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

RC1: 'Comment on essd-2023-218', Anonymous Referee #1, 17 Jul 2023

General comments: This paper studied soil nitrogen and organic carbon stock in impervious surface areas in China. In general, this is an interesting study, which could improve our understanding of the special pattern of soil N under impervious surfaces. However, the methods used in this study and the results are not convincing at the current stage. I would suggest the authors carefully revise the manuscript based on the following comments.

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

Comment 1: Abstract, line (L) 20, urbanization indeed change the permeable surface areas to impervious surface areas. Why did the urbanization not cause soil N loss?

Response: Thank you for point out this mistake. The original statement is incorrect. Our data showed the soil N density of impervious surfaces (N_{ISA}) was only about 53–69% of the national mean soil nitrogen density (2nd paragraph of section 5.1). We correct this mistake in the revised Abstract as "*The N_{ISA} was also only about 53–69% of the reported national mean soil nitrogen density, indicating ISA expansion caused soil N loss.*" (Line 19–Line 20 in the revised manuscript)

We apologize for this mistake.

Comment 2: Figure 1, the land use type of each site can be added in the figure.

Response: Information of background vegetation/land-use type were extracted from the vegetation map of China (Editorial Committee of Chinese Vegetation Map, 2021) and added to the revised Figure 1 (see below) (Line 100–Line 108 in the revised manuscript). We also made additional modifications to improve the quality of Figure 1: Because the 148 sampling sites were concentrated in 41 cities, many of the site symbols overlapped and cannot be identified in the original figure. Therefore, the revised figure only shows the 41 cities with their ID numbers that can be used for retrieving detailed information (e.g., land-use type) of the sampling sites in each city from the online dataset of this study (see Ding et al., 2023).

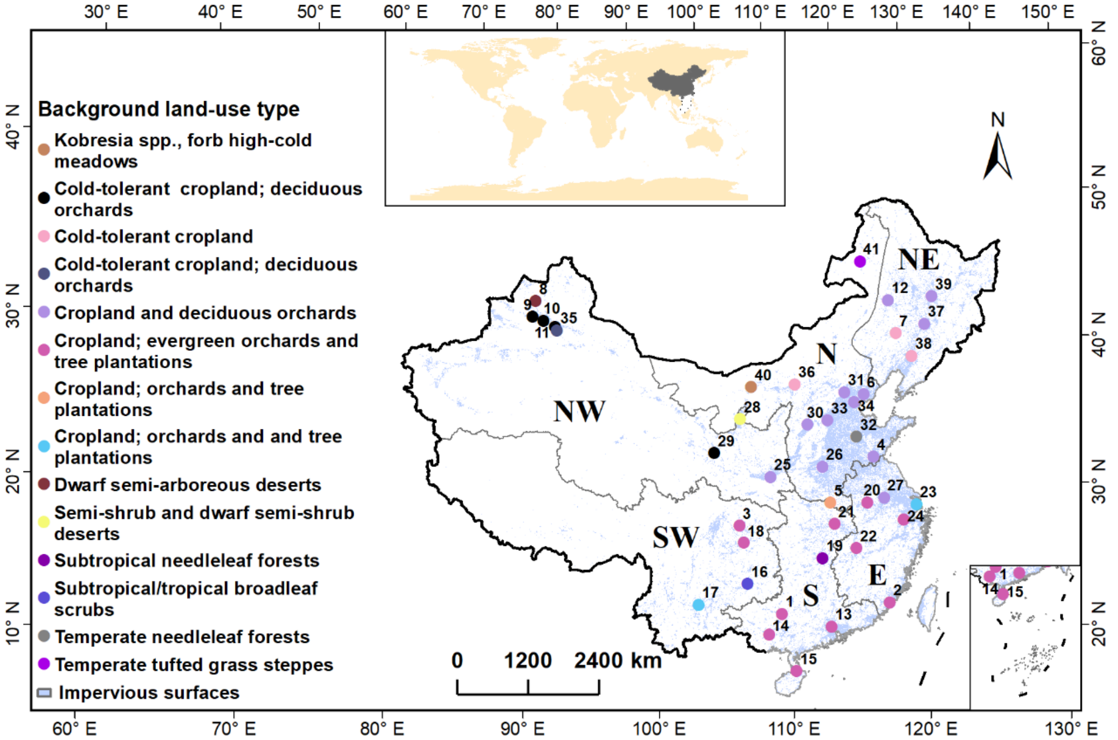

Figure 1a: Spatial distribution of the sampled cities. The numbers in the map are the IDs of the studied cities, which can be used to retrieve detailed information of the sample sites from the online dataset of this study (Ding et al., 2023). The background land-use type shows the regional dominant land-use/land-cover type where the cities locates. To facilitate spatial analysis, we divided the country into six subregions – E: eastern China, S: southern China, N: northern China, NE: northeastern China, NW: northwestern China, SW: southwestern China.

References

Editorial Committee of Chinese Vegetation Map, Chinese Academy of Sciences: 1:1 million vegetation data set in China, National Cryosphere Desert Data Center [data set], 2020.

