Response to Comments on the Manuscript (essd-2023-218):

The patterns of soil nitrogen stocks and C:N stoichiometry under impervious surfaces in China

Dear Editors and Referees,

Thanks for your comments on our study "The patterns of soil nitrogen stocks and C:N stoichiometry under impervious surfaces in China" [Paper # essd-2023-218]. We have revised the manuscript accordingly and addressed your comments point by point.

Best regards,

Qian Ding, Hua Shao, Chi Zhang, Xia Fang

RC2: 'Comment on essd-2023-218', Anonymous Referee #2, 18 Jul 2023

General comments: Ding and coauthors have conducted a national scale soil samplings and reports the patterns of soil nitrogen (N) stocks and C:N stoichiometry under impervious surfaces in China. They found that soil N density in the 0-100 cm profile under impervious surface areas was significantly lower than that under the permeable surface areas, and pointed out that the impervious surfaces could result in the convergence of soil C:N stoichiometry. Overall, this is an interesting study and provide the knowledge of biogeochemical cycles under impervious surfaces. However, I have several concerns on the present manuscript.

Response: Thanks for your comments. We have revised the manuscript accordingly and addressed your comments point by point.

Comment 1: **Introduction:** All previous studies have already demonstrated that impervious surface areas had lower soil N density than permeable surface areas, what is the novelty of comparing soil N density under impervious surface areas with that under permeable surface areas (In the present study, the authors also found that soil N density under impervious surface areas was significantly lower than that under the permeable surface areas)? Moreover, even though there is a lack of information of vertical variations in soil N densities under impervious surface areas, the authors should introduce the necessity of studying vertical distributions of soil N and should be better to propose the hypothesis (is it different from that in natural soils or the soils under permeable surface areas)? I would suggest the authors further improve the novelty and significance of their study. In addition, the data in the sentence "ISA covers …… during 2000-2030" is pretty old, please use the updated information. I am also confused with the expression in the sentence "We chose to use …… from construction materials", to the best of my knowledge, soil C:N stoichiometry represents the SOC:total N ratio rather than the total C:total N ratio, why did the authors state an information different from the common sense?

Response:

(1) The fourth paragraph of the Introduction section has been completely revised to highlight the novelty and significance of this study. We emphasized that previous studies focused on individual cities, thus were unable to gain a big picture of the large-scale distribution pattern of the soil N in impervious surface area (N_{ISA}). This limitation also makes it impossible to evaluate the correlation between N_{ISA} and the potential environmental drivers such as climate factors, geographic factors, and socio-economic factors, etc.. Finally, our literature review can only find 7 local scale case studies so far, which is far from adequate to estimate the N_{ISA} pool size at large scale. Following is the revised paragraph:

Considering the high heterogeneity of urban soils, the available observations from 7 cities around the world are far from enough to provide useful information about the storage and characteristic distribution of N_{ISA} at large scale. Previous studies focused on individual cities, but regional scale surveys are required to investigate the influences of climatic, ecological, geographic, and socioeconomic factors on N_{ISA} distribution. Such information is not only necessary to evaluate global N_{ISA} pool size, but also helpful in revealing the environmental-control mechanisms over the soil biogeochemical processes in ISA (Ding et al., 2022). For example, the urban ecosystem convergence theory suggests that cities from different regions tend to have similar soil properties (e.g., SOC density) as a result of intensive human disturbances, even if their native soil properties differ significantly (Pouyat et al., 2003). Regional soil surveys from multiple cities are required to evaluate this theory with soil nutrient data. In addition, more observational data are required to evaluate whether ISA soil has extremely high C:N ratio, which might indicate decoupling of soil C and N processes (Raciti et al., 2012; O'riordan et al., 2021).

