

## AD AND THE FUTURE OF FERTILISER

Farmers have been placed in the front line of meeting the triple challenge of delivering food security, tackling the climate crisis and reversing nature loss. Recycling nutrients through AD is the simple solution. **Jon Hughes** reports

**N**utrient management is a critical aspect of agriculture and environmental stewardship. It involves the correct application and balance of essential nutrients, typically nitrogen and phosphorus (N and P respectively), to optimise plant growth while minimising negative environmental impacts. A mounting level of evidence clearly shows we are getting the balance of use wrong to devastating effect.

Over recent years, some of the UK's most celebrated beauty spots have become the reluctant poster boys of nutrient abuse – The Wye Valley, Poole Harbour and Loch Neagh (see *Wall of Shame*). But these areas are not alone in suffering toxic algal blooms as a result of nutrient overload.

The latest report from The Rivers Trust – an umbrella association representing over 60 river trusts – is damning; our rivers are sick and in need of urgent resuscitation (see *State of Our Rivers*).

Among the principal causes is agricultural run-off from fertilisers, slurries and manures. When nitrogen and phosphorus are applied in excess to plant need they become hooligan pollutants, rampaging across land and sea.

### From the Rivers to the Sea

What goes into our rivers, flows out to sea creating dead zones (see *Ocean Health Decline*). As the oceans serve to regulate the earth's climate (and are a food source for billions of people) this poses a grave threat to efforts to keep global heating below 1.5C.

A benchmark report in *Nature Science* journal found at the turn of the decade that the open ocean has lost an estimated 2% of its oxygen over the past 50 years, during which period ocean oxygen minimum zones (OMZs) have expanded by an area about the size of mainland Europe (4.5 million km<sup>2</sup>) and the volume of water completely devoid of oxygen has more than quadrupled.

Meanwhile, since 1950, more than 500 sites in coastal waters have reported oxygen concentrations at a threshold often used to delineate 'hypoxia' – hypoxia refers to water conditions where the concentration of oxygen is so low that very few organisms can survive. Fewer than 10% of these systems were known to have hypoxia before 1950.

The report notes that over the same period, "Agricultural production has greatly increased to feed this growing population and meet demands for increased consumption of animal protein, resulting in a 10-fold increase in global fertiliser use over the same period. Nitrogen discharges from rivers to coastal waters increased by 43% in just 30 years from 1970 to 2000, with more than three times as much nitrogen derived from agriculture as from sewage."

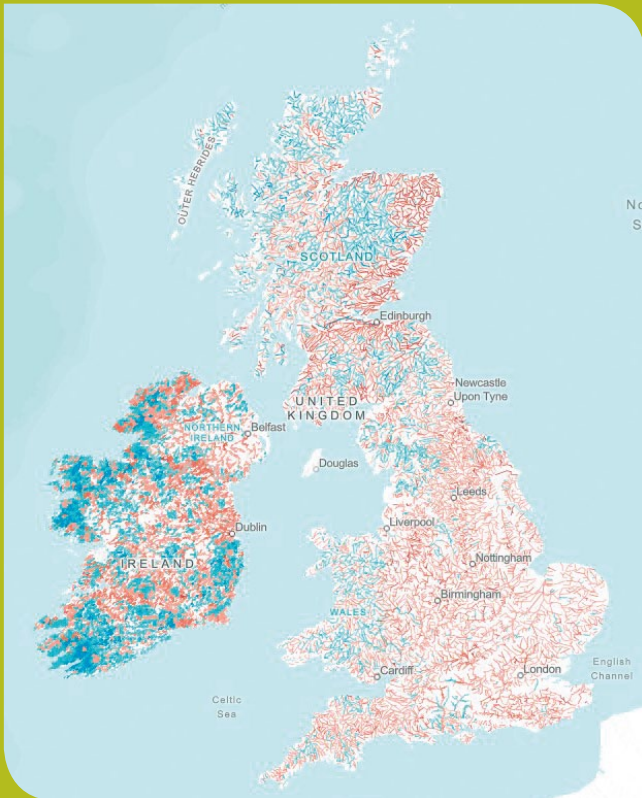
One of the key impacts of deoxygenation is it influences the movement of gases between the ocean and atmosphere. Deoxygenated deeper ocean waters produce greenhouse gases (GHGs) such as nitrous oxide (N<sub>2</sub>O), carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>) that can reach the ocean surface and be released into the atmosphere, contributing to further warming.

