Published July 11, 2019

Reply to "Comment on 'Humic Substances Extracted by Alkali Are Invalid Proxies for the Dynamics and Functions of Organic Matter in Terrestrial and Aquatic Ecosystems,' by Kleber and Lehmann (2019)"

Markus Kleber* and Johannes Lehmann

Dear Editor,

In a recent paper in *Journal of Environmental Quality* (Kleber and Lehmann, 2019), we expressed a number of concerns regarding the continued use of the term *humic substances* as a label for the materials extracted from soil by alkali. We appreciate the interest in this topic and are pleased to continue the discussion. We thank Maria De Nobili for taking the time to express alternative views that enrich the conversation. And we take the opportunity to clarify that our suggestion is not motivated by an intention to ban or censor terminology but by the concern that for a sizable segment of the scientific community, the term *humic substances* carries meaning far beyond the identification of a certain type of soil extract. To illustrate the nature of our concern, we point to examples from the recent literature, reflecting our basic premise that there remains a lack of clarity whether humus and humic substances are defined by extraction procedure or as a substance class that can be obtained without reference to alkaline extraction. For instance, one textbook will maintain that "Soil organic matter consists of two groups of compounds: *nonhumic* and *humic* substances" (Essington, 2015, p. 155), while another textbook (Sposito, 2016) does not make this distinction; in fact, it does not mention humic substances at all, other than as a quote in a problem set. The underlying dichotomy of viewpoints is increasingly acknowledged in soil organic matter science (Weil and Brady, 2017) but remains frequently overlooked in related disciplines.

Recommendations for definitions of humic substances in the literature range from "Humic substances are organic biomolecules with chemical structures which do not allow them to be placed into the category of non-humic molecules" (Baldock and Broos, 2011) to "Humic substances are complex and heterogeneous mixtures of polydispersed materials formed by biochemical and chemical reactions during the decay and transformation of plant and microbial remains (a process called humification). . . . The precise properties and structure of a given [humic substance] sample depends on the water or soil source and the specific conditions of extraction" (International Humic Substances Society, 2019).

While a plethora of suggestions to define humic substances can be found, a rigorous, unanimously accepted, chemical definition constraining the relevant molecular properties of humic substances does not exist. Consequently, the International Union of Pure and Applied Chemistry (IUPAC) does not recognize humic substances as a chemical category.

We therefore agree with De Nobili's conclusion that "there is a need for a better definition of humic substances." We posit that as long as the category "humic substances" remains tied to the alkaline extraction procedure, there may not be a productive way forward. If humic substances do exist in nature, then it must be possible to observe these substances with other, independent methods. If they make up a significant proportion of natural organic matter, it must be possible to elucidate their pathways of formation.

In our paper, we highlight our reservations about defining humic substances and advancing a "humic substance paradigm" based on an operational extraction procedure. For both logical and empirical reasons (compare Wershaw [2000] and Kleber and Lehmann [2019]), said paradigm is flawed (Wershaw, 2000) and, if used as the basis of mechanistic inference, will lead to false conclusions.

We agree with De Nobili's well-argued observation that extraction procedures will always have method-specific restrictions; in fact, this insight is part of our argument. Often, extraction procedures will attempt to separate the entirety of a substance class (such as the procedures meant to extract DNA from soil) but will only extract a subset or even create a false positive. Clearly, as De Nobili points out, such restrictions must be recognized and reflected in attempts to assign biogeochemical meaning to the extracted materials.

As we have shown previously (Kleber and Johnson, 2010), alkaline extracts of organic matter are known to have beneficial practical applications, but calling these materials humic substances invokes the humic substances paradigm (Wershaw, 2000) with its underlying, obsolete conceptual baggage. Keeping the term *humic substances* alive makes sense only when these

J. Environ. Qual. 48:790–791 (2019)
doi:10.2134/jeq2019.05.0210le
Received 26 May 2019.
Accepted 3 June 2019.
*Corresponding author (Markus.Kleber@oregonstate.edu).

