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Report

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How can farmers keep nutrients out of water?

Tim Stephens

November 2018

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Nuffield (UK) Farming Scholarships Trust Report

Date of report: November 2018

"Leading positive change in agriculture.
Inspiring passion and potential in people."

Title	How can farmers keep nutrients out of water?
Scholar	Tim Stephens
Sponsor	The Studley College Trust
Objectives of Study Tour	**Aim:** To investigate how farmers can be productive and profitable whilst keeping nitrogen and phosphorus out of water. **Objectives:** To find out: 1. What are the most effective farming practices for improving nutrient use efficiency? 2. What are the best ways to boost plant and animal performance through improving soil function? 3. How to overcome the barriers to implementing water stewardship practices. 4. How can farmers be supported in adopting these practices?
Countries Visited	Independent travel over 14 weeks to: *Denmark, France, Ireland, Netherlands, Germany, Australia, New Zealand and the USA (California, Delaware, Iowa, Wisconsin)* Plus: 2 weeks in *Brazil* for the Nuffield Contemporary Scholars Conference in *Brasilia* and post-conference tour to *Mato Grosso*
Messages	• Rising nitrogen and phosphorus concentrations in marine and freshwaters can be reversed not just by de-intensifying productive agricultural systems but by adopting practices and technology which increase nutrient use efficiency and soil health. • Once a farmer knows the nitrogen and phosphorus surplus of each enterprise then it is possible to put into place a plan to reduce it. If they do not do so, then governments, societies and consumers increasingly require them to do this anyway. • Many farmers are yet to realise the full potential of well-managed, fertile soils to hold onto nutrients and increase plant and animal performance. Conservation agriculture practices can build soil carbon and deliver a properly functioning soil, which will benefit the farmer's financial bottom line as well as the environment.

EXECUTIVE SUMMARY

Rising nitrogen and phosphorus concentrations in marine and freshwaters need to be addressed. They can be reversed by adopting farming practices which increase nutrient use efficiency and soil health, not just by de-intensifying productive agricultural systems. The total nutrient surplus generated by fertiliser and manure use on managed agricultural land in the UK remains high at 81kg/ha for nitrogen and 3.9kg/ha for phosphorus (Defra, 2018). There is scope for every farm business to be more efficient through reducing waste across the entire production cycle. If they do not, then further restrictions on nutrient use may be imposed from external sources such as government rules or market pressure. My study shows that there are many available technologies, including precision farming and nutrient recovery systems, to be harnessed to reduce nutrient loss.

These efforts should sit within a regulatory framework which takes the fairest and most proportionate rules from legislative approaches to improving water quality operating in New Zealand, the USA, Ireland, Denmark and the Netherlands. There are also lessons in how to achieve farmer ownership of solutions. Practical support for farmers to reduce nutrient surpluses must come from government, the supply chain, water companies and environmental organisations in the form of more focussed advice, research and training. Agricultural input suppliers could actively take a longer-term view and encourage more efficient use of their products by their farmer clients.

Financial assistance, to address investment, technical or skills gaps, needs to be channelled to farmers for adopting resource efficient farming practices. Funding can come from public and private sources in the form of annual payments, capital grants, loans and tax allowances, while the emerging markets for ecosystem services bringing in extra environmental investment from the private sector should not be ignored. Retailers and processors could, to their own business advantage as well, better reward farmer investment in resource efficient practices. Increasing slurry storage capacity on livestock farms to improve nutrient use and protect water quality is a high priority. Ultimately though it is down to farmers themselves to develop solutions for tackling nutrient enrichment of water and to implement the necessary changes, as groups of farmers in Wisconsin are doing.

All these steps will count for nothing if farmers do not realise the full potential of well-managed, fertile soils to hold onto nutrients, thereby increasing plant and animal performance and protecting water. Agriculture needs to move from nitrogen funded production back to a system which builds and utilises soil carbon. The examples given in this report of farmers in France, Iowa and Australia who are using conservation agriculture practices to build soil carbon demonstrate what a properly functioning soil can really look like, and what it can deliver for farmers, the environment and society.

A multi-species cover crop in Northern Tasmania
– being grown to improve soil, feed cattle, boost biodiversity and retain nutrients

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LIST OF CASE STUDIES IN MAIN REPORT

Case Studies contained in the main report are referred to in **bold text** throughout the report (e.g. see **Case Study 4 in Chapter 6**) and are to be found at the end of the relevant chapter

LIST OF CASE STUDIES IN APPENDIX 6

Case Studies contained in the appendices are referred to in *italic text* throughout the report (e.g. see *Case Study 20 in Appendix 6c*).

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1. Personal Introduction

I live in Dorset with my wife Emily and three children. I grew up on my family's beef and sheep farm in mid-Devon where my brother farms with my parents. Farming has always been my main interest, so it was an easy decision to study agriculture at university after I left school. I undertook a two-year management training programme in the fresh produce industry after I graduated. One of the secondments I enjoyed most was 6 months working with flower growers in south-west Spain to help them meet UK supermarket requirements to implement good agricultural practice around pesticide use. After moving back to the West Country in 2005 I became an agriculture lecturer teaching farm business management and agricultural science at Dorset's land-based further education college, Kingston Maurward. Four years later I became the college's head of department for agriculture, countryside and food. By 2014 I was eager to return to industry in a technical or advisory role. That year, an opportunity arose to work for a regional water company, Wessex Water, who I joined as a catchment advisor.

My main day-to-day responsibility is managing Wessex Water's catchment management programme in groundwater catchments where high and rising nitrate, and occasionally pesticides, threaten drinking water quality. We work with arable and livestock farmers who farm near boreholes, springs and reservoirs to improve the utilisation of key inputs such as fertilisers, manures and pesticides. Our primary aim is to reduce nutrient loss to ground and surface water by keeping more nutrients in the crop and soil. I am also responsible for a project in north Wiltshire which seeks to reduce phosphorus losses from lowland dairy and beef farms to a river which is failing to meet Water Framework Directive standards. As a private business Wessex Water has no regulatory power and we rely solely on farmer goodwill and the economic arguments for minimising waste.

I have always been interested in how intensive farming, which has maximum food production as its primary aim, can be made more efficient. One way is to get better at converting inputs such as nitrogen and phosphorus into outputs like meat, grain and milk. I believe that we need intensive agriculture to feed the growing global population but that most farms could improve their nutrient use efficiency. It seemed logical to put this subject at the heart of my Nuffield study and use the opportunity to travel abroad to find out how farmers in other countries are addressing a universal challenge.

2. Introduction and background to subject

Nitrogen and phosphorus enrichment of freshwater and marine waterbodies is a global issue. Studies by the Defra funded Demonstration Test Catchments programme suggest that the total economic cost of nitrogen pollution to society is estimated to be £100-200 per hectare of lowland farmland in the UK[1]. This figure is associated solely with the loss of fertiliser applied to agricultural land. The algal growth stimulated by these nutrients threatens many different habitats including Poole Harbour in Dorset, pictured in Figure 1 below. Figure 2 illustrates the extent of oxygen depletion in marine waters caused by algal growth. Nutrient enrichment of drinking water can result in expensive and energy intensive treatment processes being installed at water treatment works, as pictured in Figure 3 below.

Figure 1. *Algal mats at low tide in Poole Harbour, Dorset*[2]

The way we use artificial and organic nutrients on the average UK farm is still remarkably inefficient, despite improvements over recent decades. Nutrients which aren't taken up by the crop can accumulate in soil and pollute water. Nitrogen can also be lost to the atmosphere as ammonia. The total nutrient surplus[3] generated by fertiliser and manure use on managed agricultural land in the UK remains high at 81kg/ha for nitrogen and 3.9kg/ha for phosphorus[4]. If all of this surplus nitrogen had been purchased as artificial fertiliser then it would have cost the farmer around £66/ha to buy in. A 100ha farm would therefore spend £6,600 per year on unutilised nitrogen[5].

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[1] **Source:** Written evidence submitted to House of Commons Environmental Audit Committee Nitrate Inquiry by Penny Johnes, Professor of Biogeochemistry, University of Bristol. http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/environmental-audit-committee/nitrate/written/77052.html

[2] **Image credit***:* Douglas Kite, Natural England

[3] "*A nutrient surplus occurs when not all the fertilizers and animal manure applied to the land are absorbed by the plants or removed during harvest*": European Environment Agency definition - https://www.eea.europa.eu/data-and-maps/indicators/nutrient-surpluses

[4] **Source:** Defra (Sept 2018). Soil Nutrient Balances: England Provisional Estimates for 2017. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/740601/soilnutrientbalances-England-14sep18.pdf

[5] Based on December 2018 fertiliser prices from *AHDB UK Fertiliser Price Market Update*, January 2019 report

Over the past 30 years, numerous restrictions have been imposed on how farmers manage nutrients, manure and soil but further reductions in nutrient losses are still needed to solve environmental and drinking water issues. Yet globally we need to increase food production. Domestically we need to ensure food security through the uncertain times ahead of us**.**

The question I have set out to answer in this report is: *To produce high yields of meat, grain and milk, do we need to just accept the loss of valuable soil and nutrients every time it rains*?

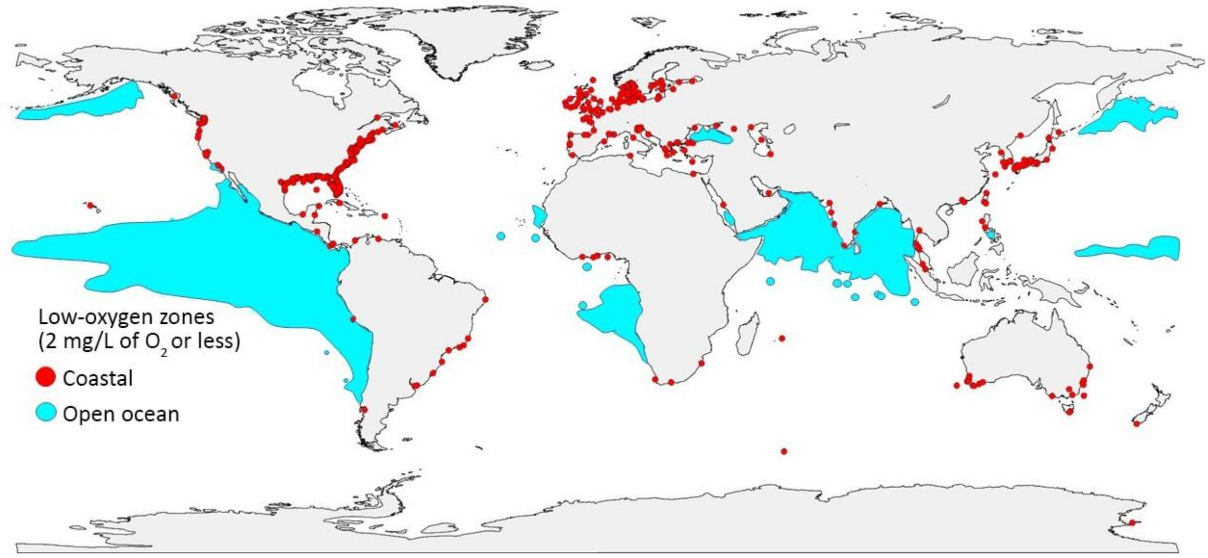


Figure 2. *Low-oxygen zones are spreading around the globe. Red dots mark places on the coast where oxygen has plummeted to 2 milligrams per litre or less, and blue areas mark zones with the same low-oxygen levels in the open ocean. These low levels of oxygen have been exacerbated, or caused, by anthropogenic nutrients such as nitrogen from fertilisers*[6].

Figure 3. *An ion-exchange nitrate removal plant at a water treatment works in Dorset*[7]

[6] **Image credit:** GO2NE working group. Data from World Ocean Atlas 2013 and provided by R. J. Diaz. https://www.si.edu/newsdesk/photos/ocean-deoxygenation-global-map
[7] **Image credit:** Wessex Water

3. My Study Tour – where I went and why

To find out how to balance food production with the need for clean water, I spent a total of 16 weeks visiting 10 different countries, all with intensive agricultural industries that face similar, or even greater, water quality challenges than the UK. The primary focus of this study and report has been on nitrogen and phosphorus loss to water as these are two of the most significant causes of ecological damage and deterioration in drinking water quality. During my travels I have also made efforts to find out how farmers are preventing pesticides, sediment and pathogens like E. coli and cryptosporidium from entering water, and how they are reducing emissions to the atmosphere of pollutants such as ammonia, methane, particulates and carbon dioxide.

I conducted over 180 meetings, interviews and visits, of which approximately half were farm visits. Over this period, I was away from home for 16 weeks, which included 13 weeks of independent travel and 2 weeks in Brazil at the Nuffield International Contemporary Scholars Conference (CSC) in Brasilia followed by a post-conference tour of farms in Mato Grosso. The countries I visited were:

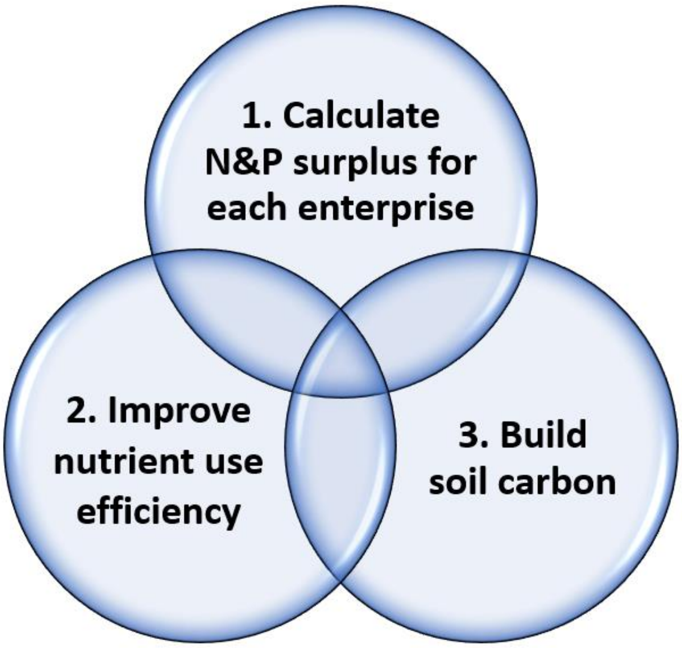
1. Brazil (2 weeks in March 2017 for the Nuffield CSC and post-CSC tour)
2. France (1 ½ weeks in May and November 2017)
3. USA – California, Delaware, Iowa, Wisconsin (4 weeks in September & October 2017, including 3 days at the World Food Prize & Borlaug Dialogue in Des Moines, Iowa)
4. Denmark (1 week in January 2018)
5. New Zealand (2 weeks in February 2018)
6. Australia (2 weeks in February 2018)
7. Ireland (4 days in April 2018)
8. Netherlands (3 days in June 2018)
9. Germany (2 days in June 2018)
10. UK (various meetings, conferences and visits during 2017 & 2018, plus 3 days in London for the pre-CSC briefings)

Figure 4. *Countries visited*

Over the course of my travels, I have concluded that farmers can:

- maintain or even increase yields,
- reduce their production costs, **and**
- reduce the amount of nitrogen (N) and phosphorus (P) lost to the environment

by following three key principles to reduce nutrient loss to water:



Chapters 4 to 6 describe how farmers can put these three principles into practice.

