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Citation classics

Soil Biology & Biochemistry Citation Classic VI

Richard G. Burns

School of Land, Crop and Food Sciences, The University of Queensland, Brisbane, Queensland 4072, Australia

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The latest SBB Citation Classic is interesting in many ways. It has direct implications for soil, water and food quality, remediation (both phyto- and bio-), biogeochemistry and the cycling of nutrients, and the myriad of essential processes performed by soil microbes. It also asks difficult scientific questions of soil biologists, chemists and physicists and microbial ecologists and is controversial because environmental agencies, politicians, economists and law makers are faced with reaching decisions and making policy with regard to the health of the soil. In addition, the paper has some fascinating bibliometric characteristics.

Giller et al. (1998) is the most recently published paper discussed in the *Soil Biology & Biochemistry* Citation Classics series yet is the 6th most cited paper since the launch of the journal in 1968. A look at SBB's top 50 most cited papers shows that you have to scan down to #24 to find another paper published in 1998 that is picking up a high number of cites (Grayston et al. (1998) 30, 369–378. 300 citations). So, if you judge the impact of a paper by the number of citations per year Giller, Witter and McGrath gets a score of 43 whilst those the top five in our hit parade (the soil microbial biomass blockbusters) get annual scores of 96 (Vance et al. (1987) 19, 703–707), 38, 41, 46 and 29. The continuing and increasing significance of this highly influential paper is further revealed when you notice that more than 50% of the citations have come in the last five years. The impact of metals on soils was, is and will continue to be of great importance in our understanding and stewardship of this precious resource.

In the original paper the authors reviewed their own work and that of many others on the impacts of heavy metals on soil microbes and processes. The information was diverse, contradictory and not easily resolved yet they generated a rational synthesis of the information, drew some conclusions, made insightful suggestions, and gave pointers to future research needs. The practice of applying sewage sludge to soils was controversial then, as it is now, because the laudable aim of adding organic waste to soil to improve its quality and increase crop yield was comparable to the age-old practice of adding farmyard manure; this was organic, sustainable and 'green'. On the other hand, adding large amounts of heavy metals such as lead, cadmium, zinc and copper, was inorganic, unsustainable and polluting.

With microbes and microbial processes, as it is with soil invertebrates and plants, the initial challenge is to measure what proportion of the total metal the organism actually 'sees' and, therefore, is likely to be influenced by. This is the defined as bioavailability, a topic that was not that well understood (or even universally accepted as an important issue) eleven years ago. Yet it is obvious that total soil heavy metal (or organic pollutant – or even plant nutrient) content of a soil is not synonymous with the proportion of the element that is available to react with the chosen bioindicator. The properties of the element in question, its speciation and the physical and chemical nature of the soil will determine what proportion of the metal is bound and biologically non-available and what proportion is in the aqueous phase and has the potential to interact with the microbes. In addition, this partitioning between liquid and solid phases is a dynamic condition because sorption and entrapment is strongly affected by such as pH, E_h, redox potential, cation exchange capacity, and organic matter composition and structure.

Furthermore, none of these soil properties are static and are influenced by many factors including microbial activity which changes inevitably once the organic matter addition has occurred. Actively growing microbes may be able to access adsorbed and absorbed metals in the same way as they do organics, or at least create a microenvironment that leads to desorption. Therefore, a flush of decomposition, mineralization and respiration following organic matter application may influence the partition of the heavy metals between the available and non-available phases. But even regarding the aqueous phase metals as uniformly bioavailable is an over-simplification because the element may not diffuse to and interact with microbes hidden deep within aggregates, protected within clay domains or housed within polysaccharidic biofilms. So an agreed definition of bioavailability to microbes is hard to come by – and even harder to quantify.

In their Citation Classic article Giller, McGrath and Witter discuss the difficult choice of bioindicator and whether to choose individual species, communities of microbes, or processes. Put another way, do you go for the usual nitrogen cycle suspects (sensitive rhizobia, nitrifiers) and assume these are keystone organisms that must be protected at all costs or choose either

E-mail address: r.burns@uq.edu.au

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casual or integrated (mycorrhizas) rhizosphere dwellers? Alternatively, do you measure shifts in genomic, proteomic and metabolomic diversity or just select microbial biomass as a gross measure? What is very clear is that community-driven processes (ammonification, respiration) are insensitive indicators. And then, how do you interpret the periodicity of the impact: short term changes in a biological property versus longer term shifts? In other words, is a 10% reduction in a process for 100 days more significant that a 50% reduction in 5 days? You pays your money and you takes your choice.

