Response to reviewer comments

Title: The effects of sealing on urban soil carbon and nutrients

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Editor's comments

We thank the editor and the reviewers once again for their comments and suggestions. We hope that the changes discussed here will lead to a clearer and improved manuscript that is considered satisfactory for publication.

RC1: Anonymous Referee #1

I have read <The effects of sealing on urban soil carbon and nutrients> with interest, of which the topic falls in the scope of SOIL.

This work investigated the effects of artificial soil sealing in urban areas on soil properties, soil carbon and soil nutrients stocks. The results highlighted the potential importance of anthropogenic additions to soil carbon stocks under sealed surface. In addition, this work reported some interesting results such as the sealed undisturbed soil had higher ammonium content but lower nitrate content as compared with the sealed anthropogenic soil.

We thank you for taking the time to read and review our manuscript, it is gratefully appreciated, and we hope to make improvements to the paper as a result. We address your comments individually below.

My major concern is the classification of sealed undisturbed (SU) soil and sealed anthropogenic soil (SA). The urban sealed soil that had >40% mass proportion of coarse sand fraction (particles in 2-200 µm are coarse sand according to IUSS) was considered as SA, because visible artefacts were found in these soils. It seems a little arbitrary, in my opinion, and more details should be given to facilitate the readers to distinguish SA and SU, such as the specific mass proportion of artefacts of the SA. The artefacts proportion is a more important index to classify anthropogenic soil. Since the SU and SA had different soil textures, the effects of soil texture on soil carbon and soil nutrients should be considered/discussed.

Thank you for your comments on the classification of SU and SA soils. We agree the threshold of 40% mass proportion of material >200 µm is arbitrary to define anthropogenic soils. We note that many soil classifications may use arbitrary thresholds to define characteristics, and so whilst we acknowledge this, we found it the best description for the soils we sampled. The mass proportion of artefacts, while a useful index, would be difficult to measure in these soils as artefacts were often fragmented and collected in the >200 µm fraction. Smaller fragments of brick, charcoal and cement were also found in the <200 µm fraction, and indicated that the artefacts had been broken up and distributed throughout the soil. Thus, distinguishing between anthropogenic particles and 'natural' particles that may otherwise have been there would make this approach impractical and subjective. We acknowledge the limitations of our method but chose it as the most consistent repeatable

approach for our samples and to enable the investigation into whether anthropogenic additions had any effect on the results.

We will clarify this in the text at line 107 as follows:

"Wet sieving was undertaken on subsamples of the sealed soils to distinguish between SU and SA soils. We used the proportion of materials in the > 200 µm fraction to determine the level of anthropogenic additions and serve as a proxy for the proportion of artefacts. Soils with visible artefacts generally exhibited more than 40 % of subsample mass in the >200 µm fraction; thus, subsamples with more than 40 % mass in the >200 µm fraction were classed as SA soils, and those with less than 40 % in the >200 µm fraction were classed as SU soils. The fragmentation of artefacts into smaller fractions made it impractical and inaccurate to use a measure the mass of artefacts alone. Using material >200 µm served to describe the samples well and enabled a consistent comparison between anthropogenic and undisturbed soils."

Specific comments:

Line 14-15, ambiguous, please revise.

- We agree this was ambiguous and will update the text to: Line 15: "Anthropogenic additions led to carbon stocks equivalent to or larger than those in greenspaces; this was likely a result of charcoal additions, leading to carbon stores with long residence times."

Line 72, soil nutrient dynamic is a broad concept, which includes nitrogen nitrification, phosphorus sorption, etc. This work did not investigate specific soil nutrients dynamics. Please revise.

- We agree and will update the text to: Line 82: "nutrient contents and stocks".

Line 175 and in other places, p = 0.006? Please add ''='' .

- Thank you for pointing this out. We will update this and the other occurrences of this in the text.

Line 342-343, urbanization will result in phosphorus enriched in soil (e.g. Water, 2019, 11: 2504). This may influence phosphorus content and stock of unban sealed soils depending on when the soil was anthropogenically covered. If the urban soil, which is already phosphorus enriched, is converted to urban sealed soil, the resulted urban sealed soil may have higher phosphorus content.