(2) We added the following paragraph to emphasize the importance of study the vertical pattern of soil N under the ISA:

Investigations on the vertical distribution pattern of soil N are also important, because the nutrient distribution patterns through soil profiles are influenced by both natural and human factors. In natural ecosystems, vertical nutrient distributions are dominated by plant cycling relative to leaching, weathering dissolution, and atmospheric deposition, leading to nutrient concentrating in topsoil (Jobbágy and Jackson, 2001). Previous studies in urban areas, however, showed that the removal of plants and topsoil in the ISA may alter the vertical pattern of SOC, resulting in a more homogeneous SOC distribution through the soil profile (Yan et al., 2015; Ding et al., 2022). Based on the observed SOC pattern, previous studies suggested that the changes in soil biogeochemistry in ISA was mainly caused by plant and topsoil removals and initial disturbance as opposed to postconstruction processes (Jobbágy and Jackson, 2001). Investigations on the vertical distribution patterns of N_{ISA} can help us to evaluate this mechanism. However, most previous studies only sampled the topsoil or upper soil layers (Table 1) and thus could not obtain a complete picture of the vertical distribution pattern of the N_{ISA}.

(3) We updated the information of global ISA expansion in the revised manuscript:

The global ISA area in 2018 was 1.5 times larger than in 1990, at approximately 7.97×10^5 km^2 (Gong et al., 2020)

(4) We agree that it is widely accepted that soil C:N stoichiometry represents the SOC:total N ratio rather than the total C:total N ratio. However, we noticed that some previous research (Hu et al., 2018; Pereira et al., 2021; O'riordan et al., 2021) used the ratio between total C and total N to investigate the C:N stoichiometry in ISA soil.

To prevent confusion, we changed all SOC:N to C:N in the revised manuscript, and discussed the issue in the revised section 2.3 (paragraph 2, see below):

The SOC density of the samples was reported in a previous study (Ding et al., 2022). We noticed that some research (Hu et al., 2018; Pereira et al., 2021; O'riordan et al., 2021) used the ratio between total C and total N to investigate the C:N stoichiometry in ISA soil. However, the content of soil inorganic C under impervious surfaces is likely altered by anthropogenic C from construction materials, and black C (Zhao et al., 2017; O'riordan et al., 2021). In this study, we used the ratio between SOC and N to investigate the soil C:N stoichiometry, just like most soil studies in both ISA (Wei et al., 2014a; Raciti et al., 2012; Piotrowska-Długosz and Charzyński, 2015) and PSA (Lu et al., 2023; Schroeder et al., 2022; Yang et al., 2021).

Reference:

Ding, Q., Shao, H., Chen, X., and Zhang, C.: Urban Land Conversion Reduces Soil Organic Carbon Density Under Impervious Surfaces, Global Biogeochemical Cycles, 36, e2021GB007293, https://doi.org/10.1029/2021GB007293, 2022.

Gong, P., Li, X., Wang, J., Bai, Y., Chen, B., Hu, T., Liu, X., Xu, B., Yang, J., Zhang, W., and Zhou, Y.: Annual maps of global artificial impervious area (GAIA) between 1985 and 2018, Remote Sensing of Environment, 236, 111510, https://doi.org/10.1016/j.rse.2019.111510, 2020.

Hu, Y., Dou, X., Li, J., and Li, F.: Impervious Surfaces Alter Soil Bacterial Communities in Urban Areas: A Case Study in Beijing, China, Frontiers in Microbiology, 9, https://doi.org/10.3389/fmicb.2018.00226, 2018.

Jobbágy, E. G. and Jackson, R. B.: The distribution of soil nutrients with depth: Global patterns and the imprint of plants, Biogeochemistry, 53, 51-77, https://doi.org/10.1023/A:1010760720215, 2001.

Lu, M., Zeng, F., Lv, S., Zhang, H., Zeng, Z., Peng, W., Song, T., Wang, K., and Du, H.: Soil C:N:P stoichiometry and its influencing factors in forest ecosystems in southern China, Frontiers in Forests and Global Change, 6, https://doi.org/10.3389/ffgc.2023.1142933, 2023.

O'Riordan, R., Davies, J., Stevens, C., and Quinton, J. N.: The effects of sealing on urban soil carbon and nutrients, SOIL, 7, 661-675, https://doi.org/10.5194/soil-7-661-2021, 2021.