Chapters 7 to 10 set out how farmers can be supported in this effort by different partners including government, researchers, advisors, supply chain partners, environmental organisations and water companies.

Chapter 4. Calculating the nitrogen and phosphorus surplus of each enterprise

Chapter summary:

The nitrogen and phosphorus surplus of the average UK farm remains high and needs to reduce in nutrient sensitive water catchments. Calculating the nutrient surplus of each farm enterprise can help farmers to identify practices which could reduce nutrient loss to water. Growing more without increasing nutrient inputs is vital to improving nutrient utilisation. Circular economy principles can be put into practice through a combination of technological advancements, management changes and soil husbandry improvements.

There are many different key performance indicators currently used for determining production efficiency in agriculture, but the nitrogen (N) and phosphorus (P) surplus of each farm enterprise should also be known by the farmer. This can then be benchmarked against similar farms and measures implemented to reduce these losses. In the UK we have some of the tools and scientific evidence to quantify nutrient loss from farms (e.g. free to access software like Planet and FarmScoper, discussed in Chapter 8), but countries like New Zealand and the Netherlands have given it greater priority - see examples in **Case Study 1** below and *Case Study 22 in Appendix 6d*.

In the Netherlands a key message to farmers seeking to reducing their N and P surplus is to grow more but without increasing nutrient inputs. Whilst in the Netherlands, I met with some of the partners who had been involved with the Vruchtbare Kringloop Achterhook project. This four-year project, 2013-2016, involved 285 farmers. It was a collaborative initiative of farmers' federation LTO Noord, Rabobank, milk co-op FrieslandCampina, the province of Gelderland, drinking water supplier Vitens, water board Waterschap Rijn en Ijssel and the animal feed company ForFarmers. The aim was to improve soil fertility and the quality of ground and surface water by reducing phosphorus and nitrogen losses. This was achieved by modifying dairy cow rations and improving forage crop yields to reduce the N and P surplus in the soil. Average milk yields on participating farms also increased, whilst the cost of disposing of excess manure fell due to increased on-farm use[8]. Wageningen University's Advanced Nutrient Cycling Assessment (ANCA) calculator, a farm management tool that calculates farm N and P surplus, played a vital role. This shows that intensive farming isn't inherently unsustainable, although farms do need to be profitable and well managed to be able to invest in and adopt sustainable practices. Fortunately for the farmer, improving nutrient use efficiency (NUE) can reduce input costs at the same time as reducing emissions to the environment.

In my travels, I found that stocking rates and nutrient inputs may need to reduce in some nutrient loss hotspots, at least on some of the less productive parts of the farm. This could involve growing different crops or changing livestock enterprises. The majority of lowland agricultural production systems in the UK rely on high levels of nutrient input. Consequent high levels of nutrient loss are considered

[8] **Source:** FrieslandCampina Circle Economy discussion paper https://www.circle-economy.com/wp-content/uploads/2016/10/the-circular-dairy-economy.pdf and quote in a personal interview with Carel De Vries, Director of Courage (Dutch dairy industry innovation organisation) on 12th June 2018.

unavoidable but the wide variation in NUE between similar farms shows that most farms could reduce nutrient losses significantly.

Nutrient surpluses can be reduced by putting into practice the circular economy approach set out in **Case Study 2** below. Closed loop nutrient cycles will require increased nutrient recovery and re-use from waste streams like sewage effluent and animal manure. Better and more affordable technology is needed for this (see Chapter 5 for further explanation of nutrient recovery systems).

Most current agricultural systems are too 'leaky' from both farmyard and field. This is illustrated in Figure 5 below.

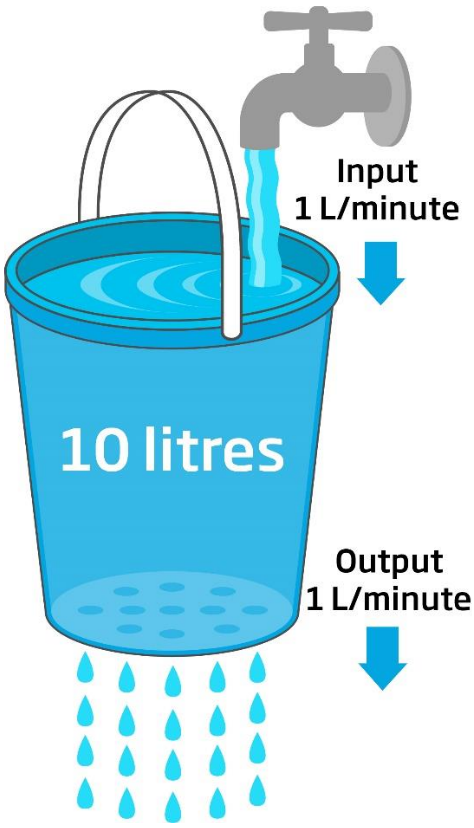


Figure 5. *The 'leaky bucket' model* [9]*. If you plug the leaks, then you also need to turn back the tap to avoid the bucket overflowing. Reducing nitrate leaching works along similar lines – if you plug some of the leaks in the system through measures such as growing over-winter cover crops, then nitrogen inputs must be reduced proportionately, otherwise leaching will not decrease in the long-term.*

Recommendations for farmers to reduce nutrient surplus:

- Find out what the farm's N and P surplus is and put a plan into place to reduce it. Benchmark nutrient surplus and efficiency against similar farms.
- Recognise that in some nutrient loss hotspots overall stocking rates and crop inputs may need to reduce, at least on the less productive parts on the farm. This may involve growing different crops, modifying livestock enterprises and taking the least productive land out of production.

[9] **Image credit:** *Wessex Water*

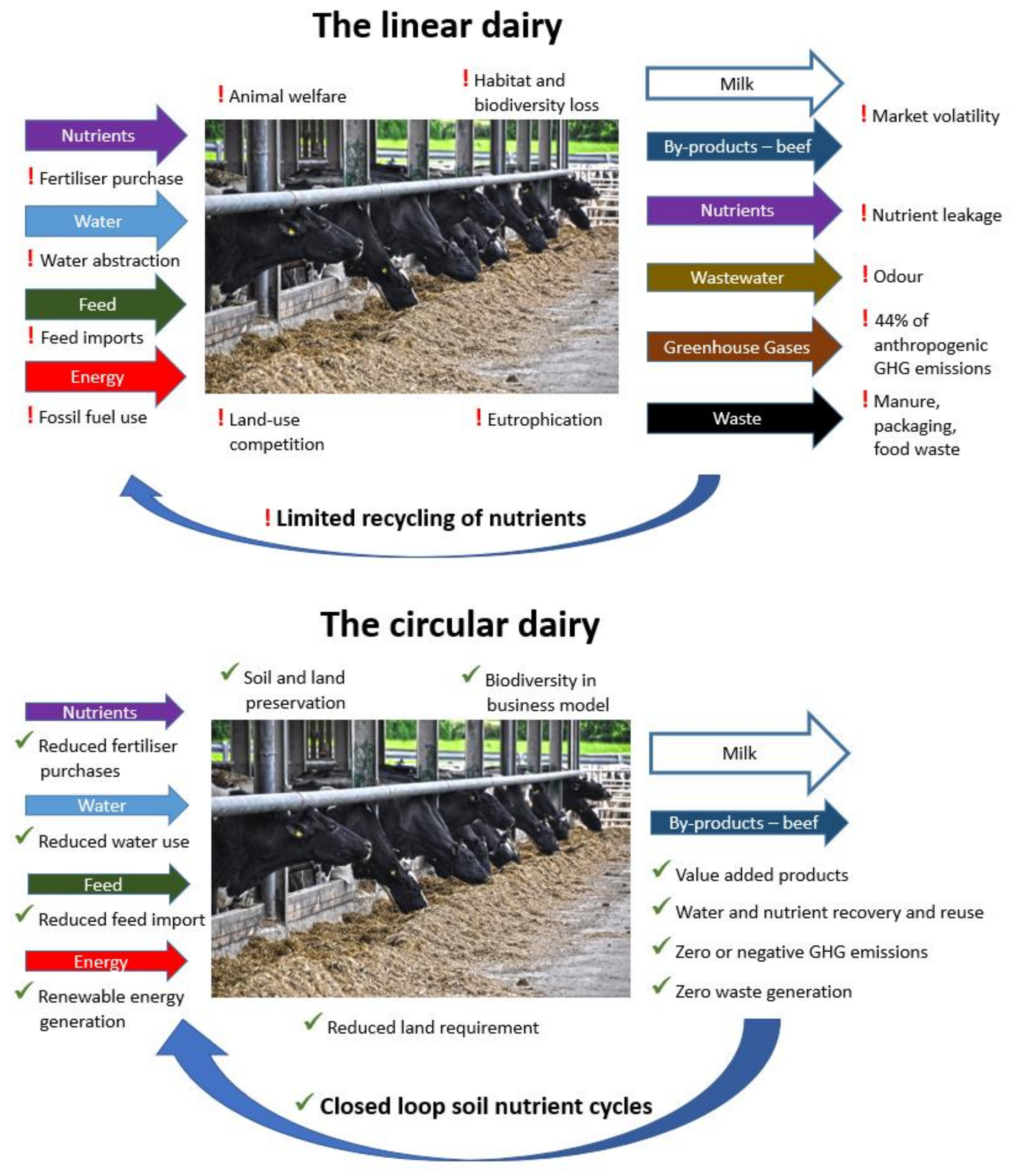
Case Study 1: Sustainability through efficiency: Align Farms, Canterbury Plains, New Zealand

A culture of individual responsibility was evident in staff at all levels of this large farming business with 5 dairy farms and 4,000 cows on the Canterbury Plains. Their Longfield dairy farm has invested heavily in renewing farm infrastructure such as irrigation pivots, buildings, tracks and fencing to maximise efficiency and reduce maintenance and repair costs. Nitrogen losses, as measured by the Overseer tool, have reduced from 56 to 46kgN/ha/yr. They have a target of reducing this further to 40kg. Excessive irrigation increases nitrate leaching so farm staff receive Irrigation NZ training in irrigation system operation and maintenance. Farm managers are given irrigation manager training to ensure they schedule irrigation as accurately as possible and use all available technology like soil moisture sensors to prevent over-irrigation. Other environmental improvements include shelter belt planting with native species and trialling the use of Ecotain, a variety of plantain which reduces nitrate leaching. Fertiliser is spread using GPS equipped spreaders to provide digital application tracking and soils have been grid sampled to enable more targeted application of fertiliser.

Align Farms head of operations Rhys Roberts and farm manager Matt Bell speaking at a field day for Canterbury farmers focussing on farm environment plans. On the right is a Massey University trial plot of a grassland sward containing Ecotain plantain. Trials have shown that Ecotain can reduce nitrate leaching by up to 40%.

Case Study 2: Closed loop nutrient cycles: The Circular Economy in the Netherlands

The diagrams below illustrate the circularity approach at work on a dairy farm, compared to the linear economy which is prevalent on most farms today. This is not a new concept as before concentrated animal feeds and fertiliser became widely available, agriculture was society's original recycler. As technology develops, particularly nutrient recovery systems, agriculture looks set to be even more important to society as a recycler of human wastes as well as animal manures.



*The diagrams above illustrate the linear and circular dairy economies. (**Adapted from:** The Circular Dairy Economy, a report by Circle Economy and Friesland Campina https://www.circle-economy.com/wp-content/uploads/2016/10/the-circular-dairy-economy.pdf). Image credit: © Lewis Clarke (cc-by-sa/2.0).*

Chapter 5. Improving nutrient use efficiency

Chapter summary:

Technology is playing an increasingly central role in improving nutrient use efficiency, but good farm management and soil husbandry are equally important. By following 4R nutrient stewardship principles farmers can reduce the amount of surplus nutrient in the soil which is available to leach or run-off. Adopting a conservation agriculture approach can slow the flow of water through the landscape, and with it soil and nutrients. Farms must be profitable to invest in the skills, infrastructure and technology needed to be sustainable in the long-term. Poor manure management is a major cause of nutrient enrichment in water. Slurry spreading is too often a waste disposal operation, but increased manure storage capacity and adoption of nutrient recovery systems would help farmers to use it more efficiently. Nutrient loss reduction practices relevant to the UK are listed in *Appendix 5*.

Every available method of improving the nutrient use efficiency (NUE) of food production needs to be harnessed (a comprehensive list of nutrient loss reduction practices can be found in *Appendix 5 - Selected practices for preventing agricultural nitrogen and phosphorus losses to water relevant to UK farmers*). There are many ways of doing this, and fortunately new solutions are emerging all the time. Advances in plant and animal breeding, biostimulants and all sorts of precision farming technology can help us grow 'more crop per drop'. Precision farming technologies, like remote sensing and variable rate application, avoid blanket application of crop inputs and can eliminate overlap (see **Case Study 3** below). Feeding a plant is like feeding an animal: little and often is usually better than lots in one go. Automation of field operations using robots will make it easier to match crop nutrient inputs to plant demand in future. Monitoring technology also helps track a wide range of variables such as nutrient levels in crops, soils and manure. High precision GPS guidance makes some conservation agriculture practices like companion cropping and controlled traffic farming much easier to implement.

Biotechnology offers huge potential for improving NUE in both plants and animals. Greater use of 'smarter' fertilisers, micronutrients, biostimulants and inoculants could all reduce N and P inputs. More independent trials of these products would give farmers confidence in their manufacturers' claims.

On my travels I observed that increasing water infiltration across the landscape reduces run-off and minimises the mobilisation of nutrients, which in turn improves water quality. This often involved addressing soil compaction and building soil organic matter levels. Examples of water interception practices (the case studies in *Appendix 6a&b* which are listed here) include the phosphorus detainment bunds featured in *Case Study 17*, landscape engineering projects (like those in Australia featured in *Case Study 18*), agroforestry (see *Case Study 13),* drainage water bioreactors and the saturated buffers described in *Case Study 16*. Another tool used is precision farming technology which can help to identify the 5-10% or so of the lowest yielding parts of the farm. These areas can then be planted with species which can slow the flow of water, and with it soil and nutrients. In the UK, it is an advantage that agri-environment schemes can provide an alternative income stream for this less productive land.

No matter how advanced the technology, I have learnt that the management skills of the farmer remain the key factor in determining nutrient utilisation. The old saying that 'the difference between a good farmer and a bad farmer is a week' holds true in this case. Timing is critical when applying fertiliser and manure.

The way a farm is organised, and limited planning are often the cause of poor water quality. For instance, many water pollution incidents by slurry are caused by lack of planning ahead by the farmer, being caught out by unforeseen weather or communication failure between the farmer and contractor or farm staff. Implementing sustainable practices whilst being profitable requires a higher level of management skill than if food production alone is the priority. The agricultural industry can learn from other sectors like manufacturing, for instance by adopting a more professionalised management approach to process improvement: for example, 'Lean Management[10]' principles for waste minimisation could be adopted on many more farms (see also a New Zealand dairy farm in *Case Study 12 in Appendix 6a*). A key element of this approach is to systematically reduce each of the 8 different kinds of waste listed in Table 1 below. Clear policies and procedures are needed for all farm staff to know what they need to do to protect water quality. Measuring and benchmarking production efficiency can highlight areas for improving NUE.

