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.*"

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). 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).

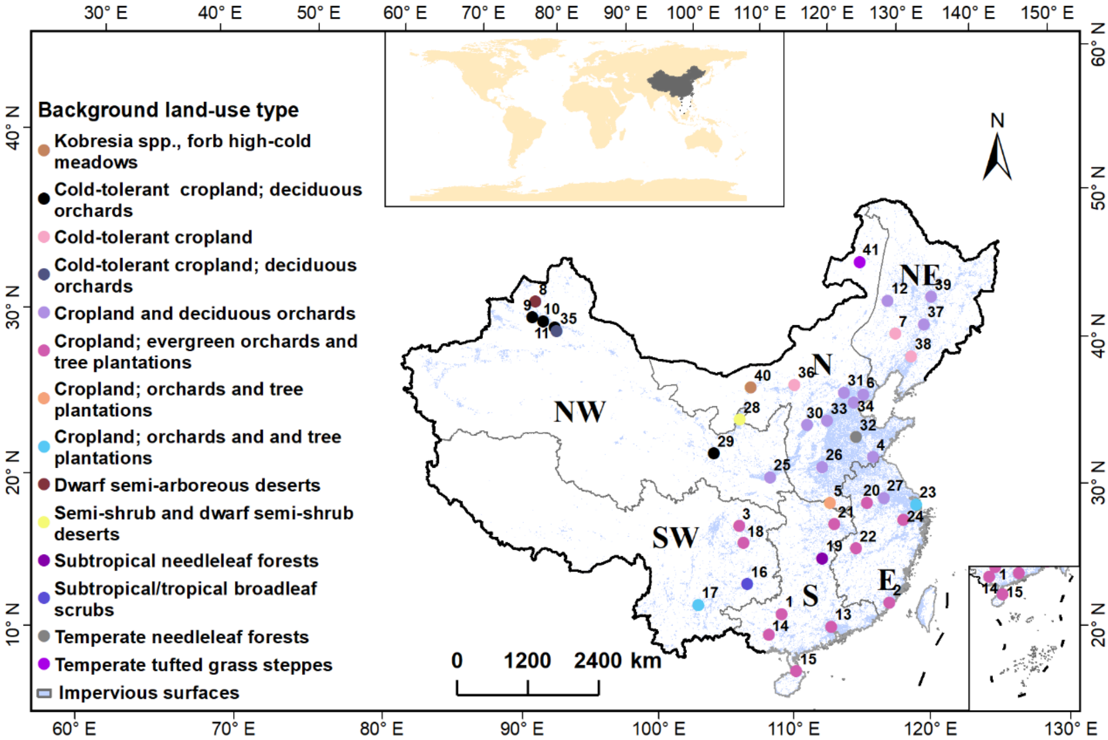

Figure 1a: Spatial distribution of the sampled cities. The numbers in the map are the IDs of the studied cities, which can be used to retrieve detailed information of the sample sites from the online dataset of this study (Ding et al., 2023). To facilitate spatial analysis, we divided the country into 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. 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:

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

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

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}).

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

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.

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

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

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

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}.

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."

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)."

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:

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 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). 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:

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

where $\mathrm{N_{Natural}}\%$ is the proportion of total N stock (in 100 cm depth) stored to depth d cm in natural soil. The equation shows that the $\mathrm{N_{Natural}}\%$ 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.

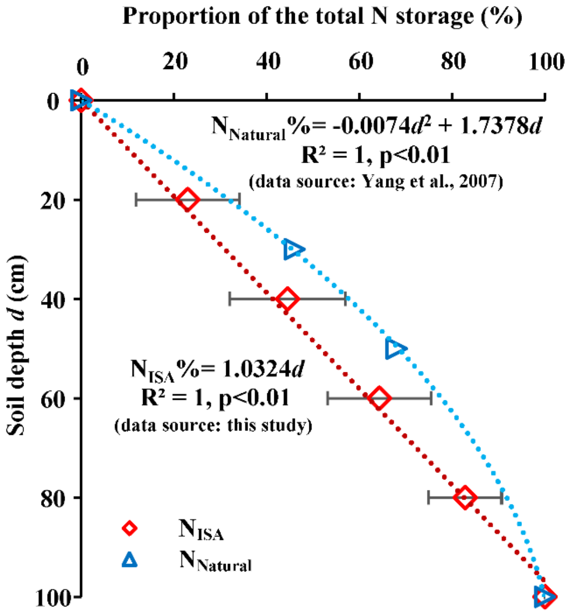

Figure 7: Comparing the vertical distribution pattern of N between the sealed soil (N_{ISA}) and the natural soil ($N_{Natural}$) in China (refer to Section 2.4 Equation 4).

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 limited understanding in the N processes under impervious surfaces, it will be inappropriate to develop a N_{ISA} map of China's 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:

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.