Ding, Q., Shao, H., Zhang, C., and Fang, X.: Observations of soil nitrogen and soil organic carbon to soil nitrogen stoichiometry under the impervious surfaces areas (ISA) of China, National Cryosphere Desert Data Center, https://doi.org/10.12072/ncdc.socn.db2851.2023, 2023.

Comment 3: L85, what kinds of roads, elevated piers, and floor buildings? It would be great if the authors can support some pictures! I am also curious how did you take soil samples from roads, elevated piers, and floor buildings? You directly dug a soil pit under different impervious surface areas? Is it possible for the floor buildings?

Response: Example photos for different type of sampling sites are added to Figure 1b (Line 100–Line 108 in the revised manuscript). As you can see in the photos below, the samples were taken in randomly selected construction sites from ongoing engineering projects in the cities, including under the roads (b1), building floors (b2, b3) and the elevated highway piers (b4).

Figure 1b: Example photos for different sampling sites.

Comment 4: The unit of parameters in ALL equations should be clarified.

Response: We have clarified the unit of parameters in all equations in the revised manuscript:

$$N_i = \frac{\mathrm{NC}_i \times \mathrm{BD}_i \times 20}{100}, \quad (1)$$

$$N_{100cm} = \sum_{i=1}^{n} N_i, \quad (2)$$

where N represents N density (kg m^{-2}), $i \in [1,5]$ represents soil layer (each 20 cm in thickness), NC is N content (g kg^{-1}), BD is soil bulk density (g cm^{-3}). (Line 134–Line 137 in the revised manuscript)

$$\text{Euclidean distance} = \sqrt{\left(C{:}N_i - C{:}N_j\right)^2}, \quad (3)$$

where $C:N_i$ and $C:N_j$ are the soil C:N ratios of site i and site j, respectively, when measuring the intra-city dissimilarity, or the city-averaged C:N ratios of city i and city j, respectively, when measuring the inter-city dissimilarity. (Line 161–Line 164 in the revised manuscript)

$$N_{Natural}\%_d = -0.0074d^2 + 1.7378d = (1.7378 - 0.0074d) \times d, \quad (4)$$

where $N_{Natural}\%$ is the proportion of total N stock (in 100 cm depth) stored to depth *d* cm in natural soil in China. (Line 173–Line 175 in the revised manuscript)

$$N_{ISA}\%_d = 1.0324d, \quad (5)$$

where $N_{ISA}\%$ *d* (%) is the percentage of total N storage (of 100 cm depth) stored in the top *d* (cm) depth of the soil. The unit of N_{ISA} is kg m^{-2}. (Line 264–Line 266 in the revised manuscript)

Comment 5: L132-133, the citation should be formatted, and other citations in similar format should also be revised.

Response: We have checked the citation format and revised the related references according to the comments. Following are the revisions:

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." (Line 170–Line 172 in the revised manuscript)

L138-139: this content has been removed in the revised 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)." (Line 225–Line 227 in the revised manuscript)

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})." (Line 296–Line 298 in the revised manuscript)

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." (Line 326–Line 329 in the revised manuscript)

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." (Line 361–Line 362 in the revised manuscript)

Reference:

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.

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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 6: The equation 3 is hard to understand. What's the meaning of 130? Why not use your own data to create the equation?

Response: We aim to compare the vertical pattern of soil N between the ISA and natural land (see the revised Figure 7 below) (Line 267–Line 268 in the revised manuscript). However, all our observations (both the ISA and PSA soil samples) were taken in urban areas. Therefore, we relied on the previous reports (Yang et al., 2007) to develop a vertical N distribution model of natural soil in China (Equation 4).

The original Equation 4 was derived by fitting Yang et al. (2007)'s data with a power equation. We recognize that the power function is hard to understand and change to use a second-order polynomial function fitting in the revised manuscript. Following is the description of the revised model (Line 173–Line 177 in the revised manuscript):

$$\mathrm{N_{Natural}}\%_d = -0.0074d^2 + 1.7378d = (1.7378 - 0.0074d) \times d, \qquad (4)$$

where $N_{Natural}\%$ is the proportion of total N stock (in 100 cm depth) stored to depth d cm in natural soil. The equation shows that the $N_{Natural}\%$ does not increase linearly with soil depth. Its growth rate (i.e., $1.7378 - 0.0074d$) reduces with soil depth d. This pattern indicates the natural soil does not have homogeneous N density through the soil profile, it decreases with depth.

