the nutrient cycle: closing the loop

green alliance…

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Edited by Hannah Hislop

Green Alliance is an independent charity. For 28 years we have worked with businesses and other environmental charities to make environmental solutions a priority in British politics. We work with representatives of all three of the main political parties to encourage new ideas, facilitate dialogue and secure new commitments to action and progress on the environment.

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contents

foreword

Ian Christie, Green Alliance Associate

Many of the environmental problems now seen as contributing to unsustainable human development have this in common: they involve a relatively rapid and large disturbance to the huge geochemical cycles that help regulate the biosphere. Human sources of carbon dioxide and other greenhouse gases may not seem significant in the context of the whole Earth system or of geological time; but they have been sending a large enough volume of emissions in a relatively short period into the atmosphere such that the overall natural balance of the carbon cycle is being disrupted.

“the nutrient cycle demands action on the least glamorous and electorally appealing aspects of environmental policy”

The potential dangers from climate change as a result of this recent disruption of the carbon cycle are now dominating political debate. There is a risk, given the complexity and scale of the climate challenge, that another cycle of great significance will be neglected. This is the nutrient cycle – made up of two great geochemical fluxes, those of nitrogen and phosphorus. The essays in this booklet explore the scale of the disruption that human development has unwittingly brought to these cycles. As with the carbon cycle, we have overloaded natural systems in a short span of time as we have industrialised, and in particular as we have developed and applied synthetic fertilisers. Again, as with the carbon cycle, our injection of vast quantities of nitrogen and phosphorus compounds into the environment has brought immense short-term gains in prosperity and output. But the price could be long-term degradation of essential natural life-support systems – adding to the greenhouse effect, damaging water quality, reducing soil quality, and soaking up resources in end-of-pipe pollution control and damage limitation.

The nitrogen and phosphorus cycles are immensely complex and ‘leaky’, as made clear in the essays that follow. The policy challenges are also complex, involving many established commercial interests, dependence on manufactured fertilisers, and the need for a radical shift in nutrient use so that we ‘close the loop’ and recycle as many nutrients as possible.

There is another important cycle to consider when we address these policy challenges. That is the political attention cycle. The fabled ‘top of the political agenda’ is always a crowded place, and environmental concerns cannot be guaranteed to remain there, with the exception (one hopes) of climate action. The risk is that climate policy comes to dominate debate and action at the expense of other, related challenges. Nutrients policy is vulnerable. The nutrient cycle demands action on the least glamorous and electorally appealing aspects of environmental policy – soil management, farming systems, the treatment of sewage sludge and so on. The nutrient cycle is not getting the attention it deserves.

The answer may be to see the disruption of the nitrogen and phosphorus cycles for what they are: closely connected to the problem of the carbon cycle that is now rightly commanding attention from governments, civil society and business worldwide. For many of the current and projected problems from climate disruption – over-heating, droughts, flash flooding and erosion – will interact with the threats that nutrient overload poses for water quality and soils. We need to see the nutrients issue as a subset of a much bigger general problem – our unwitting overloading of fundamental natural cycles and life-support systems – and as a cluster of problems that could be exacerbated severely by climate change. Dealing with the climate threat and the nutrients problem calls for a common approach rooted in closed loop management of energy, water and nutrients, bringing emissions back into balance, and achieving the great gains in resource efficiency that we know we can make.

So it will be important to make the necessary connections between strategies for climate action and measures to close the nutrients loop, many of which are discussed in the essays below. Another significant opportunity to raise the profile of the nutrients cycle is offered by emerging debates on land use and the future of farming. In this respect two developments in 2007 are worth noting, both involving the Environment Secretary, David Miliband. First, there is his call for the agriculture sector to take seriously the concept of 'One Planet Farming', drawing on the growing interest in the 'One Planet Living' concept recently promoted by WWF and BioRegional. Second, there is a wide-ranging Defra review in hand on land use, and David Miliband has called for a national debate on a sustainable vision for land use over the long term – in this case the next 80 years.

"we need to see the nutrients issue as a subset of a much bigger general problem"

Finally, the emerging debate about the mix of demands on farming – what the balance should be between food production, management of landscape and wildlife, and production of bio-fuels – provides another opportunity to give the nutrient cycle the prominence it deserves. As with the carbon cycle, the realisation that we have managed to disrupt one of the great geochemical cycles should prompt urgent rethinking of policies, technologies and attitudes, and open up huge opportunities for innovation as we try to restore the balance we have lost.

The nutrient cycle: closing the loop

Jiggy Lloyd, Green Alliance Associate

"We are fertilising the Earth on a global scale and in a largely uncontrolled experiment", Global Environment Outlook, UNEP, 1999

Society owes a lot to the nutrient cycle. As students of biology and geography know, virtually every aspect of the modern economy is dependent on the fact that nutrients such as nitrogen and phosphorus circulate in different forms through water, air and the soil.

Depicted neatly in the typical school textbook diagram, the N-cycle and the P-cycle look almost too good to be true. They are 'true' – even if, as the expert contributions to this pamphlet remind us, they are more complex than the textbooks can convey. And they are certainly 'good', in the sense that life could not function without them and the modern economy relies on them. But nutrients are also a source of pollution and the dangers of nutrient overload are recognised. So the question has to be asked – is the operation of the nutrient cycle as good as it could be?

" human activity has doubled the amount of nitrogen in circulation"

The nutrient cycles of the modern world are very different from those that existed before the joys of burning fossil fuels were discovered, before (in 1912) Haber and Bosch found they could synthesise nitrogen fertiliser and before phosphate was found to be beneficial to crop growth and important in the manufacture of detergents and other household products. Nutrients still cycle through the economy but the amount in circulation is greatly increased. In the case of nitrogen, it is estimated that human activity has doubled the amount in circulation; in the case of phosphorus, we have tripled the amount available since the industrial revolution.

This might not of itself be a concern but it needs to be considered alongside the indications that nutrients are also, on some occasions, turning up in the wrong place.

A water industry spends significant amounts of money removing phosphates from wastewater. There does not appear to be a definitive figure but some estimate it to be around £35 million a year. Furthermore, between 2005 and 2010, English water companies will have to incur capital expenditure of about £300 million and annual operating costs of £6 million to reduce nitrate levels for the public drinking water supply. Removing the phosphates is an energy-intensive process and also relies (in most cases) on chemical dosing with ferric salts. The disposal of the nitrate-rich residues of drinking water treatment is a challenge that the industry currently addresses by blending with low nitrate sources or removal via ultra filtration.

This indicates a problem with nutrients when water is being treated for human consumption and use. What about nutrients at other stages in the cycle?

The Environment Agency tells us that diffuse inputs of nutrients are a major reason why our rivers are at risk of not meeting the Good Ecological Status (GES) required by the EU Water Framework Directive by 2015. Specifically, nitrogen is cited as the problem for about 40 per cent of rivers and phosphorus for nearly half of them.

Nutrient pollution damages the countryside by altering plant growth rates, changing plant communities and disrupting the food chain for wildlife. Nutrient inputs also trigger eutrophication of shallow lakes; declines in fish diversity may be traced back to this.

About 40 per cent of UK emissions of nitrous oxide (a potent greenhouse gas) come from agriculture; emissions are closely related to the form and the manner in which nutrients are applied.

Meanwhile, we continue to add to the amount of nutrients in circulation and this has its own environmental implications. Fertiliser manufacture for the UK is believed to generate about six million tonnes of carbon dioxide per year; some estimates suggest it may be 20 million tonnes or more. World supplies of phosphate rock are finite and the transport of phosphate fertiliser takes place over long distances.

Something seems not quite right here. On the one hand, nutrients circulate through the economy and the environment and the total amount in circulation is sufficient to meet our needs. The nutrient content of available organic materials such as biosolids, green waste, biodegradeable municipal wastes and farmyard manures is sufficient to replace all use of manufactured fertilisers. On the other, we are expending both money and energy on manufacturing fertiliser, and then further money and energy because we have to deal with nutrients in the wrong place.

It doesn't sound logical does it?

But of course logic is not the only factor. Nature and history come into the story.

Nature dictates that nutrients do not cycle in perfect, leak-proof pathways. The miracle of nitrogen, in particular, is its ability to exist in a range of different forms. It is society's bad luck that the form in which it is most available to the plants, nitrate, is also the form in which it most prone to move to other media – such as water. Phosphates are slightly less fickle – they have a happier tendency to remain bound to mineral soil surfaces and incorporated into the molecular structure of soil organic matter. But they move too – and end up in the wrong places as a result. From the perspective of the farming industry, the losses of nitrogen and phosphorus that do occur (measured in energy or in money) do not look bad in comparison with the value of the end product; they can be compared quite favourably with efficiency ratios in other industrial processes (which do not have the added challenge of taking place outdoors, at the mercy of the weather!). And since the chief domestic use of phosphates is in detergents, one might be tempted to say that inevitably, the phosphates will end up in water. Nevertheless, we can't ignore the consequences.

History has got us to where we are today. Our ability to add to the pre-1912 stock of nitrogen in circulation has been the key factor underpinning the notable successes of UK agriculture, and in feeding the world's growing population.

So, few would dare argue that we reduce the amount of nutrients in circulation to their pre-industrial levels; to do so would require an accompanying proposition as to how world food production would be maintained. And it would take a real optimist to conceive of a situation in which no fluxes within and between media happened and supply always exactly matched demand, year in year out, regardless of the nuances of the weather, the soil and the market. Even the most ardent advocates of precision agriculture don't claim we can be this clever.

But there are clearly significant benefits to be realised if we can reduce the economic and environmental costs associated with nutrients in the wrong place and reduce the need to manufacture and transport additional nutrients in favour of using more effectively those that are already in circulation.

"some argue that the global nitrogen cycle has the potential to become as significant as the global carbon cycle"

The immediate benefits would be a reduction in greenhouse gas emissions – both carbon and nitrous oxide, improved water quality with benefits for biodiversity, and less expenditure of farmers' money (on fertilisers) and water customers' money (on drinking water treatment).

But there is a longer-term objective here as well. The elephant in the room (or hiding between the pages of this pamphlet) is the concern about the global implications of nutrients. Some argue that the global nitrogen cycle has the potential to become as significant as the global carbon cycle. It is certainly justified to ask ourselves the following: if the developed world has inflated the nutrient cycle this much so far, with these sorts of side effects, how much more damage is going to occur globally as food production and industrialisation continue to increase?

So whether your perspective is domestic or global, the conclusion looks the same:

- We need to stop relying on policy measures which tackle nutrients as individual substances conflicting with desired standards for soil, water or air;

- And we need to start using a policy framework which aims, at its core, to cycle nutrients through our economy with fewer unwanted effects ('leaks') and an overall gain in resource efficiency.

This would be the policy framework based on closing the nutrient loop. It would have the following principles:

1. The use of nutrients already in the economy would take priority over the manufacture and import of additional nutrients.
2. Nutrients would be transferred between the players in the nutrient cycle – the producers and users of nutrients – because of their value; regulations governing nutrient concentrations or prescribing nutrient management practices would be secondary.
3. Soils (cultivated or otherwise) would be explicitly recognised as part of the national nutrient resource bank.
4. Innovations which aided the recycling and re-use of nutrients and/or the maintenance of the nutrient resource bank would be encouraged and could be supported using measures which

discouraged further additions to the nutrient cycle in excess of demand.

5. Information on nutrient stores and transfers (involving air, soil or water) would be used to establish, at national level, the size of our nutrient surplus and the options for limiting its growth.

This policy would be used to deliver the benefits noted above and also to ensure the UK is well positioned in a global debate about nutrients - which is well overdue.

Policies for closing the nutrient loop

If this framework were in place, what would need to be done differently from, or additionally to, the plethora of nutrient-related measures already in place?

First, there are some obvious enabling measures, as identified by the expert pieces in this pamphlet and by the project partners/steering group.

The work already done by the water and food sectors to devise a safe and workable system for the use of biosolids on land (the Safe Sludge Matrix and related schemes) needs statutory underpinning. This will ensure that necessary investments can be made and, as importantly, financial commitments to less-sustainable options avoided.

We need to recognise the nutrient value of food and composting wastes and encourage the diversion of these wastes from landfill to beneficial use on land. A certification-use scheme, akin to the Safe Sludge Matrix, would enable the food industry and land managers to make the necessary commitments and underpin the transactions involved. Similar measures are needed to ensure that as we divert biodegradable municipal waste from landfills, we make it possible to use the nutrients that it contains.

Such measures might seem to run counter to the suggestion that available land might be insufficient to receive the nutrients that are potentially available. As the contributions to this pamphlet demonstrate, limitations do arise and they, coupled with the rate-response of crops to nitrogen fertilisers, have led to the current situation. Enabling measures must tackle these limitations.