The report says, "Low-oxygen zones (including shelf and coastal areas) contribute a large fraction of the total oceanic N<sub>2</sub>O emission to the atmosphere, and expansion of these systems may substantially enhance oceanic N<sub>2</sub>O emissions. Record air-sea N<sub>2</sub>O fluxes have recently [c.2018] been observed above the OMZ in the eastern tropical South Pacific."

Essentially what this describes is the ocean bottom becoming a graveyard of sealife where, deprived of oxygen, it starts to produce gas under anaerobic conditions.

One of the two principal recommendations of the report is for 'Ecosystem-based mitigation to restore and protect the environment', with the instruction to

## STATE OF OUR RIVERS



**Map key:** High Good Moderate Poor Bad No data

The map above shows the current ecological health of the UK's river network.

- 0% are in high overall status
- 23% are classed as in poor or bad overall status
- 85% of river stretches fall below good ecological standards
- only 15% achieve good or above ecological health status

### Causes of pollution:

- 62% of river stretches failed because of activities attributed to agriculture & rural land management (pollution from fertiliser or livestock)
- 54% of river stretches failed because of activities attributed to the water industry (including treated and untreated sewage discharge, and abstraction of groundwater)

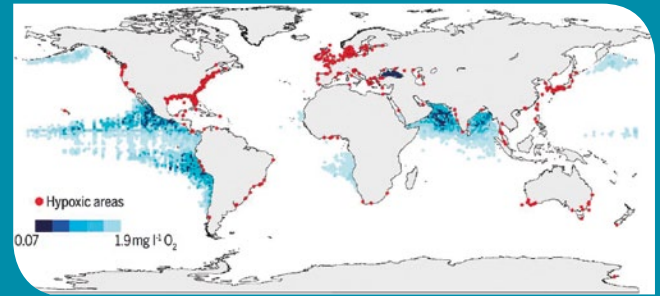
'reduce anthropogenic (man made) nutrients reaching coastal waters to reduce eutrophication-driven deoxygenation'.

## Roots, shoots and fruits

In other words, manage the use of N and P. This is literally a life-and-death challenge. Nothing grows without N and P. Alongside potassium (K), they are as fundamental to the food chain as sunlight and water.

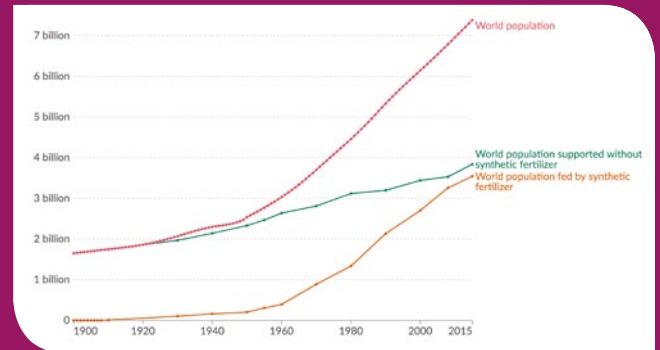
Hence the majority of mineral fertiliser applied to land in the UK (and globally) is N P K fertiliser, often marketed by the relative proportions of each mineral the product contains, i.e., 10:5:5. These primary macronutrients are respectively responsible for the production of chlorophyll (for photosynthesis), root development and reproduction. As the Royal Horticultural Society puts it: roots, shoots and fruits.

## OCEAN HEALTH DECLINE



Low and declining oxygen levels in the open ocean and coastal waters affect processes ranging from biogeochemistry to food security. The global map indicates coastal sites where nutrients from human activity have exacerbated or caused  $O_2$  declines to  $<2\text{mg liter}^{-1}$  ( $<63\ \mu\text{mol liter}^{-1}$ ) (red dots), as well as ocean oxygen-minimum zones at 300 m of depth (blue shaded regions). (Global Ocean Oxygen Network, Breitburg et al.)

## HABER BOSCH POPULATION



### World population with and without synthetic nitrogen fertilizers

Estimates of the global population reliant on synthetic nitrogenous fertilizers, produced via the Haber-Bosch process for food production. Best estimates project that just over half of the global population could be sustained without reactive nitrogen fertilizer derived from the Haber-Bosch process.

