Response to Reviewers

Dear Editor and Reviewers:

On behalf of my co-authors, I thank you very much for giving us the opportunity to revise our manuscript entitled "**Magnetic separation reveals overestimation of soil organic matter due to undecomposed particulate residues**" (Manuscript Number:**egusphere-2025-5686**).

We appreciate the positive and constructive comments from the reviewer. We have studied the comments carefully and tried our best to revise our manuscript accordingly. Revised portion are marked in **red** in the paper. Our point-by-point responses to the comments are attached, and the submitted manuscript has been improved and revised according to the comments. We hope that our responses and revisions are satisfactory and that our manuscript will now be acceptable for publication in Journal of "***SOIL***".

Again, we greatly appreciate your time and effort with manuscript. Should you have any further questions regarding the revised manuscript, please contact me by e-mail (dousen1959@126.com).

Best regards

Dou Sen

Corresponding author

Response to Reviewer 1

Response to Reviewer 1 and revisions made accordingly (Italic words are the comments from the reviewer):

Response: We appreciate your thorough review of our work and the constructive comments provided to enhance the quality of our manuscript. Below are our point-by-point responses to your feedback. We sincerely hope the updated manuscript now meets the standards for publication in **SOIL.**

Xia et al. present an interesting study in which straw and biochar are magnetized prior to an incubation experiment, enabling magnetic separation to remove incompletely decomposed amendment residues. This allowed the authors to track the persistence of amendment-derived particulate material over one year and to evaluate the extent to which observed increases in the POM fraction reflect persistent amendment fragments versus processed organic matter.

The study fits well within SOIL's scope and presents a potentially novel methodological approach to addressing a common interpretation issue in SOM fractionation studies. However, I recommend major revisions, primarily because (1) the conceptual framing regarding what "counts" as SOM is not fully aligned with current usage in soil science, (2) several methodological choices require clearer justification and/or more explicit discussion of limitations, and (3) the conclusions are broader than the evidence supports. Minor issues include occasional unclear wording and a few instances where the citation support appears weak or poorly targeted.

General comments

My main concern is that the manuscript is asserting a definition of SOM that is not consistent with how it is commonly defined and used in current soil science. In particular, the text implies that only mineral-associated OM represents "true SOM," and that undecomposed POM does not qualify as SOM. This framing risks conflating two different issues: whether carbon is present in the soil system (which can legitimately increase after organic additions), versus whether that carbon is stabilized/persistent (e.g., mineral-associated and/or physically protected) and therefore likely to contribute to longer-term SOC storage.

I suggest reframing the key message away from "overestimation of SOM/SOC" and toward the also important point that increases in operational POM fractions following amendment addition can be over-interpreted as evidence of stabilization or processed SOM formation, when they may instead reflect persistent, untransformed amendment residues. The manuscript would benefit from grounding the introduction more explicitly in the POM–MAOM conceptual framework and related literature, perhaps including a simple conceptual diagram distinguishing amendment residues vs processed OM and where each falls within SOM fractions.

A further general issue is the statistical framework. Given the treatment x time design with destructive sampling, the manuscript would benefit from a model-based approach (e.g., two-way ANOVA/linear models with treatment, time, and interaction, followed by appropriately corrected post-hoc comparisons) rather than relying primarily on Duncan's multiple range test.

The main methodological contribution (using magnetic separation to quantify residue contribution to operational POM/POC) is promising and likely of interest to the community. However, the concluding statements should be revised to avoid implying Xia et al. present an interesting study in which straw and biochar are magnetized prior to an incubation experiment, enabling magnetic separation to remove incompletely decomposed amendment residues. This allowed the authors to track the persistence of amendment-derived particulate material over one year and to evaluate the extent to which observed increases in the POM fraction reflect persistent amendment fragments versus processed organic matter.

The study fits well within SOIL's scope and presents a potentially novel methodological approach to addressing a common interpretation issue in SOM fractionation studies. However, I recommend major revisions, primarily because (1) the conceptual framing regarding what "counts" as SOM is not fully aligned with current usage in soil science, (2) several methodological choices require clearer justification and/or more explicit discussion of limitations, and (3) the conclusions are broader than the evidence supports. Minor issues include occasional unclear wording and a few instances where the citation support appears weak or poorly targeted.

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The main methodological contribution (using magnetic separation to quantify residue contribution to operational POM/POC) is promising and likely of interest to the community. However, the concluding statements should be revised to avoid implying that POM is not part of SOM and to substantially moderate the leap from *this single-soil incubation study to claims of "systematic bias in global SOM content assessments."*

Comments 1: *Line 47-48: What exactly is meant by "with the greatest binding to minerals"?*

Response: We sincerely appreciate the reviewer's valuable comment and constructive suggestion, which has helped us to clarify and refine the expression in our manuscript. To address this concern and provide a more precise and comprehensive explanation, we have revised the relevant content on Page 4, Lines 43-49 as follows: "Soil organic matter (SOM) is a complex assemblage of organic compounds formed through the decomposition and transformation of plant and animal residues. It exhibits a much stronger binding capacity to soil minerals than undecomposed or partially decomposed residues. This strong binding makes it one of the most stable organic fractions in soil and supports its long-term persistence. SOM originates from the partial microbial decomposition of plant detritus (Angst et al., 2021; Cotrufo et al., 2013; Dou et al., 2020; Vendig et al., 2023). "

Comments 2: *Line 49-52: What is meant by "the core of SOM"? This sentence is unclear to me, and I am not sure that Feng et al. 2025 should be the only citation included, given all of the claims listed.*