Defects *Extra work caused by rework, scrap and incorrect / inadequate information*	**Over-production** *Production that is more than needed, or before it is needed*	**Waiting** *Wasted time waiting for the next step in a process*	**Non-utilised talent** *Under-utilising people's talents, skills and knowledge*
Transportation *Unnecessary movement of products and materials*	**Inventory** *Excess products and materials not being processed*	**Motion** *Unnecessary movements by people (e.g. walking)*	**Extra processing** *More work or higher quality than is required by the customer*

Table 1. *The 8 Wastes (easily remembered by the acronym 'DOWNTIME')*[11]

I found that farmers can benefit from high-quality management training on topics like resource management and environmental compliance. At the field level, training of farm staff can improve manure and fertiliser application practices. Some farmers are concerned by over-reliance on the technical advice of the companies which sell farm inputs, and so have their own research and development budget and do more of their own trials (see Practical Farmers of Iowa example in *Case Study 24 in Appendix 6e).* In the UK, when farmers become FACTS qualified themselves they can be more independent, challenge their advisor's advice and discuss alternative options more easily.

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[10] Lean Management is defined by AHDB Dairy as *'a continuous improvement management model used in other industries, adapted and proven to be effective for GB dairy farming. Lean Management has sustainability and profitability at its core, by eliminating and preventing the creation of waste and maximising value from the best use of inputs. Improved profitability is the result, as more product can be produced from the same inputs or the same level of product can be produced from fewer inputs'.* https://dairy.ahdb.org.uk/technical-information/business-management/lean-management/#.XFcoo-RLFPY

[11] **Adapted from:** https://en.m.wikipedia.org/wiki/Lean_Six_Sigma

Across Iowa, farmers are being encouraged by the government and the fertiliser industry to adopt a conservation agriculture approach whenever possible. Cover crops, reduced tillage and grass buffers are all promoted as vital measures for keeping nitrogen out of water. The Iowa Nutrient Reduction Strategy has taken the well-known 4Rs of nutrient stewardship and added some soil health elements to the overall message of applying the *Right type* of fertiliser or manure, at the *Right time*, at the *Right rate* and in the *Right place* (see 4Rplus diagram in Figure 6 below, and *Appendix 3* for the effectiveness of different practices in reducing N and P losses to water in Iowa).

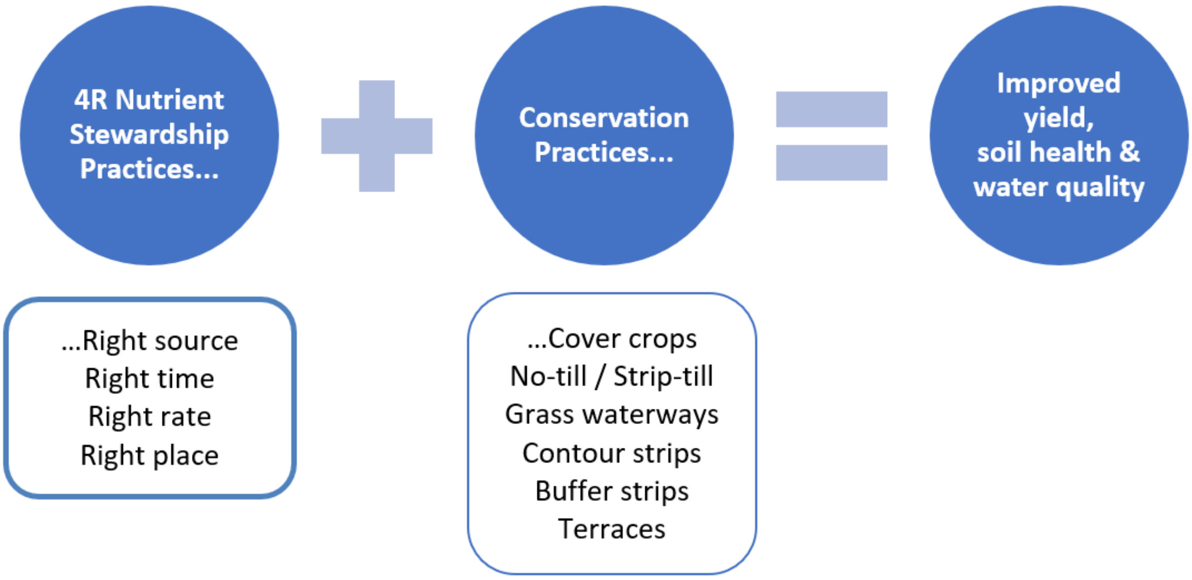


Figure 6. *4Rplus nutrient stewardship practices and examples*[12]

It must be noted that putting the 4Rs into practice can be easier said than done. For instance, when it comes to getting the right timing of manure application, farmers need as much manure storage capacity as possible to allow them to spread at the optimum time for plant growth, typically in the spring. This kind of infrastructure is expensive however, and the investment is not usually rewarded by the markets which farmers sell into. Chapter 7 discusses ways that governments can help farmers to invest in resource efficient farming practices. Farmers can help themselves by getting the basics right, for instance by mending guttering on buildings to reduce manure volume.

Agricultural contractors play a key role as so much manure and fertiliser application is carried out by them. They need confidence if they are to invest in higher capacity, lower ground pressure and more accurate application equipment that can also provide digital records to farmer clients. The Spreadmark fertiliser placement quality assurance scheme in New Zealand is a good example of how agricultural contractors can give clients and regulators confidence that they have used certified spreading machinery, trained operators and an appropriate quality management system when applying fertilisers to farmland.

Manure is a bulky and often dilute product. Technology that can dewater it, or even recover the nutrients it contains, offers great potential but is uneconomic for most farms to invest in at present.

[12] ***Adapted from*** *Agriculture's Clean Water Alliance 4Rplus*
www.acwa-rrws.org/resources/4r-plus-link/

Were nutrient recovery systems to become more affordable and reliable it would allow more farms with an N and P surplus to sell the nutrients in manure as a fertiliser to farms where there is a nutrient deficit. Concentrating nutrients in solid form makes it more economic to export them longer distances and out of sensitive water catchments. A good example of this is a large dairy farm in the US state of Indiana which takes anaerobically digested cattle slurry and passes it through a Trident nutrient recovery system[13]. Coarser manure solids are separated out by a rotary screen after which the remaining liquid undergoes dissolved air filtration, polymer treatment and disc pressing. The liquid element of the separated manure is a dilute 'tea-water' which can be freely irrigated onto fields. The nutrient dense separated solids can be processed further or applied straight to land. Some of the solids are taken to a fertiliser plant where they are combined with conventional mineral fertiliser and then ground into a fine powder so that each granule of fertiliser produced has the same nutrient value. Three different fertiliser products are marketed to the agricultural industry. There are similar examples in other US states where separated manure solids are processed into garden compost. A biological method of treating manure in California is described in *Case Study 15 in Appendix 6a*.

Recommendations for farmers to increase Nutrient Use Efficiency:

- Adopt Lean Management principles for minimising all types of wastage. Set clear policies, procedures and targets for protecting water quality on the farm.
- Find out where the 5-10% most unproductive areas on the farm are and enter them into an agri-environment scheme.
- Source high-quality management training on topics like resource management and environmental compliance. Provide farm staff with formal training in manure and fertiliser application best practice.
- Choose agricultural contractors who have invested in more accurate fertiliser and manure application equipment and can supply digital application records.
- Do your own research, development and on-farm trials. Make use of the help available through initiatives like the UK's Innovative Farmers network.
- Become FACTS qualified and challenge your advisors more.
- Fine-tune arable and grassland crop nutrition by making the most of whatever precision farming technology the business can afford.
- Review farm infrastructure and have a maintenance and investment plan: buildings, yards, drains, tracks, fences, livestock water supplies etc. Repair broken guttering and unblock drains. Slow the flow of water through the landscape to prevent erosion.
- Build more manure storage capacity with the aim of applying all manure in spring and early summer.
- Grow more. Increasing yields to produce more dry matter per hectare from the same inputs will utilise more nitrogen and phosphorus. Double cropping is another way of doing this, as is companion and relay cropping.

[13] *Information gathered via a telephone interview on 27th October 2017 with Carl Ramsey of Prairie's Edge Dairy Farm, Fair Oaks, Indiana

Case Study 3: The application of precision farming technology: Craige and Roz Mackenzie, arable and dairy farmers, Methven, Canterbury Plains, New Zealand

Craige and Roz Mackenzie utilise the full range of technology which their AgriOptics precision farming company offers. More targeted irrigation and fertiliser application is a major focus by using soil moisture sensors, soil mineral nitrogen (SMN) sampling, variable rate irrigation, yield mapping, electromagnetic soil mapping and variable rate application of N, P, K, seed and lime. Combining all these tools with good management and a varied rotation to build organic matter allows Craige to achieve very high yields with high inputs (e.g. 250kgN/ha on spring milling wheat to achieve a yield of 11t/ha). Irrigation helps maintain organic matter by stopping soils from drying out. The main nitrogen fertiliser is urea, but this is only applied just before irrigation or rainfall to prevent atmospheric losses of N. A urease inhibitor is also used. Soils are SMN tested every autumn and going into winter Craige's target is for there to be no residual nitrogen left in the soil. Craige believes that higher yielding crops have bigger root systems and are therefore better able to utilise nutrients.

Even though the farm uses the most up to date technology Craige emphasises that they are decision *support* tools rather than decision *making* tools, i.e. farmers should interpret the information rather than follow them blindly. Craige is growing some Ecotain (a variety of plantain which reduces nitrate leaching from the urine patch) and believes that it has potential to allow dairy farmers to maintain high stocking rates of up to 4 cows per hectare but still meet NZ regional council requirements to reduce nitrate losses by 30% in some areas. Craige has travelled extensively in the UK and his recommendations to British farmers for improving nitrogen utilisation are: (i) do more SMN testing, (ii) apply fertiliser more accurately, (iii) consider growing Ecotain in dairy pastures when it is available in the UK and (iv) use soil moisture and temperature probes to time fertiliser applications, even on unirrigated soils.

Variable rate centre pivot irrigators at Craige and Roz Mackenzie's farm. This is one of many precision farming tools they use to maximise resource use efficiency.

Chapter 6. Building soil carbon

Chapter summary:

We need to move away from over-reliance on purchased inputs and build soil carbon instead. Adopting conservation agriculture principles builds soil organic matter, helps water infiltration, increases soil water holding capacity and improves nutrient cycling and retention in the soil. The basics of soil testing, correcting pH, addressing compaction and improving drainage must not be neglected. Maximising pore space allows soil to hold more air, water and nutrients. Grazing livestock can improve soil, but they need careful management if nutrient overload and soil damage are to be avoided.

The one defining characteristic of all the farmers I visited who were doing great things for water quality was that they were actively managing their soil with the same degree of care and attention that they gave to their crops and livestock. If a soil has enough pore space to hold more air and water in equal quantities and enough earthworms, microbes and organic matter, then it will hold onto the nutrients for us. Less inputs are then needed due to better nutrient cycling in the soil, fertility improves and farms become more resilient to price and weather shocks. Figures 7 and 8, taken in the same field on the same day, just a few metres apart, illustrate what a well-structured soil looks like.

Figure 7. *The photo above shows a soil described as 'massive'. There is very little crumb structure and the soil is just a large dense block with no pore space which restricts air and water movement.*

Figure 8. *This photo shows much better soil structure than in Figure 7. While there is still some blockiness there is also the beginnings of crumb and much better water infiltration.*

Source of pictures and accompanying text: Soil First Farming

Building soil carbon helps to reduce soil compaction and increases the activity of soil biology, particularly earthworms and mycorrhizal fungi, which in turn improve nutrient availability and utilisation by the plant. Where the system is working well a virtuous cycle is created whereby the soil is more and more self-sufficient, and less and less reliant on purchased inputs.

All around the world there are examples of a conservation agriculture approach benefiting water quality (see **Case Studies 4 & 5** below, and *Case Studies 13 & 14 in Appendix 6a*). A key focus for the Iowa farm in Case Study 4 is getting the soil into a state which can cope with rainfall without generating run-off. Rick Bednarek, Iowa Natural Resources Conservation Service (NRCS) State Soil Scientist, believes that there are 5 core principles which underpin a conservation agriculture system[14]:

1. Maximise diversity above and below ground
2. Ensure living roots year-round
3. Little or no soil disturbance
4. Use crop residues as soil armour
5. Integrate livestock if possible

Ensuring that there are living roots year-round is particularly important for water quality. Soils take time to improve so patience is needed before benefits are visible. Longer and more diverse crop rotations are another strategy for reducing nutrient loss. Alternating nitrogen scavenging crops like wheat with nitrogen producing crops like legumes can help to reduce the overall nitrogen surplus across a rotation, as long as fertiliser inputs are adjusted to account for the nitrogen fixed from the atmosphere.

Most farmers need to increase the amount of crop residues that they return to the soil if they are to significantly increase organic matter. Brazilian agronomist John Landers said that the three most important words in a no-till system are: '*residues, residues, residues*'[15] but I believe that this advice extends beyond just no-till arable systems to all types of agriculture.

Companion cropping and agroforestry both offer great potential for improving nutrient cycling, but more independent research and advice would increase uptake of these kinds of practices. This is an example of a subject where organic and conventional farmers can learn from each other. A French organic arable farm with an agroforestry enterprise is featured in *Case Study 13 in Appendix 6a*.

I visited an Australian organic dairy farm which is producing as much dry matter per hectare as the non-organic farms in its benchmarking group do. Terry, Pauline and Brendan Hehir, farming 416ha near Wyuna in Northern Victoria, say that one of the biggest improvements made over the years has been the correction of an imbalance between calcium (Ca) and magnesium (Mg) levels in the soil. Soil trace elements are also monitored and corrected where necessary. Irrigation scheduling is based on soil moisture probe measurements. Installing six of these across the farm was a big investment but better water use efficiency has made it worthwhile. Better targeting of irrigation to where it is needed means that no water leaves the farm through drainage or runoff. Since converting to an organic system, soil organic matter levels have doubled. Despite cutting out phosphorus fertiliser, P indices in the soil have carried on increasing which Terry believes is due to improved biological function releasing

[14] **Source:** Quote by Rick Bednarek when I met him in Iowa October 2017.
[15] **Source:** Quote by John Landers when speaking at the Nuffield International Contemporary Scholars Conference in Brasilia, March 2017.

previously unavailable nutrients. Lime and gypsum are key inputs for improving cation exchange capacity. The farm renews its mixed grass, clover and chicory leys every 4 to 5 years by oversowing with a double disc seeder.

Although being organic does not automatically make a farm more nutrient efficient, some farms in nutrient sensitive areas might consider organic conversion if there is sufficient long-term demand for their produce.