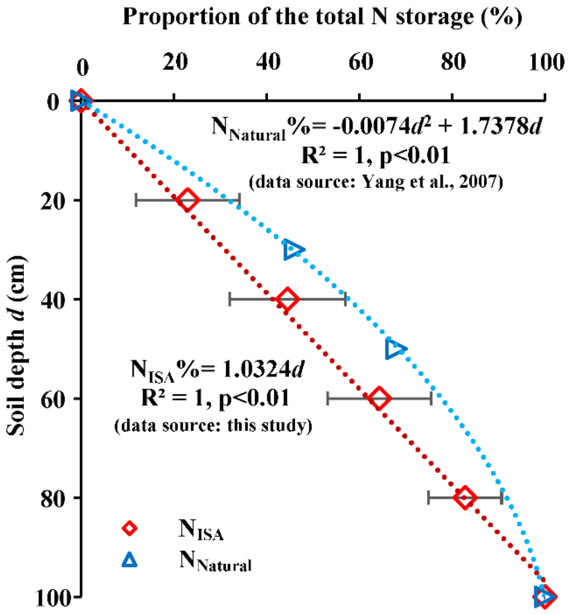

Figure 7: Comparing the vertical distribution pattern of N between the sealed soil (N_{ISA}) and the natural soil ($N_{Natural}$) in China (refer to Section 2.4 Equation 4).

Reference:

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.

Comment 7: L139-140, why did you select these parameters? Please explain and describe the detailed process of model construction.

Response: After considering the comment 7 and comment 8, we recognize that with the limited soil N observations and our limited understanding in the N processes under impervious surfaces, it will be inappropriate to develop a N_{ISA} map of China using any spatial interpolation or modelling methods. Therefore, we decide to give up such effort and remove all the related contents in the revised manuscript (please refer to our responses to the comment 8).

Instead, we analyzed the relationships between N_{ISA} and 15 potential environmental controls including climate, terrain, and social-economic factors. Following is the newly added section 2.5 in the revised manuscript that describes the selected factors and the data sources (Line 178–Line 210 in the revised manuscript):

2.5 Correlation analysis between N_{ISA} and potential environmental factors

Our large scale soil survey made it possible, for the first time, to investigate the correlations between soil N and various environmental factors so as to identify the climatic, ecological, geographical and socio-economic factors that may control or influence the N and C:N dynamics in sealed soil. In natural ecosystems, the distribution of N pools is significantly influenced by climate factors (Zhang et al., 2021). Temperature and precipitation are key drivers of soil biogeochemical processes (Wiesmeier et al., 2019). A previous study indicated that the ISA soil may also be affected indirectly by adjacent PSA (Yan et al., 2015b), because many ISAs were converted from urban PSA during urban infilling (Delgado-Baquerizo et al., 2021; Kuang, 2019; Kuang et al., 2021). The soil organic matter input is influenced by ecosystem net primary productivity (NPP) (Chan, 2001). The N_{ISA} could also be correlated with the intensity of urbanization or human disturbances, which are influenced by population size, GDP, and the spatio-temporal patterns of built-up areas in a city (Bloom et al., 2008). Moreover, elevation and terrain may influence both the soil biogeochemical processes and ISA expansion (Zhu et al., 2022; Pan et al., 2023). Therefore, we selected 15 indicators to investigate the factors associated with N_{ISA}, including mean temperature, annual precipitation, background NPP (averaged natural ecosystem NPP in a 5 km buffer outside the city), C:N_{PSA} and N_{PSA}, longitude, latitude, elevation, population density, built-up area in a city, urbanization rate as indicated by the fraction of the built-up area that expanded after 2002, ISA coverage in built-up areas, greenspace coverage in built–up areas, per capita greenspace, city GDP, and per capita GDP. We also investigated the correlation between soil BD and the N_{ISA} content.

Gridded datasets of environmental factors, including mean annual temperature (Figure 2a), annual precipitation (Figure 2b), and elevation (Figure 2d) at 1 km resolution, were obtained from the Data Center for Resource and Environmental Sciences, Chinese Academy of Sciences (http://www.resdc.cn/). The national NPP (1985–2015) estimates at 1 km resolution was obtained from the Digital Journal of Global Change Data Repository (https://www.geodoi.ac.cn/) (Figure 2c). Statistical datasets include the Ministry of Housing and Urban–Rural Development of China (www.mohurd.gov.cn/) urban built-up area, population density, built-up area green space rate, per capita built-up area green space, the National Bureau of Statistics of China (data.stats.gov.cn/) total urban GDP, and per capita GDP. We used Pearson's correlation (2-tailed) to investigate the relationships.

