The impact of pharmaceutical pollution on biogeochemical cycles

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Pharmaceuticals are now considered pollutants of emerging concern, having been detected across the globe in soils, sediments, and water bodies. Conventional wastewater treatment technologies do not remove or degrade these chemicals efficiently and so they leave the treatment process in by-products such as treated effluent and sludges and are subsequently released into the environment (Figure 1). Pharmaceuticals from human origin, such as anti-epileptic medicines, anti-depressants and painkillers are known to accumulate in soils to µg/kg levels after continual application to land via use of sludges as a soil amendment and use of treated wastewater as a source of irrigation (Kinney et al., 2006; Cha and Cupples 2009). The direct release of veterinary medicines (antibiotics) from livestock also presents route by which pharmaceuticals can enter, and persist in soil environments (Dalkmann et al., 2012). As these chemicals are biologically active, their presence in the environment presents a risk to organisms which inhabit these matrices. Numerous studies have documented the uptake and effects of pharmaceuticals in plants (Carter et al., 2014; 2015; 2018; Christou et al., 2018), however we know very little about the impact of pharmaceuticals on soil processes and functions, such as nutrient cycling.

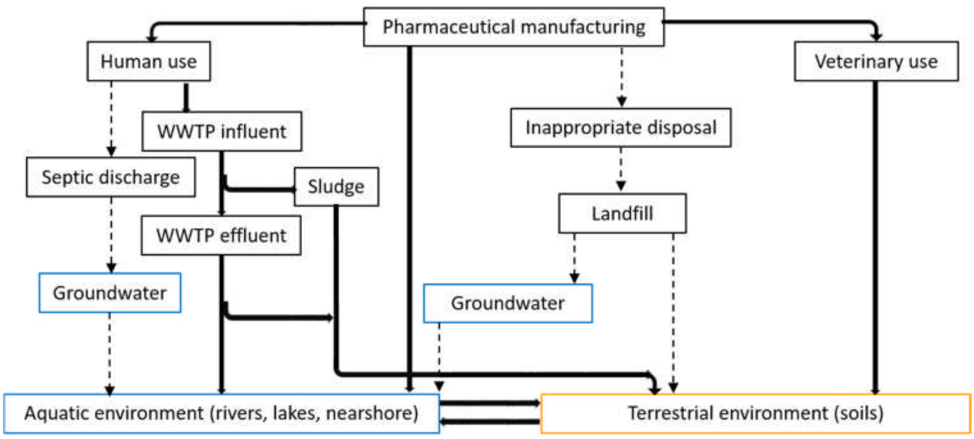

Figure 1: Pathways for pharmaceuticals to enter soils

Soil plays a vital role in ecosystems, and perform five key functions which are providing a medium for plants and a habitat for organisms, regulating water flows, acting as a filter and store to protect the quality of air and water and nutrient cycling. Soil store, moderate the release of, and cycle nutrients (such as carbon, nitrogen and phosphorus) via a number of biogeochemical processes, many of which are controlled by the microbial community. Recent research has demonstrated that antibiotics can affect soil microbial community structure (Thiele-Bruhn and Beck, 2005; UteHammesfahr et al., 2008). Effects on biogeochemical processes have also been discovered (primarily in aquatic and sludge environments) including nitrogen transformations and methanogenesis (Ding and He, 2010; Fountoulakis et al. 2004; Halling-Sørensen 2001). Studies of pharmaceutical effects on nutrient cycles are limited, with focus primarily on antibiotics.

As soils play a pivotal role in major global biogeochemical cycles, while hosting the largest diversity of organisms on land, we need to increase our understanding of the impacts of pharmaceutical pollution on nutrient cycling and in particular the microbial processes that control the transformation of nutrients between different forms (e.g. organic nitrogen to ammonium and ammonium to nitrate). By considering the cycling of nutrients as holistic systems of connected feedback loops and processes this will provide an in-depth understanding of the effects of pharmaceuticals on key biogeochemical processes.

The major aim of this project is to determine the impacts of pharmaceutical pollution on soil biogeochemical cycles using a wider suite of pharmaceuticals than has been used previously (e.g. DeVries et al., 2015). It will also investigate the factors and processes influencing the pharmaceutical induced effects on biogeochemical cycles (e.g. a range of soil types, environmental conditions). The potential for residues of pharmaceuticals to significantly alter the biogeochemical cycle of nitrogen and carbon in soil raises a number of concerns pertaining to sustainable agriculture (carbon sequestration), management of nutrient pollution (e.g. nitrate leaching to aquatic water bodies), and climate change (via losses of nitrous oxide (N_2O) and methane (CH_4)), and urgently warrants further investigation given the increasing use of treated waste water and sludges in agriculture, especially in areas of the world where water scarcity is increasing (e.g. Australia, California and Middle East).

Objectives:

In this project, you will work with scientists at the University of Leeds to quantify the impact of pharmaceutical pollution on key soil biogeochemical cycles (e.g. carbon, nitrogen) and to understand how these impacts can affect wider ecosystem functioning. This will be achieved using an experimental approach in the laboratory and environmentally controlled cabinets using soil cores collected from the field, as shown in Figure 2.
In particular, according to your particular research interests, the studentship could

1. Determine base-line data on the effect of a wide range of pharmaceuticals on biogeochemical cycles that have previously not been fully investigated.
2. Evaluate the buffering capability of ecosystems and the recovery of biogeochemical cycles after pharmaceutical removal / degradation in soils.
3. Compare the effects of pharmaceutical exposure on biogeochemical cycles in a range of different soil types to investigate the role of soil parameters in the response.
4. Determine the effects of environmental variables, for example temperature, water availability on pharmaceutical-induced effects on biogeochemical cycles.