For instance, a limitation on further use of biosolids on land is the mismatch between their available nutrient content and crop demand. In part, this is due to the effect of wastewater treatment in over-concentrating the phosphate load in relation to nitrates. A case might therefore be made for a levy on phosphates derived from non-dietary (detergent and industrial) sources, or a ban on some products containing phosphates. Discouraging their entry into wastewater and/or using levy proceeds to stimulate the ‘mining’ of phosphorus from wastewater would be a real example of closing the loop.

In some locations, a limitation on more effective use of animal wastes is the farm storage infrastructure that enables the nitrates, as well as the organic nitrogen they contain, to be returned to the land at appropriate rates and timings. In others, diffuse inputs of agriculturally-derived phosphate may be causing a water quality problem and a levy on phosphate inputs to farming (operated at the regional or catchment-level) might be a means of stimulating investment in nutrient recovery from farm waste. Nutrient storage and nutrient recovery could be the starting point for a west-to-east transfer of nutrients that would help close the loop within the UK farming sector.

The framework of a closed nutrient loop should also illuminate, from the perspective of a resource efficient economy, two key debates. The first is the case for and against a levy on nitrogen inputs to the economy. The contributions seem to suggest that improved agricultural knowledge and practice, with strong cost-drivers in farming backed up by nitrate regulations and codes of good practice, are moving us in the direction we want to go; if there is a case for using price to tip the balance further in favour of organic sources of nitrogen, it may be argued that energy taxes affecting fertiliser manufacture are already doing this. However, these lack the benefit of revenue-recycling which could be used to support the other measures already noted.

The second debate, related to the first, is how society should optimise the distribution of costs and benefits. Given that a totally closed loop may not be feasible without a significant agricultural yield reduction, some remaining costs will be internal to and paid for by, the production system; others will remain to be borne by society.

Improvements to feeding regimes in the intensive livestock sector and access to precision farming techniques in intensive arable must feature in the closing the loop framework. Both are central to the aim of reducing nutrient losses and improving efficiency.

Policies based on closing the loop should also underpin our use of land management as a means of achieving water quality objectives. If our aim is to manage nutrients better for the long-term, then it may well be the case that spending water customers' money on land management or land use adaptation schemes that will encourage nutrient storage in the soil is at least as attractive an option as yet more expenditure on the energy-intensive treatment of point sources. Such schemes also have the potential to provide other valuable benefits, such as important wildlife habitats. These arrangements must be transparent, however, and a careful distinction maintained between the most sustainable solution to an established problem, and arrangements that might imply a long-term acceptance of poor practice.

But closing the nutrient loop is also about attitudes to nutrients and an appreciation of their place in a sustainable economy.

There has been a commendable move to more precise use of nutrients in agriculture, especially in the arable and horticultural sector. This has been stimulated by the drive for efficiency and challenging markets under the new farm support regime. But it is not yet a universal approach and is associated, in the main, with enterprises making substantial use of manufactured fertilisers.

We need a more widespread and wholesale advocacy of the soil as a nutrient bank. Well-managed, with inputs not exceeding those that allow the system to function properly, it supports land-based ecosystem services including food production and nutrient management. Abused or disregarded, it becomes part of the problem. Nutrient management needs to feature more strongly in cross-compliance. There is a strong case for requiring nutrient management plans (i.e. the practice of 'closing the loop' at farm level and if necessary planning for the management of the surplus) on livestock units as part of cross-compliance. The enabling measures noted above are urgently needed to counter the caution about use of organic wastes that has been found amongst farmers, buyers and consumers, but we also need stronger messages about the long-term merits of organic, locked-in storage of nutrients. Global warming has stimulated an appreciation of the difference between carbon that is locked-up in soil, biomass and fossil fuels, and that which is causing the increased carbon concentration in the atmosphere; it shouldn't take a similar crisis in nutrients to extend this appreciation to nitrogen and phosphorus.

" abused or disregarded, soil becomes part of the problem"

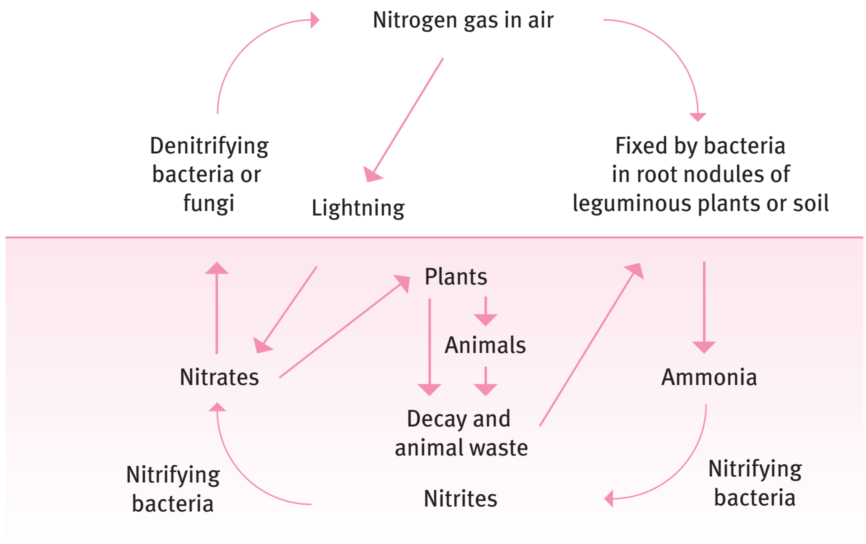
Away from the land management community, there is also scope to make nutrients a core concept in sustainability, alongside water and energy. Can we capture the current high rate of 'willingness to recycle' with convincing messages about the importance of food and municipal waste composting as a means of conserving nutrients? Is this a means of countering recycling-fatigue (why do I bother? what is it for?) with strong messages that are not just about energy but nutrients as well?

A framework based on closing the nutrient loop will inevitably raise questions about risks. It is important that, for instance, the recycling of nutrients in composting and municipal wastes is seen to be a scientific approach, not a throwback to 'primitive practices'. But the current tendency to be over-cautious about high profile and emotive risks obscures the equally significant, if different, risks of not acting sustainably. Closing the nutrient loop should be presented with this in mind.

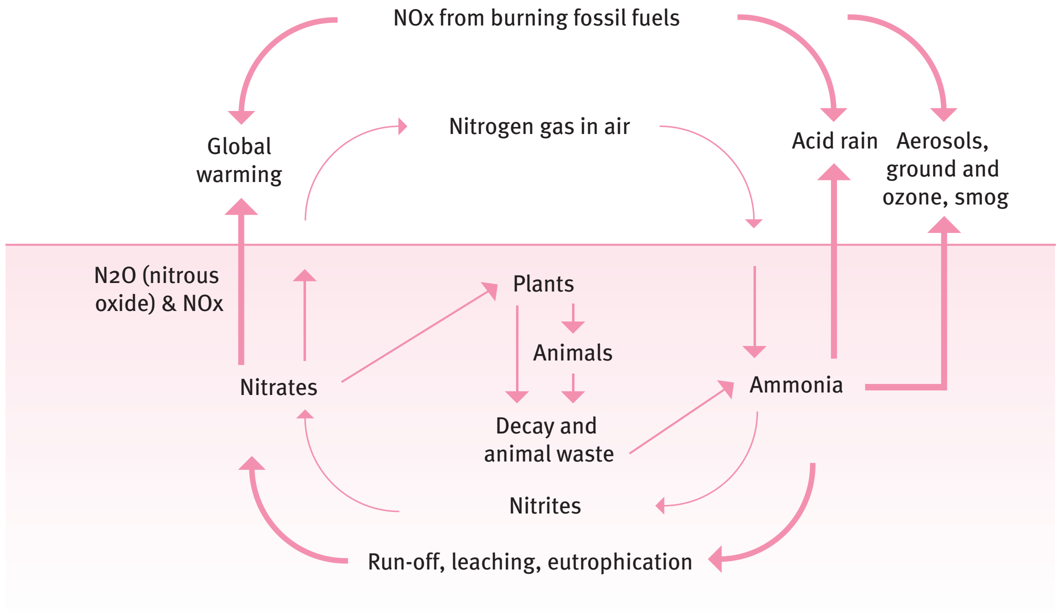
What is closing the loop?

At its simplest level, the concept of closing the loop, as applied to waste and resources, expresses a desire to move away from a linear process of resource extraction, manufacture, consumption and disposal, towards a cyclical system where resources remain in use almost indefinitely. In global terms, and particularly in 'developed' countries, a relatively small proportion of resources are cycled, or go round in loops, and a large proportion are in productive use for a very short time.

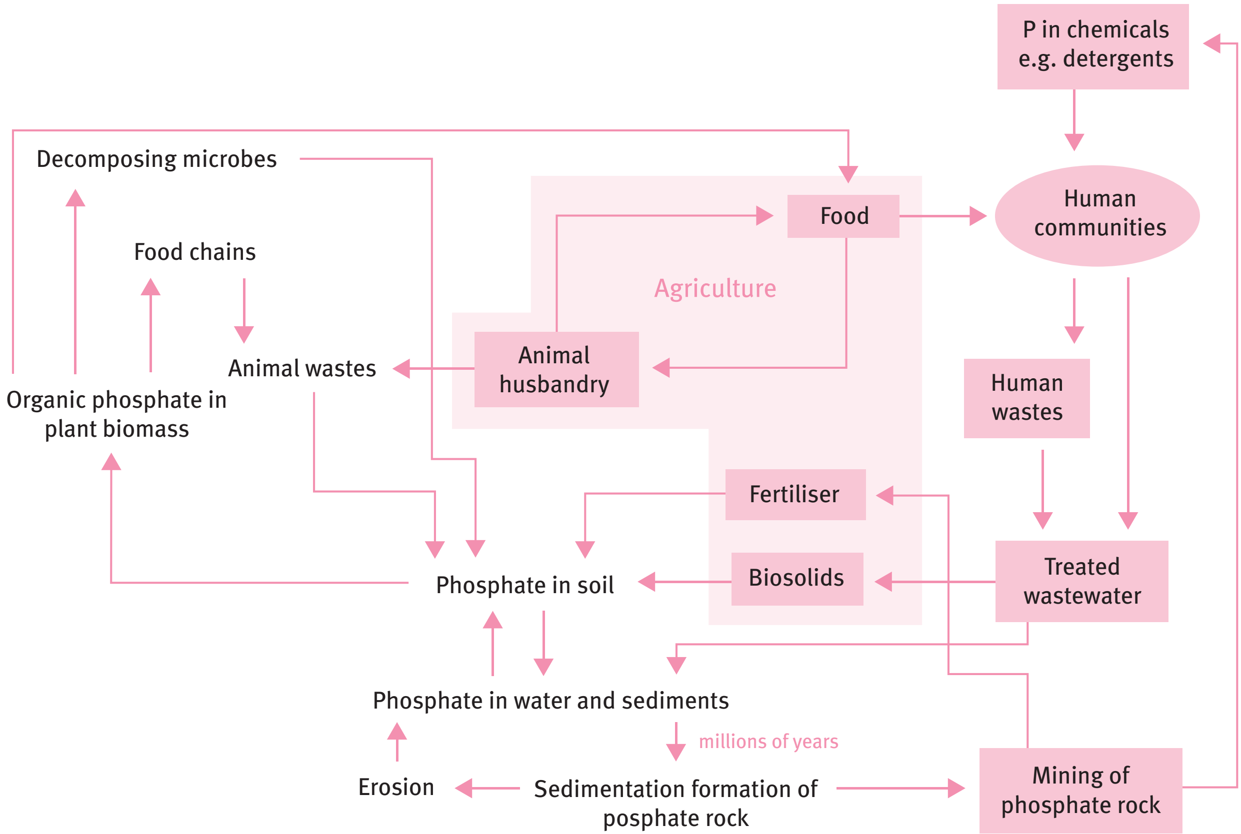
This is unsustainable because it means: depletion of non-renewable resources (minerals and metals); degradation of habitats, landscapes and biodiversity; dangerous over-use of what should be renewable resources and over-use of the environmental 'sinks' needed to absorb the pollution we generate as we produce and consume. Circulating resources around the economy, rather than just passing them through once, reduces the environmental impacts associated with extraction of resources and disposal of waste.