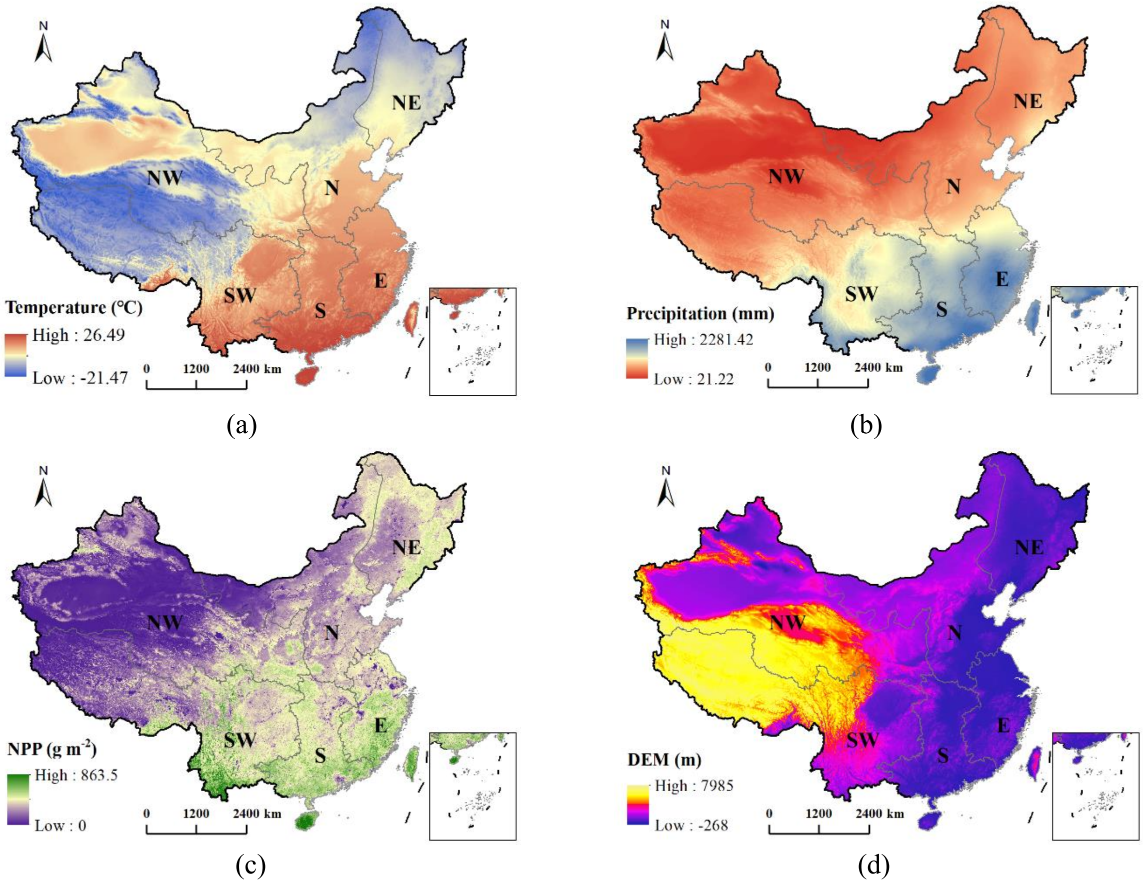

Figure 2: A subset of the spatial datasets of climatic, ecological and terrain factors whose correlations with N_{ISA} were investigated in this study, including (a) annual precipitation normal (1981–2010), (b) air temperature normal (1981–2010), (c) mean annual NPP (1985–2015), and (d) digital elevation model (DEM). E: eastern China, S: southern China, N: northern China, NE: northeastern China, NW: northwestern China, SW: southwestern China.

Reference:

Bloom, D. E., Canning, D., and Fink, G.: Urbanization and the wealth of nations, Science, 319, 772-775, https://doi.org/10.1126/science.1153057, 2008.

Chan, K. Y.: Soil particulate organic carbon under different land use and management, Soil Use and Management, 17, 217-221, https://doi.org/10.1079/sum200180, 2001.

Delgado-Baquerizo, M., Eldridge, D. J., Liu, Y. R., Sokoya, B., Wang, J. T., Hu, H. W., He, J. Z., Bastida, F., Moreno, J. L., Bamigboye, A. R., Blanco-Pastor, J. L., Cano-Diaz, C., Illan, J. G., Makhalanyane, T. P., Siebe, C., Trivedi, P., Zaady, E., Verma, J. P., Wang, L., Wang, J., Grebenc, T., Penaloza-Bojaca, G. F., Nahberger, T. U., Teixido, A. L., Zhou, X., Berdugo, M., Duran, J., Rodriguez, A., Zhou, X., Alfaro, F., Abades, S., Plaza, C., Rey, A., Singh, B. K., Tedersoo, L., and Fierer, N.: Global homogenization of the structure and function in the soil microbiome of urban greenspaces, Science Advances, 7, https://doi.org/10.1126/sciadv.abg5809, 2021.

Kuang, W.: Mapping global impervious surface area and green space within urban environments, Science China-Earth Sciences, 62, 1591-1606, https://doi.org/10.1007/s11430-018-9342-3, 2019.

Kuang, W., Liu, J., Tian, H., Shi, H., Dong, J., Song, C., Li, X., Du, G., Hou, Y., Lu, D., Chi, W., Pan, T., Zhang, S., Hamdi, R., Yin, Z., Yan, H., Yan, C., Wu, S., Li, R., Yang, J., Dou, Y., Wu, W., Liang, L., Xiang, B., and Yang, S.: Cropland redistribution to marginal lands undermines environmental sustainability, Natl. Sci. Rev., 9, nwab091-nwab091, https://doi.org/10.1093/nsr/nwab091, 2021.