Longer, more diverse rotations and re-introducing livestock to arable rotations all improve soil function. Grazing livestock need careful management to avoid harming soil and water. To prevent nutrient overload and soil damage, it helps if livestock farmers choose rotational grazing over set-stocking and manage outwintering carefully. Back-fencing and allowing the grazed area sufficient recovery time is key. **Case Study 6** below describes the approach that one New Zealand livestock farmer has taken to improve his soil.

Soil testing is a vital but too often overlooked element of improving NUE. Every field should be analysed for pH, P, K, Mg every 3 years but it is useful to also include calcium and micronutrients in the test. As well as following the principles of 4Rplus (discussed in Chapter 4), other basic soil management practices which improve NUE include preventing and addressing soil compaction and ensuring adequate field drainage.

Some farmers improve soil function so that they can use higher inputs to push for higher yields. If the crop is managed well enough to be able to hold onto these extra nutrients, then this strategy can be sustainable, but it is a risky strategy for water quality if the crop doesn't perform.

Recommendations for farmers to build soil carbon:

- Review the crop rotation. Alternate nitrogen scavenging crops like wheat with nitrogen producing crops like legumes. Adjust fertiliser inputs accordingly.
- Get the basics right: follow the 4Rs of nutrient management planning, soil test every field, correct pH, address compaction and invest in drainage.
- Adopt a conservation agriculture approach. Regardless of the type of farm, priority should be given to building organic matter levels and to returning more carbon to the soil than is removed.
- Consider organic conversion if it stacks up financially but remember that being organic does not automatically make a farm more nutrient efficient.
- Plan grazing. Choose rotational grazing over set-stocking. Manage outwintering carefully.

Case Study 4: Maximising diversity: Loran Steinlage, arable farmer, West Union, northeast Iowa

Loran Steinlage is a corn and soybean grower whose soils look like 'black cottage cheese' due to their high organic matter levels and crumb like aggregate structure. Loran has achieved this level of soil quality over several years through a combination of no-till establishment, controlled traffic farming, cover cropping and companion cropping/interseeding. He is now looking to reintroduce livestock (possibly sheep and some beehives). Loran's approach to farming is to continually experiment. He builds or adapts machinery himself whenever possible and has modified his seed-drill many times, especially to be able to interseed and cope with crop residues. Loran has tried many different combinations of interseeded species. Before maize he will grow late-drilled winter-hardy cereal rye cover crops which are planted in bands to avoid having too much bulky biomass to deal with in the spring. When the maize is established he will interseed a range of different cover crop varieties including nitroradish, oil radish, forage rape, ryegrass, buckwheat, chickling vetch, faba bean and red clover. Rye and meadowfoam are interseeded into soybeans. Meadowfoam has a secondary dormancy period so will not germinate until the soil temperature has dropped low enough in the autumn.

No P fertiliser is applied but some K is used. Loran is confident in his soil's ability to hold onto nitrogen, so he is comfortable with using higher rates of N to achieve higher yields. A variable rate nitrogen application system is used. A key focus for the farm is getting the soil into a state which can cope with rainfall without generating run-off. This results in less land being needed for erosion prevention features like grass waterways, contour strips, buffer strips and terracing. Haney and PLFA (Phospholipid Fatty Acid analysis) tests are carried out every June to determine soil nutrient status and health. One improvement which Loran thinks can be made to state rules is to allow surface application of manure in a no-till situation rather than insist on incorporation. He tends not to use advisors as he considers it his job to work out how to farm. Instead, he places great value on his interaction with like-minded farmers and gets a lot of his ideas from this network, either through informal meetings or on Twitter.

Loran Steinlage with the high-organic matter and well-structured soils which result from many years of conservation agriculture on his Iowa farm. Behind him is the residue of the recently harvested maize crop with a multi-species cover crop mix which had been interseeded into it earlier in the season.

Case Study 5: Building organic matter: Grant Sims, arable and beef farmer, northern Victoria, Australia

Conservation agriculture has taken off rapidly in Australia, due in part to its role in improving water retention in the soil. Grant Sims is an example of an arable farmer who is reducing tillage, growing cover crops and introducing cattle to what was previously a stockless rotation.

On his 4,000ha of cropland, Grant uses a NSF 12m no-till drill, a stripper header and a controlled traffic farming system (CTF). He conducted an infiltration test with paint and found that water infiltration was 4 to 5 times better on CTF soils than those that weren't. By paying attention to what goes on underground he tries to view his farm in 3D rather than only considering what happens above ground. One added benefit of CTF is that he uses less fuel because of firmer wheelings. UAN fertiliser is used rather than straight urea but whenever possible he uses biological fertilisers rather than artificial nitrogen. Liquid fertilisers containing calcium and trace elements are used. Nitrogen is also sourced biologically through use of legume companion crops; an example being growing faba beans with oilseed rape. Grant hasn't used any insecticide or fungicide for 10 years. He uses herbicides selectively and avoids anything with a residual effect.

Cattle numbers, an Angus suckler herd, on the farm are rapidly increasing as Grant's approach is to grow as many crops as possible using an appreciating asset (i.e. cattle) rather than use a depreciating asset (i.e. machinery). In a profitable year he prefers to reduce his tax bill by purchasing cattle rather than buying extra machinery. He views cattle as walking composters and they are used as a strategic tool to improve the soil in less productive fields. By feeding baled grass in poorer parts of fields the leftover forage can build organic matter levels rapidly in those areas. Grant works on the principle that rather than leaving stubbles with a C:N ratio of 100:1 between his main crops, he would rather grow a cover crop which can be grazed instead. When fed to a cow this plant material is turned into manure with a C:N of just 15:1. This in turn allows him to reduce nitrogen fertiliser use. Cell grazing is practiced wherever possible. Active soil fungi are measured, and Grant has seen a significant increase in the past 5 years. Earthworm numbers are also high. He also measures the Brix levels of his crops which tells him how much photosynthesis is occurring in the plant. Like many who have adopted a conservation agriculture system, Grant finds that his drill is in use for many more months of the year than it was in the past. In the warm but dry Victorian climate, Grant tries to drill something after every rainfall event. This also helps to spread workload.

Grant Sims and his son with suckler cows in the background. An earthworm in a state of 'estivation' is on the right.

Case Study 6: Holistic grazing strategies: Sam Lang, beef and sheep farm manager, Mangarara Station, Hawkes Bay, New Zealand

Sam co-manages a 450ha effective station which is split into 96 paddocks. Altitude is 300m above sea level. Kiwitech electric fencing and watering equipment is used to temporarily subdivide pastures to better manage pasture recovery, animal intake and impact. Cattle are a mix of Wagyu suckler cows and Angus heifers and there are 700 crossbred ewes bred to Texel rams. The farm system is shifting to supply more Angus heifers to local butchers, so stocking rates were a bit low at the time of visiting. Grazing management is adaptive, and during late spring/summer grass is allowed to grow taller so that some is trampled down by cows, helping keep the soil protected from summer heat and building healthier soil. Future possibilities include damming a valley to create an irrigation pond. This would open up the possibility of growing higher value irrigated crops like kiwi and avocado. Another idea is to create a 'tree-pad' for keeping cattle off pasture during winter, rather than a more typical stand-off pad. A tree-pad is medium density wood where cattle can be kept and fed silage during wet periods.

Sam Lang with some of the cattle and sheep on the Mangarara Station. The farm operates a holistic grazing system which relies on easy to move electric fencing and mobile water troughs.

Chapter 7. The role of government

Chapter summary:

Water quality regulations are based on either restricting nutrient inputs *or* placing limits on nutrient losses. Neither approaches are perfect, and both can have unintended consequences for farm businesses and the environment. Rules should be based on up-to-date and sound science. Financial assistance, to address investment, technical or skills gaps, needs to be channelled to farmers for adopting resource efficient farming practices. Funding can come from public and private sources in the form of annual payments, capital grants, loans and tax allowances, while the emerging markets for ecosystem services bringing in extra environmental investment from the private sector should not be ignored. **Case Studies 7 & 8** (below) & *Case Study 22 (in Appendix 6d)* draw out lessons that the UK could learn from other countries.

Farmers in most of the countries I visited were facing restrictions on how they farm due to nutrient enrichment of water. The Danish government has tightly controlled manure and fertiliser *inputs* for the past 30 years (see *Appendix 1* for evolution of nutrient rules in Denmark). Although the result has been a halving of nitrate concentrations in groundwater without affecting overall agricultural production, the investment which farmers have made to comply has led to high levels of borrowing.

In New Zealand, rather than restricting nutrient inputs and stocking rates directly, there are few limits on farm practice as long as nutrient *losses* are kept below a set limit (see *Case Study 22 in Appendix 6d* for a comparison of water quality rules in New Zealand and Australia).

Both approaches have their merits and flaws. There does need to be a minimum level of regulation to prevent bad practice, but there is such wide variation in how well individual farms manage nutrients and soil that the better run farms should not be held back by the inefficiencies of others. The best results are often achieved through a mix of voluntary and compulsory measures. **Case Studies 7 & 8** below describe how the Republic of Ireland and the State of Delaware try to strike the right balance. Both countries' experience demonstrates that strong political leadership is needed within Government to deliver an integrated approach to policy making across food, farming and the environment. Lessons can be learnt from countries where water quality research is well resourced, as the Irish have done with the Teagasc (the Irish national body providing integrated research, advisory and training services to the agriculture and food industries and rural communities) Agricultural Catchments Programme (see *Case Study 19 in Appendix 6c*). Investment is also needed in the tools which farmers and advisors use to calculate nutrient loss from each field, farm or enterprise (see Chapter 4).

Enforcement of water quality rules should be fair and proportionate. The final report of the 2018 Farm Inspection and Regulation Review[16] suggests several sensible improvements to the current system.

To achieve farmer buy-in to water quality improvement projects, it helps if they feel that non-

[16] **Source:** Farm Inspection and Regulation Review, published by Defra on 13th December 2018: https://www.gov.uk/government/publications/farm-inspection-and-regulation-review

agricultural sources of N and P are also being addressed, for instance urban wastewater treatment works and rural septic tanks (see Chapter 9 for examples).

Governments can improve NUE on farms by offering tax allowances, grants and low-interest loans (see example of Ireland in **Case Study 8** below). These are most needed to incentivise farm infrastructure modernisation and investment in technology. Planning rules can sometimes discourage farm investments that would improve water quality. Government land tenure policy could be updated to allow landlords to take a longer-term view and support their tenants with investing in more sustainable farming practices. Proposed clean air rules to reduce ammonia losses from farms should mostly benefit water quality but will be expensive for farms to implement.

There is an opportunity for governments to be innovative in facilitating third-party investment in the ecosystem services provided by agriculture. The market-based approach can play a part here, for example with payment-for-performance schemes (see example in **Case Study 10** in Chapter 9). Land protection covenants like those offered by the Queen Elizabeth II Trust in New Zealand could have a role in securing permanent land use change in nutrient sensitive catchments in the UK.

Recommendations:

GOVERNMENT INVESTMENT IN RESEARCH:

- Invest in getting the water quality science right. Replicate the Teagasc Agricultural Catchments Programme in the UK.
- Invest in improving farm-level nutrient loss calculators such as FarmScoper.

LEGISLATION AND POLITICAL LEADERSHIP:

- Political leadership is needed to deliver an integrated approach to policy making for food, farming and the environment, as is the case in the Republic of Ireland and Delaware.
- Create legislation that makes it possible for land protection covenants to secure permanent land use change in nutrient sensitive areas.

REGULATION AND FARM INSPECTION:

- The entire farm inspection and regulation system needs reforming.
- Address non-agricultural sources of N and P, e.g. rural septic tanks.
- Planning rules (and landlords) should not discourage investment which would improve water quality.

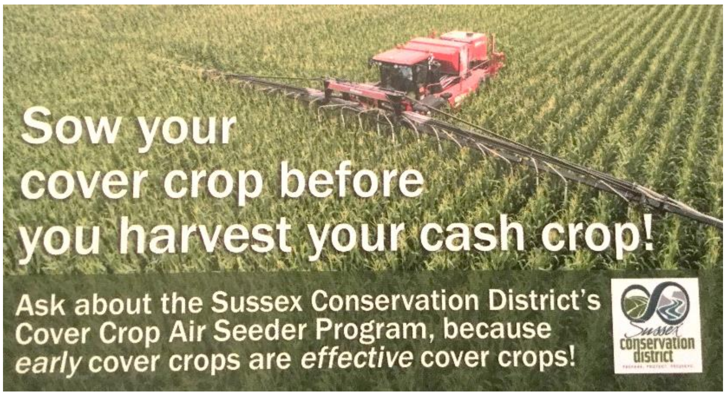
AGRI-ENVIRONMENT SCHEMES AND ADVICE SERVICES:

- Government advice services need integrating, along the lines of Teagasc in the Republic of Ireland.
- Government should incentivise investment in resource efficient practices like manure storage and nutrient recovery systems through tax allowances, capital grants and low-interest loans.
- Government should be innovative in facilitating third-party investment in ecosystem services provided by farms. The market-based approach can play a part here, for example payment-for-performance schemes.

Case Study 7: The State of Delaware Nutrient Program

Each of the six US states which make up the watershed of Chesapeake Bay have adopted their own approach to reducing nutrient loss to the Bay, including how they strike the balance between voluntary and compulsory actions by farmers. Delaware has tried to adopt a pragmatic approach by involving farmers and other stakeholders with the design and administration of the state Nutrient Program. The Nutrient Program Administrator reports to a Nutrient Commission made up of 19 commissioners. Under the rules of the program, farmers are required to complete a Nutrient Management Plan (NMP) and Animal Waste Plan and submit an implementation plan each year showing what was applied to each field. A percentage of these plans are audited by Nutrient Program staff. Farmers and advisors need to be certified as being trained and competent in nutrient management principles and practices.

To assist farmers the state makes cost-share funding available for practices like growing cover crops and exporting manure from farms with a P surplus to farms where there is a deficit. The state also helps with the cost of completing the NMP as many farmers use advisors for this. Funding and advice for water stewardship practices is also available from county conservation districts and NRCS. Good practice is recognised and publicised. The Nutrient Program Administrator ensures that the practices encouraged are evidence based by working with the EPA, academics from the state's land-grant university and the Chesapeake Bay Scientific, Technical and Advisory Committee.



This 'highboy' sprayer has been modified to interseed cover crops into standing maize. It is owned and operated by Sussex County Conservation District (SCCD) who use it to establish over 2,000ha of cover crops for local farmers each summer. SCCD also assist farmers with other environmental improvements such as building poultry manure stores and disposal facilities for dead birds.

Image credit: *Sussex County Conservation District (original photo taken by Edwin Remsburg of SARE)*

Case Study 8: Government and industry in partnership: Republic of Ireland

In Ireland there is a national strategy for the agri-food sector: FoodWise 2025. In 2010, with government support, the industry set itself the target of increasing dairy production by 50% between 2009 and 2020[17]. The industry and government both recognise that although this extra production will increase exports, add value and create employment there are potentially negative consequences for the environment.