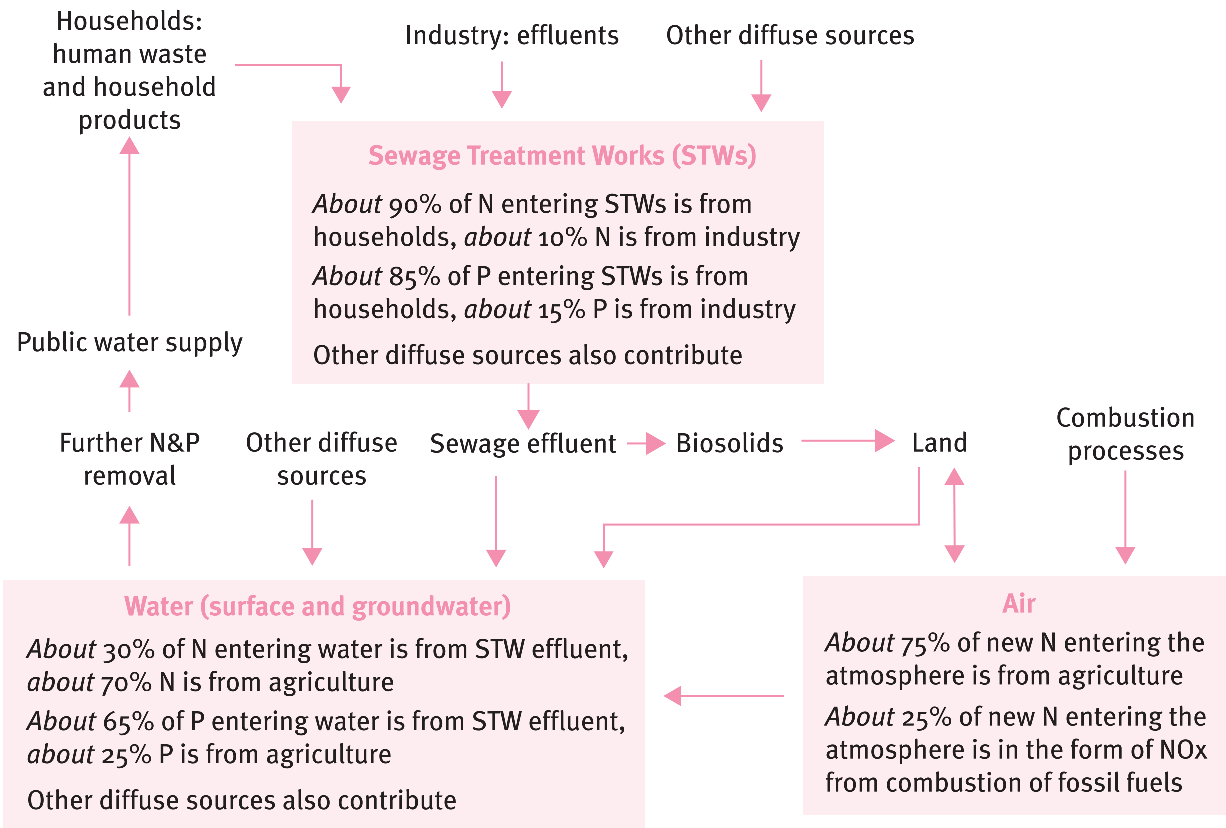
The natural nitrogen cycle



The nitrogen cycle and its human influences and effects



The natural phosphorus cycle and its human influences (shaded)



Nitrogen and phosphorus through the environment in the UK

This diagram is provided to summarise and illustrate information in this pamphlet. All figures are broad estimates and illustrative of the UK as a whole. In practice, there are significant variations depending on time and location.

the water industry's role in today's nutrient cycle

Dr Stephen Bolt

The water cycle is perhaps something we have taken for granted for too long in the UK. This is changing as the frequency of weather extremes seems to increase which, combined with increasing demands from our affluent and growing population, places more and more pressure on our water resources.

The water industry has a fundamental and invaluable role in today's society: abstracting, treating and supplying water to customers, and recovering, treating and returning to the environment wastewater and trade effluent. However, the water companies do not manage the water cycle, but tap into it in order to provide an essential service to the population. In carrying out these essential duties, there is potential to impact on virtually all aspects of the water cycle, which can affect both the quality and the quantity of this valuable resource.

Threats to water quality

Water company activity interacts with water quality in two separate ways. Firstly, surface water quality is influenced by the quality of point source discharges from sewage treatment works (STWs). Water companies also take 'raw' water into their drinking water treatment plants: the cleaner the receiving water, the less the need for expensive treatment.

Annual monitoring data from the Environment Agency shows that the quality of our waters is improving year on year. However, this doesn't quite square with a recent assessment, also by the Environment Agency, that most of the waters in England and Wales are at risk of contamination from pollution. Furthermore, companies are having to invest increasing amounts of our money to decontaminate drinking water from pesticides and nitrates. In short, the UK and its water companies have a challenge on their hands.

Pollution by nitrogen and phosphorus is known to impact significantly on the ecology of water bodies in the UK and elsewhere. The Environment Agency has identified that 38 per cent of rivers are at risk or probably at risk from diffuse active compounds of nitrogen (N)[1] and 47 per cent from phosphorus (P).[2] The risk maps do not distinguish between N and P for point sources, but identify that 18 per cent of rivers are at risk, or probably at risk, from point nutrient sources. It is estimated that approximately 60 per cent of river lengths contain concentrations greater than 0.1mg per litre P and 30 per cent concentrations greater than 30mg per litre N.[3] In general, it is recognised that P is the limiting nutrient (and hence most 'active') inland with N being the more important in estuaries and the sea. However, this is almost certainly an oversimplification and increasingly it is recognised that the N:P ratio has an impact on the biological response of an aquatic system.

The cost of increasing N removal from sewage works beyond the quantity already removed is potentially high, particularly where low-energy percolating filters are currently used and would have to be replaced with high-energy solutions. Similarly, P reduction is commonly carried out by chemical dosing with ferric or aluminium salts which have traces of hazardous substances. The less well-developed use of biological P removal has operational difficulties, and like N removal also increases energy consumption.

Removal of N and P from sewage works must therefore be carried out in conjunction with effective diffuse pollution control. The worst-case scenario is that despite high dosing levels of iron and/or aluminium salts coupled with increasingly energy hungry processes, levels of phosphorus may still not be low enough in the water to result in a biological response. In other words, all the dis-benefits of an engineering solution with none of the ecological benefits achieved. Clearly this unsustainable outcome must be resisted.

> "increasing control of point source N and P inputs will achieve little unless diffuse pollution is simultaneously addressed"

Although not driven by environmental drivers, the Drinking Water Inspectorate (DWI) requirement to achieve 50mg/l N for drinking water does have increasingly important financial implications for the water companies. The least costly (both in terms of energy and cost to customer) method is to blend high nitrate water with a low nitrate source so that the resultant drinking water passes the standard. However, in some areas low nitrate water is becoming increasingly scarce and will inevitably increase the amount of expensive N removal from the raw water source. In addition there is potential for disposal challenges with the resultant high N wastewater.

The solution? An integrated approach

Nutrient pollution and associated problems in surface and groundwater are not new, nor is this a problem restricted to the UK. Most of Europe has similar challenges, and there are many EU Directives that seek to tackle aspects of the problem. For instance, the Urban Waste Water Directive aims to identify and protect sensitive waters suffering from eutrophication, triggering significant investment by the water industry in phosphorus removal at the larger-scale sewage treatment works. Other Directives, such as the Habitats Directive, seek to limit nutrients reaching the environment. Indeed, by 2010, over half the inland population of East Anglia (an area particularly prone to eutrophication) will be served by sewage works with active P removal.

The most recent EU Directive impacting on water quality and water resources is the Water Framework Directive (WFD), which seeks to achieve good ecological and chemical status for all water bodies by 2015. Clearly, key to this ambitious target will be the successful control of nutrients reaching water. This will be achieved by setting Programmes of Measures (PoMs): actions that will need to be undertaken on a catchment scale to decrease pollution.

However, in order to meet this ambitious target, it is first important to understand sources of pollutants and factors that affect their transport to water. The first thing is to 'apportion' pollutants to sources, i.e.

be confident about from where they derive. Increasing control of point source N and P inputs, for example from sewage treatment works, will achieve little unless diffuse pollution is simultaneously addressed. It is therefore important to first know the sources of N and P into a catchment or basin so that any programme of measures has a realistic chance of achieving its targets. Indeed previous standards, imposing fixed concentrations on a sewage works depending on the size of the discharge, were often criticised as failing to understand the problem.

Much work has been carried out in seeking to apportion N and P inputs to a catchment, and it is clear that there are large variations, both between catchments and at different times of the year. For example, sewage works are responsible for 62 per cent of P to the Warwickshire Avon, with 30 per cent from agriculture, whereas in the Ant catchment in the Norfolk broads, only 18 per cent P is from sewage works with 59 per cent from livestock and 21 per cent from inorganic fertiliser.[4] In addition, there are significant differences between summer and winter when river flows and agricultural run off are very different. Many rivers in the UK consist of a high proportion of treated sewage effluent during drought periods in summer.

To support important decisions that aim to protect our water resources, we therefore need a good scientific understanding of catchment hydrology and pollution sources. It is clear that the situation is often complex, which calls for an integrated approach to a solution, tackling several pollution sources and using a variety of approaches. This philosophy moves away from what we have done to date: clean up point sources at all costs. Whereas this approach has certainly brought improvements relatively quickly, tackling diffuse pollution is now our major challenge.

Actions 'on the ground' - the catchment scale

If the UK is to achieve the goals of the WFD, it will be necessary to structure the programme of measures to deal with nutrient transport at the catchment level. Setting standards for individual sources is highly likely to fail to achieve any biological response in the receiving watercourse. The Environment Agency risk maps sought to identify controlled waters at risk or probably at risk of failing the WFD standards. The maps distinguished between waters at risk from point source and those at risk from diffuse source, however, critically, they did not seek to apportion the relative contribution between sources.

There are, therefore, some crucial questions that require answering if nutrient pollution control is to stand a chance of success and if the programme of measures is to be based on sound science.

Firstly, a concentration limit for a nutrient in water in order to achieve good ecological and chemical status must be determined and, secondly, a nutrient 'budget' for the catchment must then be determined. This then leads to a contentious issue - are these standards achievable without incurring excessive cost? Sensibly, the WFD does allow consideration of 'disproportionate cost', which means where that the options to improve water quality are very expensive, a derogation can be sought. Even more problematic is how excessive cost should be calculated - clearly it needs to include all the three pillars of sustainable development - environmental, social and economic. If there are areas where derogations would need to be sought from the European Union on grounds of excessive cost, then this will require robust evidence to support the case. This could be costly and time consuming and serious consideration needs to be given now to how this could be achieved.

The alternative to basing the programme of measures on sound science is to implement an iterative 'best endeavours' strategy. This approach seeks to implement measures that are achievable with limited resources. For instance, a catchment officer may seek to implement farm management plans based only on what can be relatively easily and inexpensively achieved and not on what is needed to achieve WFD standards. An example of this would be to seek to implement a soil management plan to reduce sediment loading and associated P loss to the local watercourse. This approach would probably result in a programme of measures with further reductions in P (and possibly) N standards on point sources, coupled with farm nutrient management plans seeking to reduce diffuse sources of nutrient. This integrated approach is probably the least cost option, but could well be interpreted as planning to fail and could be subject to third party challenge and ultimately possible infraction proceedings by the EU.

" SCaMP's vision includes improvements in water quality as well as a focus on bird populations and biodiversity"

Where next?

From a water company perspective, it will be very important that the issue of nutrient control is indeed based on robust catchment based apportionment, since it may be attractive to the regulators to over control point source N and P discharges to compensate for lack of control of the diffuse inputs. Over control of point sources should be avoided on three grounds: economic (poor value for money), social (water bills would need to increase with limited or no value to the customer), and environmental (very stringent N and P limits would be heavily energy dependent).

Given this risk, it is puzzling that Ofwat (now the Water Services Regulation Authority, the water industry economic regulator) took the view that the water industry should not contribute to WFD-driven catchment management schemes in the 2004 periodic review since the water companies had invested so much in point source control. There is a strong argument that some involvement, including financial, in widespread catchment management to answer the questions above would be very much in water customers' best interest and in the medium to long term would provide high value for money. Although Ofwat did not allow catchment management projects as part of the AMP4 programme (2005-2010), there is one notable exception of United Utilities' SCaMP (Sustainable Catchment Management Programme). SCaMP's vision includes improvements in water quality as well as a focus on bird populations and biodiversity. This was allowed partly since United Utilities own some 57,000 hectares of land and therefore have specific duties of care under the Countryside and Rights of Way Act (CROW). In addition, Ofwat recognised the strength of the RSPB lobbying between the draft and final determination. The programme is being developed in conjunction with the RSPB to develop an integrated approach to catchment management.

