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Modeling rhizosphere carbon and nitrogen cycling in *Eucalyptus* plantation soil

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SUPPLEMENTARY MATERIAL

Part 1 – Modeling fine root growth and rhizodeposition

1.1 Converting light energy into *Eucalyptus* dry matter

We used the 3-PG ecophysiological process model (Landsberg; Waring, 1997) to estimate the conversion of light energy to mass of dry matter for a mono-cultural *Eucalyptus* plantation. The role of this module is to simulate C directed to root growth and exudation in a forest plantation. To better represent the growth of plantations under tropical conditions, we used the version parameterized by Borges et al. (2012), due to its greater degree of universality in relation to the other model parameterizations (Borges, 2012). We used shoot mass estimated by the 3-PG model as input to the next step. Thus, it was possible to estimate the root length and rhizosphere volume by the ForPRAN model. For a better understanding of the equations used in the ForPRAN model, we summarized the main variables, constants and compartments in the Table 1. The 3-PG and ForPRAN models are implemented as spreadsheets in Microsoft Excel.

Table S1. Variables, constants and compartments of the fine root growth and rhizodeposition model

Name	Symbol	Unit	Default
Parameter a[1]	a	$\%^{-1}$ cm^{-1}	0.97
Soil clay content[3]	Clay	%	-
Parameter b[1]	b	unl*	-0.92
Parameter c[1]	c	unl*	0.62
C released at time zero[2]	C_0	µg cm^{-3}	2.1
Thickness of the soil layer considered[3]	TSL	cm	-
Concentration of organic carbon in soil solution regulated by fine root[4]	Ce	µg cm^{-3}	-
C/N ratio of root rhizodeposition[3]	CNrizo	µg $µg^{-1}$	-
Root length per diameter class[2]	RLdc	cm	-
Specific root length[2]	SRL	km kg^{-1}	24.54
Specific root length per diameter[2]	CREd	cm g^{-1}	-
Parameter d[1]	d	unl*	0.19
Root diameter[3]	Droot	mm	-
Parameter of the intercept f[1]	f	unl*	88
Parameter ɣ[2]	ɣ	unl*	0
Exponential decay coefficient h[1]	h	mm^{-1}	6.5
Parameter of the intercept i[1]	i	unl*	20
Exponential decay coefficient j[1]	j	mm^{-1}	1.6
Mass of dry matter of aerial part[3]	MDAP	t ha^{-1}	-
Mass of dry matter of fine roots[4]	MSfr	t ha^{-1}	-
Mass of fine roots per diameter class[4]	MSfrcd	t ha^{-1}	-
Percentage of root length ratio per diameter[4]	PAC	unl*	-
Percentage of root mass ratio per diameter[4]	PAM	unl*	-
Mean root radius[3,5]	r	cm	-
Volume of solution involving the root[4]	V	cm^3	-
Rate of efflux at the root apex[2]	α	µg C cm^{-2} h^{-1}	1.5
Relative influx of C[2]	β	µg C cm^{-1} h^{-1}	0.2

[1]Parameterization based on data from the studies of Mello et al. (1998), Neves (2000), Leles et al. (2001), Teixeira et al. (2002), Gatto et al. (2003) and Maquere (2008); [2]Personeni et al. (2007); [3]user-defined input data; [4]model output data; [5]Root mean radius = ((radius of the lower limit of the diameter class) + (radius of the upper limit of the diameter class))/2; *unitless.

1.2 Estimation of carbon partitioning to fine roots (MSfr, t ha^{-1})

An empirical model was used for partitioning of the dry matter mass to fine roots (<= 3 mm), with independent variables of clay content of the soil, thickness of the soil layer of interest, and shoot mass of the trees. The function was based on data presented in Mello et al. (1998), Neves (2000), Leles (2001), Teixeira et al. (2002), Gatto et al. (2003) and Maquere (2008). We considered fine roots to be less than 2 or 3 mm, as presented by the authors. As there was no statistical difference of dry matter partition between these two diameter limits, we proposed a general model for fine roots based on 3 mm diameter.

