

Reviewer 2

This manuscript addresses an important question related to the assessment of long-term SOC dynamics in croplands by comparing soil inventories, RothC simulations, and eddy covariance measurements. The study benefits from a unique long-term dataset and combines several independent approaches to improve understanding of SOC changes under agricultural management.

The manuscript is generally well written, and the study design is sound. The methods are described in detail, the uncertainty analysis is comprehensive, and the results are presented clearly. The discussion is extensive and supported by relevant literature. The work has clear scientific value and will be of interest to researchers working on soil carbon monitoring, modelling, and greenhouse gas accounting.

Overall, I consider this manuscript suitable for publication after minor revision. The comments below are intended to help improve the interpretation of some results and strengthen the discussion.

We thank reviewer 2 (R2) for the positive comments regarding the manuscript. Please find below the responses to R2 comments.

Lines 57-58 The statement that NBP should theoretically correspond to changes in SOC stocks may be too simplistic. NBP and SOC stock change are related but not identical quantities, particularly in agricultural systems where carbon can be stored or removed through different pathways.

We have modified the sentence in the revised manuscript which should now better emphasize the conditions when NBP should correspond to changes in SOC stocks: “Net biome productivity (NBP) can be estimated from NEE and net lateral C fluxes from agricultural activities (e.g. manure application and harvesting), and reflects changes in SOC stocks over periods without net change in vegetation C stocks, provided dissolved organic and inorganic carbon fluxes are negligible” (L56 in the revised manuscript)

Lines 61-62: The uncertainty discussion focuses primarily on EC-derived estimates. Similar emphasis should be given to uncertainties associated with SOC models, including model structure, parameterization, and initialization.

We have added a sentence on that at the end of the introduction paragraph on RothC explaining how uncertainties on SOC model outputs are quantified :

“Yet, predictions of SOC remains strongly sensitive to model structure (Wieder et al., 2014), initial conditions (Todd-Brown et al., 2013) and classical parameterization (Bruni et al., 2022; Hararuk et al., 2014), potentially biasing simulated soil C responses to climate change (Shi et al., 2018). Therefore, uncertainty quantification in soil C models remains critical for assessing the reliability of SOC predictions.”

Line 365: The justification for the criterion needs more support. Why this threshold is chosen? Any sensitivity analyses has been applied?

The answer to this comment is pooled with the one of the next comment. Please see below.

Lines 355-363: Residues entering RothC are normally partitioned using a DPM/RPM ratio. For instance, for cereal straw it is 1.44 and for woodland litter is 0.25. The presented method focuses only on DPM decomposition. However, a substantial fraction of residue C enters RPM, especially for lignified residues. Consequently, the fraction of total residue carbon decomposed may be much lower than the calculated .

We agree that our original description of the method could be interpreted as referring to total residue-C decomposition, whereas it only characterized the one related to the DPM pool. In RothC, crop residue inputs are indeed partitioned between DPM and RPM according to a DPM:RPM ratio of 1.44. Although the original f_{DPM} had only a qualitative purpose, we acknowledge that neglecting RPM led to a strong underestimation of the actual fraction of total residue carbon decomposed. Therefore, we have replaced f_{DPM} by a similar indicator that accounts for both the DPM and RPM fractions of the residue input (f_{res}):

$$f_{res} = 1 - \frac{C_{DPM}(t') + C_{RPM}(t')}{C_{DPM}(t) + C_{RPM}(t)} = 1 - \left(p_{DPM} \cdot e^{-k_{DPM} \sum_{i=t}^{t'} \xi_i} + p_{RPM} \cdot e^{-k_{RPM} \sum_{i=t}^{t'} \xi_i} \right)$$

Where $p_{DPM} = \frac{DR}{(DR+1)}$ and $p_{RPM} = 1/(DR + 1)$ are the fractions of the residue input initially allocated to DPM and RPM according to the DPM:RPM ratio ($DR = 1.44$), $k_{DPM} = 10 \text{ yr}^{-1}$ and $k_{RPM} = 0.30 \text{ yr}^{-1}$ are the corresponding RothC decomposition rate constants, and ξ_i is the monthly product of the RothC temperature, moisture, and soil-cover modifiers at month i . $f_{residue}$ therefore represents the cumulative fraction of the total residue-C input (DPM + RPM combined) that has decomposed by the end of the sowing-to-sowing interval.

We also have removed the arbitrary threshold of $f_{DPM} > 70\%$ to define ‘closed’ versus ‘open’ C budgets. This approach avoids the need to justify a specific percentage threshold and directly incorporates the RPM pool highlighted by the reviewer, while still allowing us to assess whether incomplete residue turnover contributes to biased attribution of C fluxes to individual crop periods. This is now corrected in the revised manuscript (L360). Additionally, other minor modifications have been applied, including : an update on Table 3 (new values of f_{res} instead of f_{DPM}) and deletion of the parts mentioning the threshold of 70% . These modifications are minor and do not change the conclusions or any discussion of the revised manuscript.