**Data source:** Erismann et al. (2008); Smil (2002); Stewart (2005)  
ourworldindata.org <http://tiny.cc/rxc1yz>

For millennia, agricultural crops relied on the limited quantity of these macronutrients that were occurring in soils and ecosystems, part of the natural process of nutrient recycling through the interaction of such things as decaying vegetation, meadow grasses with their various root lengths and leguminous vegetation, and manure from grazing animals.

This all changed when Fritz Haber and Carl Bosch worked out how to create ammonia ( $NH_3$ ) from  $N_2$ , the form of nitrogen that comprises 78% of the atmosphere but cannot be processed by plants.  $NH_3$  is a form of reactive nitrogen that plants can use. This was the gamechanger that resulted in the 'green revolution' of the 1970s – when warnings of limits to growth and mass starvation were debunked by the availability of mineral fertilisers.

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# Nutrient Management

## WALL OF SHAME

The unfortunate and now infamous poster boys for nutrient overload are the River Wye, Loch Neagh and Poole Harbour – all protected areas in respect of their unique features.



### River Wye

The Wye Valley is designated an area of outstanding natural beauty, an internationally important protected landscape straddling the border between England and Wales, recognised in particular for its limestone gorge scenery and dense native woodlands, as well as its wildlife, archaeological and industrial remains.

<https://tinyurl.com/bdezt8d8>



### Loch Neagh

Lough Neagh is the largest freshwater lake in the UK and Ireland, it contains over 800 billion gallons of water. Lough Neagh has a unique and diverse habitat with many rare species of plants, bugs, waterfowl, birds and fish and is designated a Ramsar Site – this is an internationally recognised treaty for the conservation of wetlands.

<http://tiny.cc/pu42yz>

### Poole Harbour

Poole is Europe's largest natural harbour and a site of nature conservation, a wetland teeming with wading birds with many international



protections in place. It is a Ramsar site which recognises wetlands of international importance particularly for wildfowl. It is also a Site of Special Scientific Interest (SSI) which recognises the country's most spectacular and beautiful habitats and a Special Protection Area (SPA).

<http://tiny.cc/yu42yz>

Studies say that today at least half of the world's population owes its existence to food enabled by manmade fertilisers (see *Haber Bosch Population*). However, their overuse has resulted in N and P exceeding planetary boundaries – a widely accepted concept from the Stockholm Resilience Centre. The boundaries represent key limits within which humanity can develop and thrive.

Crossing these boundaries 'increases the risk of generating large-scale abrupt or irreversible environmental changes', as can perhaps be seen along the length and breadth of the UK's waterways and increasingly our oceans. The use of N and P is outstripping planetary boundaries two-fold, nationally and globally (see *Planetary Boundaries – Biogeochemical Flows*).

While generally applied to land simultaneously, N and P pose particular challenges that require addressing separately to successfully curb the devastation being caused by nutrient pollution.

## The Nitrogen Cycle

The World Wildlife Fund (WWF) considers action on nitrogen as a key part of its mission 'to bend the curve of nature loss and tackle climate change by 2030', in particular 'to restore the connections between the economic, environmental and social dimensions of the food system'. To that end it commissioned the report *Nitrogen: Finding the Balance*, to compile comprehensive benchmark data sets and evidence for policy makers.

To meet planetary boundaries the WWF has said the UK's per capita nitrogen footprint must be slashed by more than 80% by 2030. The report found that "the overuse and waste of nitrogen across the UK agri-food chain would be worth approximately £2.3bn each year to buy as fertiliser – equivalent to around half of all annual agricultural profits".

It also found that only ~50% of the nitrogen applied to land as mineral fertiliser (1000 kt N) and animal manure (1000 kt N (approximately)) is used. The remainder either volatilises into gaseous form (960 kt N annually) or runs off into aquatic systems (~712 kt annually).

The report estimates the societal cost to public health, ecosystems and climate change of N pollution to be ~£11bn – of which ~£7bn (64%) can be attributed to agricultural use of N fertiliser, "(mainly particulates from ammonia (NH<sub>3</sub>); £2.4 billion), followed by ecosystem eutrophication and biodiversity impacts (N deposition and NH<sub>3</sub> and NO<sub>x</sub> gases; £4.4 billion)".