Response: We sincerely appreciate the reviewer's careful review and constructive comments on the clarity of the expression and the sufficiency of citations. To address the unclear definition of "the core of SOM" and enrich the supporting literature, we have revised the relevant content on Page 4, Lines 49-53 as follows: "Notably, the core of SOM refers to its labile and functional organic components with dynamic transformation properties. These components supply nutrients to the soil, sustain microbial activity, and regulate soil structure (Feng et al., 2025; Arumugam et al., 2025; Xu et al., 2026). Therefore, SOM should not be regarded merely as the passive accumulation of carbon-containing substances. "

Comments 3: *Line 107-109: How were these properties measured?*

Response: We sincerely appreciate the reviewer's valuable comment pointing out the lack of detailed measurement methods for soil basic properties. To address this issue and improve the methodological transparency and reproducibility of our study, we have supplemented the specific measurement protocols and corresponding data for soil basic properties on Page 7, Lines 120-128 as follows: "The basic properties of the soil were determined prior to the formal experiment as part of the initial soil characterization, with specific measurement methods following standard protocols in soil science: soil organic matter was determined by the dichromate oxidation method, total nitrogen by the Kjeldahl method, available nitrogen by the alkaline hydrolysis-diffusion method, available phosphorus by the molybdenum-antimony colorimetric method, and available potassium by flame photometry. The specific values were as follows: soil organic matter, 22.76 g kg^{-1}; total nitrogen, 1.28 g kg^{-1}; available nitrogen, 132.21 mg kg^{-1}; available phosphorus, 18.52 mg kg^{-1}; and available potassium, 99.32 mg kg^{-1}. "

Comments 4: *Line 174: Should read "soil organic carbon (SOC)" rather than "soil organic matter"*

Response: We sincerely appreciate the reviewer's careful and precise comment on the terminology, which has helped us to correct the inaccuracy in the expression. Following the reviewer's suggestion, we have revised the relevant content on Page 10, Lines 192-195 by replacing "soil organic matter" with the more accurate term "soil organic carbon (SOC)", and the revised sentence is as follows:"After the complete removal of undecomposed magnetized organic residues, the soil organic carbon (SOC) content of the original soil and each fraction was determined using the potassium dichromate oxidation method with external heating (Nelson and Sommers, 1982)."

Comments 5: *Line 175-178: Please clarify carbon quantification methods. Was the dichromate oxidation method used only for the original soils, or also for fractions?*

Why was elemental analysis not used consistently for SOC/OC across soil/fraction samples?

Response: We sincerely appreciate the reviewer's rigorous comment and request for clarification on the carbon quantification methods, which helps improve the transparency and methodological consistency of our study. To address these questions, we have revised and supplemented the detailed description of carbon determination methods on Pages 10-11, Lines 195-202 as follows: "For preliminary soil characterization, the organic carbon content of the original soil was first determined using the dichromate oxidation method. To ensure consistent and accurate measurements across all sample types, the organic carbon content of organic residue samples, the original soil, and soil fractions collected at different incubation stages was subsequently measured with an elemental analyzer (Vario EL III, Hanau, Germany). All organic carbon data reported in this study were obtained from elemental analysis and corrected for an ash-free and moisture-free basis (Ndzelu et al., 2021)."

Comments 6: *Line 181-182: Eqs. (1)–(2) are currently confusing due to unit/definition issues. MP is defined as a percentage mass proportion of the POM fraction, but Eq. (1) (POC = MP × OCP) only yields correct units if MP is treated as a mass fraction (MP/100) rather than a percent. Please clarify MP (fraction vs %) and adjust Eq. (1) accordingly. Additionally, Eq. (2) labeled "POM (%)" is actually POC/SOC × 100, i.e., the contribution of POM-C to total SOC, not the proportion of POM mass; the variable name should be changed to avoid misinterpretation.*

Response: We sincerely appreciate the reviewer's meticulous comment on the unit consistency, parameter definition, and equation labeling, which has greatly helped us eliminate ambiguity and improve the accuracy of the methodological description. To address the unit/definition issues of Eqs. (1)–(2) and avoid misinterpretation, we have revised the relevant content on Page 11, Lines 197-207 as follows: "To quantify the particulate organic carbon (POC) derived from amendment residues and its contribution to total soil organic carbon (SOC), the following equations were applied:

$$POC = M_P / 100 \times OC_P \tag{1}$$

$$POM - C\ Contribution\,(\%) = POC / SOC \times 100 \tag{2}$$

where MP denotes the relative mass proportion of the POM fraction (%, i.e., percentage by mass of POM in the soil sample), OCP represents the organic carbon content of the POM fraction (g kg^{-1}), POC refers to the calculated particulate organic carbon content of the soil sample (g kg^{-1}), SOC denotes the total soil organic carbon content of the undisturbed soil (g kg^{-1}), and POM-C Contribution (%) represents the percentage contribution of particulate organic carbon to total soil organic carbon."

Comments 7: *Line 199: Please clarify the statistical framework. As written, only Duncan's multiple range test is reported, but the manuscript does not state the test/model from which the post-hoc comparisons derive (e.g., one-way ANOVA at each time point vs a factorial treatment × time model). Given the incubation design, it is important to test treatment, time, and their interaction, and to specify the corresponding model structure and assumptions checks. I recommend a two-way ANOVA/linear model (treatment, time, treatment × time) with appropriately corrected post-hoc comparisons, or explicit justification if a different approach was used.*

Response: We sincerely appreciate the reviewer's rigorous and constructive comment on clarifying the statistical framework, which is critical for enhancing the scientific rigor and reproducibility of our data analysis. Following the reviewer's valuable suggestion, we have comprehensively revised and supplemented the description of statistical methods on Page 11, Lines 226-234 to explicitly define the analytical models and post-hoc test procedures, as shown below: "All data were first organized using Microsoft Office Excel 2022, followed by statistical analysis with IBM SPSS Statistics 25 (IBM Corporation, Armonk, NY, USA). One-way analysis of variance (ANOVA) was performed to examine differences in the measured indices across all treatments and incubation time points, with post-hoc multiple comparisons conducted using the least significant difference (LSD) test at the 0.05 significance level. Additionally, two-way ANOVA was applied to evaluate the effects of treatment, incubation time, and their interaction on soil and fraction-specific organic carbon contents, and Duncan's multiple range test (integrated in SPSS) was used for post-hoc comparison of significant differences.Graphs were generated using Origin 2022."