The Irish Government and local councils enforce water quality rules through farm inspection. To complement this, Teagasc and some milk processors are partnering to create a network of 30 sustainability officers to target high-risk farms and offer these farmers practical assistance with addressing water quality issues. Independent research and advice to government and farmers is provided by Teagasc, whose Agricultural Catchments Programme (ACP) has collected high-frequency and localised water quality data in six demonstration catchments across the country since 2008 (see *Case Study 19 in Appendix 6c*). Teagasc have also published a roadmap for each farming sector which sets out nutrient utilisation targets such as increasing national N efficiency from 25.2% in 2016 to 26.4% by 2025.

Rules have been tightened for the most intensive businesses by imposing additional requirements on the farms that operate under a derogation from the 170kgN/ha livestock manure limit which is set by the EU Nitrate Directive. The derogation allows farmers to apply up to 250kgN/ha from livestock manures. Due to the relatively small farm size in Ireland, 7,000 dairy farms[18] rely on the derogation to be able to carry enough stock to be viable. The derogation imposes additional restrictions on P inputs (affecting how much P fertiliser a farmer can purchase) and extra record keeping and soil sampling requirements. From 2020 a new rule is being introduced which means that all derogated dairy farms will need to prevent fouled water running off any farm track into a watercourse. Although this system places a higher regulatory burden on those farms with the derogation it does mean that the rules are applied on the basis of risk.

The Irish Farmers Association (IFA) is promoting 'Smart Farming' which demonstrates ways in which farmers can be more efficient and reduce waste, which in turn is good for business and the environment (see *Case Study 23 in Appendix 6e*). Milk-buyers are getting more serious about sustainability and recognising the export value of the clean and green Irish pastoral image. Assurance schemes are working to deliver a competitive advantage to farmers for this effort through Origin Green which is Ireland's national food and drink sustainability programme covering the entire supply chain. The government offers financial support for farm modernisation through grant schemes like TAMS2, although the complex application process and strict building specifications can put some farmers off applying.

A new milking shed with slatted collecting yard above a slurry store being erected in County Cork. A TAMS2 farm modernisation grant helped pay for energy efficient milking equipment and the manure storage element of the project.

[17] **Source:** www.fginsight.com/news/news/irelands-dairy-industry-united-as-it-targets-50-growth-5641
[18] **Source:** Agriland news website 6th Nov 2017: https://www.agriland.ie/farming-news/over-7000-farmers-applied-for-a-nitrates-derogation-in-2017/

Chapter 8. The importance of independent research and advice

Chapter summary:

Improving water quality needs long-term commitment from all stakeholders. To reduce nutrient loss to water farmers need independent and up-to-date research and advice. Local on-farm trials can help to demonstrate how sustainable farming practices can be commercially viable. There is an opportunity for the various farm advisory services to be more integrated. The demand for advice on improving and measuring soil health is growing.

Research

Scientific research is vital to solving water quality problems. Feeding a growing UK population whilst reducing nutrient losses to air and water is a 'Grand Challenge' and should be prioritised as such by government, industry and researchers. Grand Challenges are defined as *'difficult but important problems set by various institutions or professions to encourage solutions or advocate for the application of government or philanthropic funds….and energize not only the scientific and engineering community, but also students, journalists, the public, and their elected representatives, to develop a sense of the possibilities, an appreciation of the risks, and an urgent commitment to accelerate progress'*[19]. They are not a new concept and the Bill and Melinda Gates Foundation has set several grand challenges regarding global health. The UK Government has set them for issues such as clean growth and how to deal with an ageing society but the Grand Challenge of 'more crop per drop' of fertiliser and manure should be added to their list[20].

Nutrient management research in the UK can often be too high-level and overly reliant on corporate funding so more independent on-farm trials would help farmers make the right choices. There is also a gap in agricultural systems research, for instance there are too few independent evaluations of reduced input crop and livestock production systems. Science is lagging behind on-farm practice in the area of soil health, especially in its understanding of how organic matter is built. Other countries have given greater priority to independent research into the economic and environmental benefits of the following topics: breeding animals and plants that utilise nutrients more efficiently, reduced N and P animal diets, the plant microbiome, manure management, soil health, companion cropping, agroforestry, 'smarter' fertilisers, biostimulants and the effectiveness of measures for reducing emissions of N and P (see *Appendix 4* for a full list). Recommended List trials of both forage and arable crops could be modified to measure the NUE of different arable and forage crop varieties.

Maize growers would benefit from more independent research funding, which could be collected though a levy on maize grown (AHDB don't currently collect a levy on maize). The Maize Growers Association in the UK could then be supported to carry out larger scale research into sustainable maize growing practices, like the Foundation for Arable Research does for its farmer members in New Zealand (see *Case Study 21 in Appendix 6c*).

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[19] **Source:** Wikipedia definition https://en.wikipedia.org/wiki/Grand_Challenges
[20] **Source:** https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/industrial-strategy-the-grand-challenges

Environmental science

Farmers need to be able to trust the water quality data that is used to impose restrictions on their farming practices. There are examples of excellent catchment science projects around the world, including the Teagasc Agricultural Catchments Programme in Ireland and the University of Wisconsin Discovery Farms programme (see *Case Studies 19 & 20 in Appendix 6c*).

There are several conclusions which can be drawn from my visits to catchment science projects in places like Chesapeake Bay, Lake Michigan, Denmark and the Netherlands:

- The scale of nutrient loading reduction needed is often considerable. Major changes in agricultural practice at a whole catchment scale may be required to achieve this.
- Water quality science must be comprehensive and robust as some of the decisions made now won't have an effect for several decades. Patience is needed from all interested parties as water quality can take a long time to improve.
- Progress is quicker if all stakeholders can be kept at the table when it comes to developing catchment plans.
- Accurate source apportionment data is necessary to ensure that all causes of nutrient enrichment are tackled, including non-agricultural contributions.
- Farmers prefer to be shown locally relevant water quality information and appreciate help in collecting their own data, so that they know what the nutrient losses are from their own farms.

Current tools available in the UK for estimating the nutrient losses from different farming practices, such as the FarmScoper nutrient loss calculator, need further investment to make them fit-for-purpose. FarmScoper takes too long to use and the accuracy of its nutrient loss estimates is questionable in certain scenarios. Priority should be given by government and researchers to improving tools like FarmScoper to put them on a par with their equivalents in other countries, such as the Overseer tool in New Zealand and the ANCA in the Netherlands. Benchmarking tools like AHDB's FarmBench would be enhanced if they could also compare the nutrient efficiency and nutrient surplus of farm enterprises.

Farm advisors

Farmers can make better nutrient and soil management decisions if they have carried out their own on-farm trials of the sort that the Practical Farmers of Iowa organisation helps its members with (see *Case Study 24 in Appendix 6e*). In the UK, farmers can get assistance with trials through initiatives like the Innovative Farmers network. Farmers learn best from other farmers, so advisors add most value when they facilitate that process rather than try to answer all the questions themselves. Farmers also like to see locally relevant data and examples of water stewardship practices being tried out on nearby farms. The University of Wisconsin Discovery Farms programme is a strong example of this (see *Case Study 20 in Appendix 6c).*

Too many advisors are risk-averse so over-recommend inputs in fear of losing farmer clients due to poor crop or animal performance. Farm business advice is often needed alongside technical advice as so many of the farming practices which will improve water and soil quality require planning and investment to be implemented successfully. There is an increasing demand from farmers for advice on soil health and management. **Case Study 9** below describes a business in Iowa which is helping farmers to measure and improve soil health.

Government advice services need to be more integrated with research and education. This can be achieved by adopting the same model as the Brazilians have with Embrapa and the Irish have with Teagasc (see **Case Study 8** in Chapter 7). As the number of catchment advisors working for UK water companies grows, their role needs professionalising. One way of doing this could be to form an association of catchment advisors and officers which would set out professional standards and provide opportunities for networking and professional development.

Recommendations for farm advisors, research and knowledge transfer organisations:

- Feeding a growing UK population whilst reducing nutrient losses to air and water is a 'Grand Challenge' and should be prioritised as such by government, industry and researchers.
- Greater priority should be given to conducting independent research into fertilisers and manures, and to evaluating the practices which improve soil health and reduce N and P emissions to the environment.
- Agricultural systems research needs prioritisation, for instance evaluation of reduced input crop and livestock production systems.
- Recommended List trials should routinely measure the NUE of different forage and arable crop varieties.
- Update the ADAS *'Diffuse pollution mitigation measures handbook'* and publish it in a wiki form so that it can be updated as new evidence emerges.
- Invest in improving the ADAS FarmScoper model to put it on a par with Overseer (NZ) and ANCA (Netherlands). Benchmarking tools such as AHDB's FarmBench need to compare NUE and nutrient surplus for farm enterprises.
- The levy system needs review to ensure that more support is given to farmers in nutrient loss hotspots. Maize should be included in the levy system to fund research into more sustainable maize growing practices.
- England needs an independent national research, advisory and educational organisation like Teagasc (Republic of Ireland) or Embrapa (Brazil).
- A professional association of catchment advisors and officers should be formed.

Case Study 9: Measuring soil health: Mitchell Hora, Continuum Ag, Washington County, SE Iowa

Continuum Ag LLC is an agriculture consulting and data management company with a focus on soil health which was started by Mitchell Hora in 2016. A range of services are offered to farmer and corporate clients including soil health testing and interpretation, soil/manure/crop tissue sampling, variable rate seed and fertiliser prescriptions, data management, crop scouting, aerial imagery and contract cover crop drilling. Mitchell specialises in repeat soil health testing using methods like the Haney Test developed by Dr Rick Haney, a Texan soil scientist. By carrying out this test several times a year in the same fields, Mitchell can monitor changes in nutrient availability and microbial activity, and how management practices affect these variables. With an understanding of nutrient availability, clients can fine-tune crop inputs and timing of field operations to boost productivity and soil health. There is an increasing interest amongst some US farmers and advisors in carrying out Haney Tests, but their usefulness is limited by a lack of understanding of how to interpret results. Mitchell has developed a method of collating Haney Test data, analysing it and presenting it in a form which farmers can use. Agronomists who take their own soil samples are helped with interpreting Haney Test results.

Mitchell is trialling various other innovative techniques for measuring soil health such as an in-field carbon dioxide sensor for measuring microbial respiration in soil. He feels there is a role for this instrument to help refine nitrogen input recommendations through a better understanding of how soil microbial activity affects the rate at which the nitrogen released by cover crops becomes available. Trace genomics and PLFA tests are also carried out for clients who want to know more about the species composition of their soil microbiota community. One positive outcome for water quality of Mitchell's work is the confidence he can give farmers to reduce fertiliser inputs to maize crops. Traditionally, 1lb of N is applied for every bushel of maize grain yield, but with accurate data on the rate of release of N from cover crops, soybean crop residues and manure applications, farmers can reduce N inputs to 0.7-0.8lbN/bushel of maize yield.

Left – Mitchell Hora standing in a field on his family farm which has had slopes terraced using NRCS grant funding. Terraces reduce the rate of runoff and allow soil particles to settle out. Each terrace has a filter sump at its base to allow water to flow out in a non-erosive manner.

Right - Mitchell Hora with soil health sampling equipment.

Chapter 9. The role of water companies and environmental organisations

Chapter summary:

Water companies and environmental organisations need to support farmers to become more sustainable and can help them raise the funds needed to adopt some of the costlier nutrient stewardship practices. Water companies need to recover more of the nutrients in urban wastewater in a form which can be reused as agricultural fertiliser.

A key element of this study was to find out how water companies around the world are supporting farmers in their efforts to ensure clean water. I also met with some environmental organisations and charities. I was struck by those which, rather than criticising, were instead giving farmers practical advice and funding for reducing nutrient losses to water. One example was the conservation charity Sand County Foundation in Wisconsin which had built strong relationships with local famers to reduce phosphorus losses to the Great Lakes (see **Case Study 10** below). They had developed a 'payment-for-performance' scheme where farmers were paid for every kilo of phosphorus they prevented from entering the river.

Maize growing in the UK is an example of a farming practice which could be made more sustainable but is unfairly criticised by the green lobby. Environmental groups need to work with farmers on improving certain practices rather than campaigning to have them banned. The Clean Lakes Alliance in Wisconsin is an example of a partnership of diverse stakeholders which raises awareness of water quality issues in the lakes, streams and wetlands surrounding Madison, the state capital. It also raises funds to clean and protect the lakes, and some of this funding is made available to farmers (like the Yahara Pride Farms group described in **Case Study 11** in Chapter 10) to support their efforts to ensure clean water. This is a prime example of environmentalists and farmers working together to achieve a common goal.

To achieve truly clean waterbodies, we need to look beyond just farming. Water companies need to invest in more advanced nutrient recovery systems so that more of the nutrients which humans consume and excrete can be reused as agricultural fertiliser. A good example of this is the Middletown municipal wastewater treatment works that I visited in the US state of Delaware which has invested in a tertiary sewage treatment process. Tertiary treatment involves aeration, screening and polymer treatment. The wastewater (pictured in Figure 9) is also chlorinated to kill any pathogens. Rather than the treated effluent being discharged into the environment, the enhanced treatment process means that the effluent is safe enough to be irrigated onto 160ha of a local arable farmer's maize crops. A benefit to the farm is that they now abstract up to 2.3 million litres per year less irrigation water from boreholes. The effluent also supplies 10-15% of the maize crop's nitrogen needs. The farmer decides when he wants the water and orders it accordingly. When he doesn't need to irrigate, the town is able to irrigate onto their own grassland and sports fields, or store the effluent in their own lagoons.

The Dutch have created a 'Phosphate Value Chain Agreement' to increase the recovery and reuse of phosphorus from human and animal waste streams. This initiative recognises that there are opportunities for water companies and farmers to work together at all stages of the nutrient cycle and achieve a circular, zero-waste economy. New revenue streams for farms are also emerging as water companies develop schemes to offset nutrient discharges in wastewater by funding farmers to reduce the nutrient losses from agriculture.

Figure 9. *A sample of treated wastewater at the Middletown treatment works. This is ready to be irrigated onto a local farmer's maize crop.*

Recommendations:

- Recycle to farmland more of the N and P in sewage effluent which is currently discharged to rivers.
- Environmental organisations should offer practical support to farmers and help raise funding for farmer-led efforts to improve water quality. Overseas examples that could be replicated in the UK are the Clean Lakes Alliance and the Sand County Foundation in Wisconsin.

Case Study 10: Environmental organisations giving farmers practical support: Sand County Foundation (SCF) and The Nature Conservancy in the USA

SCF was established in 1967 to advance the conservation ideas of Aldo Leopold, author of a highly influential conservation book called 'A Sand County Almanac'. SCF works with private landowners across the USA on soil, water and habitat conservation projects. It runs several projects to improve water quality on private farmland. One example is a prairie strips project which is helping farmers in south-east Wisconsin install strips of diverse native perennial vegetation within row crop fields. These strips capture sediment and nutrients in field runoff, while also providing habitat for pollinators and birds. It has other projects including spreading gypsum for phosphorus runoff reduction, restoration of oxbows and installation of bioreactors and other drainage water management structures. In each of fourteen states, SCF awards the annual $10,000 Leopold Conservation Award to landowners who are actively committed to a land ethic.