- Thank you for bringing this study to our attention. We agree that if soils had recently been sealed they may have higher P contents; however, some may be lost due to the topsoil removal that occurs prior to sealing. We will add this reference into the text as follows: Line 359: "In addition, P may be higher in some studies where sealing has occurred more recently, as urban greenspace soils can have high P contents (Qin et al., 2019), however, length of time sealed was not included in this study."

Table 1, the statistical analysis result is not easy to be understood. Actually, these data was also presented in figures. Please incorporate the statistical results in the figures and delete Table 1.

- Thank you for this observation. We will do as you suggest and incorporate the statistical results into the figures and move table 1 to Appendix A.

RC2: Anonymous Referee #2

General comments

The manuscript “The effects of sealing on urban soil carbon and nutrients” by Roisin O'Riordan, Jess Davies, Carly Stevens and John N. Quinton presents an interesting study on sealed and unsealed urban soils (Technosols), their physical soil properties and their carbon and nutrient status. The data and information presented is useful to improve the understanding of urban soil carbon and nutrient budgets. Overall, the work is an important contribution to understanding the role and properties of urban soils, which have received insufficient attention to date. Therefore, I suggest a publication after some corrections.

I enjoyed to read the manuscript and think that this contribution fits perfect within the scope of SOIL and would be on great interest for SOIL readers. I leave suggestions, mainly as specific comments to improve the manuscript by clarifying small issues and some technical corrections. Very good presentation of the results. My comments are therefore mostly limited to the methods and the discussion. However, I have one major concern regarding the documentation of the urban soils studied (see point 6 specific comments).

I look forward to seeing this work published as an important contribution to the so far underrepresented field of urban soil studies.

We thank the reviewer for their comments and the time taken to read the manuscript and make these very useful suggestions which are gratefully appreciated. We address your comments individually below and hope to improve the paper as a result.

Specific comments

1. In addition to the important and as yet largely unexplored ecosystem services provided by urban soils (l. 24-27), these are also always associated with contamination (urban soil pollution through e.g., heavy metals). The authors should consider in the introduction for the relevance of the topic as well as in the discussion whether this point should be (briefly) included.
   Thank you for mentioning this; it is an important point. Contamination would be very different between the greenspace and sealed soils, and the anthropogenic additions could themselves be considered a form of contamination. We will update the introduction to include a brief discussion of this.
2. Authors should consider to include a brief discussion on urban soil structure (soil formation, stratigraphy) and spatial heterogeneity (l. 30-35). The role of urban soils, their functions and the fact that so far too little attention has been paid to them in research should be more highlighted in the introduction. See also: Lehmann, A. and Stahr, K.: Nature and significance of anthropogenic urban soils, J Soils Sediments, 7, 247–260, 530 doi:10.1065/jss2007.06.235, 2007.
   We agree that this is important. We will include further detail in the introduction on urban soil structure and spatial heterogeneity, and the reference you provide. We will also highlight how urban soils have rarely been studied to date.
3. Author’s mention “urban ecosystem services” (e.g., l. 67). These should be clearly defined in the introduction. With reference to the question: Which urban ecosystem services can be influenced by urban soils and their C and nutrient status?

We will update this to clarify the role that urban soil plays in providing ecosystem services in urban areas.