Comments 8: *Lines 254-260: The mechanistic language around "molecular conjugation," "electronic environment," and "enhanced aromatic structural features" is overly specific for the bulk elemental/Van Krevelen data in Fig. 2; please rephrase these interpretations more cautiously (e.g., shifts in H/C and O/C consistent with oxidative processing and changes in aliphaticity/condensation), and avoid "humification" unless operationally defined and supported with appropriate chemical evidence.*

Response: We sincerely appreciate the reviewer's careful and professional comment on the cautious use of mechanistic interpretations based on bulk elemental data. Following the reviewer's suggestion, we have revised the relevant mechanistic descriptions on Page 16, Lines 296-304 to be more conservative and consistent with the Van Krevelen elemental analysis results, as shown below: "These findings indicate that with prolonged incubation, shifts in the H/C and O/C ratios of the organic residues (evident from the bulk elemental analysis presented in Fig. 2) are consistent with oxidative transformation and changes in aliphatic content and structural condensation of the organic material. Fig. 2b further shows that the C/N ratio and carbon concentration of MCS residues declined continuously, gradually approaching those of the soil MAOM fraction. This trend reflects the progressive decomposition and transformation of organic residues toward chemical characteristics similar to those of native soil mineral-associated organic matter, consistent with observations of organic matter stabilization in previous studies (Abakumov and Eskov, 2023)."

Comments 9: *Line 290: "Artificial elevations" is misleading. The higher POM mass* *proportion reflects persistent amendment fragments captured in the operational >53 μm fraction; please rephrase as something like "residue-driven increase."*

Response: We sincerely appreciate the reviewer's precise comment on the misleading terminology, which helps us to improve the accuracy of our expression. Following the reviewer's suggestion, we have revised the relevant content on Page 18, Lines 340-343 by replacing the misleading term "artificial elevations" with the more accurate and appropriate phrase "residue-driven increases", and the revised sentence is as follows: "These results indicate that the increases in POM mass proportion observed in the CS and Bc treatments were residue-driven increases, arising from the retention of persistent amendment residues within the operationally defined >53 μm particulate fraction."

Comments 10: *Line 301: Same comment as above regarding "false increase"*

Response: We sincerely appreciate the reviewer's consistent and valuable comment on the misleading terminology of "false increase". Following the same constructive suggestion as above, we have revised the relevant content on Page 18, Lines 352-355 by replacing the inappropriate term "false increase" with the more accurate and objective phrase "residue-driven increases", and the revised sentence is as follows: "These results demonstrated that both the carbon content and mass proportion of the POM fraction exhibited residue-driven increases, resulting from the retention of persistent amendment residues within the operationally defined >53 μm particulate fraction."

Comments 11: *Section 4.1: Again please tone down the highly specific mechanistic language inferred from Fig. 2 (e.g., "molecular conjugation," "electronic environment," "humification") and avoid attributing straw–biochar differences primarily to C/N; biochar persistence is strongly controlled by feedstock/pyrolysis chemistry. Additionally, the long list of generic biochar benefits reads like background review and should be shortened or linked explicitly to your results.*

Response: We sincerely appreciate the reviewer’s professional and detailed comments on the mechanistic interpretation, the attribution of straw-biochar differences, and the conciseness of the biochar benefit description. Following the reviewer’s suggestions, we have comprehensively revised Section 4.1 on Page 24-25, Lines 452-483 as follows: “As shown in Fig. 1, the proportion of undecomposed straw residues significantly decreased over different incubation periods, with a residue rate of only 54.55% after 360 d. In sharp contrast, biochar exhibited almost no decomposition, maintaining a high residue rate of 92.48%. Based on the bulk elemental analysis in Fig. 2, the H/C and O/C ratios of magnetic straw residues shifted with incubation time, which is consistent with oxidative transformation and increased structural condensation of organic components, reflecting a gradual shift toward more stable chemical characteristics, whereas MBc residues exhibit negligible changes in elemental composition throughout the incubation period.

The contrasting decomposition dynamics between straw and biochar are primarily driven by their inherent structural differences. Straw contains abundant labile components (e.g., carbohydrates, organic acids, and amino acids) that are readily utilized by soil microorganisms, leading to rapid mineralization within 0–60 d, followed by slower decomposition of recalcitrant aromatic and polymeric fractions during 60–180 d, which aligns with the present findings and previous reports (Chen et al., 2010; Ren et al., 2021). In contrast, biochar is produced via pyrolysis of biomass at 300–700°C under anaerobic conditions (Dungait et al., 2012); during this process, labile cellulose-C in straw is converted into aromatic biochar-C with highly condensed structures, greatly enhancing its structural stability and resistance to microbial decomposition in soil (Yin et al., 2022), thus enabling biochar to remain largely as a residue (Bornø et al., 2019). Although straw has a lower C/N ratio than biochar, this difference is a secondary feature accompanying their distinct chemical structures, rather than the dominant factor controlling their decomposition rates.

