay rate constants of the pools are similar for all kind of EOM.
- To assess the possibility to estimate the pools previously determined using field data with widely available laboratory biochemical characterizations and indicators of EOM behaviour in soil.

2 MATERIALS AND METHODS

Mid- to long-term field data were collected from four field experiments displaying various types of applied EOMs, soil types, climatic conditions and management practices: 1) The Qualiagro experiment (1998 – 2009, Houot et al., 2002) situated near Paris, France, on a loamy soil cultivated with a maize/wheat rotation and receiving four different EOMs (municipal solid waste compost: MSW-Qua, farmyard manure FYM-Qua, co-compost of green waste and sludge: GWS-Qua and biowaste compost: BIO-Qua) with a dose of approximately 4 T C / ha every two years. 2) The SERAIL experiment (1995 – 2009, Berry et al., 2008) situated near Lyon, France, on a sandy loamy soil cultivated with a vegetables rotation and receiving five different EOMs (dehydrated farmyard manure “Fumeterre”: FMT-Ser, fresh farmyard manure: FYM-Ser, enriched barks compost “Algoforestier”: ALG-Ser, enriched coffee cake compost “Vegethumus”: VGH-Ser, and green waste compost: GWC-Ser) with doses based on total C or stable C equivalent contained in 30 T / ha of fresh farmyard manure each year. 3) The Ultuna experiment (1956 – 2008, Gerzabek et al., 1997) situated near Uppsala, Sweden, on a clay loam cultivated with a rotation of cereals (70%), rape crops (25%) and fodder beet (5%) until 1999 and with maize thereafter until 2007 receiving six EOMs (straw: STR-Ult, green manure: GM-Ult, sawdust: SAW-Ult, farmyard manure: FYM-Ult, sewage sludge: SLU-Ult and peat: PEA-Ult) with a dose of approximately 4 T C / ha every two years. And 4) The Askov K2 experiment (1956 – 1987, Christensen & Johnston, 1997) situated in Askov, Denmark, in a sandy soil cultivated with a four-course rotation of spring barley, fibre flax, winter cereals (wheat or rye), and maize for silage and receiving four different EOMs (matured straw: STR-Ask, sawdust: SAW-Ask, farmyard manure: FYM-Ask and peat: PEA-Ask) with a dose of 6.5 T DM / ha each year.

The RothC 26.3 model was used to simulate with a monthly time step the soil C accumulation after EOMs applications compared with non-amended control plots. The entry data of RothC included: the clay contents of soils, monthly climatic data (potential ETP, temperatures, cumulated rainfalls), soil cover (covered or not covered), C inputs from EOMs and additional C inputs from stem bases, roots or vegetables residues compared with control plots.

The initial distributions of EOM organic C into the entry pools DPM_{EOM}, RPM_{EOM} and HUM_{EOM} were adjusted to fit with the kinetics of C stocks accumulation for all treatments of the four field experiments. The DPM_{EOM} and RPM_{EOM} were set to be comprised between 0 and 100% of EOMs and the HUM_{EOM} pool was set to be ≤ 10% of EOMs. Allowing the allocation of a part of EOMs directly in the HUM pool have been shown to be more consistent with size and density fractionation data in the Qualiagro experiment (better concordance between the C contained in the soil fraction < 50 µm and the HUM pool).

The DPM_{EOM} and RPM_{EOM} pools previously adjusted to the field data were then compared with values of an indicator of potentially residual organic C in soil (I_{ROC}, Lashermes at al., 2009). The I_{ROC} can be calculated with laboratory characterizations according to the formula: $I_{ROC} = 44.5 + 0.5\ SOL - 0.2\ CEL + 0.7\ LIC - 2.3\ C_{3d}$ (values expressed in % of Total Organic C: TOC) where SOL, CEL and LIC are the soluble-, cellulose- and lignin- and cutin- like fractions of the Van Soest fractionation (Van Soest and Wine, 1967) and C_{3d} is the proportion of EOM TOC mineralized after 3 days of incubation with soil in controlled conditions at 28°C. The I_{ROC} values resulting from the characterization of the products effectively applied were used for the Qualiagro and SERAIL experiments whereas approached mean I_{ROC} values of products of the same types were used for the Ultuna and Askov K2 experiments.