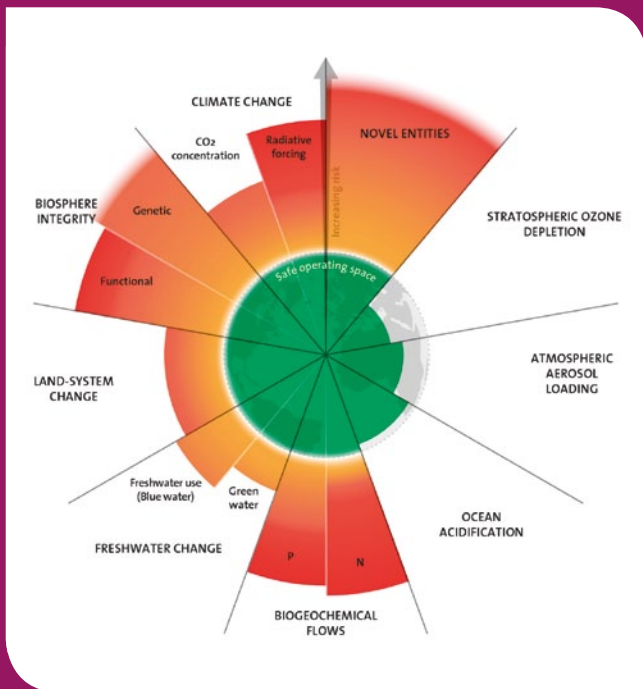
Agricultural soils are becoming a significant source of both nitric oxide (NO) and nitrous oxide (N<sub>2</sub>O) – part of the wider family commonly referred to as NO<sub>x</sub> gases. Production of both is stimulated by the excess application of fertilisers to land. Agricultural practices in the UK are projected to be responsible for 6% of UK NO<sub>x</sub> emissions by 2030.

While not a GHG itself, NO is involved in the formation of nitrogen dioxide (NO<sub>2</sub>) and tropospheric ozone (O<sub>3</sub>), both of which are significant air pollutants. N<sub>2</sub>O, however, is a GHG, with a global warming potential 265–298 times that of CO<sub>2</sub>, with an average residence time of 100 years. UK agriculture accounts for ~60% of N<sub>2</sub>O emissions.

Ammonia meanwhile is a pollutant which can have significant effects on both human health and the natural environment – responsible for chronic and fatal heart and lung conditions in humans and effect the composition of vegetation and species and cause biodiversity loss.

Where the excess nitrogen doesn't escape into the atmosphere, it leaches into

## PLANETARY BOUNDARIES – BIOGEOCHEMICAL FLOWS



The use of nitrogen and phosphorous is outstripping planetary boundaries two-fold, nationally and globally.

<http://tiny.cc/ow42yz>

groundwater or runs off into surface water bodies, such as streams, rivers and lakes, with the results as seen on the *Wall of Shame* and *State of Our Rivers*.

It is worth noting that the consequences include contamination of drinking water, which will require treating. The UK has maximum contaminant levels for nitrogen compounds in drinking water to protect public health, posing CAPEX, OPEX and compliance costs on water companies. Somewhat ironic given that water companies themselves are in the dock for their role in polluting the UK's waterways through the release of raw sewage, contributing to those contaminant levels they then have to address (see *Sewage*).

The UK standard for nitrate pollution in water is 50mg/L, to safeguard against methaemoglobinaemia (blue baby syndrome) in very young children. This is an exceedingly rare yet potentially fatal illness where nitrate is converted to nitrite in the infant's gut and interferes with the absorption of oxygen by the blood.

A final consideration is the production of nitrogen fertiliser consumes ~2% of the world's energy output and produces between 1.4-5% of global GHGs – to convert atmospheric nitrogen into reactive nitrogen of which 50% returns to the atmosphere or waterways. It is an unsustainable cycle that must be broken, to curb all the emissions associated with production of mineral fertilisers.