The high stability of biochar observed in this study confirms its unique advantages as a carbon-rich soil amendment for soil carbon sequestration and structural improvement, which is consistent with previous studies (Cao et al., 2022; Fan et al., 2021; Wang et al., 2025; Zhang et al., 2024). Characterized by slow decomposition and a surface conducive to organic molecule aggregation, biochar can effectively reduce soil bulk density (Zhang et al., 2021), increase soil porosity (He et al., 2022), alleviate soil acidification (Shi et al., 2023), retain soil moisture (Khaledi et al., 2023), and enhance nutrient absorption efficiency and nutrient cycling coordination (Burgeon et al., 2022) when applied to soil. Therefore, despite its slow decomposition in soil, biochar plays a significant role in improving soil structure and function, which is further supported by its high persistence observed in the present one-year incubation experiment."

Comments 12: *Section 4.2: The framing of a "false/artificial elevation" and "true organic matter" is misleading. The operational POM fraction can legitimately increase after amendments; the key issue is interpretation (residue-derived POM vs processed/stabilized C), not that SOM/SOC is "overestimated." Please rephrase accordingly, avoid implying POM is not SOM, and significantly moderate/justify the leap to "overestimation of global SOM content."*

Response: We sincerely appreciate the reviewer's careful and insightful comments on the misleading framing of "false/artificial elevation" and "true organic matter" in Section 4.2, as well as the constructive suggestions to clarify the status of

POM as a valid component of SOM and moderate the overgeneralized conclusion about global SOM overestimation. Following the reviewer's guidance, we have comprehensively revised Section 4.2 on Page 25-28, Lines 485-553 as follows: "The analysis of the weight proportion and organic carbon content of soil fractions presented in Figs. 3 and 4 clearly demonstrated that under the CS and Bc treatments, both the relative mass and organic carbon content of the POM fraction were consistently higher than those in the CK treatment. This finding aligns with those reported by Xie et al. (2014). The POM fraction, a valid component of soil organic matter (SOM), mainly consists of partially decomposed, chemically recalcitrant polymeric structures, such as acid-insoluble fibers formed through fragmentation, which could primarily originate from exogenous organic materials. Owing to its rapid responsiveness to environmental changes, POM can be highly sensitive to agricultural management practices (Christensen, 1992; Cotrufo et al., 2022; Guo et al., 2022; Rocci et al., 2021; Witzgall et al., 2021). Xie et al. demonstrated that increasing the input of organic materials directly influenced both SOM content and its proportion within the POM fraction. They attributed this phenomenon to the continuous accumulation of organic residues in soil induced by organic amendments (Xie et al., 2014). However, it is critical to distinguish between POM derived directly from undecomposed amendment residues and POM formed through microbial transformation of organic materials. This distinction clarifies the dynamic nature of SOM accumulation. It does not imply that residue-derived POM is an invalid component of SOM.

In this experiment, the POM mass proportion and organic carbon content for the MCS-D and MBc-D treatments were obtained by first applying the magnetic materials to the soil for a period of incubation, then extracting the magnetic residues from the soil, and subsequently testing the soil samples after removal of the undecomposed materials. The results showed that after the magnetic materials were extracted, the POM mass proportion and organic carbon content in the MCS and MBc treatments did not exhibit significant increases compared with the CK treatment. This proved that the increases in POM mass proportion and organic carbon content observed under the CS and Bc treatments were largely attributable to the direct input of straw and biochar materials, with most undecomposed organic residues remaining within the POM fraction. Moreover, the residue-driven increases in both POM mass proportion and organic carbon content under the CS treatment decreased over the incubation period, whereas the corresponding values under the Bc treatment remained nearly constant. These findings suggest that the quantity, quality, and incubation duration of organic residues are key factors driving the increase in the POM mass proportion and organic carbon content. Additionally, the extent of increase in the POM fraction was closely related to the amount and source of organic material applied.

The results shown in Fig. 4 revealed a pronounced decreasing trend in the POM fraction organic carbon content (POC) under CS treatment. This confirmed that the effect of organic material addition in the short term was predominantly reflected in the POM fraction, whereas a gradual increase in the MAOM fraction was observed.

This aligned with the conclusions of Bhattacharyya et al. (2011), Brown et al. (2014), and Stewart et al. (2012) who reported that organic amendments were primarily retained in the POM fraction, which could be more prone to mineralization, while gains in the MAOM fraction remained limited. The MAOM fraction in soil has been mainly formed over decades to centuries through long-term weathering processes involving interactions between organic matter and secondary minerals. Due to this extremely slow formation process, MAOM accumulation can be difficult to achieve in the short term (Kleber et al., 2007; Slessarev et al., 2022). Moreover, because microorganisms struggle to utilize chemically recalcitrant components within plant residues, decomposition of these highly processed structural organic residues and POM components has been reported to cause MAOM formation (Cotrufo et al., 2015). This explains why the organic carbon data for the Bc treatment in this study (Figs. 3 and 4) indicated that most undecomposed organic residues remained preserved within the POM fraction, thereby reducing the MAOM contribution to the soil. This also accounted for the consistently higher MAOM contribution observed in the CS and Bc treatments than in the MCS-D and MBc-D treatments.

Currently, some studies have suggested that abundant POM can be crucial for agroecosystem functioning and crop productivity, thereby advocating for greater research focusing on POM increments (Wood et al., 2016). However, the results of this study indicated that within the POM fraction, the dominant influencing factors were the quantity and quality of undecomposed organic residues, with temporal factors exerting a significant impact. Although the POM fraction plays an important role in nutrient supply, microbial activity promotion, and soil structure regulation, the indiscriminate addition of organic materials to soil primarily increases the amount of undecomposed organic residues, most of which reside in the POM fraction over short time periods. This practice directly increases the measured SOM content. However, most of the short-term increase originated from undecomposed amendment residues retained in the POM fraction rather than from microbially transformed and stabilized organic matter. These findings highlight the need to distinguish between residue-derived and microbially transformed POM when interpreting SOM measurements, particularly in short-term incubation studies. Without this distinction, assessments of SOM dynamics may overestimate the short-term residue-driven increases in POM. This could lead to misinterpretation of SOM stabilization and biased evaluation of stable soil carbon pools in systems receiving recent organic amendments."

