I strongly support field research and the cropping system approach instead of individual practice comparison and believe in the extra value of long-term experiments. Thus, I feel that this research will definitely contribute to the existing knowledge. Nevertheless, as the other reviewers also commented, the manuscript needs improvements before being published.

I considered all the comments of the other reviewers and will not repeat them as I mostly agree with both. I will indeed stress though that when in a cropping system the term sustainability is included then all aspects should be considered (social economic and environmental).

I hope that my recommendations along with those of the other reviewers will help you to improve the manuscript.

Thank you very much for your consideration and positive reaction. Your comments and suggestions will undoubtedly help to improve the manuscript.

The title would be more representative if it was something like "the effects of long-term conservation management on topsoil structure".

It is true that our findings are too narrow to be a comprehensive contribution to the sustainability of Mediterranean agrosystems considering all the aspect that sustainability development really involved. In fact, our main objective is the evaluation of an innovative -and pioneer in our region (Navarre)- soil and crops management strategy on topsoil properties. Moreover, there is -to our knowledge- no other agricultural field in the whole region of Navarre where soil and crop management as proposed herein (OPM) is practiced and even less for almost two decades, with the exception of precisely our small OPM test area. The uniqueness of our OPM area and then the relevance of our work would be better and clearly pointed out in the text, especially in the Introduction and in section 2.1. (Study site [former 'zone'] and treaments).

Following the reviewer suggestion and in accordance also to reviewer#1 a more appropriate title could be: *Effects of innovative long-term soil and crop management on topsoil properties of a Mediterranean soil based on detailed water retention curves.*

In the introduction, a more thorough review of the effects of the specific management practices on soil quality or at least on the WRC and soil aggregates should be included, and specific scientific questions and hypotheses should be structured.

We agree, the Introduction would be improved by incorporating the following information:

"Conservation agriculture (CA), and other soil management strategies implying a reduction of tillage have been reported to reduce soil degradation in different agroecological situations (Verhulst et al., 2010; Sartori et al., 2022), and in some cases are designed for this purpose (Virto et al., 2015).

The reasons reported for its adoption in Europe are several. In Northern Europe soil erosion control, soil crusting in loamy soils and the need to increase soil organic C storage, as well as soil trafficability are widely cited as reasons for CA implementation (Lahmar et al., 2007). In the Mediterranean countries, soil water storage and water-use efficiency can be added to this list of reasons (De Turdonnet et al., 2007). However, different studies show that the effectiveness of CA in solving these problems can be site-dependent (Costantini et al., 2020; Chenu et al., 2019). In fact, the most widely reported benefits of CA in Southwestern Europe in relation to erosion are the increased soil infiltrability and/or the protective effect of crop residues on the soil surface (Gómez et al., 2009; Espejo-Pérez et al., 2013; Virto et al., 2015), although this seems to be related to the type of soil and to the presence and activity of earthworms. In Spain, the soil water-retention capacity has been observed to be greater in semi-arid land under no-tillage (Fernández-Ugalde et al., 2009; Bescansa et al., 2006).

Other positive effects of CA on soil quality observed in semi-arid rainfed agricultural systems in Spain are related to soil organic C and nutrients storage (Ordóñez Fernández et al., 2007)".

On the other hand, we prefer not to include a hypothesis but instead the objective was reformulated more concisely: "The objective of this study was to assess the continuous application, throughout 18 years, of an innovative soil and crop management –in comparison with conventional management– for the improvement of the soil physical condition, and the optimization of the soil water balance, in rainfed cereal agrosystems in semi-arid land. This evaluation will be carried out through the analysis of detailed SWRCs and soil structure, i.e., the size-distribution of stable macro- and microaggregates and their relation to organic C storage."

The section materials and methods should be written in a clearer way.

Starting from the description of the treatments where more details should be included, such as the frequency and type of organic amendment and cover crops rather than occasional use. Also the type of mineral fertilization the quantities and frequency. Possibly a table with the crop rotation history and amendments application would be useful.

The reviewer is right. Description of the cover crops should be added to the text, and can be explained as follows:

"In OPM, both grain and straw were also removed in the 11 first years of implementation, and only stubble remained on the surface of soil when direct seeding was implemented with minimal soil perturbation. Since then, and for the 7 remaining years, the procedure was slightly modified, and only grain was removed at harvest. Therefore, chopped straw and stubble remained on the surface of the soil before direct seeding with no disruption of the soil surface. At the same time, cover crops were introduced in the system thought it is a risky practice in rainfed Mediterranean agrosystem characterized by warm and dry summers. As such, summer cover was routinely granted in this system by letting spontaneous vegetation grow in the summer, after harvest. This vegetation was dried with herbicides before seeding the crash crops in the Fall. Also, only one year the winter crop used was *Vicia villosa* Roth, and served as a cover crop for sorghum (*Sorghum vulgare* L.), which was successfully grown in the spring-fall season despite the limiting water availability in the area."