Pan, T., Kuang, W., Shao, H., Zhang, C., Wang, X., and Wang, X.: Urban expansion and intra-urban land evolution as well as their natural environmental constraints in arid/semiarid regions of China from 2000–2018, Journal of Geographical Sciences, 33, 1419-1441, https://doi.org/10.1007/s11442-023-2136-4, 2023.

Wiesmeier, M., Urbanski, L., Hobley, E., Lang, B., von Luetzow, M., Marin-Spiotta, E., van Wesemael, B., Rabot, E., Liess, M., Garcia-Franco, N., Wollschlaeger, U., Vogel, H.-J., and Koegel-Knabner, I.: Soil organic carbon storage as a key function of soils - A review of drivers and indicators at various scales, Geoderma, 333, 149-162, https://doi.org/10.1016/j.geoderma.2018.07.026, 2019.

Yan, Y., Kuang, W., Zhang, C., and Chen, C.: Impacts of impervious surface expansion on soil organic carbon - a spatially explicit study, Sci Rep, 5, 9, 10.1038/srep17905, 2015.

Zhang, Y. W., Guo, Y., Tang, Z., Feng, Y., Zhu, X., Xu, W., Bai, Y., Zhou, G., Xie, Z., and Fang, J.: Patterns of nitrogen and phosphorus pools in terrestrial ecosystems in China, Earth Syst. Sci. Data, 13, 5337-5351, https://doi.org/10.5194/essd-13-5337-2021, 2021.

Zhu, G., Zhou, L., He, X., Wei, P., Lin, D., Qian, S., Zhao, L., Luo, M., Yin, X., Zeng, L., Long, Y., Hu, S., Ouyang, X., and Yang, Y.: Effects of Elevation Gradient on Soil Carbon and Nitrogen in a Typical Karst Region of Chongqing, Southwest China, Journal of Geophysical Research: Biogeosciences, 127, e2021JG006742, https://doi.org/10.1029/2021JG006742, 2022.

Comment 8: Random forest is not an explainable model and might not be convincing. More methods are encouraged to be included in this manuscript, such as biogeochemistry model.

Response: We agree with the reviewer that using Random forest to develop a soil N_{ISA} map of China is not convincing. However, we currently know little about the biogeochemical processes under the impervious surface, and cannot find an appropriate biogeochemistry model to do the job. Therefore, we give up the effort in developing a national soil N_{ISA} map of China, and remove the related contents in the revised manuscript. Instead, we analyzed the relationships between N_{ISA} and potential environmental controls including climate, terrain, and social-economic factors (please refer to our responses to the comment 7). As shown below, the revised Section 2.5 (Line 178–Line 210 in the revised manuscript) describes the methodology; the revised Section 3.5 (Line 269–Line 283 in the revised manuscript) shows the analysis results; the revised Section 5.3 (Line 337–Line 372 in the revised manuscript) discusses the findings:

Section 2.5: (please refer to our above responses to comment 7)

Section 3.5 The natural and socioeconomic factors correlated with N_{ISA} and C:N_{ISA}

The impacts of climate and geographic factors were confirmed by correlation analyses, which showed N_{ISA} to be negatively correlated with temperature (R=–0.471) but positively correlated with latitude (R=0.386) (Table 2). In addition, the N_{ISA} had a positive correlation with the N of urban PSA (R=0.715) and a negative correlation (R=–0.34) with the urbanization rate as indicated by the fraction of the newly expanded ISA since 2002 (i.e., $f_{new\_ISA} = \frac{ISA_{2015}-ISA_{2002}}{ISA_{2015}}$). Surprisingly, we did not find significant correlations between N_{ISA} and common environmental drivers like precipitation and NPP at 95% significant level, although the N_{ISA} had a weak negative correlation with precipitation (R=–0.268) at 90% significant level.

The C:N_{ISA} was negatively correlated with both precipitation (R=–0.539) and temperature (R=–0.496) as well as longitude (R=–0.316), but positively correlated with latitude (R=0.482) (Table 2). In addition, the C:N_{ISA} had a positive correlation with the N of urban PSA (R=0.575) and a negative correlation (R=–0.485) with the NPP.

Table 2: Correlations between N_{ISA}, $C:N_{ISA}$ and potential environmental drivers

Factors	N density (kg m^{-2})		$C:N_{ISA}$	
	Correlation Coefficient	Sig. (2 tailed)	Correlation Coefficient	Sig. (2 tailed)
Longitude	0.196	0.22	–0.316*	0.04
Latitude	0.386*	0.01	0.482**	0.00
DEM (m)	0.141	0.38	0.378*	0.01
Annual precipitation (mm)	–0.268	0.09	–0.539**	0.00
Mean Temperature (°C)	–0.471**	0.00	–0.496**	0.00
NPP (g m^{-2})	–0.096	0.55	–0.485**	0.00
ISA coverage in built-up area (%)	–0.126	0.43	–0.240	0.13
Built-up area (km^2)	–0.072	0.65	0.049	0.76
Greenspace coverage in built-up area (%)	–0.229	0.15	–0.001	0.99
Population density (person/km^2)	–0.032	0.84	–0.051	0.75
Per capita GDP (person/10^4 yuan)	–0.012	0.94	0.000	1.00
City GDP (billion yuan)	–0.015	0.93	–0.028	0.86
Per capita greenspace (m^2)	0.098	0.54	0.098	0.54
Urbanization rate as represented by the fraction of the newly expanded ISA since 2002 (%)	–0.340*	0.03	–0.090	0.58
N_{PSA} density (kg m^{-2})	0.715**	0.00	NA	NA
$C:N_{PSA}$	NA	NA	0.575**	0.00
BD	–0.104	0.52	NA	NA

*$p < 0.05$;
**$p < 0.01$.