## The Phosphorous Cycle

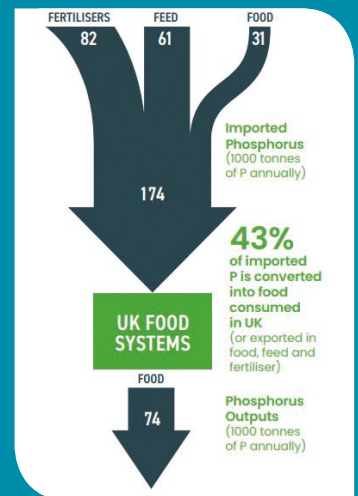
As with the nitrogen cycle, the hallmarks of the phosphorous cycle are waste and water pollution (it does not volatilise into gaseous form as nitrogen does). The UK imports 174,000 tonnes of phosphorous rock each year, of which more than half is wasted (see *Phosphorous Flows*). The cost in environmental damage caused by phosphorous leakage from land to water is valued at £39.5 billion – the asset value assigned to the UK's fresh water ecosystem (UK

## PHOSPHOROUS CYCLE

Less than half of the 174,000 tonnes of phosphorous imported into the UK each year is productively used, that is, converted into 74,000 tonnes of phosphorous in food consumed domestically and exported in food and commodities.

The RePhoKUs project's phosphorous flow analysis identified three hotspot areas of phosphorous inefficiency and loss in the UK food system:

- phosphorous accumulation in agricultural soils (90 kt P yr) (this surplus contributes to legacy phosphorous)
- phosphorous loss to water bodies (26 kt P yr)
- phosphorous sent to landfill and construction (22 kt P yr)



Natural Capital Freshwater Ecosystem Assets and Services Accounts – Office for National Statistics <http://tiny.cc/6tx0yz>.

The figures come from the RePhoKUs (The Role of Phosphorous in the Resilience and Sustainability of the UK Food System) project. The collective of eight leading institutions has been funded under the UK's Global Food Security research programme to better understand the critical role phosphorous plays in the UK food system.

Last year the project released "The UK Phosphorous Transformation Strategy; towards a circular UK food system". It warned that we were sleepwalking into a food and water security crisis because of the mismanagement of phosphorous.

Nothing grows without phosphorous – in layman's terms it is the foundation that allows all other macronutrients and biological molecules to function (including nitrogen). The UK is reliant on imports, which the report says leaves us vulnerable to supply disruption and price spikes – as was seen at the start of Russia's invasion of Ukraine.

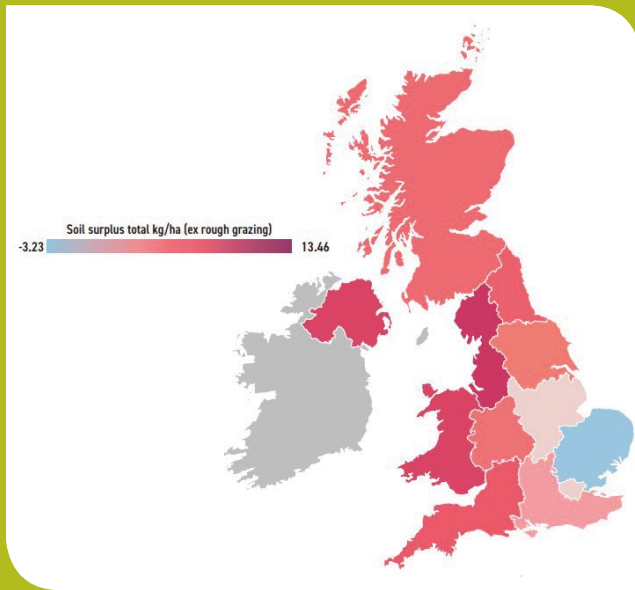
Five countries control 85 per cent of the world's phosphate rock reserves: Morocco (70%), China (5%), Egypt (4%) Algeria (3%), and Syria (3%). In terms of the annual supply of phosphate rock, just four countries were responsible for 72 per cent of global production in 2021: China (39%), Morocco (17%), the US (10%), and Russia (6%).

But the report asks, do we need to import any phosphorous? In considering regional imbalances in phosphorous availability between livestock and arable intensive areas it says, "there is more phosphorous in livestock manures than the UK imports in fertilisers" (see *map*).

So, finding innovative and cost-effective ways to extract or relocate the phosphorous in manure from livestock intensive areas like Northern Ireland and Northwest England to arable cropping areas [in the east on England], will be key to addressing regional imbalances.

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## PHOSPHOROUS IMBALANCE



Within individual regions, estimates of the availability of secondary phosphorus sources (manures, biosolids and recycled food waste) that theoretically could replace demand for imported fertilisers suggest that the North West has nearly twice as much secondary phosphorus available than is required by its pastures and crops (184%). In contrast, the Eastern region could meet only 45% of its agricultural phosphorus demand from secondary sources. A similar regional imbalance occurs in Scotland.