Ofwat also recognised the advantages in allowing Wessex Water to postpone AMP4 investment while catchment officers employed by the company seek to address specific nitrate and pesticide issues in groundwater. Unfortunately, similar approaches put forward by other water companies were not allowed in Ofwat's final determination. It is hoped that Ofwat will take a more favourable view of catchment approach projects in the next periodic review in 2009. Several water companies are interested in exploring such approaches and are meeting to discuss a possible united approach to the periodic review negotiations.

There is some scope for reducing nutrient inputs to sewage works, for instance the introduction of low P detergents can significantly reduce P input to a sewage works. However, the increase in dosing rates of phosphorus compounds to reduce plumbo-solvency (lead solubility) to meet tighter lead standards in drinking water may increase P loading to sewage works by up to 10 per cent. Conversely, there are known technologies for 'mining' P from sewage works and hence helping to recycle usable P in the form of struvite (a white crystalline substance consisting of magnesium, ammonium and phosphorus). However, unless there were financial incentives it is difficult to see what driver there would be for the water industry to invest in this technology although it has clear environmental attractions.

Once a nutrient budget for a catchment at risk is calculated and targets set, then the programme of measures needs to target sources of nutrient in an appropriate manner. If, as seems likely, diffuse pollution control is required, there is the additional difficulty of who pays for the control and how it can be effectively regulated. If the issue is agricultural input (although urban, transport and aerial must not be underestimated), then the 'polluter pays' principle would seek to increase the price of the produce in order to fund changes in farming practice that may be necessary. However, since produce procurement competes at a global level, it is unlikely that this very simple link can be effective. If the matter of who owns and ultimately pays for diffuse pollution is not addressed effectively, this increases pressure on control of point sources where full cost recovery is possible from the water and other industry through discharge consents (and indirectly through abstraction licences).

The importance of the nutrient cycle and its impact on our natural aquatic ecosystems and drinking water supplies cannot be over-emphasised. A quantitative understanding as to sources within a catchment and whole catchment based solutions is needed. Only then can we make decisions as to whether the targets of good ecological and chemical status are achievable or whether derogations need to be sought. It is becoming increasingly clear that in order to control both diffuse and point sources in an appropriate and sustainable manner, there must be a fundamental increase in both the scale and pace of progress towards these goals. With the programme of measures only three years away, there is a very real risk that a lack of overarching regulatory ownership of catchment control will lead to the failure to implement the WFD in an appropriate manner. More work is needed to look at ways to incentivise reductions in nutrient input to sewage works and the potential for nutrient recovery before discharging to controlled waters. The continued control of point source nutrient inputs needs to be considered alongside diffuse pollution and a catchment approach to better controlling the nutrient cycle adopted.

Dr Stephen Bolt is head of integrated water and environmental management, ADAS

recycling biosolids to land

Dr Stephen R Smith

Recycling organic residuals on land to improve soil for crop production was recognised by the earliest advanced human societies as one of the key principles of sustainable development. Closing the nutrient cycle by using sewage sludge on farmland is effectively the modern equivalent of this basic principle and a cornerstone of sustainability.

Sewage sludge is an essential, and inevitable, residual by-product of urban wastewater treatment. It is produced as a consequence of the removal of solids from urban wastewater, discharged from homes and industry and collected as drainage from paved surfaces, so that the treated effluent can be safely discharged to the water environment. The most important constituents requiring treatment are biodegradable organic matter and reduced forms of inorganic molecules naturally present in wastewater such as ammonia. These constituents originate primarily from dietary sources and industrial processes, but also include a large range of organic chemicals, such as surfactants, used in the home or by industry.

Wastewater treatment – the basics

Wastewater treatment typically has three principal stages that contribute to the production of sewage sludge. The first involves separating the solids that are removed by a primary sedimentation process. This process produces an effluent, settled sewage, and a residue, primary sludge. The next stage removes soluble and colloidal material from the settled sewage by the 'activated' sludge process – the most common form of aerobic biological treatment. This step relies on the activities of a complex community of microorganisms that oxidise biodegradable constituents and nitrify inorganic ammonia to nitrate. A third stage of treatment is being increasingly introduced to meet the tightening discharge consents to surface waters for the nutrients, nitrogen (which is mainly in the form of nitrate with traces of ammonia) and phosphorus. These nutrient elements originate predominantly from dietary sources, and in the case of phosphorus, from detergent residues (the relative phosphorus contribution from dietary, detergent and industrial sources is equivalent to approximately: 60, 25 and 15 per cent, respectively).

Nitrogen removal is a biological process, known as denitrification, which reduces nitrates to nitrogen gas that is released to the atmosphere. Phosphorus can also be removed biologically, but is more widely recovered by using chemical dosing techniques with, for example, ferric chloride. Phosphorus removed during wastewater treatment is transferred to the sewage sludge, thus significantly raising its concentration in sludge. Primary and secondary sludges are usually prethickened separately to increase the dry solids content, and are then combined together for subsequent treatment, by, for example, anaerobic digestion or other processes, to generate a product that is suitable for recycling as a fertiliser and soil conditioner on farmland.

The management options

Approximately 1.4 million tonnes dry solids of sewage sludge are produced annually in the UK. The main outlets for managing the residual sludge from wastewater treatment are shown in Figure 1.

The practice of dispersal at sea was ended by the EU Urban Wastewater Treatment Directive in 1998. Landfilling has never been regarded as a long-term sustainable option for sludge disposal by the UK water industry, although it provides a short-term or emergency disposal route if necessary. The Landfill Directive also places restrictions on the disposal of biodegradable waste to landfill.

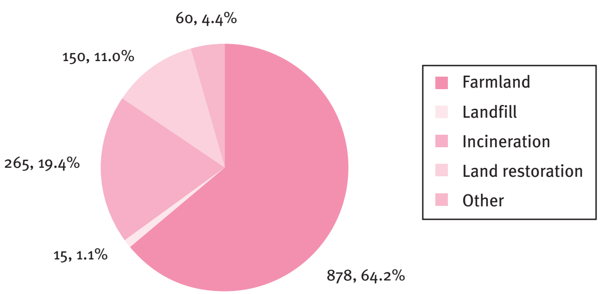


Figure 1: The main outlets for sewage sludge management in the UK for 2004 (values denote t x 1000 and per cent total production of dry solids)

Incineration

Incineration has played a sizable role in sludge management in the past and is likely to do so in future. There are currently nine sewage sludge incinerators operating in the UK, but it is amongst the most expensive of the treatment options available for sludge with high capital and operating costs. Incineration is a treatment process that maximises dry solids destruction, however, a significant amount of residual non-combustible ash material, typically equivalent to 35-40 per cent of the initial sludge dry solids, remains requiring final disposal, usually by landfilling. In some cases the ash may be classified as hazardous waste potentially increasing disposal problems and costs.

Obtaining sufficient solids content is critical for autothermic combustion of the sludge to take place, otherwise additional fuel is necessary to support combustion. This is particularly challenging for sludge due to its high initial moisture content (sludge initially contains 95–97 per cent water). With the most advanced technology available, the energy balance of an efficiently run incinerator plant may be self-sustaining without the need for an external fuel source, but there is little capacity to generate additional power from the process. The recovery of surplus energy could improve in future with the development of more energy efficient processes and effective sludge dewatering technology. For the time being, and until suitable uses for the residual ash are found, incineration should be considered as a disposal method, with little opportunity for value recovery. Incineration is justified, and is currently the only viable option available, when the concentrations of contaminants in the sludge prohibit its use in agriculture or when the sewage treatment works is located within a large conurbation and agricultural land is inaccessible.

Recycling biosolids to farmland

Applying sewage sludge to farmland is a long and well-established practice in the UK and represents the only management option that provides significant benefit from recycling of the nutrients and organic matter contained in sludge. Currently, about 64 per cent of the annual sludge production in the UK is recycled to farmland (Figure 1). All sludge is treated before it can be used on land. Mesophilic anaerobic digestion is the most common type of conventional sludge treatment process, which also has the advantage of producing renewable energy in the form of methane gas that is used for combined heat and power (CHP) generation. Heat is used for digester heating; the electrical power demand for wastewater treatment plant operation can usually be met and typically there may be a surplus of approximately 20 per cent of the electrical power generated which is supplied to the national grid. Currently, more than 50 per cent of sludge produced in the UK is treated by mesophilic anaerobic digestion.

Land application of sludge does not represent any greater risk to the environment than many other types of livestock manure or organic residual spread on land: in its 19th *Report on the Sustainable Use of Soil*, the Royal Commission on Environmental Pollution noted that there was no evidence linking the controlled use of sludge on farmland to disease in the human population. The practice receives statutory control to ensure any potential risks to the environment and human health are minimised. Agricultural recycling is regulated by European Directive 86/278/EEC, which was transposed into UK law by the Sludge (Use In Agriculture) Regulations 1989 (as amended). *A Code of Practice for Agricultural Use of Sewage Sludge* also supports the statutory regulation.

Two important features of the controls include limit values for potentially toxic elements in sewage sludge amended soil and restrictions on the use of land after application as a precaution to enable the natural attenuation of pathogenic microorganisms. The Code also includes a list of effective sludge treatment processes designed to significantly reduce the numbers of pathogens that may be present, providing an effective multi-barrier approach to the prevention of disease transmission. As a result, the UK government considers recycling sewage sludge in agriculture as the Best Practicable Environmental Option (BPEO) for sludge management under most circumstances.

Sludge treatment is designed to reduce odour and disease vectors, as well as the pathogen content. Odour is probably the single most important factor influencing negative public perceptions about recycling sludge, and effective measures to control odour are critical to successful recycling operations. The mechanisms responsible for producing malodour from sludge are poorly understood, however, so this is an area requiring further research. Contaminants in sludge are the other potential concern. Concentrations of potentially toxic elements, such as zinc and copper, and of persistent organic pollutants have declined markedly in sludge over the past 30 years with improved industrial practices, restrictions on emissions, production and use of dangerous

> "applying sewage sludge to farmland is a long and well-established practice in the UK"

substances within European Union, as well as effective trade effluent control measures taken by the water industry.

The most recent important development influencing land spreading of sludge is the voluntary agreement between the water utilities and food retail sector, known as the Safe Sludge Matrix, which defined more specifically the acceptable uses of sludge on different categories of crops. The Matrix introduced a two-tier system for use on cropped land, according to the degree of treatment of the sludge. It ended the practice of applying untreated sludge on land used for food production in December 1999, and use for non-food, industrial crops in December 2005. The categories of sludge that are acceptable for land spreading are defined as conventionally or enhanced treated and specific microbiological standards apply to each category. Furthermore, sludge treatment processes are managed following the Hazard Assessment Critical Control Point system, introduced by the food industry, to ensure that the microbiological quality standards are met. Sludge may be applied to farmland as a liquid product, typically with a dry solids content of 2-5 per cent, but increasingly it is dewatered mechanically to reduce transportation costs. The dewatering process, by centrifuge or belt press, produces a stackable cake containing approximately 25 per cent dry solids. Treated sludge that is suitable for beneficial use on land is increasingly referred to as 'biosolids' to distinguish this as a product from untreated sludge.

> "the apparent lack of progress on this important issue has been a serious constraint to the agricultural recycling of biosolids"

The Safe Sludge Matrix was adopted by the UK water industry voluntarily in 1999 and Defra agreed to incorporate these measures in an amendment of the current Statutory Instrument and Code of Practice. So far this undertaking has not been fulfilled: the first consultation on the proposals to amend the statutory controls for the agricultural use of sludge closed in January 2003. The apparent lack of progress on this important issue has been a serious constraint to the agricultural recycling of biosolids in some areas, and has the potential to severely undermine confidence in the practice within some sectors of the food industry that control the availability of the land bank for applying sludge. Concerns have also been expressed by a number of important sectors within the food industry that international markets and brands could be damaged by the use of sludge in the crop production cycle. Given that recycling on farmland is recognised as the BPEO by government, a positive and proactive stance by Defra, the Scottish Executive, the Food Standards Agency, the Environment Agency, and Scottish Environmental Protection Agency is essential to underpin confidence in agricultural recycling within the food and agricultural industries as a whole. This could include supporting the Sustainable Organic Resources Partnership (SORP), a stakeholder partnership that aims to provide a national forum for sharing and disseminating information on all organic materials applied to land to encourage the use of organic residuals on land as a long-term sustainable activity and resource.