Section 5.3 Potential driving factors of the N_{ISA} and $C:N_{ISA}$

The spatial distribution pattern of soil N was significantly correlated with climate factors such as temperature and precipitation in natural ecosystems (Yang et al., 2007). In general, the soil N in China's temperate and subtropical ecosystems were negatively correlated with temperature (Lu et al., 2017). Similarly, our study found a negative correlation between N_{ISA} and temperature, and a positive correlation between N_{ISA} and latitude. There was no significant correlation between precipitation and the soil N in natural ecosystem, except for dryland where a positive correlation has been found (Lu et al., 2017). We didn't find significant correlation between precipitation and N_{ISA} at the 95% confidence level, although there was a weak negative correlation at the 90% confidence level. Previous study showed the SOC_{ISA} was also negatively correlated with precipitation, and it was suggested that the observed soil biogeochemistry (SOC, nutrient content etc.) under impervious surface was mainly determined by the losses (esp. in topsoil) during land conversion (Majidzadeh et al., 2018; Cambou et al., 2018; Edmondson et al., 2012). Higher precipitation leads to higher soil nutrient loss during land conversion (Ding et al., 2022). The relatively weak correlation between N_{ISA} and precipitation (compared with the correlation between SOC_{ISA} and precipitation) as well as the negative correlation between $C{:}N_{ISA}$ and precipitation might indicate that the N loss during land conversion was not as significant as the loss in SOC. It is also possible that the high N deposition in urban ISA might somehow replenish the N_{ISA} pool.

N_{ISA} was not correlated with background NPP but positively correlated with the soil N in the adjacent urban PSA. This pattern agrees with the previous report that the SOC_{ISA} was mainly influenced by the SOC in the adjacent urban PSA rather than the background SOC and NPP (Ding et al., 2022). However, there was a negative correlation between $C{:}N_{ISA}$ and background NPP.

The soil C:N ratio could be a more stable parameter (Yang et al., 2021). Tian et al. (2010) found the soil C;N ratio was relatively stable among climate zones in rural ecosystems in China. It has been observed that the soil stoichiometric characteristics in China are influenced by geographical parameters such as altitude and latitude (Sheng et al., 2022). 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. Our study, however, found that the $C{:}N_{ISA}$ ratio increased with latitude and that there was a significant negative correlation between the $C{:}N_{ISA}$ ratio and temperature. The soil C:N ratio of natural ecosystems is influenced by plant litter input and N uptake. Ecosystems in warmer regions have higher NPP, resulting in higher inputs of litter with a high C:N ratio (compared with the soil C:N ratio) and higher N uptake by roots, thus reducing soil inorganic N. Therefore, the C:N ratio is positively correlated with temperature in natural ecosystems. However, the C:N ratio under the impervious surface is solely determined by the relative mineralization rate of C and N. It seems that soil ecosystems have a higher retention capacity for N than for C (C fixation is unlikely to be found in sealed soil). Therefore, while both the soil N_{ISA} pool and the SOC_{ISA} pool decrease when the temperature increases, the net N mineralization rate is lower than the C mineralization rate, leading to a negative correlation between the $C{:}N_{ISA}$ ratio and temperature.

Reference:

Cambou, A., Shaw, R. K., Huot, H., Vidal-Beaudet, L., Hunault, G., Cannavo, P., Nold, F., and Schwartz, C.: Estimation of soil organic carbon stocks of two cities, New York City and Paris, Sci. Total Environ., 644, 452-464, https://doi.org/10.1016/j.scitotenv.2018.06.322, 2018.

Edmondson, J. L., Davies, Z. G., McHugh, N., Gaston, K. J., and Leake, J. R.: Organic carbon hidden in urban ecosystems, Sci Rep, 2, https://doi.org/10.1038/srep00963, 2012.

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.

Lu, T., Zhang, W., Niu, J., Lin, Y., and Wu, M.: Study on Spatial Variability and Driving Factors of Stoichiometry of Nitrogen and Phosphorus in Soils of Typical Natural Zones of China, Acta Pedologica Sinica, 54, 682-692, 2017.

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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.

Comment 9: Figure 4, the error bars of the intra-city column should also added.