$$MSfr = aClay^{b}TSL^{c}\mathrm{MDAP}^{d}$$ Eq. S1

1.3 Estimation of the length of fine roots

To estimate the proportion of the root length in different diameters (Equation S2), we assumed a sigmoidal distribution of the percentage of the total length as a function of the diameter of the fine roots, following the original proposition of Finzi et al. (2015). For example, the model for *Eucalyptus* calculated an average of 88 % of the total length of fine roots had a diameter less than 1 mm (Table 1), as observed by Baldwin and Stewart (1987) and Mello et al. (1998).

$$PAC = \frac{1}{1+fe^{-hDroot}}$$ Eq. S2

1.4 Estimating mass partitioning to fine roots of different diameter

According to Baldwin and Stewart (1987), roots with a diameter less than or equal to 1 mm contribute more than 85 % of the total length of fine roots, but there percentage of total dry matter of fine roots was much less (approximately 20 %) (Table S1). Thus, we parameterized a sigmoidal model to represent the proportion of dry matter (PAM) in relation to total root mass according to the maximum diameter considered (Droot, Equation S3). Root mass per diameter (MSfrd, in kg ha^{-1}) was estimated using the equation 4.

$$PAM = \frac{1}{0{,}8354+ie^{-jDroot}}$$ Eq. S3

$$MSfrd = MSfr\,PAM$$ Eq. S4

1.5 Root growth per diameter class

We used total root length in Mello et al. (1998) and equations S4 and S5 to calculate specific root length (SRL, km kg^{-1}) for a root diameter class of interest (SRLd, km kg^{-1}) (Equation S5). Root length per diameter class (RLdc, km ha^{-1}) was estimated by multiplying the root mass per diameter (MSfrd, kg ha^{-1}) by the specific root length of the lower (i) and upper diameter (n) (Equation S6). After that, the value is multiplied by 10^5 to find the result in centimeter for entry into the rhizodeposition model.

$$\mathrm{SRLd} = \mathrm{SRL}\frac{(\mathrm{PAC})}{(\mathrm{PAM})}$$ Eq. S5

$$\mathrm{RLdc} = (MSrfd_n\,SRLd_n) - (MSrfd_i\,SRLd_i)$$ Eq. S6

1.6 Estimation of the rizodeposition process

We used equation S7 to describe net rhizodeposition of carbon by the root, using a model proposed by Farrar et al. (2003) and optimized and parameterized by Personeni et al. (2007). The estimation of rhizodeposition of organic N was carried out by dividing the carbon value by the C/N ratio of the rhizodeposited material (Ne, µg cm^{-3}) (Equation S8).

$$Ce = \frac{\alpha}{\beta(1-\gamma)\mathrm{RLdc}}\left[(\mathrm{RLdc}+1)^{1-\gamma}-1\right]\left(1-\mathrm{e}^{-\frac{\beta 2\pi \mathrm{rRLdc}}{\mathrm{V}}\mathrm{t}}\right)+\frac{\mathrm{C}_0}{\mathrm{V}}\mathrm{e}^{-\frac{\beta 2\pi \mathrm{rRLdc}}{\mathrm{V}}\mathrm{t}}$$ Eq. S7

$$Ne = \frac{Ce}{CN_{rizo}}$$ Eq. S8

Part 2 – Modeling C and N cycling in the rhizosphere soil (bacteria + fungi)

To estimate N rhizosphere cycling, we used the model of fine root growth and rhizosphere C flux described above coupled to the equations of Schimel and Weintraub (2003) and Allison et al. (2010), and modified and parameterized by Drake et al. (2013) in the MCNiP model. In this model, the mineralization rates depend on stoichiometry and soil temperature. To improve the temporal and spatial resolution, we considered the plant component, as previously mentioned in the module 1, and also the population dynamics module as affected by water, nutrients, temperature, and soil properties. In a very simplified way, we attribute constants to the effect of soil on the protection of the released compounds in solution, and also to the processes of microbial immigration and emigration, the effect of temperature on the enzymatic kinetics, and the organic matter effect on the rate of microbial death. Table S2 lists the variables, parameters, units, and reference values used in this part of the model.

