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EDITORIAL

Pervasive use of P_2O_5, K_2O, CaO, MgO, and basic cations, none of which exist in soil

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The use of abbreviations in a title of a paper is usually discouraged, even N (nitrogen) and P (phosphorus). However, in this case the abbreviations in the title make perfect *sense*, even if they refer to *nonsensical* molecules, as we explained in a recent Editorial for *Plant and Soil* (Lambers and Barrow 2020). Upon reading our article, the Editor in Chief of *Biology and Fertility of Soils* invited us to slightly modify our text and make it available to readers of that journal. Inevitably, this text, therefore, involves some degree of self-plagiarism.

When Carl Sprengel (Sprengel 1828; as cited in Jungk 2009) and Justus von Liebig (1855) did their groundbreaking work on plant nutrition, little was known about the chemical nature of the nutrients they showed were needed by plants. Justus von Liebig largely based his presentation of the chemicals on the doctrine of Berzelius (1814). As Geoffrey Leeper deplored in a Note on Chemical Terms in his well-known textbook,

> Unfortunately, archaic usages have lingered in soil science long past their time. Thus, the double-oxide theory of salts – the doctrine of Berzelius in 1820, that magnesium sulphate is $MgO.SO_3$- persists in two fields. Firstly, many writers still record elements as their oxides; calcium appears not as the simple element, but as CaO (which does not exist in soil) and phosphate appears as P_2O_5, which is quaintly referred to as 'phosphoric acid'. The phosphate radicle (PO_4), which does exist, should surely be preferred, or alternatively the element (P), which many Americans have already adopted. These can be converted into one another on the basis 1.00 part of P is equivalent to 2.29 P_2O_5 and to 3.06 $P0_4$. (Leeper 1948)

More than 70 years after Leeper published his textbook that became the bible in the discipline, P_2O_5, K_2O, and CaO still do not exist in soil, but the terms continue to be used in the literature. It is understandable why some fertilizer companies, but not those in Australia or New Zealand, like to print P_2O_5 on their package, as they give the impression they sell far more than is in the bag. It is a mystery, however, why soil science analytical laboratories persist showing their data as was common in the nineteenth century. When one of us (HL) recently shared Geoffrey Leeper's Note on Chemical Terms with some of his colleagues, a professor in one of the disciplines of agricultural sciences in Germany responded: "Even in exams all this is still existing although I repeatedly argue against it in my lectures. I am going to forward the pdf to my students." That is not surprising, since even top journals in agronomy persist with these nonsensical terms (Lopes and Guimarães Guilherme 2016; Song et al. 2019). Also, in horticultural journals, authors still get away with P_2O_5 (Ortas 2019). One would hope that authors who publish in *Biology and Fertility of Soils* would stick to Leeper's advice, but, alas, this turns out not to be the case (Samaddar et al. 2019; Van Dommelen et al. 2009; Tawaraya et al. 2012).

One of us (HL) decided to do a search in his own EndNote library, to be astounded by the number of papers and journals he stumbled across when looking for P_2O_5 in his PDF files, even when looking only at publications after 2000. He got the impression that there is likely no journal in which the nonsensical chemical formulas do not appear, and that the use of terms is pervasive in a wide range of countries and disciplines. Aliyu et al. (2019) in PLoS ONE consider it appropriate to feed cassava P_2O_5 and K_2O, Li et al. (2020) and Wang and Ning (2019) in *Frontiers in Plant Science* believe P_2O_5 is suitable to grow rice and maize, respectively, and *New Phytologist* publishes papers showing trees use P_2O_5 (Weber et al. 2018; Edwards et al. 2015). Respectable soil science

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journals and ditto soil scientists, who one assumes would be familiar with their bible (Leeper 1948), have not yet taken his advice on board either (Vos et al. 2019). Ectomycorrhizal fungi supposedly cope with P_2O_5, K_2O, and CaO as well as MgO (Schmalenberger et al. 2015). And if you thought that scientists focussing on transcriptome analysis or molecular biology were ahead of the game, you will be disappointed (Li et al. 2019; Giri et al. 2018). Also, highly prestigious journals happily continue with nonsensical chemical formulas (Li et al. 2007). Leeper (1948) felt than many Americans had already adopted the use of P, but even American soil scientists (Weyers et al. 2016; Ranatunga et al. 2009) and ecologists (McKee et al. 2002; Griffin et al. 2001) continue to use the obsolete terms. HL gave up on his embarrassing search in his EndNote library, feeling sorry for Geoffrey Leeper who did his very best to stop the use of terms that belong to the nineteenth century.

In a reply to one of us (NJB), some agronomists justified their use of P_2O_5 by pointing out that it was part of their country's fertilizer regulations and was used by American fertilizer manufacturers. NJB replied: "You are preparing a manuscript that you hope will be read by international scientists. In a science communication you should use the language of science. It is not relevant that your country's bureaucracy and North American fertiliser manufacturers use outmoded terminology. You should use P not P_2O_5."

If some fertilizer companies want to continue their outdated practice of selling phosphorus, calcium, magnesium, and potassium attached to oxygen that is not really in the fertilizer bag (http://ifadata.fertilizer.org/ucSearch.aspx), then that is their business, even though we do not endorse it and would like to see them change their wicked ways. However, in academic writing, the use of P_2O_5, CaO, K_2O, and MgO must really stop. We have moved on since Jöns Jakob Berzelius (1814) and Justus von Liebig (1855). It is high time we acted upon Geoffrey Leeper's advice (Leeper 1948), and used chemical formulas that belong in the twenty-first century, rather than the 1800s.

Equally, egregious is the use of terms such as "base exchange" and "basic cations." Although less common these days, these terms still appear in the scientific literature (Nakano et al. 2001; Cai et al. 2015; Zeng et al. 2017). They also appear in manuals of soil analysis (NCR-13 2011) and are very common in the extension literature. Leeper (1948) was at his acerbic best when dealing with them. "The other relic of the double-oxide theory is the term 'base exchange,' which is still often used instead of *cation exchange.* This deplorable term 'base exchange' has caused untold confusion. The cations which take part in exchange reactions include calcium, magnesium, ammonium, and hydrogen. Of these, hydrogen is the essence of acidity, and it is the height of absurdity to call it a 'base.' Ammonium is a weak acid, by virtue of its tendency to liberate hydrogen ion ($NH_4^+ \rightleftharpoons NH_3 + H^+$), so its salt ammonium chloride is acid to methyl red. The ions of the metals calcium and magnesium, though one could hardly call them acids, are most certainly not bases. A base is something which reacts with or removes acid, that is, hydrogen ion; it would be interesting to learn from the champions of the term 'base exchange' what interactions Ca^{++} and H^+ have with one another. This fallacy comes from the days when it was the *bases* CaO and MgO that were exchanged, as compared with the *ions* Ca^{++} and Mg^{++} of to-day."

The terms "base exchange" and "basic cations" are rationalized by Bache (2008) as follows. "Base saturation… is a partial misnomer because a base is a chemical compound that can react with an acid to form a salt; calcium hydroxide, $Ca(OH)_2$, is an appropriate example. In the present context, however, it is now understood to mean the *cation* of the base, that is, Ca^{2+}, as distinct from the cations $H_3O^+$and $[Al(H_2O)_6]^{3+}$, which are acids." We do not think it appropriate to use terms that are misnomers; it would be better if in this context we also used terms that belong in the twenty-first century: cation exchange, exchangeable cations, and cation saturation.

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