Also, more information about fertilization should be added to the text, and can be explained as follows:

"In both treatments, mineral fertilization consisted of phosphorus addition before seeding (120-150 $kg·ha^{-1}$ of triple superphosphate 0-46-0) and nitrogen supply of 180 $kg N·ha^{-1}$ (split and distributed into two cover dressings at 60 $kg N·ha^{-1}$ and 120 $kg N·ha^{-1}$ in January and March, respectively) as urea. Organic fertilization was not used in any of the study treatments until 2021, in which an organic amendment was applied to the soil without disturbing the surface in the OPM treatment. After harvest, pig slurry was applied with an average concentration of 2.5 $kg N·m^{-3}$, by means of a tanker equipped with a system of hanging pipes that deposit the product a few centimeters above the ground and at a time close to a forecasted rainfall event. The application rate was 60 $m^3·ha^{-1}$ of slurry. These rates are within the legal limits established by legislation for groundwater protection against pollution caused by nitrates from agricultural sources (EU Directive 91/676 (Council of the European Union, 2008)), as the area is within a vulnerable watershed according to this Directive."

The soil's initial characteristics (for the variables that are available) will give valuable information on the effects. That is an extra value of the long term experiments and you should present it.

Comparing the changes undergone by the soil under the different agricultural systems with the soil in its initial or natural state –a sort of control plot– would be ideal. However, soils in natural conditions are not found in the entire study area: they are all agricultural soils. Instead, we considered that our *initial* soil is that under conventional management (CM), and we intend to find out changes in its physical conditions induced by the proposed soil and crop management after a long period of time (almost two decades).

Focusing on the sampling procedures and especially the mixed subsample for the determination of the distribution of the aggregate, it is not clear how the required replication for the statistical analysis (at least 3 samples) happened as you indicate that "three sub-samples per sampling point, which were then mixed to obtain a composite sample)". As it is written it is not clear if you ended up with one composite sample per treatment or with three samples one at each sampling point.

There are 3 composite samples for treatment each of them consisted of three sub-samples. We will clearly indicate this in the final version.

In L: 105 you mention "Organic fertilization was not used in any of the study treatments until the experiment year in which an organic amendment was applied to the soil without disturbing the surface in the OPM treatment." What do you mean by experiment year? Before you mentioned that in the OPM there is frequent application of organic amendments. Do you mean before the beginning of the experiment? Ie 18 years ago? Rephrase the sentence.

Sorry for this ambiguity, experiment year means 2021; this sentence should be reformulated: "Organic fertilization was not used in any of the study treatments until 2021, in which an organic amendment was applied to the soil without disturbing the surface in the OPM treatment".

In the results as well as in Table 1 you should indicate where the differences were significant. Which post-hoc test did you perform?

The reviewer is right. At the request also of reviewer #2, Table 1 has been completed (see below) and significant differences have been marked in bold. The statistical analysis used was the ANOVA test.

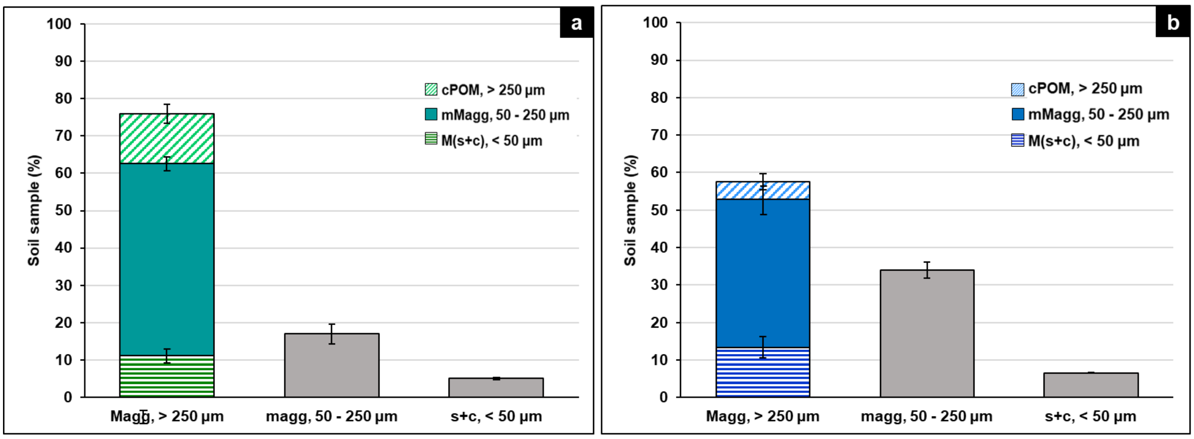
Table 1. Physical-chemical properties of the topsoil (0-30 cm) in OPM and CM treatments and the textural characterization of both treatments. Mean ± standard deviation of the mean (n = 3). Statistically significant differences ($p < 0.05$) are in bold.