Comments 13: *My main concern is that the manuscript is asserting a definition of SOM that is not consistent with how it is commonly defined and used in current soil science. In particular, the text implies that only mineral-associated OM represents "true SOM," and that undecomposed POM does not qualify as SOM. This framing risks conflating two different issues: whether carbon is present in the soil system (which can legitimately increase after organic additions), versus whether that carbon is stabilized/persistent (e.g., mineral-associated and/or physically protected) and therefore likely to contribute to longer-term SOC storage. I suggest reframing the key* *message away from "overestimation of SOM/SOC" and toward the also important point that increases in operational POM fractions following amendment addition can be over-interpreted as evidence of stabilization or processed SOM formation, when they may instead reflect persistent, untransformed amendment residues.*

Response: We sincerely appreciate the reviewer's professional and constructive suggestions on refining the core conclusions of this study. We fully agree that the expression "overestimation of soil organic matter/soil organic carbon" is prone to ambiguity.

In accordance with the reviewer's advice, we have reorganized and revised the presentation of the core viewpoints in the manuscript.

1. We have removed all expressions related to "overestimation of SOM/SOC" throughout the text;

2. We have refocused the key conclusion on the essential nature of POM increment: the increase in the operationally defined particulate organic matter (POM) fraction following organic material addition is often misinterpreted as evidence of SOM stabilization or the formation of transformed organic matter, whereas in reality, this increment largely originates from undecomposed, untransformed amendment residues rather than microbially mediated stable SOM formation.

The following is the abstract section of the article: "Soil organic matter (SOM) is a complex mixture of organic compounds derived from the decomposition of plant and animal residues. SOM that has undergone microbial transformation and formed stable associations with minerals represents the stabilized fraction of soil organic carbon, which differs from the simple physical accumulation of external organic materials. Current understanding suggests that particulate organic matter (POM) includes both undecomposed and partially decomposed residues. Conventional analytical methods cannot clearly distinguish undecomposed external residues from native SOM. Consequently, increases in operationally defined POM are often misinterpreted as evidence of SOM stabilization or microbially transformed organic carbon formation. In this study, straw and biochar were magnetized through chemical coprecipitation and applied to the soil. Magnetic separation was performed at successive incubation times to isolate undegraded magnetic residues, thereby enabling more accurate tracking of SOM dynamics. Five treatments were established: blank control (CK), untreated straw (CS), untreated biochar with carbon input equivalent to straw (Bc), magnetized straw (MCS), and magnetized biochar (MBc). The recovery of magnetized straw residues declined continuously and reached 54.55% after 360 d, whereas biochar residues remained highly persistent at 92.48%. In the CS and Bc treatments, the organic carbon content of POM fractions and their proportion in total SOM were consistently higher than in CK, particularly during early incubation. However, after removing undegraded residues by magnetic separation (MCS-D and MBc-D), values were close to those of CK. This result indicates that the observed POM increases mainly originated from undecomposed external residues rather than microbially stabilized SOM. On day 30, the apparent increase in particulate organic carbon (POC) was 63.48% in CS and 58.99% in Bc. Over time, the apparent POC increase in CS declined to 15.34% by day 360, whereas that in Bc remained high

(53.71%). These findings suggest that interpreting total POM as stabilized or microbially transformed SOM may lead to misleading conclusions about SOM stability, particularly in short-term incubations or agroecosystems receiving fresh organic amendments. This study provides a basis for a more accurate evaluation of soil organic matter transformation dynamics and content.”

Response to Reviewer #2

Response to Reviewer 2 and revisions made accordingly (Italic words are the comments from the reviewer):

Response: We appreciate your thorough review of our work and the constructive comments provided to enhance the quality of our manuscript. Below are our point-by-point responses to your feedback. We sincerely hope the updated manuscript now meets the standards for publication in **SOIL.**

General comments

This paper presents an experiment conducted in Northeast China to assess the part of undegraded organic matter remaining in soil after straw or biochar addition after several duration (up to 360 days). This undegraded part is retrieved using a prior coprecipitation process, which then allows to separate undegraded from degraded matter using an external magnetic field. This experiment shall be credited with rather long incubation durations, and a clever chemical process to separate undegraded from degraded organic matter.

My biggest concern regarding this work, as exposed also by Referee #1, is that the given definition of SOM is not appropriate, placing the whole paper on a highly fragile stand. While it is of huge importance to accurately describe the dynamics of different fractions – POM, MAOM or any other, all of them are part of the SOM and must be considered as such. Therefore, I suggest that major revisions are applied to the article to clarify this matter, as one could easily dismiss the paper based on this *questionable definition, although the efforts put into the experiment make it largely worthwhile to publish.*

Specific comments

Here are a few more specific comments – I tried not to extend too much on what Referee #1 already pointed out.

Comments 1: *L.47: agree with R#1; unclear.*

Response: We sincerely appreciate the reviewer's careful feedback and agree that the original expression was ambiguous. To improve clarity and accuracy, we have revised the relevant content on Page 4, Lines 43–49 to precisely define the composition and function of soil organic matter (SOM). The revised text now reads: "Soil organic matter (SOM) is a complex assemblage of organic compounds formed through the decomposition and transformation of plant and animal residues. It exhibits a much stronger binding capacity to soil minerals than undecomposed or partially decomposed residues. This strong binding makes it one of the most stable organic fractions in soil and supports its long-term persistence. SOM originates from the partial microbial decomposition of plant detritus (Angst et al., 2021; Cotrufo et al., 2013; Dou et al., 2020; Vendig et al., 2023)."

