Organic Phosphorus Workshop, Ambleside Cumbria UK 2016

Organic Phosphorus in the Environment: Solutions for Phosphorus Security.

Before-dinner speech by Guest of Honour A F Harrison*, given Thursday 8th September 2016.

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I am honoured to be asked to take part in this conference and to be invited back into the 'Organic Phosphorus fold', so to speak, albeit temporarily. Thanks everyone for the warm welcome. My last publication on the topic of Phosphorus was published almost 25 years ago in 1991. I was somewhat humbled by this invitation, as my knowledge of the current research output is rather scant. So it has been with very great interest for me to learn about your recent research.

I've been asked a number of times 'How did I get into Soil Phosphorus research ?' and 'Why did I work in woodlands ?'

Well, after I had finished my PhD, I managed to get a job in 1968 in the Woodland Habitat Team of The Nature Conservancy (an earlier version of the current Centre of Ecology and Hydrology) at the Research Station at Grange-over-Sands, southern Lake District. My research brief was quite simply to work on soil organic matter.

Soon after starting, I found myself involved in a collaborative whole ecosystem study of a local woodland (Meathop Wood) as part of the International Biological Programme. I became involved with a group of specialist researchers from the research station and from various Universities, in investigating the woodland biomass, tree and ground flora productivity, organic matter decomposition, soil microbiology, soil fauna and nutrient cycling in great detail. It was during the work on the nutrient aspects, that I realised that phosphorus was the key limiting nutrient in many ecosystems, eg forests, heather moorlands and upland grasslands here in the northern UK. I soon found myself constructing out of the project data provided by other researchers, a P cycling diagram for the whole woodland, giving amounts of P in kg ha^{-1} in the component biomasses, including estimates of total, organic and available P in the soil profile, and the annual transfers of P in kg P ha^{-1} yr^{-1} between all the different components, including inputs as atmospheric deposition and losses in drainage. This research I found very fascinating. I even got invited a few years later in 1976 to a high-profile conference held in London entitled 'Phosphorus in the Environment' to present a paper on it (published in 1978[1]). Incidentally, 83 papers have been published on this IBP whole woodland study. The experience gained from this project work gave me a good whole-ecosystem **perspective** for my future soil P work. I also gained a **wider perspective** from being able to compare the results with other IBP studies eg those of the Solling and Hubbard Brook projects in Germany and USA respectively and with those of other IBP biomes eg in the tundra and grasslands. Actually I think it was all this which switched me on !

After this work I resolved, in about 1974, to work on soil organic and available P in other Lake District woodlands, particularly as P deficiency could be having major impacts on woodland ecology. When I discussed this idea with colleagues, they made comments such as 'there aren't many good methods to use', 'there are many awkward soil properties which will interfere with getting decent measurements' and 'soil variability in natural ecosystem soils is horrendous, so it will be difficult to get significant results'. No significant results ! No publications ! No future !

Challenges indeed !! Anyway, despite these comments, I went on to examine the 'within' and 'between' woodland, temporal and depth variation in soils of four phosphorus properties in 10 Lake District woodlands[2]. I looked at total, organic, isotopically-exchangeable P as a measure of available P and phosphatase activity. I also measured soil bulk density for all samples taken.

Even with a modest level of replication, I was able to detect significant differences between woodlands in all properties, significant temporal variation in organic P, isotopically exchangeable P and phosphatase activity, significant soil depth differences and a number of complex interactions in addition. What is more, the results all seemed to be quite sensible and interpretable, if the results were expressed in terms of soil volume rather than by soil weight. A simple rule of thumb, which came out of the project, was that the low-level of P availability was associated with low total P per unit volume of soil and the high proportion of the P bound in organic form. Low P availability, suggesting plant P deficiency, in the Lake District Woodland soils was later confirmed through the use of the root bioassay technique which I had developed; the bioassay is based on a 'hunger response' of living plant roots[3]. Confirming P deficiency in the Lake District woodlands in this way was an important piece of ecological information in itself, but it also provided valuable **perspective** relating directly soil chemistry to plant P nutrition. Incidentally, the low total P per unit volume in the woodland soils (soils shallow and stony), as I mentioned earlier, might be linked to the fact that most Lake District woodlands have been coppiced to produce charcoal at roughly 15 year intervals over approximately three centuries, possibly resulting in a reduction in P capital of soils – a bit of historical **perspective**.