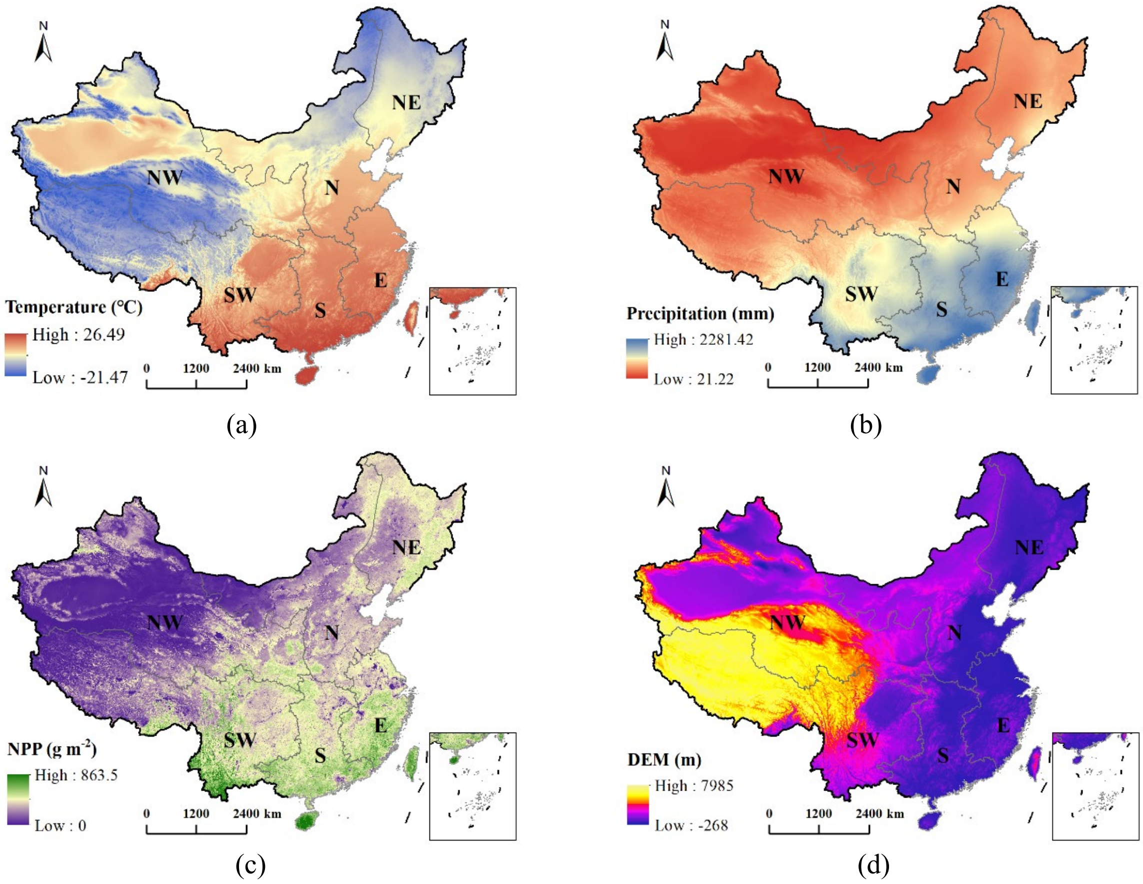

Figure 2: A subset of the spatial datasets of climatic, ecological and terrain factors whose correlations with NISA were investigated in this study, including (a) annual precipitation normal (1981–2010), (b) air temperature normal (1981–2010), (c) mean annual NPP (1985–2015), and (d) digital elevation 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.

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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 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 comment 7). As shown below, the revised Section 2.5 describes the methodology; the revised Section 3.5 shows the analysis results; the revised Section 5.3 discussed the findings:

Section 2.5: (please refer to our 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.

Majidzadeh, H., Graeme Lockaby, B., Price, R., and Governo, R.: Soil carbon and nitrogen dynamics beneath impervious surfaces, Soil Science Society of America Journal, 82, 663-670, https://doi.org/10.2136/sssaj2017.11.0381, 2018.

Sheng, H., Yin, Z., Zhou, P., and Thompson, M. L.: Soil C:N:P ratio in subtropical paddy fields: variation and correlation with environmental controls, J. Soils Sediments, 22, 21-31, https://doi.org/10.1007/s11368-021-03046-2, 2022.

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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.

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.