Treatment	**Optimized (OPM)**	**Conventional (CM)**
Bulk density (0-5 cm) ($g \cdot cm^{-3}$)	1.26 ± 0.05	1.26 ± 0.15
pH	8.00 ± 0.05	8.01 ± 0.01
Organic C (%)	**1.80 ± 0.10**	**1.51 ± 0.14**
CE ($\mu S \cdot cm^{-1}$)	**483 ± 5.66**	**795 ± 4.24**
Carbonates (%)	**31.6 ± 0.09**	**32.5 ± 0.14**
Sand (Coarse) (%)	5.05 ± 0.08	5.79 ± 0.33
Sand (Fine) (%)	30.9 ± 1.00	31.7 ± 1.25
Silt (%)	47.2 ± 1.23	43.7 ± 0.93
Clay (%)	**16.9 ± 0.46**	**18.5 ± 0.46**
Texture (USDA)	***Loam***	***Loam***

In Figure 4, you should clearly mention what the error bars represent, you should include error bars in the in-between Magg fractions also to allow comparisons, and letters on top of each bar to indicate significant differences between the two treatments.

Thanks for your sound suggestion. Following the reviewer's recommendations, we would modify Figure 4 as follows, including all error bars, and a sentence has been added to the caption to indicate the significance of differences between treatments:

Figure 4. Size-distribution of stable aggregates and individual particles in the soil under OPM (a) and CM (b) Magg: Macroaggregates; magg: microaggregates; mMagg: microaggragates within macroaggregates. s+c: silt+clay fraction; cPOM: coarse particulate organic matter >250 µm and sand particles. The error bars represent the standard error, which is the standard deviation divided by the square root of the sample size. All aggregate fractions are significantly different ($p < 0.05$) between OPM and CM, with the exception of mMagg.



Focusing more on the aggregates the authors refer to the hierarchical aggregate order concept by Tisdall and Oades (1982). The wrongly present that the authors cited, mention that the magg are bonded together to form Magg. What is actually mentioned in the majority of the cited papers (eg Oades, 1984; Six et al., 1999, 2004;) is what was revised by Oades (1984) and validated by Angers (1997) that magg are formed within the Magg and not before these. The authors should correct all this paragraph and explain their results accordingly.

We agree with the reviewer on this correction, and have changed the text accordingly. In fact, our purpose with this part of the study was to test the effect of OPM on soil aggregation, and on the stabilizing agents of soil structure. Our findings that OPM resulted in more stable macroaggregates can be related to the observed gains in coarse particulate organic matter and microbial activity and biomass, which can be considered related to the stabilization of macroaggregates (inside which microaggregates would form).

In the results and discussion section, the authors should interpret their results in terms of causes, compared them with the existing literature in a more detailed way, and give practical recommendations according to their results.

In our original submission we had tried to interpret our results as suggested by the reviewer, but also considering the extension limitations of a manuscript of this type.

Following this comment and other from other reviewers, we envisage to extend this discussion at different levels:

- First, in relation to the SWRCs, we will complete the information with changes proposed by the reviewer #2 and #5. On the one hand, we will incorporate a new bimodal equation suggested by reviewer #2 and proposed by Dexter et al. (2008). Furthermore, following the recommendations of this same reviewer, the adjusted parameters of the van Genucthen equation will be added (see more details in the answers to reviewer #2).

  On the other hand, following the suggestion of reviewer #5 we have determined a new index based on the integration of SWRCs and named water retention energy index (WRa) (Armindo and Wendroth, 2016). The accuracy of this index depends on the degree of detail of the SWRCs. Additionally, this index presents an adequate sensitivity for smaller-scale, high-precision applications and for capturing the dynamic evolution of the soil physical state (Armindo and Wendroth, 2016) (see more details in the answers to reviewer #5).

- Second, in relation to aggregation and organic C, we aim to develop the discussion by adding a new discussion on the relevance of the hierarchical model of aggregation, and its relation to organic matter cycling, as follows:

  "The main implication of this hierarchy is that agricultural management primarily affects the less stable macroaggregates, while the more stable microaggregates are less influenced. Implicit in this concept is the fact that aggregates form sequentially (Jarvis, 2012).