<http://tiny.cc/6y42yz>

## Managing N&P with digestate

Both the WWF and RePhoKUs reports recognise anaerobic digestion (AD) as a key manure processing measure that can reduce emissions associated with N and P.

At its most basic AD serves to degas manures, capturing the methane and other greenhouse gases that would otherwise be released to the atmosphere. The digestate produced as a byproduct of AD retains most of the nutrients from the original manure but does so in a more stable form, minimising the risk of volatilisation and nutrient runoff and leaching into water bodies.

The WWF report states, “For waste management, anaerobic digestion of cattle manure has the greatest GHG abatement potential and a medium to large magnitude effect on reducing  $\text{NH}_3$ ,  $\text{NO}_3$ ,  $\text{N}_2\text{O}$  and total N losses, [and] no direct impact on biodiversity.”

Of the 91 Mt of manure that is produced annually in the UK and goes untreated most is cattle manure. Cattle manure comprises 67 Mt (80%) of the total 83 Mt of UK annual livestock manure production during the housing period. (ref <http://tiny.cc/qtx0yz>) The remainder is predominantly poultry litter.

If the digestate is mechanically separated into liquid and solid fractions the benefits are magnified. Mechanical separation allows for the concentration of nutrients, particularly phosphorus and nitrogen, in the solid fraction of the digestate. The liquid fraction, correspondingly, has a lower nutrient concentration and can be more easily applied to crops without the risk of over-fertilisation.

## N&P FLOWS

### Food waste

When food is wasted, nitrogen and phosphorus are lost from the system. Food waste occurs across the supply chain from farm to fork. Both reports are clear, that where food wastes cannot first be reduced or redistributed, they should be recycled through AD, minimising the requirement to introduce additional N and P to the system.

### Sewage

Wastewater contains N and P from human waste, food and certain soaps and detergents. While wastewater companies have made great strides in the recycling of macronutrients from wastewater – through advances in ammonia stripping and struvite recovery – that counts for nothing if, as is currently the case, sewage does not reach the wastewater treatment works.

Sewage spills into England's rivers and seas by water companies more than doubled in 2023. According to the Environment Agency, there were 3.6 million hours of spills, compared to 1.75 million hours in 2022.

It is inescapable however that the increased intensification of farming has resulted in regional concentrations of nutrients that will likely exceed the requirements of the local landbank. Over 50% of the UK is considered a nitrogen vulnerable zone.

The RePhoKUs report says to address this issue support needs to be given to encourage, “finding innovative and cost-effective ways to extract or relocate phosphorus in manure from livestock intensive areas like Northern Ireland and North West England to arable cropping areas, will be key to addressing regional imbalances.”

Mechanical separation is the first step towards achieving this, making the solid fraction of digestate more economical to export.

## River Wye Action plan

The government has recognised that treating manures and exporting nutrients is required to ‘better protect and preserve’ our rivers. Earlier this year River Action sought a Judicial Review of the Environment Agency (EA), alleging it has acted unlawfully in allowing destructive levels of nutrients from chicken manure to enter the River Wye.

It basically accused the EA of not doing its job, having not made one prosecution under Farming Rules for Water in the six years since the legislation was introduced. The legislation is designed to prevent nutrients being applied to land in excess to crop need.

Pre-empting the outcome of the review, the government announced an action plan to rescue the River Wye on April 12. The action plan includes, “requiring large poultry farms to export manure away from areas where they would otherwise cause excess pollution”.

It also says it will provide up to £35m in grant support for on-farm poultry manure combustors (PMCs) – subject to planning permission – “in the Wye Special Area of Conservation catchment to facilitate the export of poultry litter to where it is needed”.

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## POOLE HARBOUR – POLLUTER PAYS

In 2015, Fish Legal, Angling Trust and WWF launched a judicial review challenge against Defra and the Environment Agency, alleging they were failing to meet their obligations under the Water Framework Directive, determining not to use crucial measures such as the creation of “Water Protection Zones” (WPZs) to prevent agricultural pollution in protected sites.

The campaigners won. As a result, the Government was instructed to evaluate the use of mandatory WPZs, alongside voluntary steps by farmers. A WPZ was drafted, drawing an angry backlash from farmers. It went so far as to suggest arable land be reduced by 40% and livestock numbers by 50%, to bring nutrient run off under control. Think that sounds ludicrous? It is happening in the Netherlands, grappling with similar levels of nutrient pollution.