Pereira, M. C., O'Riordan, R., and Stevens, C.: Urban soil microbial community and microbial-related carbon storage are severely limited by sealing, J. Soils Sediments, 21, 1455-1465, https://doi.org/10.1007/s11368-021-02881-7, 2021.

Piotrowska-Długosz, A. and Charzyński, P.: The impact of the soil sealing degree on microbial biomass, enzymatic activity, and physicochemical properties in the Ekranic Technosols of Toruń (Poland), J. Soils Sediments, 15, 47-59, https://doi.org/10.1007/s11368-014-0963-8, 2015.

Pouyat, R. V., Russell-Anelli, J., Yesilonis, I. D., and Groffman, P. M.: Soil carbon in urban forest ecosystems, in: Potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect, CRC Press, 347-362, 2003.

Raciti, S. M., Hutyra, L. R., and Finzi, A. C.: Depleted soil carbon and nitrogen pools beneath impervious surfaces, Environmental Pollution, 164, 248-251, https://doi.org/10.1016/j.envpol.2012.01.046, 2012.

Schroeder, J., Peplau, T., Pennekamp, F., Gregorich, E., Tebbe, C. C., and Poeplau, C.: Deforestation for agriculture increases microbial carbon use efficiency in subarctic soils, Biology and Fertility of Soils, https://doi.org/10.1007/s00374-022-01669-2, 2022.

Wei, Z., Wu, S., Yan, X., and Zhou, S.: Density and Stability of Soil Organic Carbon beneath Impervious Surfaces in Urban Areas, Plos One, 9, https://doi.org/10.1371/journal.pone.0109380, 2014.

Yang, J., Yuan, D., Zhao, Y., He, Y., and Zhang, G.: Stoichiometric relations of C, N, and P in urban top soils in Nanjing, China, and their biogeochemical implications, J. Soils Sediments, 21, 2154-2164, https://doi.org/10.1007/s11368-020-02826-6, 2021.

Zhao, H., Wu, S., Xu, X., Zhou, S., and Li, X.: Spatial Distribution of Soil Inorganic Carbon in Urban Soil and Its Relationship with Urbanization History of the City, Acta Pedologica Sinica, 54, 1540-1546, https://doi.org/10.11766/trxb201703300075, 2017.

Comment 2: Materials and methods: A big concern is the calculation of soil N density, why the authors did not consider the rock fragments in calculating the soil N density? For calculating the soil C and N density, using the fine earth bulk density and soil N concentration can provide more accurate N density estimation. In addition, there are some mistakes for the citation formats, for example, Yang et al. (2007) (Yang et al., 2007), Zhang et al. (2021) (Zhang et al., 2021), the authors should treat their manuscript more carefully throughout the whole manuscript.

Response:

(1) Sorry for fail to described our soil sampling method in detail in the manuscript. Yes, we tried to exclude large amount of rock fragments in soil sampling treatment. As you can see below, we added detailed description of our sampling treatment methodology in the revised section 2.1:

Our study across China found that most of the Ekranic (sealed) Technosol profiles have a clear boundary between the building material layer and the soil. Where the boundary is unclear, we treated the topsoil with a high amount of hard building materials, where artifacts >0.15 mm accounted for over half of the soil volume, as the building material layer. We only took samples in the soil below the building material layer. Samples with notable additions of anthropogenic artifacts, e.g., coal fly ash, mixed in the soil were discarded. Following the protocol of China's National Soil Surveys, the visible non-soil artifacts in the remaining soil samples, such as fragmentations of bricks, glasses, stones, roots, etc., were picked out and discarded (Shi et al., 2004).

(2) We have checked the citation formats and revised the related references according to the comments. Following are the corrected citations.

L132-133 is changed to “According to Yang et al. (2007), 46% of the N stock (in 1 m depth) of natural soil is stored in the top 0–30 cm soil, and 68% of the N stock is stored in the top 0–50 cm.”

L138-139: this content has been removed from the manuscript.