At a national level, nutrients are returned to less than 1 per cent of the agricultural land in biosolids, which is a comparatively small input relative to that of livestock manures, for example. As the total volume of organic resources recycled to land increases (including composted materials and industrial biowastes, due to their diversion from landfill), there will be greater competition for the available landbank for spreading all organic materials in future. The question arises whether, given the increased amounts of wastes going to land and the restrictions on application rates in Nitrate Vulnerable Zones (NVZs), and other future constraints that may be required by the WFD, there is sufficient land available to receive the volume of organic material generated. To answer this, Defra is currently funding the development of a tool to quantify the national capacity of agricultural land to accept organic residuals: Agricultural Land and Organic Waste – A National Capacity Estimator (ALOWANCE), which will be critical in developing an integrated land-based approach for recycling organic residuals.

The role of biosolids in closing the loop

The total concentrations of nutrients in dewatered biosolids are typically in the range of 4-5 per cent for nitrogen and 2-3 per cent for phosphorus. However, phosphorus removal during wastewater treatment can more than double the concentration of this nutrient in sludge. The contribution of biosolids nitrogen to agricultural systems is equivalent to approximately 3 per cent of the total N applied to all crops in Great Britain in mineral fertilisers. Phosphorus supplied in sludge, on the other hand, supplies a much larger contribution, equivalent to approximately 15 per cent of the total phosphorus in mineral fertilisers - a significant quantity relative to artificial fertiliser. Together, the notional fertiliser replacement value of the nutrients supplied in biosolids is in the region of £20 million. Other beneficial nutrient elements supplied in sludge include useful quantities of sulphur and magnesium.

> “ the notional fertiliser replacement value of the nutrients supplied in biosolids is in the region of £20 million”

A major economic incentive to farmers for accepting sludge is the nitrogen replacement and yield response value. Recent field investigations by Imperial College London on a range of dewatered biosolids showed that the nitrogen fertiliser replacement value of biosolids is equivalent to approximately 35-40 per cent of the total nitrogen content of artificial fertiliser. This compares well with solid farmyard manure, for example, which may have a nitrogen availability of up to 25 per cent.

Spreading rates used in the UK are determined by the nitrogen content of the sludge. Within NVZs, an average maximum farm-based limit on the total amount of nitrogen that can be applied in all organic manures (including sludge) to arable land is 170kg per hectare, in compliance with the EU Nitrates Directive. For grassland the UK limit is 250kg per hectare. There is also a maximum field-based limit of 250kg N per hectare in any 12 month period and restrictions on timing applications of liquid digested sludge to prevent spreading of this high nitrogen availability product (nitrogen availability in this case is approximately 60 per cent, due to the large content of mineral nitrogen, and is similar to livestock slurry) in the autumn period, when there is greatest risk of nitrate leaching. The Code of Good Agricultural Practice for the Protection of Water (The Water Code) recommends a limit of 500kg N per hectare in alternate years for dewatered sludge types outside the NVZs in England and Wales, and 250kg N per hectare is allowed per year for liquid forms. The rates of sludge application are adjusted in accordance with these limits on maximum nitrogen additions. Consequently, the water industry adheres to strict controls on the amounts of nitrogen that can be applied in sludge, and the timing and frequency of sludge applications within, as well as outside, NVZs, to reduce potential impacts on water resources of nitrate leaching from agricultural utilisation.

In terms of the sustainability of the practice, recycling phosphorus in the food chain is arguably more important than for nitrogen. Sludge provides a long-term maintenance dressing for this nutrient and can replace phosphorus inputs from inorganic fertilisers in a crop rotation. Recycling phosphorus to soil in biosolids has a much wider global benefit than simply reducing farmers' costs, however, by contributing to the conservation of geological mineral phosphorus reserves and reducing external inputs of geogenic cadmium into the food chain. World reserves of currently exploitable phosphate rock are estimated to be 40 billion tonnes and, at the present rate of consumption (150 million tonnes per year), this will be exhausted within 250 years. Cadmium inputs to soil from rock phosphate fertiliser production has also been a concern with long-term implications for soil fertility and human health. Recycling phosphorus in biosolids is therefore a key prerogative for long-term sustainability. Phosphorus recovery during wastewater treatment is highly efficient and the sludge is an effective phosphorus fertiliser source that closes the nutrient loop through the food chain, provided it is carefully managed. Under these circumstances, it may not be necessary to control inputs of phosphorus to the wastewater collection system. In any case, the largest input of phosphorus originates from dietary sources, which emphasises the important link apparent between recycling in sludge and the food chain.

Much research has been completed to determine the fertiliser replacement value of nitrogen, and to a lesser extent phosphorus, in sludge: the phosphorus availability in sludge is typically given as 50 per cent relative to mineral fertiliser. This information is readily available to operators and farmers in the form of advisory fertiliser recommendations, for example the Fertiliser Recommendations for Agricultural and Horticultural Crops (RB 209). Phosphorus inputs in sludge exceed the demand of the first receiving crop, however, recommendations are given on the basis that a single dressing of dewatered biosolids will supply adequate phosphate for most three to four year crop rotations. This is justified on the basis that phosphorus is retained in sludge-amended soil; recent research shows that phosphorus applied in this form is bioavailable to crops, yet it is less susceptible to leaching and run-off compared to applications in livestock manures. However, improved understanding of the release of residual phosphorus applied to soil in biosolids in the growing seasons after application is an area requiring further attention to more precisely define the long-term phosphorus balance in sludge-amended soil. As the UK moves towards implementing the EU Water Framework Directive, action is likely to be taken to reduce diffuse pollution from agricultural sources, focussing particularly on nitrogen and phosphorus. It is unclear at this stage what form these measures are likely to take and what their potential impact on recycling biosolids would be. Recognising that land varies in terms of its potential risk of contributing nutrients to receiving waters may provide a pragmatic approach to managing nutrient inputs to soil in biosolids and avoid unacceptable losses to the water environment.

Ensuring that full account is taken of the nutrient value provided by biosolids, as well as in other organic manures, by adjusting supplementary mineral fertiliser applications to amended soil is critical to reduce wastage, impacts on crop quality and losses of nutrients to the environment. Further progress could be made in this area and would have direct benefits in terms of improved nutrient use and reduced pollution as well as providing economic savings in fertiliser costs.

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implications of farm management on the nutrient cycle

Professor Mark Kibblewhite

Farm businesses produce food to make profits. Nutrients are valuable resources that should be managed effectively to support profitable production; they are imported onto farms in animal feed, organic manures, composts and waste materials spread to land, as well as in chemical fertilisers. Unfortunately, agricultural systems use nutrients inefficiently, particularly nitrogen and phosphorus, and 'leakage' to the wider environment is widespread, substantial and, at some level, inevitable.

About half the nitrogen added to soil as fertiliser for arable crops and grass is either emitted to the atmosphere as ammonia, nitrous oxide or other gaseous forms, or finds its way into surface and ground waters as nitrate. The conversion efficiency of nitrogen in feedstuffs to animal protein is less than 10 per cent, and a significant proportion of the nitrogen in manures and slurries is emitted to the environment, rather than being incorporated into the soil, taken up by plants and so either incorporated into food products or recycled in the agricultural system. Agriculture accounts for about 60 per cent of UK emissions of nitrous oxide, a gas which is 296 times more potent as a greenhouse gas than carbon dioxide. Some 90 per cent of UK ammonia emissions to air are from agriculture. Nitrogen emitted to the atmosphere as ammonia returns to land as wet and dry deposition, sometimes causing damage via nutrient enrichment to sensitive ecosystems, such as heath land, or contributing to acid rain. The amount of nitrogen deposited to soil surfaces in England and Wales has not reduced materially over the past two decades. Large reduction in non-agricultural industrial emissions have lowered long-range nitrogen exports to Scandinavia but agriculture and other sources such as transport, have ensured that local deposition has persisted. The quantities being deposited vary geographically but often exceed 20kg per hectare per year, which is biologically significant. The majority of nitrate in UK surface waters is from agriculture. Excess nitrate entering ground and surface waters compromises natural ecosystems and degrades water supplies. Nitrate nitrogen persists in many aquifers for decades so their pollution is irreversible in the medium-term. The environmental damage from agriculture to the wider UK economy arising from these different nitrogen emissions to air and water – nutrient removal by the water industry, greenhouse gas emissions, and remediation of damaged aquatic and terrestrial habitats – is considerable.

About a quarter of the phosphate in UK surface waters is thought to be from agricultural sources, (although this can vary widely from less than 10 per cent in the Thames to over 60 per cent in western

Wales).[5] This is a consequence of inefficient uptake by crops and grass of the phosphate present in fertilisers, manures and slurries. The natural availability of phosphate limits the productivity of aquatic ecosystems and their characteristic biodiversities reflect this constraint; phosphate pollution from agriculture, as well as other sources, damages these ecosystems and in more severe cases leads to eutrophication - a condition where high nutrient availability causes excessive algal growth.

There is great variety and variability in the types and scales of agricultural production. A useful distinction is between intensive and extensive systems. Intensive systems maximise production and profits per hectare via larger inputs, including fertiliser and animal feed. Examples are cereal, oil seed and potato production, dairy and cattle enterprises with higher stocking densities and large-scale pig and poultry production. In these systems, high nutrient inputs are used to maximise yields and so greater emissions to water and air are likely. Extensive systems optimise profits where land is not suited to intensive production by controlling inputs at maintenance levels and relying more on natural nutrient cycles. Examples are sheep and beef cattle production in the uplands. In extensive systems, inputs are lower and the risk to the environment from nutrient leakage is reduced. Nonetheless the environmental impact of farming remains significant in extensive systems, particularly because of nitrogen emissions from animal wastes and where soil erosion releases phosphate-containing sediments into surface waters. In all cases the impact of farming systems is strongly influenced by the effectiveness of management; a poorly managed extensive system can be as, or even more, polluting than a well managed intensive one.

Not surprisingly, a tension exists between agricultural businesses, who perceive that continued use of higher nutrient inputs is a pre-condition for profitable farming, and wider society, which is paying for the environmental damage. The challenge for society is to encourage the adoption of agricultural systems and management practices that can sustain food production while releasing fewer nutrients.

The mid-term reform of the Common Agricultural Policy (CAP) is likely to encourage a permanent shift to extensive land management. For example, with the decoupling of production and support payments, it makes sense to put arable land down to grass, where cereal and other commodity crop yields are not sufficient to fully recover production costs at market prices. However, the market prices can go up as well as down, influencing land managers' decision-making differently. At present, in the UK, marginal livestock enterprises appear to be withdrawing from production or adopting more extensive approaches. Such trends will tend to reduce the environmental burden of nutrients from agriculture. But conversely land that continues to be used for commodity production can be expected to be managed in larger and more intensive units to maximise profits under unsupported market conditions, which may present a greater risk to the environment if protective measures are insufficient.

Agricultural systems are open ones - they absorb and release energy and materials from and in to the environment. Agriculture requires natural resources such as soil and water to support a profitable level of food production, but to be sustainable it must also only return nutrients at levels which can be safely absorbed by these same natural resources. Overall, current emissions of nutrients exceed the capacity of the wider environment to absorb them. Better information is needed on the natural capacity of local environments to assimilate nutrients and on the emissions from different agricultural systems. And where capacity is exceeded, agriculture has to change, either by reducing emissions through improved efficiency, reducing production, or shifting to a different type of production. This change is unlikely to happen if left to market forces because many environmental damage costs are not included in on-farm costs. The benefits of nutrient additions accrue to the farmer while many damage costs present beyond the farm gate and are met elsewhere, either directly as remediation costs or through loss of resource quality. And it is irrational for a farmer seeking to maximise individual farm profit to forego profit for the benefit of the wider community. Nutrients such as nitrogen are relatively cheap and are a highly cost-effective means to improve yields of arable crops and grass. In the absence of regulatory controls, it pays to apply a little more fertiliser than is strictly necessary, as an insurance against reduced yields, even if this causes environmental damage. A legal framework that addresses this market failure is essential, which may include a mix of environmental regulations, incentives and voluntary measures. The current legal framework is incomplete. For example, Nitrate Vulnerable Zones (NVZs) may protect the water environment, but at present there are no controls on nitrogen emissions from agriculture to the atmosphere, except from those larger pig and poultry units controlled under the Pollution Prevention and Control (PPC) regulations.

“in the absence of regulatory controls, it pays to apply a little more fertiliser than is strictly necessary”

The introduction of Single Farm Payments, accompanied by cross compliance measures, is a highly important step towards encouraging better land and soil management, and this should reduce nutrient emissions to the environment. For example, the requirement for implementation of a soil management plan to reduce erosion risk will lower the risk of transfer to surface waters of phosphate bound to soil particles. Looking ahead, further CAP reform may offer opportunities to introduce cross-compliance conditions or agri-environment measures that require specific actions to reduce nitrogen and other nutrient emissions, in return for continued support payments. A good start has been made with agri-environment schemes, which include measures such as buffer zones to limit phosphate pollution of surface waters.