3 RESULTS AND DISCUSSION

3.1 Adjustment of the RothC entry pools on the kinetics of C accumulation in the field experiments

The EOM applied had contrasted capacities at increasing soil C stocks as illustrated by the proportions of total C inputs remaining in the soil (proportion of EOM C and additional C inputs from crop residues remaining in soil compared to control plots, Table 1). For example, the increase of soil C stock was equivalent to 18.0% of the C inputs in the plots with straw applications in the Askov K2 experiment and 54.7% of the C inputs in the biowaste compost treatment of the Qualiagro experiment. The proportions of C inputs retained in soil determined with field results were related to the values of I_{ROC} ($r = 0.89$) estimating the potentially residual organic C in soil from laboratory characterisations (Table 1).

The kinetics of C accumulation after EOMs applications were successfully simulated with RothC after adjusting the entry pools DPM_{EOM}, RPM_{EOM} and HUM_{EOM} for the Qualiagro experiment (CV of 13.6 to 19.4%), the Ultuna experiment (CV of 12.1 to 23.1%) and the Askov K2 experiment (CV of 11.7 to 17.6%). The accuracy of the simulations was lower for the SERAIL experiment (CV of 41.1 to 71.0%) due to the higher experimental variability of the measured C stocks in this experiment. However the simulations reproduced fairly well the C accumulation patterns for the SERAIL experiment, so the adjusted pools were considered as remaining valid.

The adjusted RothC pools had contrasted values related to the composition of the EOMs. Products well stabilized like BIO-Qua (mainly made from green wastes) or ALG-Ser (mainly made from barks) had high RPM_{EOM} values (90 and 96.2% respectively) whereas more decomposable products had high values of DPM_{EOM} like GM-Ult (grass) or STR-Ult (87.3 and 86.3% respectively). Some treatments with application of very stable EOMs (PEA-Ult, PEA-Ask, SLU-Ult, GWC-Ser) leading to very large increase of C stocks could not be correctly adjusted with the constrain HUM_{EOM} < 10%. The C storage following sludge application in the Ultuna experiment was surprisingly important, sewage sludge being usually highly biodegradable (low value of I_{ROC} = 51.2%, calculated from the mean of 36 sewage sludges from an EOMs database).

TABLE 1 **Results of the adjustment of the RothC entry pools on the field experiments Askov K2, Qualiagro, SERAIL and Ultuna. % of C inputs retained in soil compared to control plots, I_{ROC} values. RMSE: root mean squared error between measured and simulated C stocks increases, CV: coefficient of variation = RMSE / mean of measured C stock increases * 100**

	DPM_{EOM}	RPM_{EOM}	HUM_{EOM}	R^2	RMSE	CV	% of C inputs retained in soil	I_{ROC}
	--------------(% TOC)-------------				(T C / ha)	(%)	(%)	(% TOC)
STR-Ask	68.7	22.9	8.5	0.90	1.5	12.2	18.0	53.6
SAW-Ask	53.3	36.7	10.0	0.88	2.8	17.6	27.3	60.1
FYM-Ask	16.0	74.0	10.0	0.95	1.8	11.7	35.2	70.4
PEA-Ask	46.0	0.0	54.0	0.97	3.2	10.5	54.9	81.5
MSW-Qua	63.3	36.7	0.0	0.92	0.7	17.2	29.6	45.4
FYM-Qua	21.9	68.1	10.0	0.95	1.0	13.6	50.4	71.5
GWS-Qua	19.1	70.9	10.0	0.96	1.1	14.0	52.4	81.1
BIO-Qua	0.0	90.0	10.0	0.93	1.5	19.4	54.7	79.5
FMT-Ser	83.0	7.6	9.4	0.66	2.3	49.1	21.1	49.3
FYM-Ser	76.3	18.8	4.9	0.47	3.3	71.0	22.9	49.3
VGH-Ser	50.2	49.8	0.0	0.11	3.8	60.6	26.3	69.4
ALG-Ser	2.1	96.2	1.7	0.42	3.8	41.1	41.1	82.7
GWC-Ser	27.2	0.2	72.6	0.73	4.0	34.8	70.4	92.2
STR-Ult	86.4	13.6	0.0	0.67	2.3	23.3	16.0	44.3
GM-Ult	87.3	12.7	0.0	0.80	1.9	17.3	16.9	44.3
SAW-Ult	50.8	47.8	1.5	0.90	1.7	12.2	26.2	60.1
FYM-Ult	16.0	84.0	0.0	0.89	2.3	12.1	31.5	70.4
SLU-Ult	0.0	78.1	21.9	0.72	6.5	21.1	47.5	51.2
PEA-Ult	0.0	55.4	44.6	0.84	5.8	16.4	63.7	81.5