  Although the relationship between organic matter cycling and soil structural stabilization has been observed to be soil-dependent (Rasmussen et al., 2018), and the calcareous nature of the studied soil may interact with it by stabilizing Magg and magg to a greater extent than in Ca-free soils (Fernández-Ugalde et al., 2011; Rowley et al., 2018, 2021), these results suggest that the response of soil structure to the reduction of tillage and the increase in organic C inputs corresponded to that observed previously in other soil types (Six et al., 2004; Fernández-Ugalde et al., 2016), and in soils of the same type in the region (Virto et al., 2007; Yagüe et al., 2016)."

- Third, in relation to organic C storage, as indicated in the response to reviewer #1 (Joan Bouma), we are proposing to add a whole new section to the R&D section entitled "Organic C storage and soil microbial diversity".

- Finally, in the conclusions of our work, we aim to provide some preliminary recommendations for agricultural soil management in the region, based on the design of our OPM system.

  “In summary, our results suggest that this type of system that includes, among other techniques, the suppression of tillage, crop rotations, and the application of organic amendments, is providing good results from the viewpoint of the physical quality of the soil, and can be recommended for a higher soil sustainability in Mediterranean agrosystems. However, the optimized management analyzed herein is not currently a widespread practice in the region, most likely because the high initial investment and the farmer’s concern that crop yield would be reduced. This work illustrates the need for an adequate assessment and dissemination to overcome these reluctances of farmers and other potential barriers to the adoption of this type of systems.”

References

Armindo, R. A. and Wendroth, O.: Physical Soil Structure Evaluation based on Hydraulic Energy Functions, Soil Sci. Soc. Am. J., 80, 1167–1180, https://doi.org/10.2136/sssaj2016.03.0058, 2016.

Bescansa, P., Imaz, M. J., Virto, I., Enrique, A., and Hoogmoed, W. B.: Soil water retention as affected by tillage and residue management in semiarid Spain, Soil Tillage Res., 87, 19–27, https://doi.org/10.1016/j.still.2005.02.028, 2006.

Chenu, C., Angers, D. A., Barré, P., Derrien, D., Arrouays, D., and Balesdent, J.: Increasing organic stocks in agricultural soils: Knowledge gaps and potential innovations, Soil Tillage Res., 188, 41–52, https://doi.org/10.1016/j.still.2018.04.011, 2019.

Costantini, E. A. C., Antichi, D., Almagro, M., Hedlund, K., Sarno, G., and Virto, I.: Local adaptation strategies to increase or maintain soil organic carbon content under arable farming in Europe: Inspirational ideas for setting operational groups within the European innovation partnership, J. Rural Stud., 79, 102–115, https://doi.org/10.1016/j.jrurstud.2020.08.005, 2020.

Council of the European Union: Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources, , L 269, 1–15, 2008.

Dexter, A. R., Czyz, E. A., Richard, G., and Reszkowska, A.: A user-friendly water retention function that takes account of the textural and structural pore spaces in soil, Geoderma, 143, 243–253, https://doi.org/10.1016/j.geoderma.2007.11.010, 2008.

Espejo-Pérez, A. J., Rodríguez-Lizana, A., Ordóñez, R., and Giráldez, J. V.: Soil Loss and Runoff Reduction in Olive-Tree Dry-Farming with Cover Crops, Soil Sci. Soc. Am. J., 77, 2140–2148, https://doi.org/10.2136/sssaj2013.06.0250, 2013.

Fernández-Ugalde, O., Virto, I., Bescansa, P., Imaz, M. J., Enrique, A., and Karlen, D. L.: No-tillage improvement of soil physical quality in calcareous, degradation-prone, semiarid soils, Soil Tillage Res., 106, 29–35, https://doi.org/10.1016/j.still.2009.09.012, 2009.

Fernández-Ugalde, O., Virto, I., Barré, P., Gartzia-Bengoetxea, N., Enrique, A., Imaz, M. J., and Bescansa, P.: Effect of carbonates on the hierarchical model of aggregation in calcareous semi-arid Mediterranean soils, Geoderma, 164, 203–214, https://doi.org/10.1016/j.geoderma.2011.06.008, 2011.

Fernández-Ugalde, O., Barré, P., Virto, I., Hubert, F., Billiou, D., and Chenu, C.: Does phyllosilicate mineralogy explain organic matter stabilization in different particle-size fractions in a 19-year C3/C4 chronosequence in a temperate Cambisol?, Geoderma, 264, 171–178, https://doi.org/10.1016/j.geoderma.2015.10.017, 2016.