The following part was modified into the revised manuscript :

“To draw meaningful conclusions regarding the influence of crop species on SOC stock variations, we quantified the potential carry-over C residues over the sowing-to-sowing crop period by calculating the fraction of the C input allocated to the DPM and RPM pools in RothC (f_{res}) as follows :

$$f_{res} = 1 - \frac{C_{DPM}(t') + C_{RPM}(t')}{C_{DPM}(t) + C_{RPM}(t)} = 1 - \left(p_{DPM} \cdot e^{-k_{DPM} \sum_{i=t}^{t'} \xi_i} + p_{RPM} \cdot e^{-k_{RPM} \sum_{i=t}^{t'} \xi_i} \right) \quad (17)$$

where C_{DPM} and C_{RPM} are the C in the DPM and RPM pools respectively, ξ_i is the product of RothC rate modifiers for temperature, soil moisture and soil cover over a month of index i between t and t' , k_{DPM} and k_{RPM} are the monthly DPM and RPM decomposition rate constants (0.83 month⁻¹ and 0.025 month⁻¹ respectively), and $p_{DPM} = \frac{DR}{DR+1}$ and $p_{RPM} = \frac{1}{DR+1}$ are the fraction of C residue attributed to the DPM and RPM pool respectively with DR the DPM:RPM ratio of 1.44. The summation is taken over the months included in the sowing-to-sowing period from t to t' . We focused on DPM and RPM as it corresponds to the pools most likely to generate a short-term carry-over of newly added residue C across successive sowing-to-sowing periods. Since BIO and HUM have substantially lower decomposition rate constants and represent slower C dynamics, they were not used in the calculation of f_{res} . Periods with low f_{res} were interpreted as periods with substantial carry-over of DPM and RPM C beyond the end of the crop period. In these cases, the attribution of residue-related C turnover and associated C losses to an individual crop period may be biased, and the resulting sink or source classification should be interpreted with caution."

Line 377: "All monthly predictions are then pooled to derive typical statistical parameters." Suppose there are 10,000 simulations 240 months, Then pooling all values together creates predictions. However uncertainty should generally be calculated for each month separately, rather than across all months.

We would like to clarify that uncertainty was in fact calculated separately for each month, not pooled across all 240 months. It was properly done in our processing but the way it was explained in the manuscript could have led to a misunderstanding. This has been clarified in the revised manuscript.

Lines 370-379: It is assumed that . It was itself an assumption likely carrying uncertainty. This uncertainty should ideally also be propagated.

The answer to this comment is pooled with the one of the next comment. Please see below.

Lines 368-379: The Monte Carlo analysis appears to assume that all parameters and inputs are independent. However, this assumption may not always be realistic. For example, uncertainties in temperature and moisture modifiers may be related, decomposition rate constants may be correlated, and carbon inputs may be influenced by climate conditions. Ignoring these relationships can either increase or decrease the estimated uncertainty. The authors should acknowledge this assumption and discuss its potential effect on the results.

We agree that our Monte Carlo procedure assumes independence among the perturbed parameters and inputs (temperature, precipitation, evapotranspiration, farmyard manure and biomass inputs, the temperature and moisture parameters, and the pool decomposition rate constants), and that this assumption is a simplification of the underlying physical and biological relationships.

Several of these variables are indeed expected to be correlated. For example, higher air temperature is typically associated with higher potential evapotranspiration, which would tend to jointly affect the temperature modifier and the moisture modifier in RothC in the same direction during the MC sampling procedure. Therefore, a more robust procedure would consist in imposing an empirically estimated correlation structure that explicitly constrains the direction of co-variation between perturbed variables during sampling.

We have added a paragraph to the revised manuscript acknowledging this limitation and its potential consequences on the results (L 685) : “However, our methodology did not consider potential correlations among the perturbed parameters and drivers. All Monte Carlo simulations were based on independent sampling. Several of these variables are however likely correlated: temperature and evapotranspiration typically co-vary within the same climatic events, decomposition rate constants are usually derived from a joint calibration, and biomass inputs may respond to the same climatic drivers used to modify decomposition. Ignoring these dependencies can bias the estimated uncertainty in either direction: positive, reinforcing correlations would lead independent sampling to underestimate true variability, whereas opposing correlations could cause overestimation. As the correlation structure among RothC parameters and drivers was not quantified at our site, we cannot determine a priori whether the reported uncertainty bounds over- or underestimated the true predictive uncertainty. Future applications should consider a joint sampling scheme informed by the empirical covariance among climatic drivers and model parameters. Additionally, using multiple soil C models within an ensemble framework could provide a more robust assessment of uncertainties arising from model structural differences (Bruni et al., 2022; Farina et al., 2021). Recent efforts to develop a single interface for generating projections from multiple SOC models in forest soils pave the way towards more accessible and robust predictions of SOC stocks over croplands (Bruni et al., 2026)”

Lines 380-400: The comparison between NBP and Δ SOC RothC should be interpreted with caution because the two variables do not represent exactly the same carbon fluxes. NBP reflects the overall ecosystem carbon balance, including plant carbon uptake and respiration processes, whereas RothC only simulates changes in soil organic carbon based on estimated carbon inputs and decomposition. Therefore, agreement in source or sink classification may be expected, but close agreement in magnitude should not necessarily be assumed or interpreted as model accuracy.