This project helped me to gain good starter **perspective** in soil P work and gave me confidence to continue with the research theme. It also provided me with a number of satisfying publications in Soil Biol. Biochem[4,5,6,7], Oikos[8] and Journal of Applied Ecology[3]. Bearing in mind my colleagues' comments about the potential difficulties of working on soil phosphorus, my message from this experience is "**yes listen to sceptics, but don't let them win by being negative !** ".

I want now to come onto the Soil Organic P review, which was published in 1987[9]. Why did I do this ? My objective was to get a proper overview of soil organic P literature and a global **perspective** on the subject. The review brought together, most if not all of the references available at that time. By doing the statistical analyses on data extracted from published literature I was able, I think, to unlock latent information on organic P in soils, its relationship with other soil properties and how overall it might vary globally with geology, soil type, land use and so on. I hoped that the review and the statistical analyses contained within it, would provide some useful background **perspective** on the research topic. I gather from your kind comments, that the review has attained these objectives.

Just a little historical background here. During the compilation of this review 30 and more years ago, I didn't have the internet to help access the literature – I had to read through Soils and Fertilisers and bibliographies to find references and get photocopies (>900) of publications from the British Lending Library ! In addition, I didn't have any data base programmes to help me to organise information. I had to use my brain and remember what was published where, or Excel to organise data. I didn't have SAS for statistical analyses on a laptop either…. no such thing as a laptop at that time ! There was no 'Powerpoint' for preparing and printing diagrams either. Some of the diagrams were created using Letraset and the graphs were plotted on a flat-bed printer ! I am mentioning all these points to re-emphasise that the review was done long-ago.

So let us fast forward to today. You all now have access to newer more sophisticated methods to analyse organic P (eg ^{31}P NMR, HPLC, LC-HRMS). You have many automated instruments for these analyses making them easier to perform and with potentially better quality control. Computing has developed enormous potential giving you easy access to data base programmes, Excel, SAS or other statistical packages and Web of Science to get almost instantly the information you need. With this increased technological development and 30 year's of more research, you have access to more data and results. **With these much improved facilities, you all should have made lots of real research advances !!** So you now need to ask yourselves "How has the science progressed over the last 30 years ?", " What have been the key new developments ?" and above all " Where has the science been going ?" and "Where does it need to go ?". Clearly there is a need for a sequel to the organic P review I did 30 years ago. Don't look at me …. you are the ones with the up-to-date knowledge and awareness of the state of the current science !!

Regarding the latter point, Where does it need to go ?, I feel strongly there is a need to broaden the **perspective** of the current research. I feel there is a big missing dimension. Imagine..... (and I am sorry this is a quite cliché d conceptual model), imagine there is a big box of knowledge labelled "Research on Soil Organic Phosphorus". From what I have seen, most if not all of your research topics seem to start off **inside** this box. Most projects seem to get ever deeper into this box looking at details of increasing complexity as evidenced by this conference. Other research projects also start off **inside** the box, but try to look outwards towards trends with external factors, such as across ecosystems, plant successions or pedogenetic developments.

I think that at least some of you should start your projects off from **outside the box** and look in. What do I mean ? Some of you should start, for example, by addressing the important environmental issues of our time.

Some possible outline examples are :

Effects of atmospheric acid deposition : Many UK soils have been subjected to pollutant acid deposition for more than a century. In the past two to three decades, the amount of deposition has declined steadily. As a result, many acidic soils, eg on the Pennine hills in northern England (soils mostly peaty-topped ones), seem to be recovering with respect to pH .. some by a half to one pH unit. What effect has this increasing pH had on P cycling from soil organic phosphorus ? Has it had consequences that have fed through to plant P nutrition in these sheep-grazed upland grasslands, perhaps even changing soil microbial and micro-faunal communities ?