L200-203 is changed to “To facilitate spatial analysis, we divided the country into six subregions – the northeast, north, northwest, east, south, and southwest, according to geography, climate, and socioeconomics following Ding et al. (2022) (Figure 1a).”

L227-229 is changed to “Our observed N_{ISA} content (0.4 g kg^{-1}) in the 20–40 cm soil layer in Beijing was also comparable to the reports by Zhao et al. (2012) (0.26–0.42 g kg^{-1}).”

L256-260 is changed to “Similarly, Wei et al. (2014a) found that $C:N_{ISA}$ was lower than $C:N_{PSA}$ in Yixing city, China, and O’Riordan et al. (2021) found a significant positive correlation between N and C in ISA soil in Greater Manchester, UK, even though they also observed an increased total C:total N ratio in ISA soil compared to PSA soil.”

L280-281 is changed to “Lu et al. (2023) found a lower C:N ratio at higher latitudes in China, suggesting a positive correlation between C:N and temperature in natural ecosystem soils.”

Reference:

Shi, X., Yu, D., Warner, E., Pan, X., Petersen, G., Gong, Z., and Weindorf, D.: Soil database of 1: 1,000,000 digital soil survey and reference system of the Chinese genetic soil classification system, Soil Survey Horizons, 45, 129-136, https://doi.org/10.2136/sh2004.4.0129, 2004.

Yang, Y., Ma, W., Mohammat, A., and Fang, J.: Storage, Patterns and Controls of Soil Nitrogen in China, Pedosphere, 17, 776-785, https://doi.org/10.1016/S1002-0160(07)60093-9, 2007.

Ding, Q., Shao, H., Chen, X., and Zhang, C.: Urban Land Conversion Reduces Soil Organic Carbon Density Under Impervious Surfaces, Global Biogeochemical Cycles, 36, e2021GB007293, https://doi.org/10.1029/2021GB007293, 2022.

Zhao, D., Li, F., Wang, R., Yang, Q., and Ni, H.: Effect of soil sealing on the microbial biomass, N transformation and related enzyme activities at various depths of soils in urban area of Beijing, China, J. Soils 435 Sediments, 12, 519-530, https://doi.org/10.1007/s11368-012-0472-6, 2012.

Wei, Z., Wu, S., Yan, X., and Zhou, S.: Density and Stability of Soil Organic Carbon beneath Impervious Surfaces in Urban Areas, Plos One, 9, https://doi.org/10.1371/journal.pone.0109380, 2014a.

O'Riordan, R., Davies, J., Stevens, C., and Quinton, J. N.: The effects of sealing on urban soil carbon and nutrients, SOIL, 7, 661-675, https://doi.org/10.5194/soil-7-661-2021, 2021.

Lu, M., Zeng, F., Lv, S., Zhang, H., Zeng, Z., Peng, W., Song, T., Wang, K., and Du, H.: Soil C:N:P stoichiometry and its influencing factors in forest ecosystems in southern China, Frontiers in Forests and 360 Global Change, 6, https://doi.org/10.3389/ffgc.2023.1142933, 2023.

Comment 3: **Results:** I am a little bit confused about the Figure 4 and its description, please make it clearer.

Response: Sorry for the confusion. The intra-city analysis aimed to quantify the soil C:N variations among the samples within the same city, i.e., the local scale variation in soil C:N stoichiometry. The inter-city analysis aimed to quantify the soil C:N variations among different cities, i.e., the national scale variation in soil C:N stoichiometry. In the revised work, we changed to use dissimilarity which measure the distance between each pair of sample points to quantify the variation among the samples, according to the comments of other reviewers.

(1) In the revised section 2.3 (paragraph 3), we explained the goal of this analysis and the methodology:

According to the urban ecosystem convergence theory, intensive human disturbances (e.g., soil sealing) could reduce variations in soil property at large scale (i.e., among different cities) even if the intensively disturbed areas may have similar or higher variations in soil properties at city scale compared to the less disturbed areas (e.g., PSA) (Pouyat et al., 2003). To evaluate this theory, we compared the mean inter-city C:N stoichiometry dissimilarity and the mean intra-city C:N stoichiometry dissimilarity between the ISA and PSA. The inter-city dissimilarity (or regional scale variation) measured the Euclidean distance in C:N between each pair of different cities, while the intra-city dissimilarity (or local scale variation) measured the Euclidean distance in C:N between each pair of sampling sites within the same city, all combinations included. If the urban ecosystem convergence theory was correct, we expect to see ISA having lower inter-city C:N dissimilarity than PSA, but higher or similar intra-city C:N dissimilarity than/to PSA.