We thank the reviewer for raising this important point. The submitted manuscript lacked a clear explanation why both approaches can be strictly compared over sowing-to-sowing periods. The rationale behind the data selection is based on the statement that, over any time period, and assuming that dissolved organic/inorganic C fluxes are negligible, the ecosystem carbon balance corresponds to changes in both the living plant biomass C pools (ΔC_{vege}) and the soil C pools (ΔC_{SOC}) as:

$$NBP = NEE - C_{imp} + C_{exp} = \Delta C_{SOC} + \Delta C_{vege}$$

Since RothC strictly models ΔC_{SOC} , both approaches can be compared only over periods of time when $\Delta C_{vege} \sim 0$. At the beginning of the period, no vegetation is on the field resulting

in ΔC_{vege} near zero. At the end of the period (sowing of the subsequent crop, which can occur a few months after harvest), vegetation C stocks also returned to a near-zero state since aboveground crop residues at harvest enter the soil through ploughing. This step is explicitly considered in RothC, where all living biomass remaining after harvest is prescribed to DPM and RPM pools. Belowground crop residues – consisting of root material that is built during the cultivation period – are measured by NBP through NEE and are also prescribed to the model through allometric equations based on yield. Any respiratory flux resulting from harvest residue mineralization are also accounted for by both approaches.

The following part was added to the revised manuscript at the beginning of section 2.8: “This structural difference defines the conditions under which the two quantities can be compared. Over any given interval, the ecosystem carbon balance can be decomposed as the sum of the net changes in soil C stocks and in living biomass C stocks. Since RothC predicts changes in SOC stocks only, EC-based C budgets and RothC simulations can only be compared when changes in living biomass C stocks are negligible over the selected period. We therefore restricted the comparison to sowing-to-sowing periods. At the beginning of the period, no vegetation is present on the field and living biomass C stocks are zero. At the end of the period (sowing of the subsequent crop, which can occur a few months after harvest), living biomass C stocks have also returned to near zero, since crop residues left in the field after harvest enter the soil through ploughing. This step is explicitly considered in RothC, where aboveground residues left on the field are prescribed to the DPM and RPM pools at the month of harvest. Belowground crop residues, consisting of root material built up during the cultivation period, are captured by NBP through NEE and are likewise prescribed to RothC through allometric equations based on yield. Any respiratory flux resulting from harvest residue mineralization is accounted for by both approaches. Carbon losses through DOC and DIC leaching or erosion were assumed negligible at this site and are not accounted for in either method.”

Finally, we would like to remind that the sowing-to-sowing periods ensure that any post-harvest respiratory fluxes are attributed to the crop period of origin rather than to a ‘bare soil’ category which would have inevitably bias the C budget for each crop. This specific point was already highlighted in the submitted manuscript (section 2.3) as: “This sowing-to-sowing definition ensured that most of CO₂ emissions arising from post-harvest crop residue decomposition were attributed to the crop of origin rather than to the following crop, thereby enabling a more robust estimation of the influence of crop species on SOC stock variations.”

Lines 598-610 : This section discussing subsoil carbon dynamics is informative and highlights an important limitation of the RothC simulations. However, the potential impact of subsoil processes remains largely qualitative. It would be good if the discussion could be strengthened by providing a simple estimate of the possible magnitude of subsoil carbon inputs based on the reported root biomass measurements. This would help readers assess whether subsoil dynamics are likely to explain a meaningful portion of the difference between NBP and ΔSOC_{RothC} .

We have already provided at L640 (revised manuscript) qualitative assessment of the potential inclusion of subsoil C input into the simulated SOC stock changes in RothC. This would have likely exacerbated the difference between RothC and budget from EC by enhancing the simulated SOC sequestration due to greater stabilization of harvest residues with depth. Therefore our results present somehow a lower bound of the difference between NPB and RothC over the 21y period.

Finally, several parts of the discussion appear to compare NBP and $\Delta\text{SOC}_{\text{RothC}}$ as if they represent the same quantity. However, NBP describes the overall ecosystem carbon balance, while RothC simulates changes in soil organic carbon stocks. It may be useful to remind readers that agreement in source or sink classification may be expected, but agreement in magnitude should not necessarily be expected. A short clarification in the discussion would help avoid potential over-interpretation of the comparison.

After the integration of the response of the previous comments into the revised manuscript, we believe now that this point is clarified.