4. Regarding the study area map (l. 82) a localization of Manchester on the basis of a general map (location in the UK) would be helpful. Furthermore, the question arises whether the sampling sites in the north-east belong to the town of Rochdale? If so, this should be indicated. Either by labelling or by an additional detailed map in the planal map.
   Thank you for highlighting this. We will update the map to show the location of Manchester within the UK, and will label the town of Rochdale to the north-east on a more detailed map.
5. Within the section "2.2. Soil sampling" I would like to encourage to add some additional information: a) describe the "litter layer" in l. 89, b) describe "imported construction materials" in l. 90, c) give information about the bulk density cores used (e.g., material, diameter). Additionally, information about the sample transport and storage (bags, vessels?) for the fresh soil samples are missing. Please add the information with regard to the subsequent analyses (e.g., C-analytics and plastic vessels would be incompatible)
   We will add further detail and update the text to the following:
   a) (L. 89) All soils were sampled to a depth of 10 cm of available soil. In greenspaces, soils were sampled from open grassed areas where litter consisted of roots and dead grass leaves. The turf and root mat were removed and the soil was sampled down to 10 cm.
   b) (L. 90) In sealed soils, imported construction materials consisted of limestone gravel or chips, construction rubble including brick or concrete, sharp sand, charcoal and ash. Profiles and horizons were not consistent across the sites due to the heterogeneous nature of soil sealing. In general, profiles consisted of a sealed surface, various layers of road or pavement foundation materials, and the soil underneath which was often a clay rich subsoil. The depth of construction materials varied from 30-110cm depth, but most samples were collected between 60-80cm depth, sampling the top 10cm of available soil under the construction materials.
   c) (L. 92) At all sites two samples were collected, one using a metal bulk density core (6 cm diameter), and a second sample using a trowel for additional analyses using fresh soil. Samples were collected in plastic bags, kept in a cool box while transported, and refrigerated until fresh soil analyses were undertaken within one week.
      Please could the reviewer expand on their comment on carbon analytics and plastic vessels?
6. Regarding the soil sampling and urban soil categorization I miss information on the soil description as in the case of sealed soils: exact profile structure, soil type, texture, other properties and, in the case of greenspace soils, the horizon structure, texture and a designation according to WRB. Due to the lack of research on urban soils and their high heterogeneity, it would be desirable to obtain more detailed information on soil structure. For me, this leads to one (and the only) major concern, since differences in the later interpretation of the data obtained can also be attributed to the heterogeneity of the urban soils. I would therefore suggest the following improvements:
   - Add a brief description of profile structures, horizons and a designation according to WRB to the different urban soil categories within section 2.3.1
   - In greenspaces, soils were sampled only to 10cm depth and the full profile was not excavated, thus description of the profile and horizons is not possible. For the sealed soils, horizons were not consistent across the various sites sampled, in part, due to anthropogenic disturbance. We acknowledge that further detail on these soils would be beneficial for the study of urban soils, however unfortunately, we are not able to

provide all these additional details, for example the diagnostic criteria required by WRB, in this paper.

- Define and name the type of artefacts (l. 101) found within the section 2.3.1 or later within the results
- We will add the text: (L. 117) These artefacts appeared to be fragments of the materials used in the road or pavement construction (as described above) which had disintegrated and been mixed into the soil.
- Figure 2 could be supplemented by specifying soil horizons according to FAO 2015, brief description or naming of the materials (especially for the sealing materials) and depth ranges.
- More information will now be provided with additional text (please see 5b) as well as the photographs and brief descriptions of the profiles in Appendix A.
- Finally, it would be easier for the reader to get an impression if selected photos of the sampling sites and, if applicable, of the profile structure were summarized with a short description in an SI.
- Thank you for this suggestion, we will include some photographs in Appendix A.

