Plant Soil (2020) 452:1–4
https://doi.org/10.1007/s11104-020-04593-2

EDITORIAL

P_2O_5, K_2O, CaO, MgO, and basic cations: pervasive use of references to molecules that do not exist in soil

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Received: 3 May 2020 / Accepted: 3 June 2020 / Published online: 9Jume2020

Plant and Soil usually strongly discourages the use of abbreviations in a title of any paper, even N (nitrogen) and P (phosphorus). However, in this case these abbreviations make perfect *sense*, even if they refer to *nonsensical* molecules, as we will explain below.

When Justus von Liebig did his ground-breaking work towards what we now know as the law of the minimum (von Liebig 1840; Liebig 1855a, b), little was known about the chemical nature of the nutrients he showed were needed by plants. Whilst many are familiar with this law and tend to refer to it as Liebig's law of the minimum, in all fairness, we should refer to it as "Sprengel-Liebig's Law of the Minimum" and give credit to Carl Sprengel (Sprengel 1828; as cited in Jungk 2009). By elucidating the mineral theory, and the law of the minimum, Sprengel (1787–1859) laid the foundation of plant nutrition (van der Ploeg et al. 1999).

Justus von Liebig largely based his presentation of the chemicals on the doctrine of Berzelius (1814), captured in a book that is freely available online, courtesy of Google books. 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 they continue to be used. It is understandable why some fertiliser 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 19th century. When I (HL) recently shared Geoffrey Leeper's Note on Chemical Terms with some of my 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 of us (HL) decided to do a search in his own EndNote library, to be astounded by the number of

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papers and journals he stumbled across when looking for P_2O_5 in his PDF files, even when looking only at publications after 2000. To his horror, it even included papers published in *Plant and Soil* (Chieppa et al. 2019; White et al. 2018). 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 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, 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 19th century.

One of us (HL) recently tried to persuade a plant ecologist to make some changes to an online manuscript that had not yet been formally published, and wrote in an email: “In your Abstract, you wrote: “Three species utilized $AlPO_4$ and P_2O_5”. P_2O_5 may be written on fertiliser bags, but that compound does not exist. It is not something that should be written in scientific publications, and I would like to suggest you tell your readers what you really used. It surely was NOT P_2O_5.” The response was: “We used P_2O_5 instead of KH_2PO_4 or NaH_2PO_4 in our experiment for the following reasons. (1) We focused on O-P. P_2O_5 is dissolved in water and thus forms PO_4, which might be a good proxy of O-P; (2) if we used KH_2PO_4 or NaH_2PO_4, we couldn’t exclude the effects of K or Na.” Needless to say, the crusade continued, and I finally did get the message across. At least, the reference to P_2O_5 disappeared from the Abstract, but an equally nonsensical compound that was mentioned, $Fe_4(P_2O_7)_3$, which was considered an organic form of P, still features in the article .

If some fertiliser companies want to continue their outdated practice of selling phosphorus, calcium, magnesium and potassium attached to oxygen that is not really in the fertiliser 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 Berzelius (1814) and von Liebig (1855b). It is high time we acted upon Geoffrey Leeper’s advice (Leeper 1948), and used chemical formulas that belong in the 21st 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 rationalised 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 21st century: cation exchange, exchangeable cations and cation saturation.

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