Table S2. Variables, constants and compartments of the microbial rhizosphere model

Name	Symbol	Unit	Default
C in microbial biomass in one hour[2]	BCm	$\mu g\ g^{-1}\ h^{-1}$	-
N in microbial biomass in one hour[2]	BNm	$\mu g\ g^{-1}\ h^{-1}$	-
Soil moisture[3]	CAD	%	-
Enzyme C/N ratio[2,3]	CNenz	$\mu g\ \mu g^{-1}$	3
Microbiota C/N ratio[2,3]	CNm	$\mu g\ \mu g^{-1}$	7
Soil C/N ratio[2,3]	CNs	$\mu g\ \mu g^{-1}$	12
Rate of C release from dead microbes that return to DOC[4]	CYc	$\mu g\ g^{-1}\ h^{-1}$	-
Rate of N release from dead microbes that return to DON[4]	CYn	$\mu g\ g^{-1}\ h^{-1}$	-
Depolymerization rate of soil organic C[4]	Dc	$\mu g\ g^{-1}\ h^{-1}$	-
Depolymerization rate of soil organic N[4]	Dn	$\mu g\ g^{-1}\ h^{-1}$	-
Organic C in solution in one hour[4]	DOC	$\mu g\ g^{-1}\ h^{-1}$	-
Organic N in solution in one hour[4]	DON	$\mu g\ g^{-1}\ h^{-1}$	-
Density of particules[3]	Dp	$g\ cm^{-3}$	-
Density of the soil[3]	Ds	$g\ cm^{-3}$	-
Activation energy for absorption of DOC[1]	Eauptake	$kJ\ mol^{-1}\ °C^{-1}$	47
Enzyme C in one hour[4]	EC	$\mu g\ g^{-1}\ h^{-1}$	-
Enzyme N in one hour[4]	EN	$\mu g\ g^{-1}\ h^{-1}$	-
Enzyme decay constant[4]	K_1	$\mu g\ \mu g^{-1}\ h^{-1}$	0.05
Rate of enzymatic degradation of C[4]	ELc	$\mu g\ g^{-1}\ h^{-1}$	-
Rate of enzymatic degradation of N[4]	ELn	$\mu g\ g^{-1}\ h^{-1}$	-
Rate of enzyme production of C[4]	EPc	$\mu g\ g^{-1}\ h^{-1}$	-
Rate of enzyme production of N[4]	EPn	$\mu g\ g^{-1}\ h^{-1}$	-
Universal gas constant[1]	Gasconstant	$kJ\ mol^{-1}\ K^{-1}$	0.008314
Microbial immobilization rate[4]	Jn	$\mu g\ g^{-1}\ h^{-1}$	-
Temperature-dependent SOC decomposition factor[4]	kappaD	$\mu g\ g^{-1}\ h^{-1}$	-
Rate of enzymatic production per unit of biomass[1]	Kep	$\mu g\ \mu g^{-1}\ h^{-1}$	0.0005
Half-saturation Michaelis-Menten constant[1]	Kes	unl*	0.3
Microbial maintenance respiration rate[1]	Km	$\mu g\ \mu g^{-1}\ h^{-1}$	0.01
Temperature-dependent Michaelis constant[4]	Kmuptake	$\mu g\ C\ g^{-1}$	-
km of DOC uptake at 0 °C[1]	Kmuptake0	$\mu g\ C\ g^{-1}$	0.154
Rate of increase of km uptake with temperature[1]	Kmuptakeslope	$\mu g\ C\ g^{-1}\ °C^{-1}$	0.015
Basic proportion of microbiota death[1]	Kb	unl*	0.012

(To be continued...) [1]Based on studies of Schimel e Weintraub (2003), Allison et al. (2010), Drake et al. (2013), Sato et al. (2000), Neergaarda and Magid (2001) and Silva et al. (2011); [2]suggested initial values; [3]user-defined input data; [4]model output data; *unitless.