SCF offers practical solutions to the conservation challenges presented by modern agriculture and recognises that farmers need to be able to make a living from their land. It is trialling a pay-for-performance approach to distributing limited conservation programme funding: *'Instead of paying* *for specific farm practices, such as cover crops and riparian buffers, it calculates farmer payments based on the net environmental improvement'*[21]. SCF worked on a project supported by the Great Lakes Protection Fund to offset nutrient discharges from wastewater treatment by using the pay-for-performance approach to invest in agricultural phosphorus runoff reductions upstream of the Milwaukee Metropolitan Sewerage District. Participating farmers are paid $25 per pound of P runoff reduction, as measured by a University of Wisconsin model called SnapPlus. One farmer was able to reduce P runoff by 280lb through a combination of measures which include growing cover crops, switching from chisel ploughing to vertical tillage, managing his alfalfa differently and introducing wheat into a mostly maize rotation.

SCF Field Projects Director Greg Olson and Program Director Craig Ficenec standing in a prairie strip sown with diverse perennial native vegetation which has been funded by the foundation. Greg carries out water quality monitoring to study the impact of the different conservation practices which SCF promote.

The Nature Conservancy (TNC) is another US charity which is offering farmers practical support with nutrient management improvement. In the Lake Erie watershed of the Mid-West, TNC is working with partners including ag retailers (fertiliser merchants) to promote a voluntary 4R Nutrient Stewardship Program. The goal of the program is to educate agriculture professionals such as ag retailer field staff in the principles of 4R. These 'nutrient service providers' agree to become certified which involves *'meeting 41 benchmarks over 3 years including the creation of digital field boundary maps that identify sensitive features, soil tests and yield maps as well as the provision of on-farm data showing improvement of crop yield without increased risk to water quality'*[22].

[21] **Source:** Sand County Foundation: https://sandcountyfoundation.org/our-work/soil-and-water-conservation/pay-for-performance
[22] **Source:** The Nature Conservancy: www.nature.org/ourinitiatives/regions/northamerica/areas/greatlakes

Chapter 10. The role of farmers and their representatives

Chapter summary:

Consumer demand for food produced with a reduced environmental footprint is growing but the 'green bar' is rising constantly and what is best practice today will be standard practice tomorrow. Agricultural industry efforts to do the right thing for the environment need greater communication to consumers. Farm environment awards are one way of doing this. To address water quality issues at a catchment scale farmers need to work together to present a united front. This requires the support of the whole supply chain, from farm input suppliers right through to supermarket retailers. The farming industry needs to be more pro-active and ambitious in setting itself sustainability targets.

Leadership and recognition of good practice

An inspiring example of farmers joining together to take ownership of water quality issues and solutions is a group of dairy farmers in Wisconsin called Peninsula Pride Farms (see **Case Study 11** below). This approach allows farmers to present a united front and attract third party funding from public and private sources to help them implement some of the costlier nutrient management practices. Initiatives like this demonstrate the value to farmers of being proactive in finding solutions to water quality challenges rather than waiting until they are compelled to do so.

The agricultural industry's efforts to improve water quality could be communicated to consumers more effectively. One way of doing this is shown by the Ballance Farm Environment Awards which are run by the New Zealand Farm Environment Trust. Not only do the awards celebrate and recognise the efforts of farmers to do the right thing for the environment, but they are also effective in raising public awareness of farmer efforts to protect water.

Water quality improvement often needs farmers to go beyond the legal minimum and take full advantage of the help on offer for implementing the necessary measures. Easy wins, those which most farmers can adopt without significant investment or system change, include reducing the N and P content of animal diets, putting the least productive 5-10% of land into agri-environment schemes, avoiding bare soil over-winter and addressing soil compaction. Lessons which UK landlords could learn from abroad include requiring higher standards of soil management and farm infrastructure maintenance by tenants. Examples include writing minimum soil organic matter and fertility levels into tenancy agreements and requiring maintenance of building guttering and field drainage systems.

The farming industry could demonstrate greater leadership in the search for solutions to environmental challenges. To counter misrepresentation of some environmental issues by the green lobby, more thought leadership could come from the organisations who represent mainstream agriculture. This could be provided by an organisation like the Australian Farm Institute[23]. Industry organisations like the Irish Farmers Association are proactive in promoting and supporting resource efficient farming, for instance through their Smart Farming programme (described in *Case Study 23 in*

[23] The Australian Farm Institute is an independent institute researching policy issues that affect Australian agriculture. www.farminstitute.org.au

Appendix 6e). The Irish dairy industry provides a strong example of collaboration right along the supply chain through its creation of the Dairy Sustainability Ireland initiative.

Progress towards achieving water quality improvement targets would be faster with more ambitious sustainability roadmaps for each farming sector. The industry needs to set itself more stretching soil and nutrient management targets if government and consumers are to have confidence that sufficient effort is being made to reduce nutrient losses to water.

Organisations from across the intensive livestock sectors could collaborate to establish an equivalent of 'Newtrient'[24]. This is an independent organisation in the USA set up to independently evaluate all available nutrient recovery systems and attempt to verify their manufacturers claims.

The economics of improving water quality

Sustainable farming practices are good business. Consumer demand for food produced with a reduced environmental footprint is growing. The vegetable growing business pictured in Figure 10 has switched to growing broccoli using strip-till establishment rather than the more traditional and costly heavy cultivation method, which can lead to nitrate leaching and soil erosion. The route to higher farm net margins is through adding value not volume: selling higher value farm products rather than just producing more. Around the world the 'green bar' is rising constantly and what is best practice today will be standard practice tomorrow (the 'green bar' refers to how sustainable consumers expect food production systems to be).

Figure 10. *Strip-till broccoli growing in northern Tasmania. An example of how a high-value crop can be grown at lower cost and in a more sustainable manner.*

Less productive parts of many fields are often more profitable when entered into an environmental stewardship scheme. An example of this is shown in Figures 11 and 12. Adoption of environmental stewardship practices can also be used as evidence of corporate and social responsibility. An example of this is contained in *Appendix 2* where there is a list of the sustainability targets that Ingleby Farms & Forests, a large international farming business whose dairy farm in Tasmania I visited, sets itself.

[24] **Source:** Newtrient LLC - http://www.newtrient.com

All members of the food supply chain (e.g. agricultural input suppliers, farmers, food processors/manufacturers and retailers) need to resist the urge to 'greenwash'. Greenwashing is defined by the Cambridge Dictionary as *"making people believe that your company is doing more to protect the environment than it really is"*[25]. It is possible to secure a competitive advantage in the market by going beyond legal minimum production standards and demonstrating real commitment to reducing nutrient loss to water.

Some US agricultural input suppliers in the feed and fertiliser sectors are taking a longer-term view and encouraging more efficient use of their products: for example, the fertiliser industry in Iowa does this by supporting the 4Rplus nutrient stewardship initiative described in Chapter 5. Other examples include carrying out soil health tests for farmers, reviewing N and P contents of animal diets and providing benchmarking services to clients. **Case Study 10** in Chapter 9 highlights the partnership between the fertiliser industry in the Midwest USA and The Nature Conservancy, a conservation charity. Good farm practice can be spread when it is recognised and rewarded by the market and by all those who benefit from improved water quality: food processors and retailers increasingly demand evidence of sustainability from their suppliers, but they need to reward farmers for investing in resource efficient practices.

Many of the countries which are making concerted efforts to improve water quality have also realised that the economic benefits of sustainable farming go beyond the farm gate. The jobs created drilling cover crops and constructing wetlands are a good example, as is an increase in rural tourism.

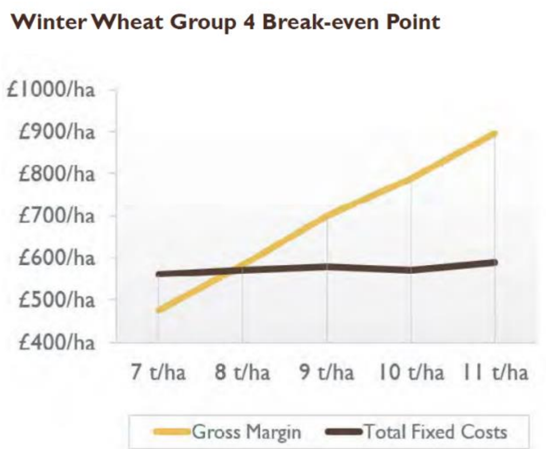

Figure 11. *Group 4 winter wheat breakeven point*

Image credit: *CEH / Wildlife Farming Company*[26]. *The graph shows that the typical breakeven point for a crop of winter feed wheat is a yield of 8-9t/ha. With the yield-mapping technology now available to farmers it should be relatively simple to identify field areas consistently averaging less than this and enter them into agri-environment schemes.*

Figure 12*. A recurring wet spot in an arable field. This part of the field would be more profitable as wildlife habitat, possibly a constructed wetland. Arable field wet spots like this are a direct route for nutrients and pesticides to enter watercourses.*

[25] **Source:** https://dictionary.cambridge.org/dictionary/english

[26] **Source:** Nowakowski, M. & Pywell, R. (2016). *Habitat Creation & Management for Pollinators.* Wildlife Farming Company and Centre for Ecology & Hydrology (**Image credit**: Paul Pickford)

Recommendations for the wider agricultural industry:

- Communicate what farmers are doing to improve water quality to the public.
- Replicate the New Zealand Farm Environment Trust Awards to raise the profile of farmer efforts to protect water and to encourage other farmers to make the necessary changes.
- The organisations which represent farmers need to demonstrate greater leadership in developing solutions to water quality challenges.
- Promote and support resource efficient farming. For example, the NFU could replicate the Irish Farmers Association Smart Farming programme.
- Sustainability roadmaps for farming sectors need to set more ambitious targets regarding soil and nutrient management, which go beyond just complying with existing regulations.
- In catchments where farming practices are under scrutiny for their role in water quality deterioration, farmers should collaborate to develop and implement voluntary actions before they are made compulsory.
- More thought leadership on sustainability is needed from the organisations which represent mainstream agriculture to match that coming from environmental lobbyists. This could be provided by an organisation like the Australian Farm Institute.
- Landlords should require higher standards of soil management and farm infrastructure maintenance by tenants. Examples could be writing minimum soil organic matter and fertility levels into tenancy agreements and enforcing maintenance of guttering and field drainage systems.
- Organisations from across the intensive livestock sectors should collaborate to establish an equivalent of ‘Newtrient’ (an independent organisation in the USA set up to independently evaluate all the available nutrient recovery systems and verify their manufacturers claims).

Recommendations for the supply chain:

- All parts of the supply chain need to go beyond the legal minimum and demonstrate real commitment to reducing nutrient loss to water.
- Retailers and processors need to find better ways of rewarding farmers for investment in resource efficient practices.
- Agricultural input suppliers in the feed and fertiliser sectors need to take a longer-term view and encourage more efficient use of their products.
- All parts of the food supply chain, particularly farmers, water companies and fertiliser manufacturers, should commit to recovering and using more phosphorus from waste streams, as the Dutch have done with their ‘Phosphate Value Chain Agreement’.

Case Study 11: Farmer-led change: Peninsula Pride Farms (PPF) and Yahara Pride Farms (YPF), Wisconsin

PPF and YPF are farmer-led, not-for-profit organisations working to improve soil and water quality in Wisconsin. YPF members farm in the Yahara watershed which surrounds the state capital, Madison. PPF members farm in Kewaunee and Door Counties in the northeast of the state. YPF began in 2011 and grew to 72 members in 2 years. PPF, which formed in 2016, has 50 members. This represents half of the cows and tillable acres in the PPF area. The groups were formed in response to criticism of farmers for their role in eutrophication of lakes or contamination of groundwater with nitrate and pathogens. PPF run a programme called Water Well which ensures clean water for rural residents with private boreholes who are at risk of getting ill from E. coli. PPF pays for bottled water, a well inspection for these homeowners and helps with the costs of a water treatment system and its servicing costs. Funding is available regardless of whether the source of the E. coli is human, bovine or other.

Both groups pilot and showcase ways of keeping N and P out of the water through better manure and nutrient management. They work with agronomists and university scientists to collect data to help understand where water quality issues are coming from and what the most effective nutrient loss reduction practices are. YPF and PPF both have cost-share programmes for funding cover crops. To access these funds, YPF have implemented a Farm Certification Program that recognises farmers for good stewardship and makes recommendations for correcting conservation weaknesses. Support is offered to those who don't meet the certification standard. In 2017 YPF members collectively reduced 8.5t of P from entering watercourses. Their annual phosphorus report describes how this was achieved[27]. Practices such as low-disturbance manure injection, strip-tillage, headland stacking of manure and manure composting are also incentivised by YPF. In 2018 PPF offered cost-share programs to its members for establishing cover crops and harvestable buffers, splitting applications of nitrogen and carrying out depth of soil to bedrock testing.


Left - Don Niles, Chairman of PPF (second from left) with fellow directors Tony Brey and Nathan Nysse meeting a local newspaper editor to communicate the water stewardship efforts of their members.
Right - Low-disturbance manure injection into alfalfa being demonstrated at a YPF field day which was organised in partnership with local government agencies and the University of Wisconsin extension service.

[27] **Source:** Yahara Pride Farms 2017 Phosphorus Reduction Report: http://www.yaharapridefarms.org/phosphorus-reduction-report/

11. Conclusions

There are many challenges which farmers face in reducing nutrient losses to water. However, rising nitrogen and phosphorus concentrations in water are harming natural habitats and causing a deterioration in drinking water quality. Looking at experience across the various countries I visited, there are three key messages for farmers seeking to reduce nutrient losses to water:

1. Calculate the N and P surplus for each farm enterprise
2. Improve nutrient use efficiency
3. Build soil carbon

There are new, some still emerging, technologies which will improve nutrient stewardship. For instance, nutrient recovery systems for manure and precision farming both hold great potential. Improvements in farm infrastructure, such as increasing manure storage capacity, can increase effective use of nutrients.

Farmers cannot do it alone. They need the support of a range of different stakeholders, both public and private, to achieve water quality improvement targets because of cost and adverse market forces. Governments need to enforce water quality rules fairly and proportionately, but farmers need to take ownership of water quality issues and solutions. Further research and better tools for measuring nutrient loss to water are needed. Financial assistance is needed to support some of the costlier to implement nutrient stewardship practices. The market needs to recognise the costs and the benefits to all and incentivise farming sector actions which will improve the environment.

Productive and profitable farming **is** compatible with clean water, but a change of mindset and farm management is required in many cases. I don't think that most UK farmers are managing their soils badly. I do think that many of them under-estimate just how much better their soils could be, were they to move away from a system which is funded mostly by nitrogen inputs to one that is fuelled by soil carbon instead.

***Figure 14**. **Make Soil Great Again** - T-Shirts and a baseball cap from Iowa. Getting the soils message across.*

12. After my Study Tour

After my Nuffield study I will continue working with farmers to implement the three key steps I have outlined in this report. I also want to help farmers to get rewarded for providing public goods like clean water, whether that be through persuading customers to pay more for sustainably produced food, or by helping farmers to value and sell eco-system services like clean water.

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References

References are given throughout the report as footnotes.