(2) We also revised section 3.2 (paragraph 2) to describe the analysis result:

Figure 5 shows the ISA soil samples had lower inter-city C:N dissimilarity (1.86±1.40 vs. 2.43±2.15) than PSA, but similar intra-city C:N dissimilarity to PSA. This pattern indicates that although the ISA soil and the PSA soil had similar variations in C:N stoichiometry at the local scale (within a city), the C:N variations at national scale (among the cities) were reduced for the ISA soil, possibly due to the intensive human disturbances on ISA soil as predicted by the urban ecosystem convergence theory (Pouyat et al., 2003).

(3) Finally, we revised the caption of the figure to clarify the issue:

Figure 5: Comparing the inter–city variation and the intra–city variation of C:N ratios between the ISA and PSA. The variations were measured using the dissimilarity of (or the Euclidean distance between) paired observations. For intra–city variation, the soil C:N dissimilarity between each pair of different sampling sites within the same city were calculated and averaged; for inter-city variation, the soil C:N dissimilarity between each pair of different cities under investigation were calculated and averaged. The letters indicate the significance of the difference among the groups.

Reference:

Pouyat, R. V., Russell-Anelli, J., Yesilonis, I. D., and Groffman, P. M.: Soil carbon in urban forest ecosystems, in: Potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect, CRC Press, 347-362, 2003.

Comment 4: Discussion: A big concern in the discussion is that can the authors differentiate the impacts of impervious surfaces and natural soil background on soil N density? For example, "The northern region accounted for the largest share (33%) of the NISA stock in China (Figure 8d), mainly due to its large area of impervious surfaces", is this true after considering the natural soil background?

Response: Thank you for the comment. To address the reviewer's concern, we focus on comparing the observed N_{ISA} density with the previously reported N density in the natural soil of China (Tian et al., 2006) in the revised manuscript. Following is the newly added section 5.4 in the revised manuscript:

Our study and Tian et al. (2006)'s study on China's soil N had same subregion zone design. However, we found the urban soil (both the ISA and PSA) in the East zone had the highest N density while Tian et al. (2006) found the rural soil N density in the East zone was among the lowest in the country. The relatively high precipitation and temperature in the East China may lead to high SOM decomposition rate and nutrient leaching rate, which explains its low rural soil N density (Tian et al., 2010). However, the East region was also the most developed region in China for the last several centuries. Its cities had high population density and long urbanization history. The long-term intensive human activities might leave profoundly footprint in the soil biogeochemical processes, significantly elevated its N content. This finding, together with the relatively low inter-city C:N variations/dissimilarities in the ISA (see section 3.2), indicate intensive human disturbances might override the nature environmental effects in shaping regional distribution pattern of soil N processes, further confirmed the urban ecosystem convergence theory (Pouyat et al., 2003).

Reference:

Pouyat, R. V., Russell-Anelli, J., Yesilonis, I. D., and Groffman, P. M.: Soil carbon in urban forest ecosystems, in: Potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect, CRC Press, 347-362, 2003.

Tian, H., Chen, G., Zhang, C., Melillo, J. M., and Hall, C. A. S.: Pattern and variation of C:N:P ratios in China's soils: a synthesis of observational data, Biogeochemistry, 98, 139-151, https://doi.org/10.1007/s10533-009-9382-0, 2010.

Tian, H., Wang, S., Liu, J., Pan, S., Chen, H., Zhang, C., and Shi, X.: Patterns of soil nitrogen storage in China, Global Biogeochemical Cycles, 20, https://doi.org/10.1029/2005GB002464, 2006.