Table S2. Variables, constants and compartments of the microbial rhizosphere model

Name	Symbol	Unit	Default
Immigration constant flow[2]	Ki	$\mu g\ g^{-1}\ h^{-1}$	0.01
Emigration constant flow[2]	Ke	$\mu g\ g^{-1}\ h^{-1}$	0.005
Proportion of biomass dying due to water deficiency[4]	K_U	unl*	-
Proportion of DOC and DON that is protected by soil[4]	Kpr	unl*	0.15
Rate of death by limitation by level of fertility[4]	Kft	unl*	-
Death by limitation for physical reasons[4]	Kpt	unl*	-
Final rate of microbial death[4]	Kmf	unl*	-
Root length[4]	L	cm	-
Microbial rate of mineralization[4]	Mn	$\mu g\ g^{-1}\ h^{-1}$	-
N loss[2]	Nloss	unl*	0.4
Inorganic N in one hour[4]	Nin	$\mu g\ g^{-1}\ h^{-1}$	-
Microbial respiration rate for enzymatic production	Re	$\mu g\ g^{-1}\ h^{-1}$	-
Rate of microbial respiration for growth	Rg	$\mu g\ g^{-1}\ h^{-1}$	-
Maintenance respiration rate	Rm	$\mu g\ g^{-1}\ h^{-1}$	-
Overflow respiration rate	Ro	$\mu g\ g^{-1}\ h^{-1}$	-
Substrate use efficiency	SUE	$\mu g\ \mu g^{-1}$	0.3
Soil temperature	Ts	°C	-
Rate of C uptake by microbes	Uc	$\mu g\ g^{-1}\ h^{-1}$	-
Rate of N uptake by microbes	Un	$\mu g\ g^{-1}\ h^{-1}$	-
Maximum inflow of C and N by microbiota	Vmaxuptake	$\mu g\ C\ \mu g^{-1}\ h^{-1}$	-
Pre-exponential rate of C uptake	Vmaxuptake0	$\mu g\ C\ g^{-1}\ h^{-1}$	$1.5\ 10^{8}$
Rhizosphere volume (or mass)	Vrhizo	cm^3 (or g)	-
Rhizodeposition volume factor	frhizo	$cm^3\ cm^{-3}$	0.21
N concentration in the rhizodeposition	Nrhizo	$\mu g\ cm^{-3}$	-
Rhizodeposition volume	Vrhizodep	cm^3	-
Root mean radius	r	cm	-
Rhizosphere thickness	Z	cm	-
Parameter p_1[2]	p_1	unl*	1
Parameter p_2[2]	p_2	unl*	-12.206
Parameter p_3[2]	p_3	$(cm^3\ cm^{-3})^{-1}$	51.060
Parameter p_4[2]	p_4	$(cm^3\ cm^{-3})^{-2}$	-49.239
Parameter z_1	z1	unl*	1
Parameter z_2	z2	unl*	3.805
Parameter z_3	z3	$\%^{-1}$	0.135

[1]Based on studies of Schimel e Weintraub (2003), Allison et al. (2010), Drake et al. (2013), Sato et al. (2000), Neergaarda and Magid (2001) and Silva et al. (2011); [2]suggested initial values (or default values); [3]user-defined input data; [4]model output data; [5]Root mean radius = ((radius of the lower limit of the diameter class) + (radius of the upper limit of the diameter class))/2; *unitless.

2. 1 Soil organic matter (SOM) depolymerization by microbes

The rate of depolymerization of C (SOC) and soil organic N (SON) to produce C (DOC) and N (DON) forms in soil solution was described as a Michaelis-Menten kinetic model, related to the concentration of enzymes in soil (EC) (Equation S9) (Schimel; Weintraub, 2003; Drake et al., 2013). According to these authors, the depolymerization fluxes of SOC and SON (Dc and Dn) are linked by the C/N ratio of the soil (Equation S9). Depolymerization would theoretically be limited by the stocks of SOC and SON, but we assumed on average that roots do not have sufficient longevity to exhaust the entire stocks of SOC and SON. Nevertheless, we consider that once the entire stock of organic matter in the soil is depleted, the microorganisms will be supplied solely by the rhizodeposition flux.

