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Reply to Sun: Real-world bulk density changes support high carbon sequestration potential of biochar

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We thank Sun (1) for their interest in our paper (2) and welcome this opportunity to clarify our approach. Although we value constructive scientific exchange, Sun's comments stem from a fundamental misinterpretation of our work, and the computational method they propose is highly idealized and not applicable to real soil systems.

First, the soil bulk density values with and without biochar application in our dataset were taken directly from the original studies. They were not imputed or assigned by us, as implied by Sun's comment. Our carbon sequestration calculations (presented in *SI Appendix*) included only studies that reported bulk density values and therefore remain valid. In our dataset, bulk density decreased significantly, by 7.1% and 8.3% in paddy and upland soils, respectively, and by 11.0% and 11.3% under long-term continuous application (longer than 5 y) (Fig. 1 *A* and *B*). These changes are consistent with previous studies (3–5) and with Sun's expectation. However, Sun's Fig. 1 appears to present only bulk density values from control plots without biochar addition. As a result, the absence of a significant trend in that figure does not support the conclusion they draw. When the appropriate data are analyzed, namely, the data from soils receiving biochar, strong and highly significant relationships between application rate and bulk density appear for both paddy and upland soils (Fig. 1 *C* and *D*).

Sun's own equations inadvertently illustrate the magnitude of error that results from relying on theoretical rather than measured bulk densities. Using their formulas, we calculated theoretical soil bulk densities—both with and without biochar—based on the soil bulk densities they reported (0.78, 1.25, and 1.76 g cm^{-3} for clay, loam, and sand) and

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The authors declare no competing interest.

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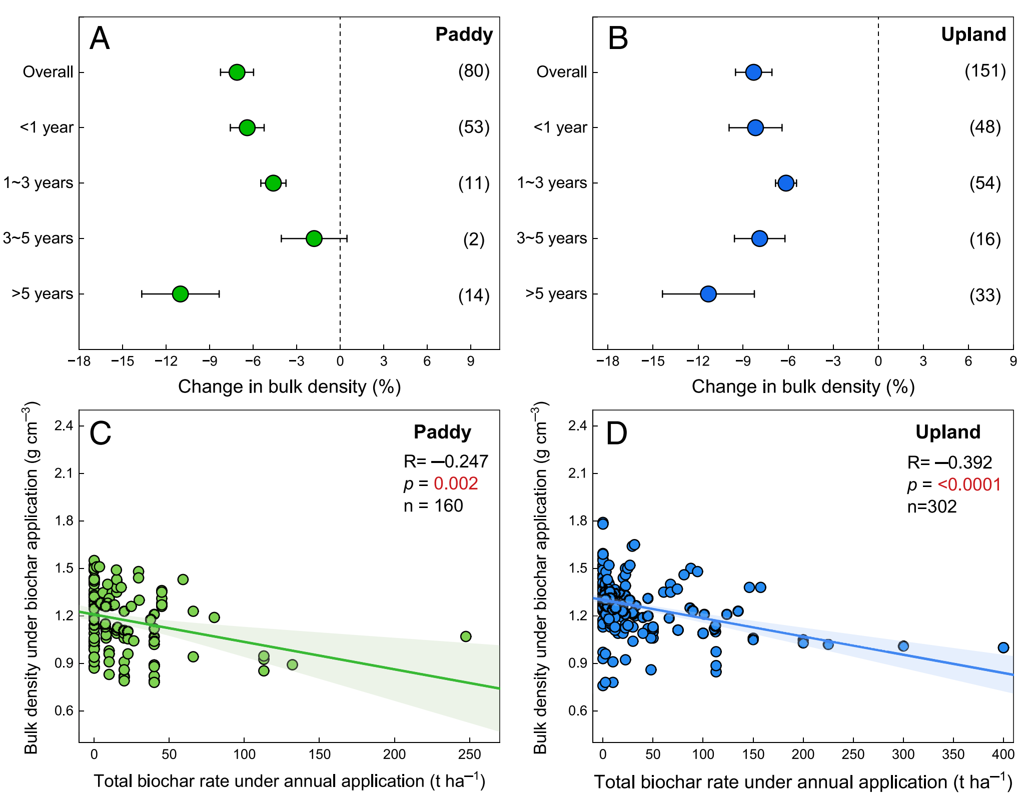

Fig. 1. Changes in soil bulk density in paddy (*A*) and upland fields (*B*) under long-term continuous biochar application, and the correlations between bulk density and total biochar rate in paddy (*C*) and upland fields (*D*).