3.2 Estimation of the adjusted entry pools of RothC using laboratory characterizations

In order to determine the values of the RothC entry pools from laboratory characterizations, a linear regression was computed to predict the values of DPM_{EOM} and RPM_{EOM} previously adjusted on kinetics of C stock increase in field conditions with values of an indicator of potentially residual organic C in soil (I_{ROC}, Lashermes et al., 2009). Only the EOMs that could be adjusted with the constraint $HUM_{EOM} \leq 10\%$ were considered for those regressions. The I_{ROC} evaluates the proportion of EOM remaining in soil after application over the long-term. The adjusted DPM_{EOM} and RPM_{EOM} could be predicted with the I_{ROC} with R^2 = 0.893 and 0.856 respectively and with coefficients of variation equivalent to 22.9 and 24.2% of the mean, respectively (Figure 1). The low difference between the RMSE and the RMSE of cross validation ($RMSE_{CV}$, Figure 1) indicated that the regression equation was fairly robust when a sample was predicted with a regression equation computed with the rest of the samples.

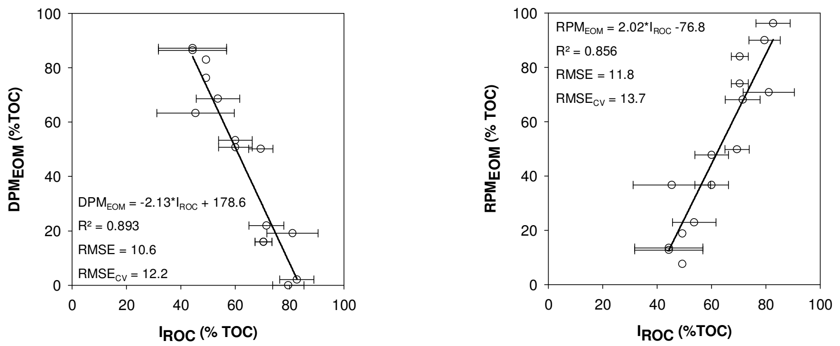

FIGURE 1 **Relationships between the indicator of potentially residual organic C in soil (I_{ROC}) and the adjusted entry pools of the RothC model. Error bars are standard deviations of the I_{ROC}. $RMSE_{CV}$: RMSE calculated with independently predicted values during cross validation**

The regression equations previously developed (Figure 1) were then used to predict the values of DPM_{EOM} and RPM_{EOM} for each treatments of the field experiments, the HUM_{DPM} pools were calculated by difference as $HUM_{EOM} = 100 - DPM_{EOM} - RPM_{EOM}$. The so predicted pools were used in RothC instead of the adjusted pools presented in Table 1 to simulate C stocks evolutions in the field experiments. The use of those predicted pools led to a mean increase of the coefficients of variation of 3.6% compared to the use of the fitted pools. Those regression equations could thus be used to determine the RothC entry pools with acceptable additional errors for various types of EOMs.

4 CONCLUSIONS

Our study aimed at parameterizing the pools of the RothC model to account for the diversity of EOMs types in the simulation of C sequestration in soil after EOMs applications. The entry pools DPM_{EOM}, RPM_{EOM} and HUM_{EOM} of RothC were adjusted on the data of four mid- to long-term field experiments with EOM applications. The model successfully simulated the C accumulation patterns after EOMs applications in the field experiments. The entry pools could be fitted with a maximum of 10% of the EOM allocated to the humified pool HUM_{EOM} for all EOMs except very stable products (peat, green waste compost from the SERAIL experiment and sewage sludge from the Ultuna experiment).

The DPM_{EOM} and RPM_{EOM} pools previously fitted could be predicted using the indicator of potential residual organic C in soil (I_{ROC}) calculated with biochemical fractions of the Van Soest fractionation and proportions of C mineralized after three days of incubation at 28 °C. The accuracy of those predictions was fairly satisfying ($R^2 = 0.893$ for DPM_{EOM} and $R^2 = 0.856$ for RPM_{EOM}), their use in RothC to simulate C sequestration from EOMs led to an increase of the coefficient of variation of 3.6% compared to the use of fitted parameters. Those regression equations could thus be used to determine entry pools and simulate C sequestration from EOMs with RothC. Further study will aim at refining the regression equations for the prediction of the RothC entry pools by performing additional laboratory characterisations on the EOMs applied in the Ultuna experiment.

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