M. Kleber, Dep. of Crop and Soil Science, Oregon State Univ., 2750 SW Campus Way, Corvallis, OR 97331; J. Lehmann, Soil and Crop Science, School of Integrative Plant Science, 909 Bradfield Hall, and Atkinson Center for a Sustainable Future, Rice Hall, Cornell Univ., Ithaca, NY 14853, and Institute for Advanced Studies, Technical Univ. Munich, Lichtenbergstrasse 2a. 85748 Garching, Germany. Assigned to Associate Editor Tsutomu Ohno.

materials represent a category of organic compounds that can in some fashion be distinguished from other organic materials in the soil. Unfortunately, the alkaline extraction procedure is unable to achieve a rigorous, chemically expressible distinction of molecular properties.

Again, our motivation to engage in this discussion is not a misguided desire to stir up trouble. As the community continues the discussion, we always want to recognize that we are working on an issue that has been raised many times in the past (Waksman, 1936; Oades and Ladd, 1977; Wershaw, 2000; von Lützow et al., 2006) but that has evaded final clarification so far (Baveye and Wander, 2019), leaving us with the discrepancies between textbooks and definitions reported above.

The resulting state of conceptual confusion is undesirable for all of us and particularly detrimental to the next generation of soil scientists. Consequently, we will continue to contribute to any discussion that enhances the rigor of the nomenclature in the field, and we remain convinced that this desire unites us with all other scientists who aim for progress and an evolution of meaningful paradigms.

References

Baldock, J.A., and K. Broos. 2011. Soil organic matter: In: Handbook of soil sciences. CRC Press, Boca Raton, FL. p. 11-11–11-52.

Baveye, P.C., and M. Wander. 2019. The (bio)chemistry of soil humus and humic substances: Why is the "new view" still considered novel after more than 80 years? Front. Environ. Sci. 7. doi:10.3389/fenvs.2019.00027

Essington, M.E. 2015. Soil and water chemistry: An integrative approach. CRC Press, Boca Raton, FL. doi:10.1201/b18385

International Humic Substances Society. 2019. What are humic substances. IHSS. http://humic-substances.org/what-are-humic-substances-2/ (accessed 3 June 2019).

Kleber, M., and M.G. Johnson. 2010. Advances in understanding the molecular structure of soil organic matter: Implications for interactions in the environment. Adv. Agron. 106:77–142. doi:10.1016/S0065-2113(10)06003-7

Kleber, M., and J. Lehmann. 2019. Humic substances extracted by alkali are invalid proxies for the dynamics and functions of organic matter in terrestrial and aquatic ecosystems. J. Environ. Qual. 48:207–216. doi:10.2134/jeq2019.01.0036

Oades, J.M., and J.N. Ladd. 1977. Biochemical properties: Carbon and nitrogen metabolism. In: J.S. Russell and E.L. Greacen, editors, Soil factors in crop production in a semi-arid environment. Univ. of Queensland Press, St. Lucia, QLD, Australia.

Sposito, G. 2016. The chemistry of soils. 3rd ed. Oxford Univ. Press, New York.

von Lützow, M., I. Koegel-Knabner, K. Ekschmitt, E. Matzner, G. Guggenberger, B. Marschner, et al. 2006. Stabilization of organic matter in temperate soils: Mechanisms and their relevance under different soil conditions—A review. Eur. J. Soil Sci. 57:426–445. doi:10.1111/j.1365-2389.2006.00809.x

Waksman, S.A. 1936. Humus: Origin, chemical composition, and importance in nature. Williams and Wilkins, Baltimore, MD. doi:10.1097/00010694-193605000-00010

Weil, R., and N.C. Brady. 2017. The nature and properties of soils. 15th ed. Pearson Education, Harlow, UK.

Wershaw, R.L. 2000. The study of humic substances: In search of a paradigm. In: E.A. Ghabbour and G. Davies, editors, Humic substances, versatile components of plants, soil, and water. The Royal Society of Chemistry, Cambridge, UK. p. 1–7. doi:10.1016/B978-1-85573-807-2.50005-9