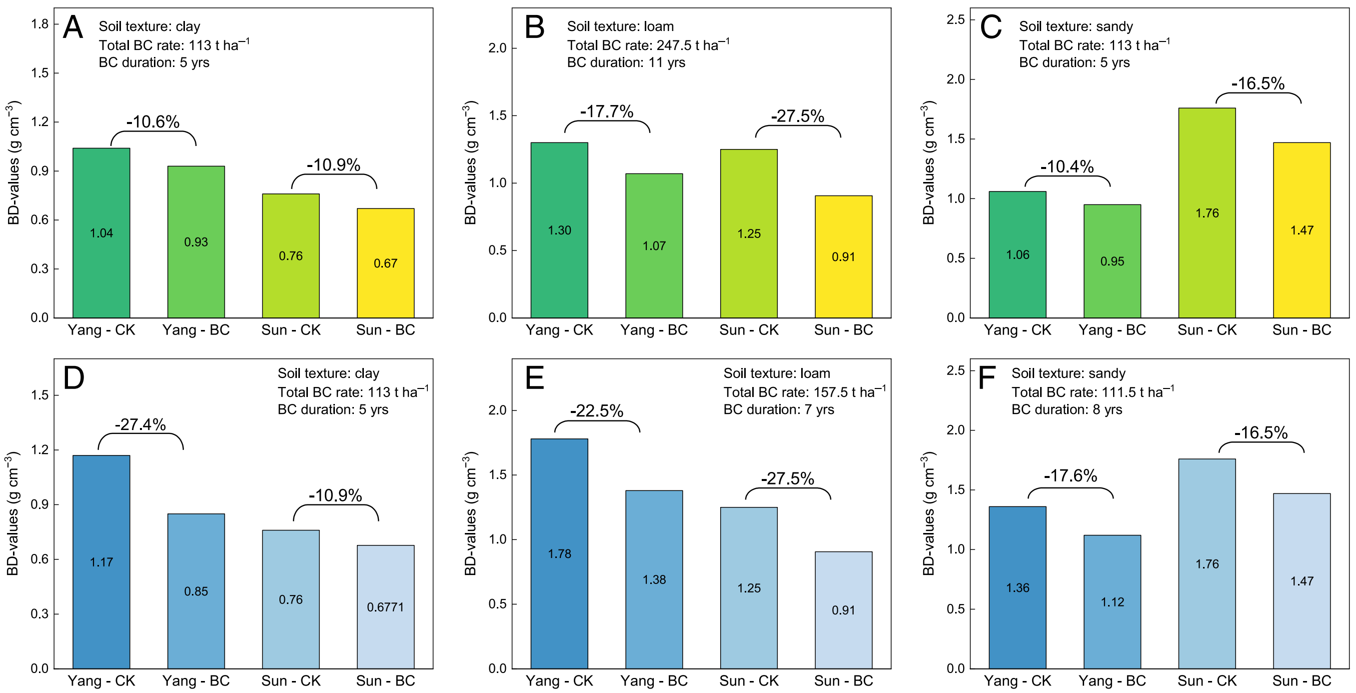

Fig. 2. Theoretical (Sun-CK and Sun-BC) and measured values (Yang-CK: without biochar; Yang-BC: with biochar) of soil bulk density in paddy (*A*–*C*) and upland fields (*D*–*F*) with varying soil textures. Data in panels *A*–*F* are derived from studies 343, 429, 343, and 343, 34, 328, respectively, in the database of Yang et al. (2). We selected these long-term trials based on the longest possible durations and to cover three different soil textures.

the midpoint biochar bulk density (0.24 g cm^{-3}) for a range of long-term experiments in our dataset. In paddy soils, theoretically predicted decreases in soil bulk density with biochar application were generally *larger* than measured decreases (Fig. 2 *A*–*C*). In upland soils, predicted decreases were *smaller* than actual decreases (Fig. 2 *D*–*F*). Consequently, SOC sequestration rates calculated using theoretical bulk density values are too low in paddy fields and too high in upland fields.

Several factors can explain why bulk density changes in long-term field experiments are different from theoretical predictions. For example, biochar applied at the surface undergoes aging and fragmentation into nanoscale particles with high vertical mobility (6); the loss of these particles from the topsoil can lessen the expected decrease in bulk density. In addition, small biochar particles can occupy soil pores, reducing porosity and partially offsetting declines in bulk density (7). On the other hand, biochar application often increases soil aggregation (7), a process that generally reduces bulk density in upland soil (8).

In conclusion, the bulk density values used in our carbon sequestration calculations were measured values from peer-reviewed studies, not arbitrary inputs. Theoretical estimates such as those proposed by Sun are unnecessary and can substantially misrepresent real-world conditions. This reinforces the need for empirically grounded assessments of biochar–soil interactions.

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