Pesticides: Pesticides, and there are seemingly hundreds of different types, are ever increasingly being used in the environment. These often accumulate significantly in soils and are also dispersed further from points of release by wind or water into the environments beyond the crop. What effects do pesticides, particularly bactericides, fungicides and insecticides, have on P cycling from soil organic matter and organic phosphorus ? What do the pesticide effects on processes tell us about the role of different organisms involved with these processes ? What effects do fungicides have on mycorrhizas ?

Climate change: Climate change is having major influences on our environment. Not only are soils increasing in temperature but many are subject to major changes in moisture...wet soils drying out or are subject to occasional drought or flooding. There are also indications in the literature that climate change is affecting the C:N:P ratios in SOM in some environments. Are temperature increases and moisture changes reducing the P limitations to plant growth by speeding up P cycling ? Will these effects result in improved vegetation productivity and / or changing plant communities and their associated soil microorganism and faunal populations, in cold climate and even temperate regions ?

Carbon sequestration in soils: There are strong suggestions that there should be some land management changes, possibly in grasslands, to foster the accumulation of carbon as organic matter in soils, as a way of trying to mitigate the effects of fossil fuel induced rising CO_2 levels in the atmosphere. How will the increases on SOM affect the P cycling from the expected organic P accumulation in the soil and the subsequent plant productivity ?

Biodiversity loss: Biodiversity in the environment is in decline across the globe for various reasons. Many wild plant community types are how they are because of P deficiency and high organic phosphorus content in soils. Four examples from England are Lake District woodlands, upland moorlands on the Pennine hills, species-rich hill meadows and lowland heathlands. I am sure there are other wildlife habitats in other parts of the world, to which this applies. The plant communities in these places are highly dependent on very specific mycorrhizal associations to enable individual plants both to survive and thrive. We need to know much more about how plants in these communities function with respect to their acquisition of P.... very likely to come from soil organic phosphorus via mycorrhizas.

Research on P cycling in wild plant communities is ripe for scientific development, and the information gained could be very helpful in aiding wild life conservation programmes.

By citing these examples, I am not saying you should throw away your ^{31}P NMR machine or your HPLC. But I am saying at least some of you need to **stand outside** the soil organic phosphorus box and start some new research thinking. You need to broaden the research perspective !

It has been suggested that at this point I might introduce a few 'words of wisdom'……I am not sure I have many of those left !

I can't help thinking that the current research is **far too heavily focussed** on detailed chemical and enzymological studies related to soil organic P and its turnover. Do you really need all that detail ! You need to justify the detail before getting it. In my view, the type of research data you are collecting is still quite remote from any direct field application. For any wider practical application of the knowledge gained, there will be a need **for simple integrating indicator measures** of soil P process rates or chemical state. I see it as your job as scientists to develop these integrating indicators, alongside your very detailed research projects.

I am also a bit concerned about the fundamental hypothesis underlying your research, namely that mobilisation of soil organic P can be a long-term sustainable approach to crop production without P fertiliser. This will essentially be soil P mining and it will lead eventually to reduced overall soil fertility. I think we may need to look backwards for ideas to find out how crop production was maintained in the past. Straight forward approaches adopted then was by rotating crops eg the Norfolk rotation in the UK. For tropical regions, the growing of Acacia to increase soil fertility, rotated with cropping and a repeat cycle of Acacia, is a well-tried system. We should be investigating soil organic P cycling in these rotation systems. Unfortunately there is a problem here ! The necessary experiments have not yet been established, as far as I am aware. I understand some crop-rotation experiments, based on the Norfolk rotation, are being planned at Rothamsted. Soil liming also is a well-known and tested way of mobilising soil organic P in soils. However, soil liming has not been mentioned at all during this conference. Why not !

My last comments also relate to the past. Particularly for you younger scientists, you **must read and digest** the science of research done years ago……… even pre 1980 work, which might not be available via the Web of Science. The scientists of yesteryear have developed many useful concepts and research results, which you may be in danger of repeating. The work you intend to do may have already have been done and published, except perhaps for the isotope applications. So please don't try to reinvent the wheel !!

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