Appendices

Appendix 1. Evolution of Danish water quality rules since 1985

The major Danish nitrate (N) policy measures implemented over the past three decades with the Danish action plans (AP) in 1985 (NPo), 1987 (AP-1), 1991 (AP for a more sustainable agriculture), 1998 (AP-II), 2001 (ammonia AP), 2004 (AP-III), 2009 (Green Growth AP) and 2016 (Food and agriculture package AP) (updated from Dalgaard et al.32).

Year	Nitrogen measures imposed	Nitrogen measures abandoned
1985	• Max. stock density • Mandatory slurry tank floating barriers • No runoff from silage clamps and manure heaps • Min. slurry storage capacity and ban on winter spreading of slurry for spring crops	
1987	• Mandatory fertiliser and crop rotation plans • Min. proportion of area with winter crops • Mandatory manure incorporation within 12 hours	
1991	• Statutory limits for fertiliser N application to specific crops • Max. N applied to crops equalling *economic optimum* • Subsidies for low-N grasslands in environmentally sensitive areas	
1998	• Max. N applied *10% below economic optimum* • 6% obligatory cover/catch crops • Subsidies for more organic farming, wetlands, extensification and afforestation • Site-specific groundwater protection zones	
2001	• Promotion of low nutrient excretion livestock feeding	
2004	• More cover/catch crops • Tightened ammonia restrictions (e.g. broadcasting banned), and special restrictions near sensitive nature areas • Subsidies to promote better manure handling and animal housing	
2009	• 10m buffer zones around streams, lakes and sensitive habitats • Max. N applied *15% below economic optimum* • Promotion of optimised animal feeding practices	
2016	• Less national N regulation, but more spatially differentiated N regulation with locally targeted measures. e.g. constructed wetlands and additional cover/catch crops	• Compulsory 10m buffer zones reduced to 2m • Max. N applied *15% below economic optimum* rule changed back to *economic optimum*

Source: Adapted from Journal of Nature - Groundwater nitrate response to sustainable nitrogen management. B. Hansen et al. Published:17 August 2017 https://www.nature.com/articles/s41598-017-07147-2 (licensed for reuse under a Creative Commons License http://creativecommons.org/licenses/by/4.0/).

Appendix 2. The 14 Ingleby Goals from the Ingleby Guidelines

"The 'Green Bible' contains all the rules and regulations that we follow to become better farmers. It describes what we must do to care for our land and our animals in an optimum way, as well as how we should protect the environment and wildlife that live on our farms and the communities in which we farm" (quote from The Ingleby Guidelines http://inglebyfarms.com/publications/)

1. IMPROVE ANNUAL KEY PRODUCTION AND EFFICIENCY METRICS BY 1 - 2%
In a 10-year-spectrum, we want to increase our key crop production metrics by 1% per year, i.e. improving yields, as well as nutrient and water use efficiency. Furthermore, we want to increase energy use efficiency by 2% per year. While supporting financial results, this will also benefit the environment and climate.

2. BUILD TOP SOIL BY 2 MM PER YEAR
It is our constant goal to grow the top soil layer by 2 mm per year. Crops respond positively to soil with good structure, high water holding and cation exchange capacity. The better and deeper the top soil, the larger an area for the plant roots to find water and nutrients, and the stronger the crop.

3. KEEP AND PLANT SOLITARY TREES IN THE LANDSCAPE
We keep and plant solitary trees in the landscape to let them become a general characteristic of our farms. If possible, we plant them where they historically stood.

4. SPEND 2% OF YEARLY WORKING HOURS ON TRAINING
Training is important to keep our farm teams updated and motivated. Our goal is that 2% of yearly working hours is spent on training. This approximately equals one week of training per full-time team member per year. The goal of 2% training is an average for the whole farm team, and not an individual goal.

5. ESTABLISH 10 METRE BUFFER STRIPS ALONG ALL MAJOR STREAMS, RIVERS AND LAKES
We create non-cultivated and unsprayed buffer zones of 10 metres around water bodies. These help diminish nutrient leaching and pesticide run-off into the water. Buffer strips are best planted in locally sourced, native meadow seeds. They can be cut late in the season in a varied mosaic, every 1, 2, 3 or 4 years.

6. PLANT NATURAL, NATIVE GRASS WATERWAYS IN EROSION-PRONE AREAS
We plant belts of permanent grass in low parts of the fields where water runs during wet conditions. The grass waterways channel excess water to larger waterways and help reduce water velocity and the risk of erosion. Grass waterways are best planted and cut in a similar way as described under goal 5.

7. NO MECHANICAL SOIL TREATMENT ON EROSION-PRONE SLOPES
We keep erosion prone slopes under permanent grass/plantings to avoid erosion. These areas can be left for natural regeneration or planted in native species.

8. CONTOUR CULTIVATION IN STEEP AREAS
To avoid erosion, we never cultivate fields straight up and down the hills. Instead we cultivate along the contours.

9. PROMOTE A "SCRUFFY" LOOK IN THE OPEN LANDSCAPE
We avoid designing landscapes with manicured lawns and plantings in neat patterns. Instead we leave grass uncut and aim for a natural look. Also, we leave standing and lying dead wood, as they are important habitats.

10. GROW A MIX OF INSECT/BEE PLANTS ON THE FARM
We grow a mixture of plants that blossom at different times of the season to provide pollen and nectar forage for bees and other insects. We recommend permanent plants. This way we ensure feed for our pollinators throughout the season.

11. DEVELOP WELCOMING AVENUES ALONG FARM MAIN DRIVEWAYS
We want to provide a welcoming atmosphere when you enter our farms. Over time an avenue develops into a characteristic landscape element. Avenues are always two rows of trees and must be planted with high quality, hard wood species.

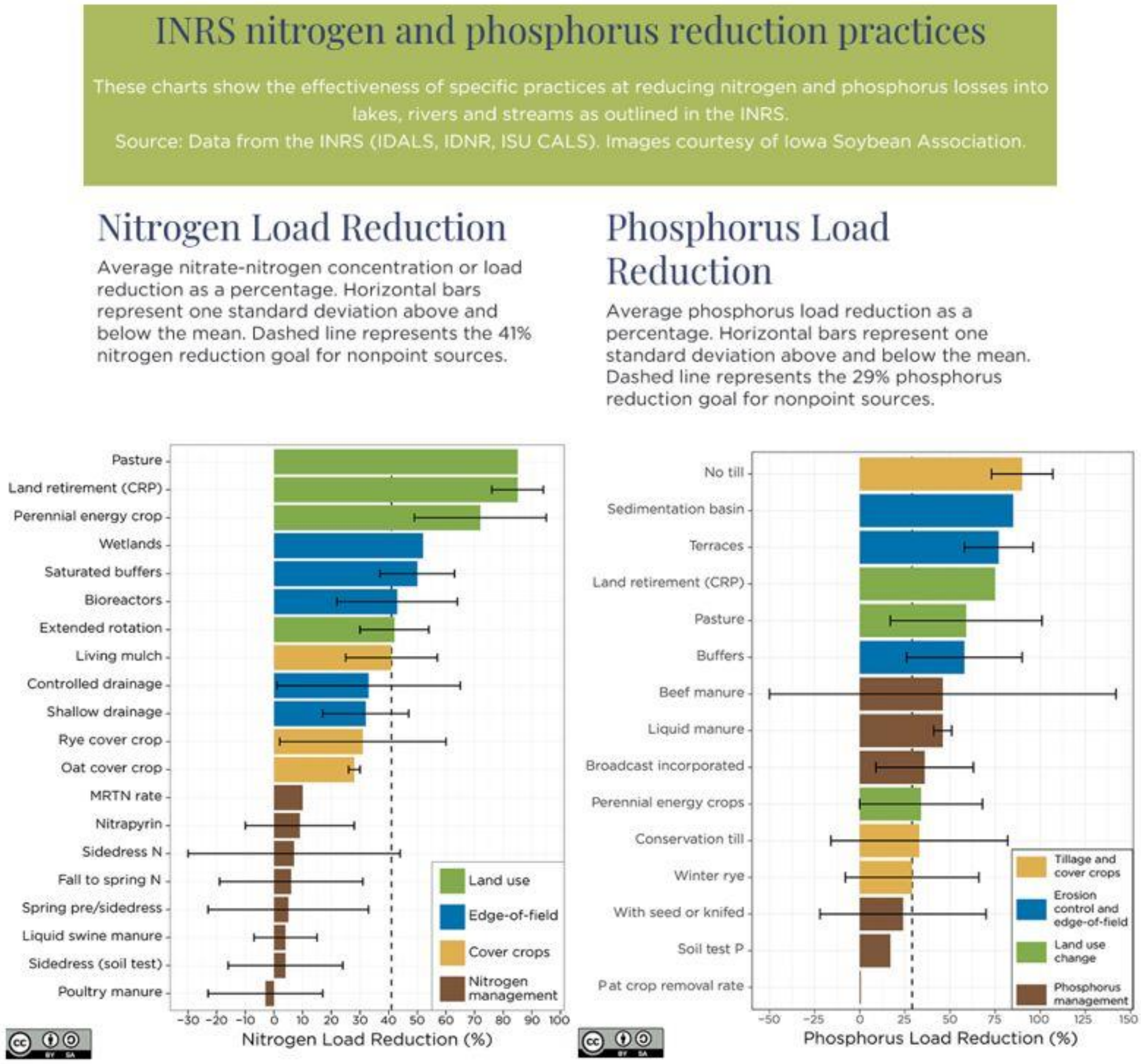
12. SURROUND LARGER BUILDINGS WITH APPROPRIATE PLANTING
Planting greenery around buildings contribute to aesthetic value and create a "green touch" to our farms.

13. CONVERT 1% OF EACH FARM'S AREA TO WATER HABITATS
Because water bodies enhance biodiversity, we want water habitats on 1% of our farmland. These water habitats should have summer holding water, surrounding vegetation, trees for nesting, and natural borders, etc. Several small ponds are encouraged rather than a few large. Please find inspiration in the Ingleby guidelines for establishing ponds.

14. CONVERT 10% OF EACH FARM'S AREA TO NATURAL HABITATS
We avoid cultivating small field triangles, convert obsolete or low yielding areas into habitats, or use several of the initiatives specified above.

Source: http://inglebyfarms.com/wp-content/uploads/2017/12/Ingleby-Guidelines-July-2017.pdf

Appendix 3. The Iowa Nutrient Reduction Strategy (INRS)



Source / image credit: *4Rplus nutrient reduction strategy:* *https://www.4rplus.org/iowa-nutrient-reduction-strategy/*

Appendix 4. UK water quality and nutrient management research needs

As a result of my Nuffield travels, I have identified the following topics which UK farmers would benefit from greater independent scientific research into:

Building and strengthening the evidence base for the effectiveness of different diffuse pollution mitigation measures. This evidence should be published in wiki form so that it can be updated continually.
Development of an effective modelling tool for predicting the effect of different farming practices on diffuse pollution.
Long-term systems research looking at the economic and environmental effects of changing whole farming systems, rather than just studying the effect of changing single variables. For example, closer evaluation is needed of the profitability and environmental benefits of reduced input livestock and crop production systems.
How can less commonly practiced techniques like companion cropping and agroforestry help to reduce nutrient losses to water?
Independent trials of different types of 'smarter' fertilisers, slow release fertilisers, nitrification inhibitors, urease inhibitors, micronutrients, biostimulants and inoculants (such as N-fixing bacteria) to ensure that plant nutrition recommendations (e.g. RB209) reflect improved scientific understanding of soil biology.
Animal nutrition trials to determine optimum diets for reducing nitrogen, phosphorus, ammonia and greenhouse gas emissions.
Soil health – how you measure it, what farmers should aim for and how they can achieve that. For instance, how can soil health be optimised to better hold onto nutrients in high-input systems?
The best ways of managing manure to minimise emissions to air and water and maximise crop performance and soil health benefits. For instance, how can manure be applied in a no-till situation without increasing ammonia emissions? Can more manure be safely spread onto cover crops? What sort of manure applications help earthworms and what harms them?

Appendix 5. Selected practices for preventing agricultural nitrogen and phosphorus losses to water relevant to UK farmers

In-field measures	Fertiliser & manure application	Edge-of-field measures	Farm infrastructure & technology	Management practices
CROPPING & ROTATIONS -Only grow crops which are suitable for the area, farm or field -Incorporate high C:N ratio crop residues to immobilise N (e.g. chop straw rather than bale and remove) -Reduce artificial N use through use of legumes and grass leys in the arable rotation -Rotate N efficient and N inefficient crops -Maximise above & below-ground diversity both across the rotation and in-year -Harvest crops earlier to allow earlier establishment of autumn sown crops (e.g. choose earlier maturing maize varieties and grow maize under film on marginal sites) -Choose plant varieties with better NUE -Grow cover crops and catch crops -Grow companion crops (e.g. under sow grass/legumes into maize, grow fabola (beans/OSR), peola (peas/OSR), nurse crops like spring barley with undersown lucerne, relay crops, and legume understories such as clover under wheat and berseem clover under OSR) -Switch to lower leaching crops: • Biomass crops (e.g. reed canary grass) • Lower N input crops (e.g. rye, triticale, spring cereals, linseed) -Adopt agro-ecological practices such as agro-forestry TILLAGE -Choose appropriate tillage strategy: • Type of cultivation (e.g. adopt min-till/zero-till) • Timing (e.g. in spring not autumn/winter, no over-winter ploughing) • Cultivate across slopes -Manage tramlines to avoid run-off (e.g. position across the slope) -Address soil compaction GRAZING & LIVESTOCK MANAGEMENT -Appropriate outwintering: • Select suitable site (slope, soil type, away from watercourses) • Manage stock to avoid soil/nutrient loss (e.g. back-fencing, regular moving of feeders, nose-ringing of pigs) • Manage farm vehicle access (e.g. avoid/reduce vehicles entering field and keep wheelings across slope) -Correct timing (avoid high-risk times of the year though winter housing and restrict duration) -Minimise/reduce stocking rates (e.g. reduce youngstock numbers by improving herd longevity) -Manage supplementary feeding (appropriate placement and management of feeders and watering points) -Reduce artificial N use through use of clover/grazing legumes and herbal leys -Reseed inefficient pasture	-Always practice the 4Rs *(Right Product in the Right Amount and in the Right Place at the Right Time)* -Targeted manure application: • Product (right type of manure for use) • Correct timing (e.g. avoid high-risk times of the year) • Rate (little & often, rate matched to demand) • Placement (precise application) • Accurate application method: - Avoid splash plate, use dribble bar, trailing shoe or injection - Know rate applied (e.g. weigh loads, use flow-meters) - Use precision technology (e.g. GPS guidance, variable rate, NIRS analysis) - Incorporation rather than surface app. -Targeted artificial fertiliser application: • Use most suitable product type: - Quality and consistency are vital - Inhibitors to improve timing of release - Enhancers to improve efficiency of uptake - Urea vs. ammonium nitrate • Correct timing (e.g. avoid high-risk times of the year) • Rate (little & often, rate matched to crop demand and soil index) • Placement (precise application) • Analyse manure (use on-farm test kits, lab tests or NIRS on spreaders) • Accurate application method: - Liquid fertiliser better than granular - Regular calibration and maintenance - Use precision technology (e.g. GPS guidance, auto-shutoff, variable rate) -Keep digital application records	-Establish buffer strips, contour strips, grass waterways, beetle banks & in-field wildflower strips and plant hedges -Build retention bunds and / or treatment wetlands to allow sediment and nutrient to settle out -Reversion of less productive arable or intensive grassland areas to: • Reduced input grass • Zero-input grass • Woodland -Manage field drainage: • Install denitrifying bioreactors, saturated buffers and constructed wetlands • Manage drainage to hold back water in field at high risk times • In-ditch filters for phosphorus removal and reuse	-Use manure separators -Install manure dewatering technology -Install nutrient recovery technology -Optimise manure storage: • Maximise storage capacity (e.g. number of months) and minimise manure production • Ensure proper construction and lining of stores and avoid field storage • Cover manure stores to reduce rainwater dilution of liquids and leaching/run-off from solid heaps • Install sand-separation to make slurry easier to handle • Use manure additives (e.g. slurry bugs), compost solids -Reduce fouled water running off yards into slurry stores or watercourses -Locate livestock watering points away from watercourses -Exclude livestock from riparian areas with fencing -Construct bridges over watercourses -Relocate gateways away from bottom of slopes and watercourses -Manage and maintain farm tracks to minimise run-off -Precision irrigation to avoid unnecessary run-off and leaching (e.g. use soil moisture sensors, variable rate irrigation technology, sub-surface drip irrigation etc)	-Ensure staff are trained: • Advisors • Managers • Operators -Ensure that nutrient management planning (NMP) is ongoing, accurate, implemented in practice & recorded: • Assess crop demand realistically and accurately • Assessing soil, manure & atmospheric nutrient supply frequently, realistically and accurately (e.g. regular soil testing) -Calculate baseline N&P losses and model different scenarios to assess impact of changing practices. Models include: NLT, NDCIEA, FarmScoper, ANCA, Planet, Manner, Overseer, SNAP+ -Avoid overfeeding of protein & phosphorus in animal diets and use enzymes and amino acids to reduce protein and P in ration -Export manure to farms with nutrient deficits -Breed animals for better NUE (e.g. use low urine-N bulls) -Ensure good management practices and husbandry to maximise nutrient utilisation per unit of inputs