Response: In the original manuscript, we used coefficient of variation (CV) to evaluate the variance of soil C:N among the cities (i.e., the inter-city variation in C:N). Because the mean C:N of each city was treated as one sample to calculate the CV, we are unable to estimate the uncertainty of the derived CV itself, thus unable to add an error bar. However, we agree with the reviewer that it's better to also estimate the uncertainty in the inter-city variation.

To estimate the uncertainty in the inter-city variation in the revised manuscript, we change to use dissimilarity to quantify the variation of the C:N among the cities. The dissimilarity measured the Euclidean distance in C:N between each pair of cities. In this case, the C:N dissimilarity of each pair of cities can be treated as one sample of the variation. Their mean value is an unbiased estimate of the inter-city variation in C:N ratio and the standard deviation can be added to the chart as the error bar of the estimate. A description of the method is provided in the revised methodology section (Line 154-line164). The revised figure is shown below (Line 243–Line 248 in the revised manuscript):

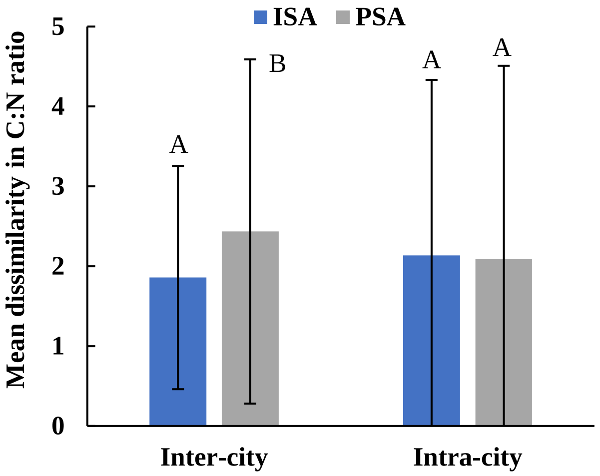


Figure 5: Comparing the inter–city variation and the intra–city variation of C:N ratios between the ISA and PSA. The variations were measured by the dissimilarity of (or the Euclidean distance between) paired observations. For intra–city variation, the soil C:N dissimilarity between each pair of different 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.

Comment 10: Figure 5, the origin coordinates should also be indicated to distinguish different directions.

Response: Thanks for the suggestion, we added the origin coordinates to the figures (Line 258 in the revised manuscript).

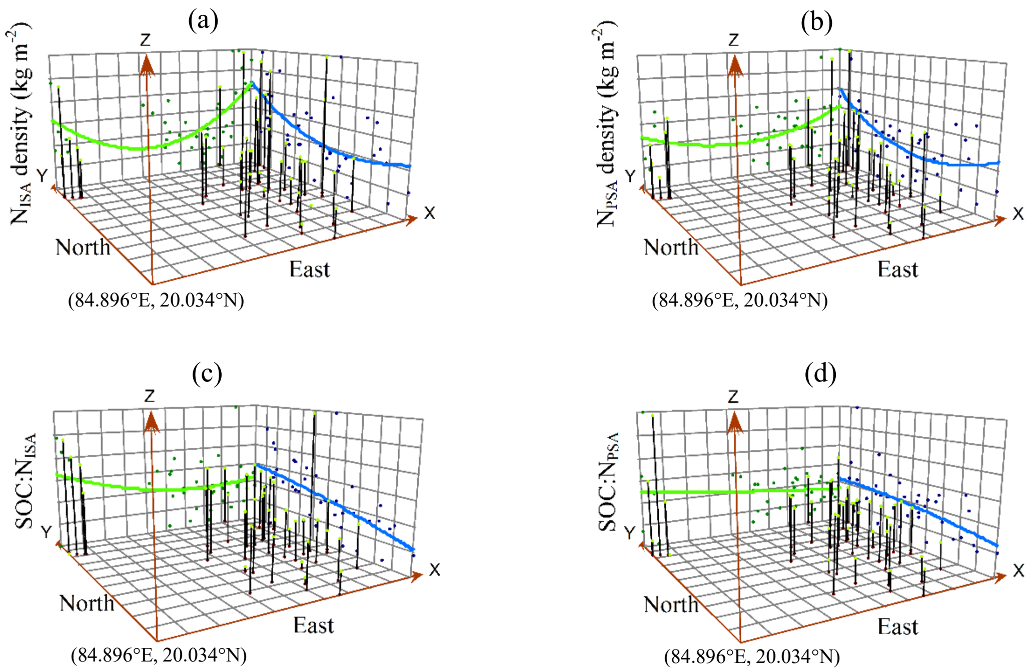


Figure 6: The variation trend of N and C:N under the two surfaces.

Comment 11: In equation 4, N_{ISA}% was 2.31 when d=0, which should not be the case. Please revise the equation.