However, there was an appetite for an alternative, as to impose the WPZ would have required costly primary legislation and ongoing enforcement (and perhaps political capital in Dorset and wider farming regions) and taken time to implement. The upshot was the development of the Poole Harbour Nutrient Management Scheme.

In the aftermath of the Judicial Review the EA developed a nitrogen leaching tool, mining data from the 1980s when Poole Harbour was last in good condition. On the basis of that analysis, the EA said the catchment needs to reduce nitrogen leaching to 18.7 kg per hectare.



This is the target being pursued by members of the scheme, who farm over 80% of land in the Poole Harbour catchment area. The members are all committed to a flight path to achieve the 18.1kg leaching by 2030. Currently the rate stands at ~26.5kg. Those who are not members of the scheme must achieve 18.1kg immediately.

All farmers in the catchment area have to monitor and report their nutrient management activity, building an increasingly sophisticated database, sensitive to impacts of different winter cover crops and types of fertilisers and identifying legacy nutrient issues. Next year a trading element – farmer to farmer – will start, with N credits per hectare issued, meaning those who use most fertiliser purchasing credits from those who use least; a variation of polluter pays.

PMC is a form of energy from waste (incineration) where chicken litter is viewed as biomass. The government press release states, “Combusting poultry manure provides a source of renewable energy and converts manure to a nutrient rich ash, which is a valuable fertiliser that is easier to transport and use on farms - reducing risk to the environment.”

It does, but it does not optimise resource recovery and recycling in the way treatment through AD would. PMC will destroy ~30% of mineral content, the antithesis to the recycling called for in the RePhoKUs analysis. The report calls on the government to back phosphorous recovery and recycling and assist in stimulating an export market.

The action plan does however also include a commitment to, “Proving the concept of a circular economy in manure nutrients with the potential added benefit of boosting rural renewable energy, through a carefully supported Pilot Farm Trial of Micro Anaerobic Digesters (AD).”

These are clearly steps in the right direction. Previously, following an earlier Judicial Review, a cull was mooted (see *Poole Harbour – polluter pays*).

## Joined Up Thinking

Farmers have been placed in the front line of meeting the triple challenge of delivering food security, tackling the climate crisis and reversing nature loss. As both the RePhoKUs and WWF reports make clear – anaerobic digestion is the gateway technology that allows for the management of nitrogen and phosphorous. Simply by degassing manures and slurries, the technology has a profound impact. Mechanical separation further enhances the benefits and creates the potential for fertilisers to be exported to where they are needed.

Yet this is just the tip of the iceberg of what is possible. R&D across the sector is advancing the natural fertiliser frontier at pace – across all scales.

Project Nomad is piloting a mobile digester to allow small farms to access the advantages of digestate. Meanwhile a host of modular systems, from the likes of FreEnergy and BioFactory, increasingly offer affordable ways for farmers to access scalable AD systems.

Nijhuis Industries has developed a process to isolate phosphorous from wastewater treatment biosolids and ammonia (NH<sub>3</sub>) from food waste and on-farm digestate; N<sub>2</sub> Applied a way to fix nitrogen in digestate to prevent 80% of ammonia emissions; CCm Technologies a means to utilise the CO<sub>2</sub> from biomethane production to turn biosolids into pelletised fertiliser that looks and acts like mineral fertiliser. These all represent pathways to either replace mineral fertilisers or create macronutrient feedstocks for mineral fertiliser production.

Yara, one of the world’s largest mineral fertiliser producers, has committed to recovering and recycling nutrients in preference to using the Haber Bosch process. CNHi has developed a biomethane tractor to run on AD derived transport fuel, to further help decarbonise the agriculture sector.

What is evident is that deploying AD to tackle the nutrient crisis represents an opportunity to maximise synergies across policy goals for climate, food and energy security while feeding into the agendas to level up and create skilled ‘green jobs’. Post-Brexit we have the opportunity to incentivise the use of digestate, develop solutions to one of the greatest threats the planet faces and create a market for recycled nutrients.

Nitrogen and phosphorous are globally traded commodities in the food supply chain and this is a nascent market that needs nurturing, to grow the sector and foster innovation and entrepreneurship. The UK could gain first mover advantage in framing the future of nutrient management, a much-needed local imperative with global application.