Comments 2: *L.49: same.*

Response: We sincerely appreciate the reviewer's careful review and constructive comments on the clarity of the expression and the sufficiency of citations. To address the unclear definition of "the core of SOM" and enrich the supporting literature, we have revised the relevant content on Page 4, Lines 49-53 as follows: "Notably, the core of SOM refers to its labile and functional organic components with dynamic transformation properties. These components supply nutrients to the soil, sustain microbial activity, and regulate soil structure (Feng et al., 2025; Arumugam et al., 2025; Xu et al., 2026). Therefore, SOM should not be regarded merely as the passive accumulation of carbon-containing substances. ”

Comments 3: *L.169: I am not familiar with coprecipitated compounds. How do you make sure your organic matter does not separate from the iron particles even without biological decomposition? On the other hand – how do you ensure your organic matter is indeed de-magnetized after biological decomposition?*

Response: We sincerely appreciate the reviewer’s professional questions about the coprecipitation mechanism and the reliability of magnetic tracking. To address these concerns, we have supplemented a detailed explanation in the revised manuscript at Page 5-6, Lines 89-96: “ Iron particles form stable chemical bonds with organic materials, rather than simple physical adsorption. The surfaces of these materials contain abundant oxygen-containing functional groups such as hydroxyl, carboxyl, and carbonyl groups. During coprecipitation, these groups react with Fe^{2+} and Fe^{3+} to form coordinated and covalent bonds (Zhou et al., 2019; Duan et al., 2022). The resulting magnetic nanoparticles are uniformly embedded within the porous structure of the organic materials. This embedding prevents their detachment under non-biodegradation conditions, such as physical disturbance or soil hydration. When soil microorganisms decompose organic components, including cellulose, hemicellulose, and lignin, the functional groups that bind iron particles are disrupted. As a result, magnetic nanoparticles detach or disperse into non-magnetic fine particles smaller than 10 nm, which cannot be captured by magnetic fields. Consequently, decomposed residues completely lose their magnetism (Li et al., 2024).”

Comments 4: *L.182: agree with R#1; the use of ‘POM’ to designate the proportion of POC is disturbing. POM refers to the whole particulate organic matter fraction, which carbon forms the POC. This shouldn’t be used the way you define it.*

Response: We sincerely appreciate the reviewer’s precise feedback on the terminology confusion. To eliminate ambiguity and align with standard soil science definitions, we have revised the labeling of Eq. (2) on Page 11, Line 204 as follows:

$$POM - C\ Contribution\ (\%) = POC / SOC \times 100 \qquad (2)$$

Comments 5: *L.194: 'M1 is the dry mass of the applied straw or biochar' à you mean the mass of straw or biochar before magnetization?*

Response: We sincerely appreciate the reviewer's careful attention to the definition of M1, which helps to eliminate potential ambiguity. To clarify this point, we have revised the description of M1on Page 12, Lines 219-222 as follows:

" M1 is the dry mass of the unmagnetized straw or biochar applied in the CS and Bc treatments (g). For the magnetized treatments (MCS and MBc), the applied mass of magnetized materials was calculated based on the same M1 to ensure equal organic carbon input across all treatments."

Comments 6: *L.216: once again, I am not used to this technique. After coprecipitation, isn't the straw (or biochar) coated with iron particles? Couldn't this make it less 'attractive' for micro-organisms? From what you write, I can agree, from a stoichiometric point of view, that the coprecipitated organic matter has not been modified. However, could it now be kind of physically protected?*

Response: We sincerely appreciate the reviewer's careful question about potential physical protection and microbial accessibility of the magnetized organic materials. To clarify this concern, we have supplemented a detailed explanation in the revised manuscript at Page 13, Lines 248–254: "The metallic nanoparticles produced by coprecipitation were uniformly distributed on the surfaces of straw and biochar within a narrow size range. They formed a discontinuous and porous coating, rather than a dense and impermeable layer. This nanoscale coating does not block surface functional groups or internal pore structures, thereby preserving the natural accessibility of organic materials to soil microorganisms (Panda et al., 2026). As a result, the decomposition behavior of the magnetized materials remained consistent with that of the unmodified materials, supporting their reliability in tracking SOM transformation processes. "

Comments 7: *L.233: no, it did not necessarily become 'stabilized'! Specifically, you cannot talk about stabilization without precising the duration you consider: decadal scale? Centennial? Millenial? Or, you have to compare it: more stabilized than X.*

Response: We sincerely appreciate the reviewer's professional and rigorous comment on the terminology of organic matter stability. Following the reviewer's suggestion, we have removed the absolute and ambiguous term "stability" and revised the description to focus only on relative comparison within the timescale of our experiment. The relevant content on Page 14, Lines 273–276 is now revised to: "Conversely, the biochar fraction in MBc was significantly more resistant to microbial decomposition and more persistent than straw throughout the experiment, as evidenced by its consistently higher residue rate (92.48% at 360 d) compared to straw (54.55% at 360 d)."

Comments 8: *L.263: you stated earlier (L.233) that the MCS that underwent biological degradation had become more stable, but you say now that MBc is more stable, so stable that it couldn't undergo biological degradation… This also contradicts your claim (L.62-66) that 'undecomposed organic material' that is part of POM is 'short-term' and 'susceptible to decomposition'.*

Response: We sincerely appreciate the reviewer for pointing out the potential logical contradiction. We have revised the description on Page 16, Lines 304-307 to avoid absolute terms such as "stable" and to clarify the difference between straw and biochar:

"Conversely, the changes in these parameters for MBc residues were relatively small, indicating that the organic components of MBc residues were more resistant to microbial decomposition and transformation than straw residues within the 360-day incubation period."