Better management of nutrients within intensive systems is both needed and possible. Greater policy emphasis is needed on supporting the development of improved technology and encouraging its widespread adoption. The role of the agricultural engineer is critical. There is existing commercial technology which can reduce nutrient inputs while sustaining or even slightly increasing yields, based on precision nutrient application rates derived from analysis of information about soil conditions, previous cropping and weather patterns. These precision agriculture techniques have the potential to materially reduce polluting emissions to air and water but have not been targeted by UK policy, although they are mature and have been widely adopted elsewhere in the world. UK farmers need incentives to adopt (precision agriculture) this technology. More positively, the animal sector is introducing altered nutritional regimes, which increase protein conversion efficiency, reducing waste nitrogen emissions. And the leaders in the pig industry are shifting to energy recovery from slurries via anaerobic digestion in place of direct slurry application to land, which offers better controls on nutrient management as well as making an important contribution to reducing greenhouse gas emissions.

A particular challenge is to make extensive agricultural systems and also organic ones more efficient in their use of nutrients. While these systems import less nutrients and rely more on nutrient cycling and on natural inputs and biological fixation of atmospheric nitrogen, they are also less easily controlled, which increases the risk of fugitive losses to the wider environment. For example, animal wastes arising directly during grazing or spread from winter housing may be washed into surface waters during wet periods and this may neither be predictable or avoided entirely. In truth, there are different but significant risks associated with both intensive animal production systems, which have constructed facilities for waste containment, and extensive systems with little waste management infrastructure. Those farms that combine some intensive practices with extensive ones, such as many dairy units, present many opportunities for nutrient emissions to both water and air, which argues for their closer regulation; including by an extension of the PPC regulations to cover larger dairy units. For example: to minimise losses to the environment, the timing of fertiliser applications to permanent grass is critical, but can often be constrained by grazing schedules, and local stocking densities may exceed the carrying capacity of the land in winter months where there is inadequate investment in housing and waste management. Current good practice requires that animal wastes are collected, stored, treated and returned to land at rates and with timings that maximise recovery of nutrients back in to the production cycle, so minimising emissions. There is clear scope to improve performance, via a combination of regulation and capital support for better nutrient management infrastructure, such as slurry stores and additional winter-housing.

Agriculture delivers services other than food and fibre production, including waste management. Organic materials that would otherwise go to landfill or be incinerated can and are spread on land where some of the nutrients they contain are recovered in to production. This service is an important means of recycling nutrients in food wastes and sewage sludge. Nonetheless land spreading such materials may harm the environment if nutrient additions are not estimated and matched to the requirements of the agricultural system.

> "UK farmers need incentives to adopt precision agriculture technology"

There is a relatively good understanding of the processes that release nutrients to water from nitrogen and phosphate fertilisers. There is scope for improved management, such as by introducing precision techniques, but the immediate high priority is to lower nitrogen emissions to the atmosphere. For this, a better understanding is required of the processes and patterns of nitrogen releases to the atmosphere, especially from grazed land, as a basis for effective controls and innovative technology.

"continued CAP reform should encourage a shift to more extensive systems, especially on poorer land, as the link between subsidy and yields is broken"

Continued CAP reform should encourage a shift to more extensive systems, especially on poorer land, as the link between subsidy and yields is broken. This should lower overall agricultural emissions of nutrients to the environment. But CAP reform will also drive the emergence of larger intensive and mixed intensive-extensive operations that may present higher environmental risks. There is an urgent need to ensure that more intensive agricultural systems are not sited where there is inadequate environmental capacity to absorb their emissions. Alongside this there is a requirement for a combination of public investment in research and incentives and advisory services that are targeted at improving the efficiency of nutrient use, via new and better adoption of existing technology and higher standards of management.

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the role of composting in closing the nutrients loop

Dr Jane Gilbert

The composting industry is a relatively new arrival in the UK. In little more than ten years it has grown from back garden compost heaps to a multimillion pound industry which is making a positive contribution to increasing recycling, reducing landfill and returning significant amounts of carbon and nitrogen to the soil.

While the industry might still be young, composting, that is to say, the process of producing compost through aerobic decomposition of biodegradable organic matter, has taken place since the dawn of time. For the vast majority of that time, composting took place with little input from people and no technology. The composting of human faecal matter, night soil, together with other vegetable and animal manure waste has been practised in China for centuries. It has been considered the key to supporting high population densities and maintaining soil fertility and structure over some 4,000 years. Even without the benefit of scientific studies, farmers throughout history recognised the importance of returning nutrients to the soil.

However, since the Industrial Revolution this crucial link between food production and returning surplus organic matter to soils has become severely diminished. In the rush towards industrialisation, this historical knowledge was discarded and it has only been in relatively recent years that mainstream scientists and farmers have once again recognised the importance of recycling organic waste back to the soil. Classifying these materials as 'wastes' and requiring sanitary disposal methods, such as landfill or incineration, in order to safeguard public health in our growing urban areas, inadvertently resulted in a loss of valuable nutrients and organic matter which we are only now rectifying. The words of Dr F.H. King ring even truer today than when they were first published nearly a century ago:

"Man is the most extravagant accelerator of waste the world has ever endured. His withering blight has fallen upon every living thing within his reach, himself not excepted; and his besom of destruction in the uncontrolled hands of a generation has swept into the sea soil fertility which only centuries of life could accumulate, and yet this fertility is the substratum of all that is living."[6]

> "composting has taken place since the dawn of time"

It is only in recent years that the environmental impact of these waste disposal techniques has been questioned and that European governments have begun to act upon them. The principal driver behind this development has been the EU Landfill Directive (EC/31/99), which aims to reduce emissions of the potent greenhouse gas methane into the atmosphere.

The Directive sets binding targets for member states to divert biodegradable municipal waste from landfill; the knock-on effect of this is that local authorities in the UK are now collecting garden and food wastes separately for biological treatment, either through composting or anaerobic digestion. The UK's composting industry currently processes in excess of three million tonnes of waste a year, producing more than a million tonnes of compost. Impressive though this may sound, especially when compared to the few thousand tonnes composted in the early nineties, this increased need for recycling means that the composting industry is set to witness somewhere between a three and five-fold increase in production within the next 10-15 years.

The benefits of compost use are wide and varied. The 'black gold' loved by gardeners is now the subject of serious scientific study by academics across the world, who have begun to translate qualitative effects into quantitative benefits. The complexity of soils and the flora and fauna they support suggest that benefits are diverse, with synergistic effects observed in long-term trials.

A range of research projects and trials have been carried out in the last five years to prove the benefit of compost use in a range of applications. The evidence from these trials has shown that compost can play a pivotal role in the adoption of sustainable practises in certain markets. Compost's moisture retention capabilities and its slow release nutrients have made it an attractive option to landscapers and horticulturists. Recent trials in agriculture have shown that the application of compost to soil can increase yields over three to five years of repeated application. Furthermore, compost also has a potentially large market in restoring and 'repairing' soil on brownfield sites such as former factories and industrial areas, as it can be an ideal component in topsoil manufacture where existing soil is scarce or of poor quality.

Most notably though, composts have a direct impact on the soil's physical structure, helping to increase organic matter content, improve structure and workability, reducing erosion and compaction as well as acting as a sponge to help hold-in moisture. This water-retention capacity has direct agronomic benefits especially as parts of the UK are now starting to experience greater periods of low rainfall followed by intense precipitation. An added benefit is that the organic matter acts as a buffer, helping to mop up and retain inorganic fertilisers that would otherwise run-off and pollute water courses.

> "compost can play a pivotal role in the adoption of sustainable practises"

Compost, being a living substrate, introduces beneficial microorganisms into the soil, and helps provide food for indigenous soil fauna. The development of ever more sophisticated molecular biology techniques has moved the understanding of the microbiology of composting to new horizons. Scientists are now able to track the growth and succession of microbial communities during composting and assess how these interact with soil microbes. One area that is receiving considerable interest is the ability of composts to suppress plant pathogens. Research into the disease suppressive effects of compost began in the United States over

30 years ago. Since then, there has been a significant amount of research into the effects of composts made from a wide range of feedstock wastes on plant diseases. One material that has real potential for disease suppression is green waste compost. Where these pathogens are of agronomic concern, the application of compost can help reduce a farmer's reliance on artificial pesticides, which have over the years been linked to numerous environmental problems.

Notably, composts contain a range of plant nutrients. The macronutrients N, P and K are available to plants in different ways. In temperate regions between 10-15 per cent of the total nitrogen content in compost is typically available for plant growth during the first year of application. This means that applying composts helps build up a 'bank' of nutrients that are released into the soil over time so that benefits are observed over a period of years. Compost use can, therefore, help improve soil fertility and crop yields not only in its year of application, but also in subsequent years. The benefits of compost application to crops have been demonstrated in numerous long-term field-scale trials globally. Recent studies in the UK have suggested that after three years yield increases of 7 per cent compared with conventional fertiliser applications were observed.[7]

Research in Germany has suggested that not all of the nitrogen in compost is used as a fertiliser. Rather, a proportion is retained in the soil and used by soil microbes to help generate more organic matter *in situ*. As the UK, in particular, has experienced significant organic matter loss during the last century, this benefit cannot be overstated. Figures from England and Wales show that percentage of soils with less than 3.6 per cent organic matter rose from 35 per cent to 42 per cent in the period 1980-1995.[8] Recent research published in *Nature* suggests that loss of soil carbon is linked to climate change.[9] By inference, the controlled application of compost can help counter some of this loss, thus mitigating carbon dioxide emissions. The Composting Association has provisionally calculated that composting an estimated 15 million tonnes of biowaste could have the potential to offset carbon dioxide emissions equivalent to those of over a million cars a year.

The UK now produces a ready supply of quality assured compost. Compost produced to meet the BSI PAS 100 standard and the Quality Protocol for Compost means that it need no longer be classified as a waste in England and Wales. Compost is the first recovered waste type to be subject to a quality protocol. It was chosen because of the growing demand from landscapers, horticulturists, developers and farmers who know the benefits of applying compost to their soil and because there is a professional industry in place to meet this demand.

The Quality Protocol for Compost sets out criteria for the production of compost from specific waste types, and compliance with these criteria is considered sufficient to ensure that the recovered product can be classified as fully recycled and used without risk to the environment or harm to human health.

In the UK, the Single Payment Scheme has replaced previous Common Agricultural Policy

"composting 15 million tonnes of biowaste could have the potential to offset carbon dioxide emissions equivalent to a million cars a year" payment schemes. Organic matter decline in European soils is one the main emerging issues in EU policy terms, because it is threatening the capacity of soils within EU Member States to remain fertile and to keep performing their environmental functions. In order to receive their subsidy payment, farmers must comply with Statutory Management Requirements and Good Agricultural Environmental Condition (GAEC) standards. Better productivity is linked with good soil management that prevents soil erosion from fields. The effective maintenance of soil organic matter and good soil structure are central to meeting the GAEC standards. In addition, agri-environment schemes within the UK provide additional funding to farmers and other land managers who deliver effective environmental management on their land. Although the schemes differ in some details, soil and manure management planning is a common element to all.

" it's time that we reconnected the link between organic waste and the soils on which they arose in the first place"

The Composting Association believes that the relevance of certified quality assured composts should be made more apparent in government GAEC standards, agri-environment scheme guidance and in any associated guidance on the reformed Common Agricultural Policy, and that government considers policy drivers that would provide a clear link between biowaste and soil management practices.

Soil comprises a delicate balance of minerals and living organisms but our recent emphasis on applying inorganic fertilisers has rapidly destroyed this ecosystem. Compost can play a vital role in returning nutrients to the soil and thereby arrest the decline in the quality of soil in this country. The nutrients present in quality compost will provide a source of food for microbes in the soil and help farmers to move as close as possible to closing the organic loop.

With our rush towards the use of fertilisers the organic loop has been broken; it's time that we reconnected that link between organic waste and the soils on which they arose in the first place. Farmers throughout history have known that it was important to return waste to the soil, they might not have known why it was important or what they were doing but they knew it was important and that it worked. The use of inorganic fertilisers may have had short-term benefits but it has had massive repercussions in the longer run. This will change. Recycling and composting are high on the government's agenda, the Quality Protocol for Compost has been published and there is a real desire amongst the public to recycle and take more care of the environment. With potentially in excess of 7 million tonnes of compost produced every year, this could represent just under a million tonnes of organic carbon and over 50,000 tonnes of nitrogen which would otherwise be lost. We now have the knowledge and the opportunity to improve the quality of soil and to move in the right direction; our agri-environment schemes need to reflect this.