$$Dc = kappa_D \frac{EC}{Kes+EC} \quad \text{Eq. S9}$$

$$Dn = \frac{Dc}{CN_S} \quad \text{Eq. S10}$$

We assumed that temperature influences enzymatic kinetics by being optimal in the range 25°C to 40°C and decreasing rapidly at higher and lower values, which is consistent with Brock and Madigan (1991) and Drake et al. (2013).

$$\begin{cases} if\ T \leq 25\ °C, kappaD\ =\ 0.1014e^{0.1478T} \\ if\ 25 < T \leq 40\ °C, kappaD = 4.0809 \\ if\ T > 40\ °C, kappaD\ =\ 2 * 10^{6}e^{-0.337T} \end{cases} \quad \text{Eq. S11}$$

2.2 Flow of carbon and nitrogen uptake from the soil by the microbiota

The uptake of DOC and DON by the microbes presented in Drake et al. (2013) followed the original proposal of Allison et al. (2010). The maximum velocity (Vmax) and the half-saturation constant of uptake (Km) was calculated as a function of soil temperature, according to equations S12 and S13. To estimate the soil temperature (to the depth of up to 20 cm) from air temperature, we used the daily time-step model proposed by Paul et al. (2004) for ecosystems with trees. The uptake of DOC (Uc) and DON (Un) is estimated according to the Michaelis-Menten model presented in equations S14 e S15. Uptake rates are limited by substrate availability, which means that Uc and Un cannot exceed DOC and DON, respectively (Equations S16 and S17).

$$Vmaxuptake = Vmaxuptake0\ e^{-1(Eauptake\ \div\ Gasconst\cdot(T\ +273.15))} \quad \text{Eq. S12}$$

$$\text{Kmuptake}\ =\ \text{kmuptakeslope T}\ +\ \text{Kmuptake0} \quad \text{Eq. S13}$$

$$Uc = \frac{Vmaxuptake\ BCm\ DOC}{Kmuptake+DOC} \quad \text{Eq. S14}$$

$$Un = \frac{Vmaxuptake\ BNm\ DON}{Kmuptake+DON} \quad \text{Eq. S15}$$

$$\text{Uc}\ = \begin{cases} \text{Uc}, & \text{se Uc} < DOC \\ \text{DOC}, & \text{se Uc} > DOC \end{cases} \quad \text{Eq. S16}$$

$$\text{Un}\ = \begin{cases} \text{Un}, & \text{se Un} < DON \\ \text{DON}, & \text{se Un} > DON \end{cases} \quad \text{Eq. S17}$$

2.3 Microbial metabolism

In the model, microbial demand considers the fact that microorganisms use C and N to synthesize exoenzymes and for the maintenance of the biomass via respiration (Schimel; Weintraub, 2003; Allison et al. 2010; Drake et al., 2013). The calculation of demand aims to determine which of the two nutrients is more limiting to the growth of the microbiota, according to equation S18. Therefore, in each step of the model, if DOC uptake does not reach a value that meets microbial demand (Uc), microorganisms are considered limited by C (Schimel; Weintraub, 2003; Allison et al. 2010; Drake et al., 2013). Otherwise, when Uc exceeds or equals microbial demand for C, microorganisms are assumed to be limited by N (Schimel; Weintraub, 2003; Drake et al., 2013).

$$\begin{cases} Uc < Rm + \frac{EP_c}{SUE} + (Un - EP_n)\frac{CN_m}{SUE}, \text{therefore, it is limited by C} \\ Uc \geq Rm + \frac{EP_c}{SUE} + (Un - EP_n)\frac{CN_m}{SUE}, \text{therefore, it is limited by N} \end{cases} \quad \text{Eq. S18}$$

2.4 Mineralization and immobilization

The immobilization rate of N (Jn) is zero with C limitation, or immobilization occurs under N limitation (Equation S19) (Schimel; Weintraub, 2003; Allison et al. 2010; Drake et al., 2013). Microorganisms mineralize N during C limitation, but N mineralization is zero when limited by N (Equation S20) (Schimel; Weintraub, 2003; Allison et al. 2010; Drake et al., 2013).