Comments 9: *L.281 and 288: you could remind (in very few words) what -O and -D* *stand for, to help the reader.*

Response: We sincerely appreciate the reviewer's constructive suggestion for improving the readability of the manuscript. Following this advice, we have added brief annotations to clarify the meanings of -O and -D at the first appearance of MCS-O, MBc-O, MCS-D and MBc-D in the text (Page 17–18, Lines 329–339). The revised content is as follows:

"Notably, no significant differences were observed between the MCS-O and MBc-O (magnetized treatments without removing magnetic organic residues at harvest) and the CS and Bc treatments at any sampling time, supporting the applicability of magnetized materials in soil applications.

At 30, 60, 180, and 360 d of incubation, the mass proportion of the POM fraction (MP) in the CS treatment increased by 18.94%, 11.97%, 8.78%, and 7.05%, respectively, compared with CK. For the Bc treatment, the corresponding increases were 17.22%, 17.16%, 16.95%, and 16.83%, respectively. However, after the removal of magnetized organic residues from the soil, no significant changes in POM mass proportion were observed in the MCS-D and MBc-D (magnetized treatments with magnetic organic residues removed before analysis) treatments compared with CK."

Comments 10: *L.290: agree with R#1. It is not artificial: you even stated that Bc (and MBc) persists in soil and is not degraded by micro-organisms.*

Response: We sincerely appreciate the reviewer's precise comment on the misleading terminology, which helps us to improve the accuracy of our expression. Following the reviewer's suggestion, we have revised the relevant content on Page 18, Lines 339-342 by replacing the misleading term "artificial elevations" with the more accurate and appropriate phrase "residue-driven increases", and the revised sentence is as follows: "These results indicate that the increases in POM mass proportion observed in the CS and Bc treatments were residue-driven increases, arising from the retention of persistent amendment residues within the operationally defined >53 μm particulate fraction. "

Comments 11: *L.362: POM to SOM ratio and POC to SOC ratio shouldn't be the same…*

Response: We sincerely appreciate the reviewer for pointing out this conceptual confusion. We fully agree that POM (particulate organic matter, mass fraction) and POC (particulate organic carbon, carbon content) represent different properties, and they cannot be used interchangeably.

We have revised the relevant sentence to strictly use the accurate term "contribution of POC to total SOC (POC/SOC)" instead of the misleading "proportion of POM to total SOM", as follows: "The proportion of POC to total SOC (POC/SOC) in the CS and Bc treatments was significantly higher than that in CK. "

Comments 12: *Discussion: I agree with R#1. This section must be re-written to include undecomposed OM as 'valid' SOM and not treat it as 'artifical' or 'superficial' addition. Also, I don't fully understand: you expect POM to contribute to microbial activity; then say undecomposed POM is there for a short period of time (so, it is easily degraded? Meaning it contributes to microbial activity?); but undegraded POM doesn't count as true SOM. You must be clearer on the role of the different fractions. Either SOC is respired by micro-organisms, then it doesn't stay in soils; or you want SOC to persist, but then it must not be respired.*

Response: We sincerely appreciate the reviewer's rigorous and constructive comments on the Discussion section. We have carefully revised and restructured the relevant content in Section 4.2 (Pages 25–28, Lines 484–552) according to the reviewer's guidance, with major improvements as follows:

"The analysis of the weight proportion and organic carbon content of soil fractions presented in Figs. 3 and 4 clearly demonstrated that under the CS and Bc treatments, both the relative mass and organic carbon content of the POM fraction were consistently higher than those in the CK treatment. This finding aligns with those reported by Xie et al. (2014). The POM fraction, a valid component of soil organic matter (SOM), mainly consists of partially decomposed, chemically recalcitrant polymeric structures, such as acid-insoluble fibers formed through fragmentation, which could primarily originate from exogenous organic materials. Owing to its rapid responsiveness to environmental changes, POM can be highly sensitive to agricultural management practices (Christensen, 1992; Cotrufo et al., 2022; Guo et al., 2022; Rocci et al., 2021; Witzgall et al., 2021). Xie et al. demonstrated that increasing the input of organic materials directly influenced both SOM content and its proportion within the POM fraction. They attributed this phenomenon to the continuous accumulation of organic residues in soil induced by organic amendments (Xie et al., 2014). However, it is critical to distinguish between POM derived directly from undecomposed amendment residues and POM formed through microbial transformation of organic materials. This distinction clarifies the dynamic nature of SOM accumulation. It does not imply that residue-derived POM is an invalid component of SOM.

In this experiment, the POM mass proportion and organic carbon content for the MCS-D and MBc-D treatments were obtained by first applying the magnetic materials to the soil for a period of incubation, then extracting the magnetic residues from the soil, and subsequently testing the soil samples after removal of the undecomposed materials. The results showed that after the magnetic materials were extracted, the POM mass proportion and organic carbon content in the MCS and MBc treatments did not exhibit significant increases compared with the CK treatment. This proved that the increases in POM mass proportion and organic carbon content observed under the CS and Bc treatments were largely attributable to the direct input of straw and biochar materials, with most undecomposed organic residues remaining within the POM fraction. Moreover, the residue-driven increases in both POM mass proportion and organic carbon content under the CS treatment decreased over the incubation period, whereas the corresponding values under the Bc treatment remained nearly constant. These findings suggest that the quantity, quality, and incubation duration of organic residues are key factors driving the increase in the POM mass proportion and organic carbon content. Additionally, the extent of increase in the POM fraction was closely related to the amount and source of organic material applied.