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. The revised figure is shown below:

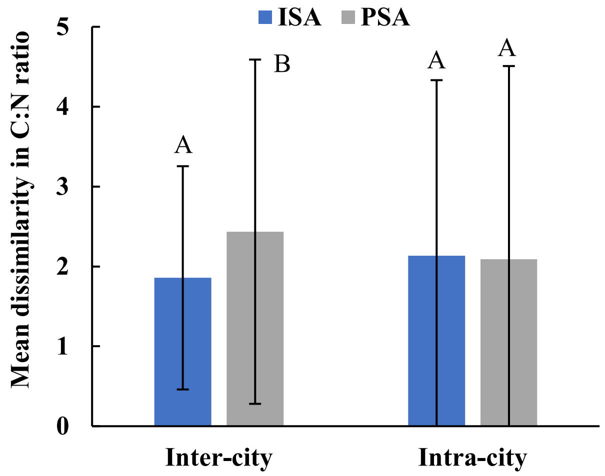


Figure 5: Comparing the inter–city variation and the intra–city variation of C:N ratios between the ISA and PSA. The variations were measured by the dissimilarity of (or the Euclidean distance between) paired observations. For intra–city variation, the soil C:N dissimilarity between each pair of different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

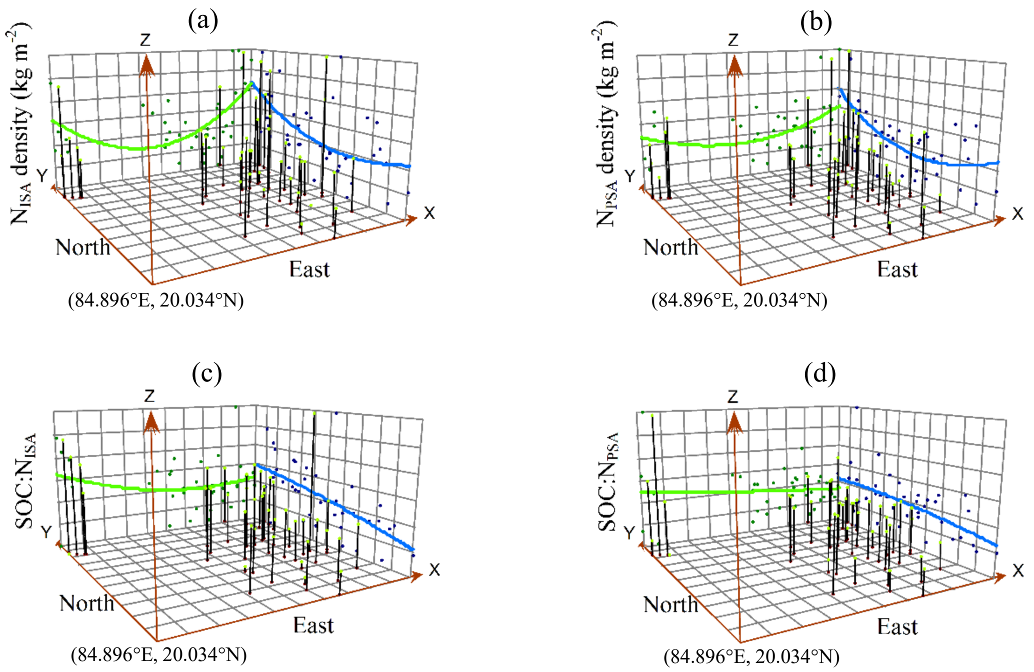


Figure 6: The variation trend of N and C:N under the two surfaces.

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:

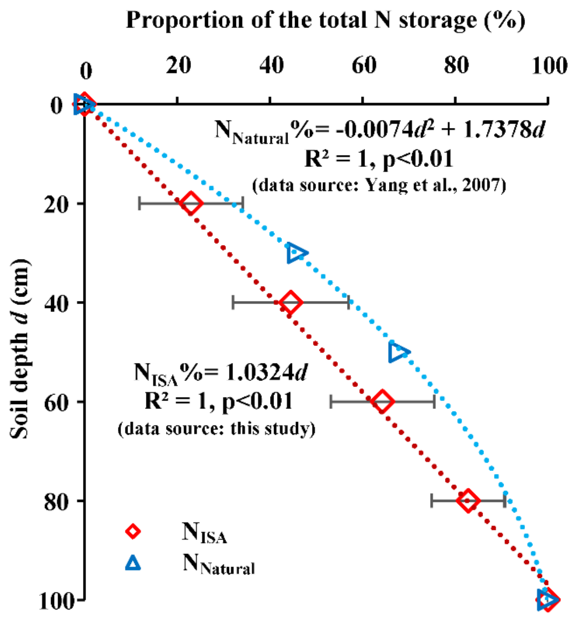
$$N_{ISA}\%_d = 1.0324d \qquad (5)$$

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 soil. 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:



We also revised section 2.4 (see below) 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):

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

where $N_{Natural}\%$ is the proportion of total N stock (in 100 cm depth) stored to depth d cm in natural soil in China. The equation shows that the $N_{Natural}\%$ 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 responses to the comment 7).