$$Jn = \begin{cases} 0, & \text{if is limited by C} \\ \left(Uc - Rm - \frac{EPc}{SUE}\right)\left(\frac{SUE}{CN_m}\right) - EPn - Un, & \text{if is limited by N} \end{cases} \quad \text{Eq. S19}$$

$$Mn = \begin{cases} Un - EPn - \left(Uc - Rm - \frac{EPc}{SUE}\right)\left(\frac{SUE}{CN_m}\right), & \text{if is limited by C} \\ 0, & \text{if is limited by N} \end{cases} \quad \text{Eq. S20}$$

2.5 Production and degradation of enzymes

It was assumed that the rate of enzyme production by the microbiota is directly proportional to microbial biomass (Equation S21) and that the degradation of the enzymes was described by a constant that is multiplied by the amount of enzymes in rhizosphere soil (Equation S22), as presented Allison et al. (2010) and Drake et al. (2013). Similarly, N transferred during enzymatic (EPn) and degradation (ELn) production was represented by equations S23 and S24, respectively.

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$$EPc = Kep\ BCm \quad \text{Eq. S21}$$

$$ELc = K_1 EC \quad \text{Eq. S22}$$

$$EPn = \frac{EPc}{CN_{enz}} \quad \text{Eq. S23}$$

$$ELn = \frac{ELc}{CN_{enz}} \quad \text{Eq. S24}$$

2.6 Respiration process

Microorganisms use C in the respiratory process to support the maintenance of biomass (Rm) (Equation S25), enzyme production (Re) (Equation S26), growth (Rg) (Equation S27) and "overflow" metabolism (Equation S28) (Schimel; Weintraub, 2003; Allison et al. 2010; Drake et al., 2013). At this point in particular, the 'Law of the Minimum' in the respiratory process for growth is applied, so whether C or N is missing determines the magnitude of respiration.

$$Rm = Km\ BCm \quad \text{Eq. S25}$$

$$Re = \frac{EPc\ (1-SUE)}{SUE} \quad \text{Eq. S26}$$

$$Rg = \begin{cases} \left(Uc - \frac{EPc}{SUE} - Rm\right)(1 - SUE), & \text{if limited by C} \\ (Un - J_n - EP_n)CN_m \frac{(1-SUE)}{SUE}, & \text{if limited by N} \end{cases} \quad \text{Eq. S27}$$

$$Ro = \begin{cases} 0, & \text{if limited by C} \\ \left(Uc - Rm - \frac{EP_c}{SUE}\right) - (Un + Jn - EPn)\frac{CN_m}{SUE}, & \text{if limited by N} \end{cases} \quad \text{Eq. S28}$$

2.7 Population dynamics

In addition to the MCNiP model, the processes of microbial immigration and emigration, are represented by constant inputs to and outputs from the rhizosphere. As for Schimel e Weintraub (2003), Allison et al. (2010) and Drake et al. (2013), there is an assumed rate (kb) of death of microorganisms each hour. However, differently from the above authors, we consider this rate for standard conditions for the survival of the rhizosphere microorganisms to be increased by a multiplicative factor (K_U) under inadequate water conditions, as previously commented. For this purpose, we used a logistic model based on data presented in Sato et al. (2000). We also consider important that soil physical conditions affected the death of the microbiota by changes in the availability of O_2, water retention and access to substrates. Thus, we adjusted an equation that aims to correct the rate of death of microbial biomass as a function of changes in total soil porosity (K_{pt}), according to data presented in Silva et al. (2011). The standard particle density was 2.6 g cm^{-3}, but can be changed as needed.

We also considered the effect of fertility on microbial death (K_{ft}), based on data presented about of the difference in microbial biomass between fertile and infertile soils (Neergaarda; Magid, 2001). These modifications were the main improvements made in the MCNiP model.