The results shown in Fig. 4 revealed a pronounced decreasing trend in the POM fraction organic carbon content (POC) under CS treatment. This confirmed that the effect of organic material addition in the short term was predominantly reflected in the POM fraction, whereas a gradual increase in the MAOM fraction was observed. This aligned with the conclusions of Bhattacharyya et al. (2011), Brown et al. (2014), and Stewart et al. (2012) who reported that organic amendments were primarily retained in the POM fraction, which could be more prone to mineralization, while gains in the MAOM fraction remained limited. The MAOM fraction in soil has been mainly formed over decades to centuries through long-term weathering processes involving interactions between organic matter and secondary minerals. Due to this extremely slow formation process, MAOM accumulation can be difficult to achieve in the short term (Kleber et al., 2007; Slessarev et al., 2022). Moreover, because microorganisms struggle to utilize chemically recalcitrant components within plant residues, decomposition of these highly processed structural organic residues and POM components has been reported to cause MAOM formation (Cotrufo et al., 2015). This explains why the organic carbon data for the Bc treatment in this study (Figs. 3 and 4) indicated that most undecomposed organic residues remained preserved within the POM fraction, thereby reducing the MAOM contribution to the soil. This also accounted for the consistently higher MAOM contribution observed in the CS and Bc treatments than in the MCS-D and MBc-D treatments.

Currently, some studies have suggested that abundant POM can be crucial for agroecosystem functioning and crop productivity, thereby advocating for greater research focusing on POM increments (Wood et al., 2016). However, the results of this study indicated that within the POM fraction, the dominant influencing factors were the quantity and quality of undecomposed organic residues, with temporal factors exerting a significant impact. Although the POM fraction plays an important role in nutrient supply, microbial activity promotion, and soil structure regulation, the indiscriminate addition of organic materials to soil primarily increases the amount of undecomposed organic residues, most of which reside in the POM fraction over short time periods. This practice directly increases the measured SOM content. However, most of the short-term increase originated from undecomposed amendment residues retained in the POM fraction rather than from microbially transformed and stabilized organic matter. These findings highlight the need to distinguish between residue-derived and microbially transformed POM when interpreting SOM measurements, particularly in short-term incubation studies. Without this distinction, assessments of SOM dynamics may overestimate the short-term residue-driven increases in POM. This could lead to misinterpretation of SOM stabilization and biased evaluation of stable soil carbon pools in systems receiving recent organic amendments."

Comments 13: *My biggest concern regarding this work, as exposed also by Referee #1, is that the given definition of SOM is not appropriate, placing the whole paper on a highly fragile stand. While it is of huge importance to accurately describe the dynamics of different fractions – POM, MAOM or any other, all of them are part of the SOM and must be considered as such. Therefore, I suggest that major revisions are applied to the article to clarify this matter, as one could easily dismiss the paper based on this questionable definition, although the efforts put into the experiment make it largely worthwhile to publish.*

Response: We sincerely appreciate the reviewer's professional and constructive suggestions on refining the core conclusions of this study. We fully agree that the expression "overestimation of soil organic matter/soil organic carbon" is prone to ambiguity.

In accordance with the reviewer's advice, we have reorganized and revised the presentation of the core viewpoints in the manuscript.

3. We have removed all expressions related to "overestimation of SOM/SOC" throughout the text;

4. We have refocused the key conclusion on the essential nature of POM increment: the increase in the operationally defined particulate organic matter (POM) fraction following organic material addition is often misinterpreted as evidence of SOM stabilization or the formation of transformed organic matter, whereas in reality, this increment largely originates from undecomposed, untransformed amendment residues rather than microbially mediated stable SOM formation.

The following is the abstract section of the article: “Soil organic matter (SOM) is a complex mixture of organic compounds derived from the decomposition of plant and animal residues. SOM that has undergone microbial transformation and formed stable associations with minerals represents the stabilized fraction of soil organic carbon, which differs from the simple physical accumulation of external organic materials. Current understanding suggests that particulate organic matter (POM) includes both undecomposed and partially decomposed residues. Conventional analytical methods cannot clearly distinguish undecomposed external residues from native SOM. Consequently, increases in operationally defined POM are often misinterpreted as evidence of SOM stabilization or microbially transformed organic carbon formation. In this study, straw and biochar were magnetized through chemical coprecipitation and applied to the soil. Magnetic separation was performed at successive incubation times to isolate undegraded magnetic residues, thereby enabling more accurate tracking of SOM dynamics. Five treatments were established: blank control (CK), untreated straw (CS), untreated biochar with carbon input equivalent to straw (Bc), magnetized straw (MCS), and magnetized biochar (MBc). The recovery of magnetized straw residues declined continuously and reached 54.55% after 360 d, whereas biochar residues remained highly persistent at 92.48%. In the CS and Bc treatments, the organic carbon content of POM fractions and their proportion in total SOM were consistently higher than in CK, particularly during early incubation. However, after removing undegraded residues by magnetic separation (MCS-D and MBc-D), values were close to those of CK. This result indicates that the observed POM increases mainly originated from undecomposed external residues rather than microbially stabilized SOM. On day 30, the apparent increase in particulate organic carbon (POC) was 63.48% in CS and 58.99% in Bc. Over time, the apparent POC increase in CS declined to 15.34% by day 360, whereas that in Bc remained high (53.71%). These findings suggest that interpreting total POM as stabilized or microbially transformed SOM may lead to misleading conclusions about SOM stability, particularly in short-term incubations or agroecosystems receiving fresh organic amendments. This study provides a basis for a more accurate evaluation of soil organic matter transformation dynamics and content.”