7. A clearer formulation of which sample was used for each analysis should be provided (e.g., l. 128).
   We will clarify which samples were used for which analysis by adding the following text: Following drying to 70 °C, homogenising and sieving, subsamples were taken for analyses of total P, extractable OC and inorganic C. Further subsamples were then dried to 105 °C prior to CN analysis and loss on ignition. Bulk density cores were used to determine bulk density and soil moisture content. They were then used to measure the proportion of material >200 µm by sieving to determine soils with anthropogenic additions.
8. Section 2.3.1 (l. 106-111) indicates that the level / proportion of artefacts was analyzed. The values or chairs should be provided within the results section or Table 1.
   We did not measure the proportion of artefacts in the soil. We will clarify this in the text with the following:
   Wet sieving was undertaken on subsamples of the sealed soils to distinguish between SU and SA soils. We used the proportion of material in the > 200 µm fraction to determine the level of anthropogenic additions and serve as a proxy for the proportion of artefacts. Soils with visible artefacts generally exhibited more than 40 % of subsample mass in the >200 µm fraction; thus, subsamples with more than 40 % mass in the >200 µm fraction were classed as SA soils, and those with less than 40 % in the >200 µm fraction were classed as SU soils.
9. Regarding the “additions of anthropogenic materials” (l. 236 a well as l. 255-256) and subsequently discussion: This point coincides with the previous one. Please specify the type and proportion of artefacts found, if you derive conclusions from these findings regarding the C pools in urban soils.
   Determining the proportion of artefacts in the soil was not practical for this context as artefacts had disintegrated into very small fragments, hence why we chose an alternative approach. We note that descriptions of the additions are included in this discussion point, for example charcoal and cinders, concrete and limestone rubble.
10. Within section 4.1.2 and regarding the discussion of difference in C stocks of sealed and greenspace soil, please verify if the studied greenspace soils are “free” from anthropogenic influences? In my opinion, urban soils of greenspaces within a central urban area, have often been used for other purposes in the past. If we find green spaces with, for example, Hortisols today, they may also contain a large proportion of anthropogenic artefacts from

earlier use. As you have written elsewhere, understanding the history of soil in urban areas is essential. Please consider this point in the discussion.
Thank you for making this really interesting point. Indeed, it's hard to find a soil anywhere in the world that hasn't had some anthropogenic influence! We agree that many urban soils will have had some form of anthropogenic influence, whether that is direct additions to the soil or indirect such as atmospheric deposition. We will highlight this with additional text in the discussion section (L 313). This is something we hope to work on further in future studies.

11. Statements about denitrification from l. 368 onwards are attributed, among other factors, to reducing conditions. However, these are not mentioned in the results (perhaps because of an incomplete description of the soils studied). How were the redoximorphic features determined (according to FAO, 2015)? What proportion do they account for and do they affect all SU soils?
    You are correct in that these were observations of some samples but were not captured or measured across all samples, and therefore it is not possible to include them in the results, much as that would have been useful. We determined redoximorphic features as areas of grey, brown and orange, suggesting areas lacking in oxygen (grey) and those with oxygen (brown and orange) as described in Weil and Brady (2016) *The Nature and Properties of Soils*. We included this as a discussion point to give additional observations and background to the statements.
12. Conclusion (l. 396): As you present a novel research for urban soil studies, please suggest specific suggestions for further studies based on your results
    Thank you for highlighting this. We will add further text to the conclusion to make suggestions for future work. These will focus on further study into the carbon in sealed soils, and whether anthropogenic additions might provide a long-term C store. We will also suggest gaining further understanding on anthropogenic influences on urban greenspace soils.

Technical corrections

1. The term "wider urban C stocks" in l. 67 should be clarified.
   We will update this text to: (L 67) To gain a clearer picture of how [sealed soils] contribute to C stocks across the wider urban area.
2. Please add a reference for the statement on the population (l. 75).
   We will add this reference: ONS (2021) Estimates of the population for the UK, England and Wales, Scotland and Northern Ireland.
3. Please add a cross-reference to Figure 1 ("Fig. 1") at the end of the sentence in l. 77.
   We will add this reference to Figure 1.
4. Please add the value range of distances between sealed and greenspace sites (l. 88).
   The range of values will be added (0.25 m – 330 m).
5. The term "technosols" should be written as "**T**echnosols" (e.g., line 100, 247, 268) within the entire manuscript. I am not a native speaker myself, but I think this would be the correct spelling for a proper name.
   We agree; we will update all instances of Technosols.
6. Please give the information and specifications on the used pH probe in l. 123.
   We will add this information.
7. Please add a reference for the LOI procedure in l. 132.
   We will add this reference: Heiri et al. (2001) Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results.

8. Please raise the 3 within (g/cm^3) in the caption of Figure 3.
   We will update this text in the figures.
9. Regarding l. 277: Which type of minerals from concrete?
   This refers to calcium minerals. We will add this text in.