Even if you can agree on the microbial target for the bioassay does it carry a fixed set of properties or a constant set of genotypes? We now know that microbial genotypes (and consequently their phenotypes) are plastic and that horizontal gene transfer and complex regulatory processes may turn what was assumed as a constant property associated with a defined species or community into one that can be lost and re-emerge in another species. Particularly relevant here is that heavy metal resistance is often carried on transmissible plasmids.

This brings us to another important point made by our citation classicists and that is the potentially great difference between acute impacts and longer term chronic exposures. More often than not the former is the basis for laboratory experiments whilst the latter is the situation in the field. Long-term exposure may manifest itself in two ways: the first is a single initial impact and then the elapse of time; the second is continuous exposure over an extended period. Old pollutants will have 'aged' and are likely to have a different physico-chemical relationship with the soil components (especially the clays and humates) in comparison to those recently applied. But either way, selection pressures on the versatile microbial community will be at work and the pre-existing tolerant and resistant strains will become dominant along with the mutant strains that find themselves favoured by the now stressed environment. In general, resistance and resilience are features of complex communities and this is writ large in the microbial world. Thus, immediate impacts on previously non-contaminated soils may be very different from those recorded in soils that have been subject to continuous disruptive inputs and where the new microbial community may have different properties in comparison to the original.

The interpretation of the above pre-supposes that there is an agreement as to which extractant to use that will enable you to distinguish between total and soluble and bioavailable and non-bioavailable heavy metal and what methods you use to measure how microbes respond to or report on the impact. But as the plant people know, this is whole new set of concerns and debate!

The final questions touched upon by Giller, McGrath and Witter is: who listens to your research and suggestions and how do they respond? If ever there was a controversy waiting to happen then the question around the sludge/metal environmental impacts was it. The arguments and the legislative responses are still with us today and our Citation Classic authors point out the divide between Europe and the USA with regard to how we protect our soils. Of course, the up side of this is the transparent need for more and better funded research. Translating that into hard cash and good science is a challenge for the future.

After Rothamsted, Ken Giller went to Wye College, University of London where he was promoted to a personal chair in 1996. He then spent three years at the University of Zimbabwe until he moved to Wageningen University as Professor of Plant Production Systems in 2001. Ken's research has focused on legumes and nitrogen fixation, including molecular ecology studies with rhizobia. Currently, he leads a group of scientists using the tools of systems analysis to scale from fields to farms and farming systems. He has lasting interest in soil fertility management in tropical agriculture and has worked extensively on plant litter quality and decomposition.

Steve McGrath is an internationally recognised authority on the chemical forms of pollutants in soils, their uptake and fate in plants and their effects on soil microorganisms. Currently he is Programme Leader of Soil Protection and Bioremediation Research and Deputy Head of the Soil Science Department at Rothamsted Research in the UK. Since 2001 he has held the position of Special Professor in the School of Biosciences in Nottingham University. He is a partner in many international research programmes including those of the EU, UNEP and FAO and is currently Secretary of the International Society for Trace Element Biogeochemistry.

These two eminent soil biologists have published well over 400 papers between them and at least thirty of these have been cited more than 100 times.

Ernst Witter became associate professor at the Swedish University of Agricultural Sciences (SLU) at Uppsala in 1998 after which his work changed focus from metals in agricultural soils to plant nutrition and soil fertility. Ernst remained at SLU until the end of 2003 after which he decided to make a change. During 2004 and 2005 he worked as a teacher at an agricultural college in Eritrea and, upon returning to Sweden, re-trained as a secondary school teacher. He is still involved with scientific research but now primarily teaches crop science, chemistry and biology at an agricultural secondary school in Sweden, making a huge contribution to the education and future of young people. With this training some of his pupils may even author the SBB Citation Classics of the future!

Reference

Giller, K.E., Witter, E., McGrath, S.P., 1998. Toxicity of heavy metals to microorganisms and microbial processes in agricultural soils: a review. Soil Biology & Biochemistry 30, 1389–1414 (cited 489 times).