Applying compost to the soil will have major benefits to the environment. After all, there's a reason why farmers have been doing it for 40 centuries.

Dr Jane Gilbert is chief executive of the Composting Association

too much of a good thing? the impact of nutrients on birds and other biodiversity

M A MacDonald, J M Densham, R Davis and S Armstrong-Brown

Human activity is altering the fertility of the countryside. Industrialisation and agricultural intensification have been accompanied by dramatic changes to the natural cycling of plant nutrients - specificially nitrogen and phosphorus. On a global scale, human activity has more than doubled the fixation of nitrogen gas from the atmosphere into forms that can affect the environment. Humans have also tripled the amount of biologically available phosphorus available since the industrial revolution.

Both these nutrients directly affect plant growth in natural and semi-natural habitats with knock-on consequences for wildlife. It is difficult to disentangle the effects of nutrients from the other pressures contributing to the decline in individual species but the effects can be viewed by looking in detail at the effects on habitats. This chapter summarises a detailed review of the evidence for indirect (including food-chain) effects of phosphorus and nitrogen on UK bird populations.[10] It focusses on the impacts of nutrients on farmland, aquatic habitats and upland moor and lowland heath habitats.

Farmland

Farmland is a deliberately fertilised habitat. The plant growth acceleration properties of nutrients are key to increasing yields and have helped to change the way crops, including grassland, are grown and managed. Inorganic fertiliser use has been one factor that has helped to drive a massive intensification of agriculture since the 1950s. Problems arise when intensification has negative environmental consequences; when nutrients affect non-crop plants on farmland; or when unused nutrients are dispersed from the agricultural system.

Vegetation structure

Some organisms are directly affected by the toxicity of nutrients applied to the land, but the majority of wildlife impacts are indirect. Fertilisers promote faster and earlier spring growth and lead to taller, denser and more uniform crops and grass swards. Fertilisers applied onto field margins in the application process also alter these habitats. This has a number of consequences for non-crop plants and animals in farmland.

> “human activity has more than doubled the fixation of nitrogen gas from the atmosphere into forms that can affect the environment”

Species richness

Increased fertiliser applications generally reduce the variety of plant species found in fields. The first to disappear are the most sensitive plants which cannot tolerate increased nutrient levels or compete with nutrient hungry crops, for example, lambs succory and annual knowle. This can have knock-on effects for invertebrate species such as butterflies and carabid beetles[11] which require these plants as hosts, and has the potential to decrease invertebrate biodiversity on farmland.

Whilst some plant eating invertebrates may benefit from the increased nutritive content of fertilised crops and grass, some, such as grasshoppers and crickets, are adapted to a specific sward structure within fields. When fertilisers cause a change to the structure of plants these insects are affected[12] but in addition, they are disturbed by intensive grazing and cutting regimes because of their longer life cycles and relatively low recolonisation ability. This means that they are more likely to disappear from intensively managed farmland. The loss of these large invertebrates may also be a major cause of impacts on birds, such as cirl bunting and red-backed shrike, and breeding waders in grassland.[13] Dense grass and crops also dry the soil forcing earthworms deeper into the ground making them unavailable to birds such as snipe, starling and chough, that probe the soil for food.

Land management

Silage production, with its intensive use of fertilisers for rapid grass growth and repeated cutting, probably has the most radical effect on vegetation and the food-chain of wildlife, of any farmland management. It has probably also had the greatest effect on farmland bird populations because in addition to reducing food resources, nest destruction during silage cutting has a major impact on ground nesting birds such as whinchat and corncrake.[14] Furthermore, intensive grazing on fertilised grassland can lead to increased nest trampling in ground nesting species such as skylark[15] and lapwing.[16]

Farming systems

At the landscape scale the use of inorganic fertilisers has led to changes in patterns of land-use by releasing farmers from the need to graze livestock for manure production and/or to rotate leguminous crops in order to provide plant nutrients. As a result there has been a loss of mixed farming landscapes and a polarisation of agriculture in the United Kingdom towards arable farming in the south and east, and pastoral farming in the north and west. Birds such as starling and lapwing prefer the juxtaposition of arable fields and pasture and are likely to have been affected by the loss of mixed farming from the landscape.[17]

Aquatic habitats

In some forms nitrogen and phosphorus can be transported away from their intended targets, for example in silage fields, and can disrupt habitats elsewhere. Nutrients also enter the aquatic environment as pollution from some sewage treatment works. This pollution can cause aquatic systems to become eutrophic with complex and highly localised effects on the food-chain. There are winners and losers when aquatic habitats become eutrophic: increases in nutrient concentrations may be beneficial to wildlife by increasing food supply but too great a change can radically impact the habitats on which species rely for food and nesting sites.

Upland freshwater lakes

Upland lakes in the UK are mostly naturally low in nutrients and plant life making them sensitive to minor increases in nutrient loadings. Shallow freshwater lakes are especially susceptible to eutrophication with the resultant shifts in water quality and impacts on biodiversity being noticable relatively quickly. Eutrophication of shallow lakes leads to a reduction of fish diversity, with roach and bream becoming dominant at the expense of perch, tench and rudd.[18] The rare bittern may be affected by this reduction in the numbers of rudd, one of its major food items in Britain and its adaptation to life in reedbeds may also mean it is affected by the action of nutrients in changing the structure and composition of plant communities. An example of this change has been seen in the Norfolk Broads where increases in nitrates in water have caused the decline of a particular floating form of reed, used by bitterns, known as hover.[19]

> "shallow freshwater lakes are especially susceptible to eutrophication"

Invertebrate communities in freshwater are also sensitive to nutrients, for example eutrophic conditions can radically affect the invertebrates living at the bottom of water bodies, leading to a loss of sensitive groups of species such as molluscs. Diving birds, such as pochard, which dive from the surface to feed on them suffer from the resultant reduced food supply.[20] Phosphates are commonly transported to the aquatic environment by being bound to sediments. This mechanism of pollution can increase phosphate levels in water but the sediments themselves can also cloud water, prevent the growth of submerged plants, clog gravel needed for salmonid eggs to survive and hatch, and affect freshwater pearl mussel and native white-clawed crayfish.

Estuaries and coastal waters

Nutrients flowing downstream reach esturaries and coastal waters where their effects are less persistent because they are generally more quickly flushed through with water. However, where eutrophication occurs it typically leads to a decline in plant communities, such as seagrass and eelgrass beds, and their replacement by algal mats and phytoplankton blooms.[21] This growth can starve the water of oxygen and force invertebrates to the surface providing a short-term flush of food for organisms higher up the foodchain. This phenomenon can occur in freshwater too, killing invertebrates and fish in an affected stretch of water. Small aquatic crustaceans such as the mud shrimp and polychaetes like ragworm are relatively tolerant of eutrophic conditions and can provide abundant food resources to shorebirds in eutrophic tidal areas. These birds generally benefit from human influenced nutrient inputs, for example, from sewage outflows, although birds with specific prey requirements or foraging habits, such as shelduck, may not.[22]

Upland moor and lowland heath

Upland moor and lowland heath, dominated by heather, are naturally nutrient poor habitats that are sensitive to increases in nutrient inputs. Fertilisers are not generally applied to moorland or lowland heathland as a land management tool. Instead, increases in nutrient loading are the result of atmospheric nitrogen deposition. This source of nitrogen has increased enormously over the past century, despite some reductions over the past two decades.

Vegetation

Heather cover in UK upland moorland and lowland heath declined by 40 per cent between 1947 and 1980[23] due to overgrazing, afforestation, conversion to farmland, invasion of grasses, and succession to scrub. Nitrogen deposition in the form of nitrous oxides may have accelerated these processes, such as by increasing the nitrogen content of heather leaves, affecting the plant's structure leaving it sensitive to drying and attack by heather beetle,[24] which feeds exclusively on it. Exacerbated by grazing disturbance, dieback can occur which allows grasses to invade, themselves fertilised by the atmospheric nitrogen. Plant-eating invertebrates may be helped by the enhanced nutritive value of heather or through a preference for grasses but ultimately changes to the mosaic of grass and heather and intensive grazing of moorland will remove foliage to the detriment of these invertebrate communities.

Birds

In upland moorland, the shift from heather to grass moorland over a large scale is likely to be the most important indirect effect on birds of nitrogen deposition. A number of bird species have been identified as sensitive to heather loss, especially red grouse and stonechat. It is, therefore, possible that these birds are adversely affected by the impacts of atmospheric nutrient deposition.

Conclusions

Increased levels of nutrients are damaging habitats across the UK. Nutrient pollution force-feeds the countryside, altering plant growth rates, changing plant communities and disrupting the food chain for wildlife. Red backed shrike is now extinct in the UK; its decline was largely driven by management change linked to fertiliser application to grassland. This process also helped drive corncrake and cirl bunting to the brink of extinction in the UK. These two species are slowly recovering as a result of intensive conservation effort. Tougher action must be taken to ensure the efficient use and recycling of nitrogen and phosphorus, and limit losses to the environment. The knowledge and technologies exist to achieve this, through capturing and re-using the nutrients present in organic wastes. Now, policies are required to put this knowledge into practice, through a mixture of better regulation, incentives and education.

This article is a summary of a recent evidence review by RSPB. The full report is available at http://www.rspb.org.uk/ourwork/policy/water/issues/diffuse.asp

energy and cost implications of today's nutrient cycle

Rob Lillywhite

Underpinning all agricultural production, the two most important nutrient cycles in the UK are those of nitrogen and phosphorus. However they are natural cycles and are prone to leakages and inefficiencies.

All food crops with the exception of legumes respond positively to added nutrients. The yield of a crop of well-fertilised winter wheat will be double that of a crop which received no additional nutrients. In vegetable crops, additional nutrients can be the difference between a marketable crop and no crop at all – cauliflowers grown with limited nutrients may fail to form a curd whereas those with adequate nutrients will form big marketable heads. To ensure an economic return on agricultural production, farmers add to the naturally available nutrients with synthesised fertilisers.

Nitrogen is an essential element, perhaps *the* essential element. It is a component of the DNA of all animals and plants and is critical for plant growth. Globally, there is no shortage since our atmosphere is 80 per cent nitrogen. The problem is that atmospheric nitrogen is inert and cannot be used by plants and animals in that form. Plants need the 'reactive' nitrogen compounds ammonium and nitrate for growth that are normally provided from the breakdown of plant and animal remains in the soil.

Synthesised fertilisers, manufactured using nitrogen from the atmosphere by the Haber-Bosch process can supplement this 'natural' supply. In fact, the large increase in world population since 1910 can be linked to this process that revolutionized modern agriculture and food production.

Humans have, of course, been supplementing the background or natural nitrogen cycle for hundreds of years but industrialisation and the manufacture of industrial inorganic fertilisers have since resulted in a doubling of the reactive nitrogen in the biosphere. The Global Nitrogen Enrichment Thematic Programme (GANE) suggests, "While the global carbon cycle is being perturbed by less than 10 per cent, the global reactive N cycle is being perturbed by over 90 per cent".[25] The increase can be attributed to the increased demand for food and to the fact that food production is nitrogen inefficient. Cereal crops, the most efficient users of nitrogen, are only able to take up 50 per cent of the nitrogen in the soil. Other agricultural systems are even more inefficient: the production of beef uses only 9 per cent of the nitrogen supplied to it.

> "while the global carbon cycle is being perturbed by less than 10 per cent, the global reactive N cycle is being perturbed by over 90 per cent"

Within the UK, two industries, agriculture and power generation add between them 2 million tonnes of new reactive nitrogen to the environment every year: 1.1 million tonnes of nitrogen fertiliser, 0.4 million tonnes of agricultural nitrous oxides and ammonia and 0.5 million tonnes of nitrogen oxides from the combustion of fossil fuels. Although only the nitrogen fertiliser is deliberately applied to agricultural soils, the other compounds are also returned to the soils as wet and dry deposition.[26]

The costs and implications of adding this much nitrogen to the UK environment on an annual basis are significant, but defining and quantifying them is not easy. Some are financial; some environmental - and there is no easy way to make them comparable.