Gómez, J. A., Sobrinho, T. A., Giráldez, J. V., and Fereres, E.: Soil management effects on runoff, erosion and soil properties in an olive grove of Southern Spain, Soil Tillage Res., 102, 5–13, https://doi.org/10.1016/j.still.2008.05.005, 2009.

Jarvis, S.: Landmark papers, Eur. J. Soil Sci., 63, 1–21, https://doi.org/10.1111/j.1365-2389.2011.01408.x, 2012.

Lahmar, R., Arrúe, J. L., Denardin, J. E., Gupta, R. K., Ribeiro, M. F. S., de Tourdonnet, S., Abrol, I. P., Barz, P., de Benito, A., Bianchini, A., and Al., E.: Knowledge Assessment and Sharing on Sustainable Agriculture. Synthesis Report;, Montpellier, France, 125 pp., 2007.

Ordóñez Fernández, R., González Fernández, P., Giráldez Cervera, J. V., and Perea Torres, F.: Soil properties and crop yields after 21 years of direct drilling trials in southern Spain, Soil Tillage Res., 94, 47–54, https://doi.org/10.1016/j.still.2006.07.003, 2007.

Rasmussen, C., Heckman, K., Wieder, W. R., Keiluweit, M., Lawrence, C. R., Berhe, A. A., Blankinship, J. C., Crow, S. E., Druhan, J. L., Hicks Pries, C. E., Marin-Spiotta, E., Plante, A. F., Schädel, C., Schimel, J. P., Sierra, C. A., Thompson, A., and Wagai, R.: Beyond clay: towards an improved set of variables for predicting soil organic matter content, Biogeochemistry, 137, 297–306, https://doi.org/10.1007/s10533-018-0424-3, 2018.

Rowley, M. C., Grand, S., and Verrecchia, É. P.: Calcium-mediated stabilisation of soil organic carbon, Biogeochemistry, 137, 27–49, https://doi.org/10.1007/s10533-017-0410-1, 2018.

Rowley, M. C., Grand, S., Spangenberg, J. E., and Verrecchia, E. P.: Evidence linking calcium to increased organo-mineral association in soils, Biogeochemistry, 153, 223–241, https://doi.org/10.1007/s10533-021-00779-7, 2021.

Sartori, F., Piccoli, I., Polese, R., and Berti, A.: Transition to conservation agriculture: How tillage intensity and covering affect soil physical parameters, 8, 213–222, https://doi.org/10.5194/soil-8-213-2022, 2022.

Six, J., Bossuyt, H., Degryze, S., and Denef, K.: A history of research on the link between (micro)aggregates, soil biota, and soil organic matter dynamics, Soil Tillage Res., 79, 7–31, https://doi.org/10.1016/j.still.2004.03.008, 2004.

De Turdonnet, S., Nozières, A., Barz, P., Chenu, C., Düring, R.-A., Frielinghaus, M., Kõlli, R. ., Kubat, J., Magid, J., Medvedev, V., and Al., E.: Comprehensive Inventory and Assessment of Existing Knowledge on Sustainable Agriculture in the European Platform of KASSA, Montpellier, France, 55 pp., 2007.

Verhulst, N., Govaerts, B., Verachtert, E., Mezzalama, M., Wall, P. C., Chocobar, a, Deckers, J., and Sayre, K. D.: Improving Soil Quality for Sustainable Production Systems?, Food Secur. Soil Qual., 1–55, 2010.

Virto, I., Imaz, M. J., Enrique, A., Hoogmoed, W., and Bescansa, P.: Burning crop residues under no-till in semi-arid land, Northern Spain - Effects on soil organic matter, aggregation, and earthworm populations, Aust. J. Soil Res., 45, 414–421, https://doi.org/10.1071/SR07021, 2007.

Virto, I., Imaz, M. J., Fernández-Ugalde, O., Gartzia-Bengoetxea, N., Enrique, A., and Bescansa, P.: Soil degradation and soil quality in Western Europe: Current situation and future perspectives, Sustain., 7, 313–365, https://doi.org/10.3390/su7010313, 2015.

Yagüe, M. R., Domingo-Olivé, F., Bosch-Serra, À. D., Poch, R. M., and Boixadera, J.: Dairy Cattle Manure Effects on Soil Quality: Porosity, Earthworms, Aggregates and Soil Organic Carbon Fractions, L. Degrad. Dev., 27, 1753–1762, https://doi.org/10.1002/ldr.2477, 2016.