Immigration and emigration

$$Im = Ki \quad \text{Eq. S29}$$

$$Em = Ke \quad \text{Eq. S30}$$

Death by water limitation

$$K_U = \left(\frac{z1}{z1+z2e^{(-z3CAD)}}\right)^{-1} \quad \text{Eq. S31}$$

Death by physical conditions limitations

$$K_{Pt} = \frac{p1}{p2+\ p3\ Pt\ +p4\ Pt^2} \quad \text{Eq. S32}$$

$$Pt = 1 - \frac{Ds}{Dp}$$

Death by soil fertility limitations

$$K_{ft} = \frac{Kb}{level\ n} \quad \text{Eq. S33}$$

Level 1 (low fertility) = 1 (SOM ≤ 1.2 dag kg^{-1})
Level 5 (medium fertility) = 3 (1.2 dag kg^{-1} < SOM ≤ 4 dag kg^{-1})
Level 10 (high fertility) = 10 (4 dag kg^{-1} < SOM ≤ 8 dag kg^{-1})

Final rate of microbial death

$$Kmf = K_b K_U K_{pt} K_{ft} \quad \text{Eq. S34}$$

2.8 Internal cycling of the dead microbiota

The ratio (Kmf) of the C and N contained in microbes that due death process returns to the DOC (CY_c) and DON (CY_n) compartments is described in equations S35 and S36.

$$CY_c = KmfBC \quad \text{Eq. S35}$$

$$CY_n = \frac{CY_c}{CN} \quad \text{Eq. S36}$$

2.9 Module of changes in the compartments of rhizosphere C and N

This module integrates C and N cycling in relation to rhizosphere microbes and soil, constituting the main outputs of the ForPRAN model. Changes in the different compartments are simulated over time at an hourly time-step, using equations S37-S48. Another modification in relation to the MCNiP was to consider that only one proportion (1-Kpr) of the DOC and DON compartment as able to be absorbed by microbes, so that a value (Kpr DOC and Kpr DON) is protected by soil from microbial attack returning to the compartment C and N of the soil (SOC and SON).

Table S3. Equations used to calculate compartment changes

N°	Compartiment	Equation
S37	Microbial biomass (carbon, µg cm^{-3})	$\mathrm{BCm\ (i+1) = BCm\ (i) + Uc - CYc - EPc - Ro - Re - Rm - Rg + Imc - Emc}$
S38	Microbial biomass (nitrogen, µg cm^{-3})	$\mathrm{BNm\ (i+1) = BN\ (i) + Un - CYn - EPn - Mn + Jn + Imn - Emn}$
S39	Enzymes (carbon, µg cm^{-3})	$EC(i+1) = EC(i) + EPc - ELc$
S40	Enzymes (nitrogen, µg cm^{-3})	$EN\ (i+1) = EN(i) + EPn - ELn$
S41	Carbon in solution (DOC, µg cm^{-3})	$DOC\ (i+1) = (1 - Kpr)(DOC(i) + Ce + Dc + CYc + ELc) - Uc$
S42	Nitrogen in solution (DON, µg cm^{-3})	$DON\ (i+1) = (1 - Kpr)(DON(i) + Ne + Dn + CYn + ELn) - Un$
S43	Soil organic carbon (SOC, µg cm^{-3})	$\mathrm{SOC\ (i+1) = SOC\ (i) - Dc_{i+1} + Kpr\ (}DOC(i) + Dc_i + Ce + CYc + ELc)$
S44	Soil organic nitrogen (SON, µg cm^{-3})	$\mathrm{SON\ (i+1) = SON(i) - Dn_{i+1} + Kpr\ (}DON(i) + Dn_i + Ne + CYn + ELn)$
S45	Inorganic nitrogen (µg cm^{-3})	N (i+1) = (1-loss)[N (i) + Mn – Jn]
S46	Vrhizosphere	Vrhizosphere = 2πr RLdc Z
S47	Vrhizodeposition	Vrhizodeposition = f_{rhizo}Vrhizosphere
S48	N balance (kg ha^{-1})	ΔN = (N inorgânico Vrhizosphere)– (Ne Vrhizodeposition)