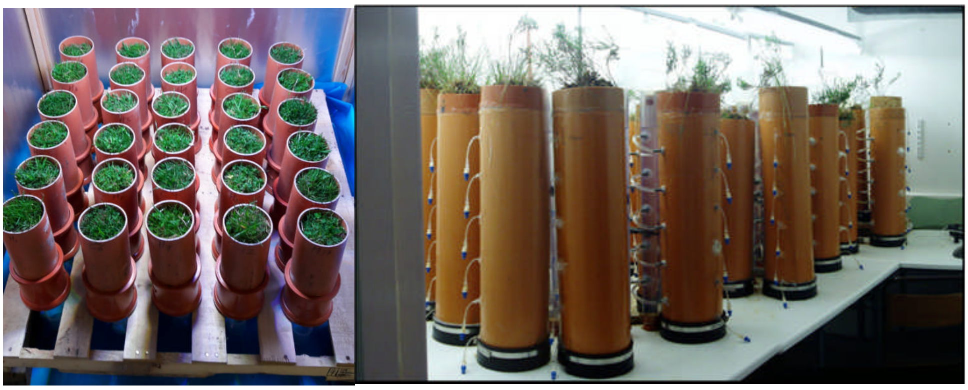

Figure 2. *Left*: Soil mesocosms in a controlled environmental cabinet treated with wastewater containing different concentration of pharmaceuticals. *Right*: Soil cores from which the soil solution can be extracted (via rhizon samplers placed at different depths) for nitrate and ammonium analysis.

Fit to NERC Science

This project is aligned to both the NERC ‘Pollution waste and resources’ research area and the ‘Terrestrial and freshwater environments’ research area. Specifically the project aligns to the following NERC research areas: (1) **Pollution** – by considering interaction and effects of substances which are present at concentrations above those normally expected in a clean environment and understanding the long-term availability and fate of pollutants and waste materials (2) **Biogeochemical cycles** – by considering the fluxes and cycling of matter within and between the biosphere and the physical environment (3) **Land - atmosphere interactions** – through quantification of the fluxes and transformations of material between the land (including the biosphere) and the atmosphere. The project fits with NERC’s stated aim of understanding how the Earth works (in this case how pharmaceutical pollutants can interact with the environment in terms of key biogeochemical cycles) in the present and future.

Potential for high impact outcome

The project will enable significant, timely advancements to be made in understanding the impact and risk to agriculture resulting from irrigation with treated waste water and sludge application to land. This aligns with the UK Water Industry Research ‘Big Questions’ including “How will we deliver an environmentally sustainable wastewater service?” Where wastewater treatment by-products are currently applied to fields, this will facilitate better management of these resources to ensure maximum agricultural productivity. For example, in Israel, TWW has become a major source of water for farmers, supplying >40% of the country’s needs for agricultural irrigation. Thus the outputs from this project will be of international relevance.

The project will produce several outputs, including (i) 3–4 academic publications, at least one of which we anticipate being suitable for submission to a high-impact journal and (ii) policy briefing notes to inform the development of guidelines around waste water use and sludge application to land. This will be of benefit to countries, like the UK, who have the potential to adopt these practices in an attempt to mitigate against projected water scarcity combined with the need to dispose of wastewater by-products in an environmentally safe way. In 2012, approximately 3 million m^3 of wastewater was reused (mainly as golf course irrigation) however, the UK does not currently use treated waste water for agricultural irrigation, but has potential to adopt treated waste water irrigation in the future to meet increasing demands on freshwater resources. However, the risks to soil health, and hence sustainable agriculture, need to be adequately and urgently quantified.

Training

The student will work under the supervision of Dr Laura Carter and Professor Pippa Chapman within the River Basin Processes and Management research cluster in the School of Geography, University of Leeds. The successful candidate will develop a range of research skills, including experimental design, field sampling, chemical analysis, statistical analysis and data interpretation, academic writing skills and giving presentations. Training will be provided in field/laboratory health and safety procedures and the use of field and analytical equipment. In addition the candidate will develop their understanding of (i) environmental pollution, in particular the impact of pharmaceuticals, (ii) chemistry of pharmaceuticals and their degradation prodcuts, and (iii) soil processes and fluxes related to the cycling of nitrogen and carbon.

The student will be supported throughout the studentship by a comprehensive PGR skills training programme that follows the VITAE Research Development Framework and focuses on knowledge and intellectual abilities; personal effectiveness; research governance and organisation; and engagement, influence and impact. Training needs will be assessed at the beginning of the project and at key stages throughout the project and the student will be encouraged to participate in the numerous training and development course that are run within the NERC DTP and the University of Leeds to support PGR students, including statistics training (e.g. R, SPSS), academic writing skills, grant writing etc (http://www.emeskillstraining.leeds.ac.uk/). Supervision will involve regular meetings between all supervisors and further support of a research support group.

Student profile:

The student should have a keen interest in soil processes and environmental pollution with a strong background in a physical geography, earth sciences, soil chemistry, environmental sciences or related discipline. Strong analytical/statistical/fieldwork skills are desirable but not essential, as full training will be provided during the PhD.

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