The nitrogen cycle, due to the mobility of nitrate, is inherently leaky and the subsequent environmental effects of excess nitrogen are well documented: acidified soils, loss of plant diversity and high nitrate levels and eutrophication in fresh and marine waters. Whilst most people would agree that these effects have a negative value it is far more difficult to ascertain their cost. Let's start with the basics. Every year half a million tonnes of nitrogen is leached from agriculture soils. Although it's only partially true, for the purposes of this exercise we will assume that this is all commercial ammonium nitrate fertiliser costing £160 per tonne (£464 per tonne of nitrogen). In financial terms, this means that £232 million is wasted.[27]

"agriculture and power generation add between them two million tonnes of new reactive nitrogen to the environment every year"

Costs can also be measured in terms of the energy used. To manufacture one tonne of nitrogen for ammonium-nitrate fertiliser takes 40 gigajoules (GJ) and releases the equivalent of 5.29 tonnes of CO_2,[28] which means that the 0.5 million tonnes of nitrogen lost as leachate every year required 20 million GJ to manufacture and emitted the equivalent of 2.65 million tonnes CO_2. In total, the 1.1 million tonnes of nitrogen fertiliser used in the UK required 44 million GJ of energy to manufacture and emitted the equivalent of 5.8 million tonnes CO_2.

The cost of transporting and applying fertiliser requires some assumptions but we estimate that another 1.3 million GJ are required to transport and apply the unused nitrogen, equivalent to another 0.01 million tonnes of CO_2.

Unused reactive nitrogen has been accumulating within our environment for years. The task of assessing and if necessary making safe or removing that nitrogen is the responsibility of the Environment Agency and water companies. In England approximately 29 per cent of all rivers are classified as having nitrate concentrations greater than 30 mg/l with some areas such as the midlands, Anglian and Thames recording concentrations of up to 80 mg/l. Wales, Scotland and Northern Ireland have much lower levels due to less intensive agriculture. In order to meet the EU drinking water limit of 50 mg/l, water companies must either blend high concentration water with lower concentration water or must remove nitrate by ion exchange or reverse osmosis. Both of these processes are expensive to construct and operate: Ofwat has suggested that between 2005 and 2010, English water companies will have to incur capital expenditure of about £300m and annual operating costs of £6m to reduce nitrate levels for the public drinking water supply.

In summary, unused agricultural nitrogen fertiliser that cost £232 million to manufacture also has a significant environmental cost - although the only direct costs are those operating costs borne by the water companies of £6 million per annum.

The fertiliser form of phosphorus is phosphate, of which the UK used 278,000 tonnes in 2004. Phosphates like nitrates are implicated in eutrophication although they are less mobile in soil and therefore less likely to leach. The current best estimate is that 10 per cent of applied phosphates are lost from the soil on an annual basis which assuming an average cost of £150 per tonne for triple super phosphate (or £319 per tonne of phosphate) is £8.9 million pounds wasted.

Phosphate fertilisers are manufactured from mined rock phosphate with an average energy input of 5 GJ per tonne, although this energy input could be offset by subsequent processing into triple super phosphate that can release 3.8 GJ per tonne. However for the purposes of assessing the energy lost within the nutrient cycle we will use 5 GJ per tonne which for 27,800 tonnes is 139,000 GJ or 3320 tonnes of oil equivalent and 10,000 tonnes of carbon dioxide.

However, losses of nutrients and their impact on the environment, be they economic or physical, must be contrasted against the gains: food production. Economically the £241 million cost of unused fertiliser and £55 million that is spent annually in removing it from drinking water is substantial. But is it significant? The farm gate value of UK produced food is £16,000 million so the £296 million bill for waste represents only 1.85 per cent. In many commercial industries that level of waste would be acceptable.

Summing up the leakage in terms of energy is slightly more difficult. The embodied energy contained within UK produced food and animal feedstock's production is estimated to be 548 million GJ, which is over ten times the amount contained within unused fertiliser. Of course there are other energy inputs into agricultural production systems but these figures still illustrate the large gap between input and output.

So there are certainly costs involved in leakages from the UK's nutrient cycles which if considered in isolation appear substantial. However, they should not be considered in isolation but in context of natural biological efficiency and overall food production. The use of nutrients in agricultural production systems and therefore the amounts of these nutrients lost to the environment have been reducing year on year for the last ten years. In that time plant physiology hasn't changed but the total amount of nutrients applied in the UK has dropped from 2.1 million tonnes per annum to 1.8 million tonnes, without any reduction in overall agricultural output.

It is possible that the use of nutrients in agriculture is nearing the point of diminishing returns and that further reductions will only come at the expense of reduced food production and taking vast swathes of land out of agriculture. If we have reached that position and accept that leakages and topping up are a necessary but evil part of food production then perhaps we need to explore different ways of reducing the impact of applied nutrients.

If UK agriculture cannot do without added nutrients then perhaps we need to rethink the form that those nutrients take. What would happen if we didn't use synthesised fertiliser and grew all our food using some of the strategies lifted from organic farming? Synthesised ammonium nitrate, as remarked on earlier, is very energy expensive to produce. So replacing it with low energy alternatives would reduce the energy bill and perhaps diffuse pollution as well. Alternatives do exist, for example, bulky 'natural' materials such as farm yard manures, slurries, composts, sewage sludges and digestates contain plant nutrients and are readily available but have been largely replaced in modern conventional agriculture by more easily handled synthesised granular fertilisers. Although concerns regarding hazards to both health and the environment have been expressed for some of these materials, these are overcome by adhering to existing strict Codes of Practice such as the Safe Sludge Matrix and the new Quality Protocol for Compost.

"the general public would have to accept that the true cost of food is higher than it is now"

If the concerns of the Environment Agency, the major retailers and their customers can be overcome there is no shortage of these natural materials since meeting the demands of the Landfill Directive will ensure that biodegradable organic material which in the past would have been land filled is now available for spreading to land. In terms of overall nutrient supply, a combination of source segregated biodegradable municipal waste, green waste, sewage sludge and farmyard manures could replace all use of manufactured fertilisers. However, a note of caution here. To implement such a complete sea change in agricultural practice would involve not only engaging UK farmers but also government and the general public. Farmers would initially have to bear the increased financial costs of implementing and using new systems but far more importantly, the general public would need to accept the concept of reusing biodegradable organic material as alternatives to synthesised fertiliser and would have to accept that the true cost of food is higher than it is now. However, in the long term, the benefits in terms of improvements to the environment and energy saved could be substantial.

In these days of increasing environmental awareness, ecological footprints, climate change and air miles, the task of reconnecting the general public to food and farming is already underway. Recycling and reusing materials is now part of our everyday lives so extending that concept to the reuse of manures and sewage sludges would seem logical. In the last few years, public opinion has shifted to a point where the green agenda is no longer a minority position, so selling the new fertiliser has already begun although it would take determined government action and the support of the green and environmental groups to make the change possible. However, if we are reduce or replace synthesised fertilisers, reduce our energy demand and close the loop we need to start by overcoming our own prejudices.

Whether food is produced domestically or imported, 'leakages' and 'topping up' are unavoidable components of agricultural systems. Different management strategies in agriculture and UK and European legislation have reduced the impacts and costs over the years, however there is still room for improvement.

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Notes and references

1 Environment Agency, 2004, *Map: Rivers at risk from diffuse source pressures* (*nutrient nitrogen*), available at http://www.environment-agency.gov.uk/commondata/acrobat/r_diff_nitrogen_v1_1008185.pdf

2 Environment Agency, 2004, *Map: Rivers at risk from diffuse source pressures* (*nutrient phosphorus*), available at http://www.environment-agency.gov.uk/commondata/acrobat/r_diff_phos_v1_1008201.pdf

3 Defra, 2002, *Directing the flow: priorities for future water policy*, available at http://www.defra.gov.uk/environment/water/strategy/pdf/directing_the_flow.pdf

4 Ibid.

5 Defra, 2006, *Updating the estimate of the sources of phosphorus in UK waters*, available at http://www2.defra.gov.uk/research/project_data/More.asp?I=WT0701CSF&M=KWS&V=csf&SCOPE=0

6 F.H King, 1911, *Farmers of Forty Centuries or Permanent Agriculture In China, Korea And Japan*, Chapter 9 The Utilisation of Waste.

7 Wallace, P., 2006, *Compost Use in Agriculture*, Enviros Consulting Ltd.

8 Favoino, E. and Hogg, D., 2006, *The potential contribution of Biowaste to tackle climate change: shortcomings of life cycle analysis concerning Biowaste and relevance to policy-making*, Orbit 2006 Proceedings.

9 Bellamy, P., Loveland, P.J., Bradley, I., Murray Lark, R. &. Kirk G.J.D., 2005, *Carbon losses from all soils across England and Wales*, 1978–2003 Nature Vol 437.

10 MacDonald, M A., 2006, *The indirect effects of increased nutrient inputs on birds in the United Kingdom: a review*, RSPB, available at http://www.rspb.org.uk/ourwork/library/reports.asp

11 Kirkham, F.W., Sherwood, A.J., Oakley, J.N. and Fielder, A.G, 1999, *Botanical composition and invertebrate populations in sown grass and wildflower margins*, Aspects of Applied Biology 54 pp291-298.

12 van Wingerden, W.K.R.E., van Kreveld, A.R. and Bongers, W., 1992, *Analysis of species composition of grasshoppers* (Orth., Acrididae) *in natural and fertilised grasslands*, Journal of Applied Entomology 113 pp138-152.

13 Beintema, A.J. 1991, *Insect fauna and grassland birds*. In: Curtis, D.J., Bignal, E.M. and Curtis, M.A. (eds), Birds and pastoral agriculture in Europe. Proceedings of the second European Forum on birds and pastoralism. Port Erin, Isle of Man, 26-30 October 1990. Scottish Chough Study Group: pp 97-101.

14 Green, R.E. and Stowe, T.J., 1993, *The decline of the corncrake Crex crex in Britain and Ireland in relation to habitat change*, Journal of Applied Ecology 30, pp689-695.

15 Donald, P.F., Evans, A.D., Muirhead, L.B., Buckingham, D.L., Kirby, W.B. and Schmitt, S.I.A. 2002. Survival rates, causes of failure and productivity of skylark *Alauda arvensis* nests on lowland farmland. Ibis 144, pp652-664.

16 Shrubb, M., 1990, *Effects of agricultural change on nesting lapwings Vanellus vanellus in England and Wales*. Bird Study 37, pp115-127.

17 Wilson, A.M., Vickery, J.A. and Browne, S.J. 2001, *Numbers and distribution of northern lapwings* Vanellus vanellus *breeding in England and Wales in 1998*, Bird Study 48, pp2-17.

18 Leach, J.M., Johnson, M.G., Kelso, J.R.M., Hartmann, J., Numann, W. and Entz, B. 1977, *Responses of percid fishes and their habitat to eutrophication*, Journal of the Fisheries Research Board of Canada 34, 1964-1971.

19 Crook, C.F., Boar, R.R. and Moss, B., 1983, *The decline of the reedswamp in the Norfolk Broadland: causes, consequences and solutions*, Report to the Broads Authority, Norwich, UK.

20 Allen, D., Mellon, C., Enlander, I. and Watson, G., 2004, *Lough Neagh diving ducks: recent changes in wintering populations*, Irish Birds 7, pp327-336.

21 Herbert, R.A. 1999, *Nitrogen cycling in coastal marine ecosystems*, FEMS Microbiology Reviews 23, pp563-590.

22 Burton, N.H.K., Jones, T.E., Austin, G.E., Watt, G.A., Rehfisch, M.M. and Hutchins, C.J., 2004, *Effects of reductions in organic and nutrient loading on bird populations in estuaries and coastal waters of England Wales. Phase 2 report*, Report by the BTO for English Nature, English Nature Research Report No. 586, English Nature, Peterborough.

23 Thompson, D.B.A., MacDonald, A.J., Marsden, J.H. and Galbraith, C.A., 1995, *Upland heather moorland in Great Britain: a review of international importance, vegetation change and some objectives for nature conservation*, Biological Conservation 71, pp163-178.

24 Brunsting, A.M.H. and Heil, G.W., 1985, *The role of nutrients in the interactions between a herbivorous beetle and some competing plant species in heathlands*, Oikos 44, pp23-26.

25 Lillywhite, R. and Rahn, C., 2005, *Nitrogen UK*, p6, Warwick HRI

26 Dry deposition occurs when a nitrogen compound is removed from the atmosphere by contact with the surface of the land or an aerial-borne particle that subsequently falls to land. Wet deposition occurs when a nitrogen compound is dissolved into water vapour and returned to land as rain.

27 Commercial ammonium nitrate fertiliser contains 34.5 per cent nitrogen. To covert weight of nitrogen to weight of fertiliser multiply by 2.9 or to convert weight of fertiliser to weight of nitrogen, divide by 2.9.

28 Jenssen, T.K. and Kongshaug, G., 2003, *Energy consumption and greenhouse gas emissions in fertiliser production*, The International Fertiliser Society, Proceedings No. 509, 1-28.

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