Response: We set the intercept to 0 and refit the linear model (Line 264–Line 266 in the revised manuscript):

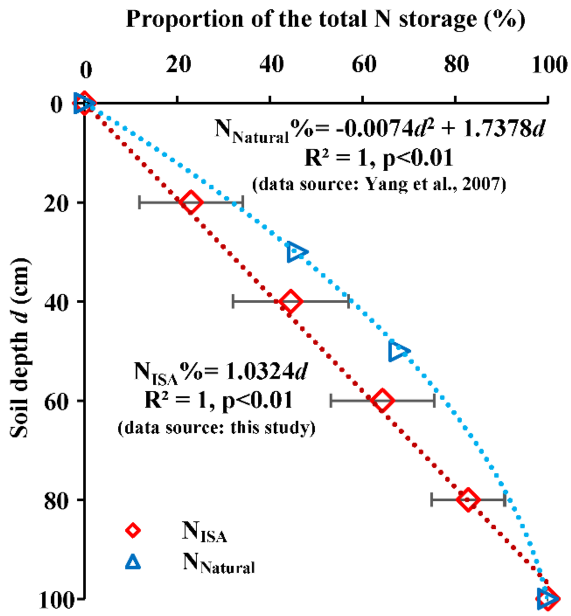
$$N_{ISA}\%_d = 1.0324d, \qquad (5)$$

where $N_{ISA}\%\ d$ (%) is the percentage of total N storage (of 100 cm depth) stored in the top d (cm) depth of the soil. The unit of N_{ISA} is kg m^{-2}.

Comment 12: Figure 6, which data did you use in this figure? Why not include all of the sampling points?

Response: Sorry for the confusion. This figure aims to compare the vertical patterns of N between ISA soil and natural soil. Because our study area focused on urban area, we didn't collect samples in natural soils. Therefore, we relied on a pervious study (Yang et al., 2007), which compared the soil N storage to the 30 cm depth, 50 cm depth and 100 cm depth in natural soil in China, to derive the vertical pattern of N stock in natural soil (the blue line in the figure).

To prevent confusion, we added descriptions of the data sources directly in the revised figure as you can see below (Line 267–Line 268 in the revised manuscript):



We also revised section 2.4 (see below) (Line 165–Line 177 in the revised manuscript) to clarify the issue:

2.4 Investigating the vertical pattern of N_{ISA}

Unlike other studies that focused on topsoil, our multiple–layer soil sampling data made it possible to study the vertical pattern of N_{ISA} to a 100 cm depth. The proportions of N stored in the 0–20 cm depth, 0–40 cm depth, 0–60 cm depth, and 0–80 cm depth to the total (100 cm depth) N stock in each sample profile were calculated and plotted against the soil depth to reveal the vertical distribution pattern of N_{ISA} and N_{PSA}. Based on these data, we could model how N storage changed with soil depth. 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, translating into a power function fitting model (Figure 7):

$$\mathrm{N_{Natural}}\%_d = -0.0074d^2 + 1.7378d = (1.7378 - 0.0074d) \times d, \quad (4)$$

where $\mathrm{N_{Natural}}\%$ is the proportion of total N stock (in 100 cm depth) stored to depth d cm in natural soil in China. The equation shows that the $\mathrm{N_{Natural}}\%$ does not increase linearly with soil depth, its increasing rate (i.e., $1.7378 - 0.0074d$) reduces with soil depth d. This pattern indicates the natural soil N does not have homogeneous N density through the soil profile, it decreases with depth.

Reference:

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.

Comment 13: From the data of figure 7, the predicted NISA density will be overestimated when the value is lower than ~ 0.6 kg m−2, while the opposite when the value is higher than ~ 0.6 kg m−2. The worth thing is the deviation will be much higher when the value is far away from ~ 0.6 kg m−2. Thus, I strongly suggest the authors optimize their model and the predicted value.

Response: This figure was removed, because we recognize that the Random Forest method is not appropriate for this study and give up the effort to develop a national soil N_{ISA} map (please refer to our responses to the comment 8). Instead, we focused on analyzing the relationships between N_{ISA} and the potential environmental control factors (please refer to our above responses to the comment 7 and comment 8).

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) To address the reviewer's concern, 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 (Line 58–Line 69 in the revised manuscript):

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) As recommended by the reviewer, we added the following paragraph to emphasize the importance of studying the vertical pattern of soil N under the ISA (Line 70–Line 81 in the revised manuscript):

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) As recommended by the reviewer, we updated the citation to including more recent information of global ISA expansion in the revised manuscript (Line 38–

Line 39 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 with the reviewer on 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) (Line 143–Line 149 in the revised manuscript):

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 failing to described our soil sampling method in detail in the manuscript. Actually, we have 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 (Line 112–Line 119 in the revised manuscript):

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." (Line 170–Line 172 in the revised manuscript)

L138-139: this content has been removed in the revised 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)." (Line 225–Line 227 in the revised manuscript)

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})." (Line 296–Line 298 in the revised manuscript)

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." (Line 326–Line 329 in the revised manuscript)

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." (Line 361–Line 362 in the revised manuscript)

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 (Line 151–Line 160 in the revised manuscript):

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 (Line 238–Line 242 in the revised manuscript):

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 (Line 243–Line 248 in the revised manuscript):

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 (Line 374–Line 384 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.