*Most of the strategies above will reduce nitrogen and phosphorus losses to water but some may only mitigate of one of these. **Sources of information:** Tim Stephens Nuffield Scholarship, Wessex Water, Newcastle University (*Toolbox of cost effective strategies for on-farm reductions in N losses to water*) and Adas (*Inventory of Mitigation Methods and Guide to their Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia*). **NB.** NUE = Nutrient Use Efficiency.

Appendix 6. Additional case studies

Appendix 6a. Additional case studies: Farmers

Case Study 12: Lean Management in practice: Mat and Jana Hocken's Grassmere Dairy, Feilding, Manawatu, New Zealand

The picture below illustrates lean management principles in daily use on the wall of the team-room at Mat Hocken's Grassmere Dairy near Palmerston North in New Zealand. The farm uses Visual Management Boards (a key lean tool), as a core part of their farm management system to drive efficiencies and reduce waste through better communication, employee ownership and visibility, metric monitoring and action focus. The farm has also implemented other key lean tools such as 5S and Standardisation to eliminate waste and optimise its operations and productivity.

Mat Hocken and the Visual Management Board in the dairy office.

Case Study 13: Integrating agroforestry: Pierre Pujos, organic arable farmer, Saint-Puy, southwest France

Pierre has a 210ha arable farm and began organic conversion in 1998. He stopped ploughing soon after due to soil erosion problems. He minimises cultivation and has a range of cultivators for different situations. He avoids purchasing any crop inputs and tries instead to build fertility through a diverse rotation, high biomass & leguminous cover crops, perennial crops such as lucerne and some agroforestry. Direct drilled lucerne is used to reset the system in the event of any weed or soil problems. Pierre will sometimes direct drill wheat into the lucerne, with older wheat varieties proving better for this. The 'living mulch' which the lucerne provides under the wheat ensures that soil is always covered. Being organic, glyphosate herbicides cannot be used to terminate cover crops, so a crimper roller is used instead.

Heritage wheat varieties are grown, and different varieties mixed together to improve disease resistance. Wheat yields are low at 2.5t/ha but grain is sold at a premium for €600/t to a local baker, so the gross margin is better than conventional milling wheat. As well as wheat, Pierre grows 9 other autumn and spring sown crops; barley, spelt, triticale, linseed, sunflowers, lentils, beans and chickpeas. Drilling is spread throughout the year. Pierre thinks that organic no-till is something he can achieve one day but feels that more innovation in machinery design is needed first. He is trialling a new type of crimper roller with a seeder box mounted on top which can be used for one-pass establishment of cash crops into cover crops without using glyphosate. The machine can be offset so that the crimper roller can travel between rows of maize and soybeans. The agroforestry system runs with the contours to prevent soil erosion and rows are spaced 25m apart to allow arable cropping between them. There are 8 different species of tree, mostly hardwoods and nuts. Future plans for the farm include starting a sheep enterprise to aid weed control and build soil fertility.

Left - Pierre Pujos' agro-forestry system of rows of trees every 25m with the cultivated area in between.

Right – Pierre explaining the workings of a prototype cover crop crimper roller with mounted seeder unit designed by a group of French farmers.

Case Study 14: Putting conservation agriculture into practice: Tibault Presles, arable farmer near Vichy, Central France and Jacques Champdavoine, arable farmer near Chateaudun, north central France

Although Tibault Presles and Jacques Champdavoine farm in different parts of France they both follow conservation agriculture principles. Both grow combinable crops such as cereals, legumes, grain maize and oilseeds and both improve soil with cover crops, companion cropping and strip-till / no-till crop establishment. They grow as much of their own cover crop seed as possible.

Tibault is trying to reduce pesticide use and has trialled a stinging nettle extract in place of a fungicide. He always leaves a small section of every field untreated so that he can see what value purchased inputs such as fertilisers and pesticides are adding to the crop. Only a small section of the farm is irrigated and Tibault was initially planning to expand this area. Since embracing conservation agriculture he has decided to invest in improving his soils first as he believes he can significantly improve their moisture retention. He may invest in more irrigation in the future, but priority has been given to purchasing strip-till and no-till drills.

Jacques has been no-till on his farm since 2003 but uses a strip-till drill to establish maize. He grows catch crops between harvest of one crop and autumn establishment of the next. An example of this is buckwheat which is autocast in June from the combine header into winter barley stubble and then combined in October. The buckwheat seed is either sold for human consumption or kept as cover crop seed. Beans and lentils are also grown as catch crops. Jacques and his brothers were very well set up for getting cover and catch crops drilled promptly by storing home-mixed seed in mobile bins which can be easily transported to the seed drill. Their cover crop strategy is to use a mix containing at least one species from each of five key plant families: one cereal, one legume, one brassica and so on. The farm is in a relatively dry region, so a priority is retaining moisture by keeping crop residues on the soil surface. The farm is located on a limestone plateau where the underlying aquifer suffers high nitrate and some pesticide issues. Local water quality information is displayed on the village noticeboard for all residents to see.

Two contrasting approaches to soil management. The left-hand picture shows the Champdavoine's neighbour's soil and maize rooting under a plough and deep cultivation system. Note the lack of moisture and poor soil aggregation. The right-hand picture shows the Champdavoine's strip-tilled maize a few metres away. Note the surface residue, the improved moisture retention and the soil aggregation.

Left – the Champdavoine's five species cover crop mix ready to drill as soon as crops are harvested.

Right – Tibault Presles' strip-till drill for establishing maize.

Case Study 15: Californian solutions to manure management: Kevin Prins, Prins Dairy, Modesto, California

Kevin Prins milks 600 cows in the Central Valley of California. A slurry separator with an ultrafine screen (0.2mm) is used to produce a dilute liquid fraction. The solid element is composted and reused as cow bedding and has a beneficial effect on soil when it is applied to the land. The separated liquid is pumped into a settlement lagoon where more solids are settled out before flowing into a second pond and finally a third pond. Mixers float on the surface of the final two ponds and stir the effluent to keep it homogenous. By the time effluent has reached the third pond it is clean enough to be reused for flushing the cow cubicles without causing cow foot health problems. The process then repeats itself. Water is also pumped from the lagoons to flood irrigate the farm's arable fields. Kevin has noticed soil health benefits from using aerated effluent for irrigation compared to when it was untreated. The N:P ratio of the effluent is also more in balance with what Kevin needs for his crops.

Kevin Prins in a free-stall barn and the second-stage manure storage pond with floating mixers.

Appendix 6b. Additional case studies: Slowing the flow of water

Case Study 16: Reducing nitrogen loss to water in Iowa: Saturated buffers

Tim Recker is a farmer and agricultural contractor in Fayette County, northeast Iowa. Tim has connected 32ha of tile drains on his farm into a 250m long saturated buffer which removes 40-70% of the nitrogen in the drainage water through a combination of vegetative uptake and denitrification by soil bacteria. Saturated buffers store water within the soil of buffer strips, by diverting tile water into shallow laterals that raise the water table within the buffer and slow outflow. Using LiDAR satellite imaging which can pick out the degree of land contouring from space, Iowa NRCS is able to identify suitable locations for drainage water bioreactors and saturated buffers.

Tim Recker (right of picture) talking about regulating water flow through a saturated buffer.

Case Study 17: Slowing the flow: Phosphorus Detainment Bunds, Rotorua, New Zealand

John Paterson has three passions; he is project manager for the independent farmer governed Phosphorus Mitigation Project Inc., a Sustainable Farming Advisor for Bay of Plenty Regional Council and a deer farmer who in 2005 co-ordinated the production of the NZ Deer Industry Landcare Manual. Lake Rotorua has a nitrogen surplus which needs to fall by 300tN/yr and a phosphorus surplus that also needs to be reduced. The eutrophication arising from this nutrient overload has caused blooms of harmful algae that in the past has resulted in swimming bans being imposed for the lake. John has many years' experience working with farmers to reduce the effects of storm water run-off on water quality in Lake Rotorua. Since 2010 he has been developing in-field Detainment Bunds which hold back ephemeral overland flows of water for long enough that sediment, and with it some particulate bound phosphorus, can settle out. The bunds have an outlet riser that skims excess storm water from the surface layer of the pond, which is the cleanest part of the ponded water column. In the area surrounding Lake Rotorua water will flow overland if rainfall intensity exceeds 10mm per hour, which typically happens 5 or 6 times per year. Annual rainfall is 2,000mm. The Detainment Bunds treat storm water from catchment areas of up to 50ha and have a plug which the farmer can pull to drain the water before pasture is compromised by submergence. All the farmers operating the 22 Detainment Bunds now in operation have a memorandum of understanding that includes a stipulation that ponded water should not be held for more than 3 days to avoid any risk of productivity loss from the pasture.

John identifies potential sites for these bunds using GIS LiDAR data with 1m contour on high resolution satellite images. The Phosphorus Mitigation Project Inc has engaged a PhD student who is currently precisely quantifying the benefits of the bunds for capture of both phosphorus and sediment, which are important exacerbators of the water quality issue in Lake Rotorua. Early results are promising, and the PhD will be completed in 2019. John has found that a minimum of 120m3 of ponding capacity per hectare of catchment is needed to maximise settlement of sediment in the storm water. These bunds can also be sited to protect constructed wetlands from sediment overload. Once the water has subsided John finds that the sight of the deposited sediment opens a useful conversation with the farmer about how to prevent sediment loss in the first place. Bunds are designed to have as little impact on the farmer as possible, so tractors can drive over them to cut grass and animals can graze them. John has also designed and built these bunds for the New Zealand Transport Authority to prevent flooding of highways during heavy rainfall. Two further projects are in the pipeline; a GIS modelling tool to predict landscape suitability for installation of Detainment Bunds in other parts of NZ and more research on the bunds to see if they are effective for reducing E. coli loads in storm water leaving farms.

Left *- A phosphorus detainment bund on a dairy farm near Rotorua. Water running off 50ha of farmland flows from the left to right of the picture and up to 5,000m3 can be held back for up to 3 days by the grassed over bund.* ***Right*** *- Upstand riser skimming the uppermost layer of ponded water.* **Image credit:** *John Paterson.*

Case Study 18: Landscape engineering in New South Wales: WaterNSW & South East Local Land Services

WaterNSW and South East Local Land Services (SELLS) have a partnership program, known as the Rural Landscape Program, for addressing grazing management risks in the Sydney Drinking Water Catchment. SELLS is the NSW state government agency which supports farmers with animal production, biosecurity, natural resource management and emergencies. WaterNSW is the bulk water supplier to Sydney and protects drinking water catchments from contamination from pathogens and nutrients. WaterNSW funds projects which SELLS advisors help farmers deliver. Part of the Rural Landscape Program includes gully erosion mitigation, particularly in drier parts of the catchment. This aims to restore degraded river banks and ephemeral flow pathways to reduce sediment loss during storms. These highly erodible soils can be very badly damaged if livestock grazing has denuded them of vegetation and loosened soil. As well as riparian fencing and planting, they can also fund the relocation of livestock drinking points if animals previously drank from the creek. Strict specifications are set so that the work is done to a high standard. A newly launched Dairy Program is aimed at dairy farmers and offers grants to improve dairy effluent management, calf paddock management (to prevent *cryptosporidium* contamination of water), farm laneways and apply riparian fencing to keep stock out of creeks.

Left *- After decades of overgrazing by sheep, 8ha of dry valley in the picture above was very badly eroded. The WaterNSW funded and SELLS delivered project involved scraping back much of the soil on the severely eroded slopes, spreading gypsum to improve soil structure, laying of woodchip mulch and then stabilising all of this with coir netting and coir logs.*

Right *– A badly eroded river bank: WaterNSW funding was used to erect fencing to exclude livestock. The area will be planted with native vegetation. A new livestock watering system was also installed as part of the project.*

The valley in the picture above channels rain falling on a 20ha area of pasture towards a creek below. A series of concrete flumes has been constructed to channel runoff water into a new retention pond which reduces the water's velocity and its erosive impact on the landscape. The project also worked with the farmer to manage livestock grazing to increase ground cover and improve water infiltration. Construction was carried out by a SELLS engineering team.

Appendix 6c. Additional case studies: Research projects

Case Study 19: High-frequency water quality monitoring: Teagasc Agricultural Catchments Programme, Republic of Ireland

Teagasc is the Irish national body providing integrated research, advisory and training services to the agriculture and food industries and rural communities. It has over 50 research, advisory and training centres. It's Agricultural Catchments Programme is based at Johnstown Castle in southeast Ireland but it has six test catchments around the country. Each has been chosen to be representative of Ireland's main farming sectors and regions. Each catchment has a multi-disciplinary team to evaluate the environmental and economic effects of different farming practices upon water quality, and to develop evidence-based solutions to these challenges. The data collected is invaluable for informing both government and farmer decision making on matters like closed periods for spreading slurry and maximum stocking rates.

The pictures above are of water quality monitoring equipment in the Timoleague catchment in County Cork. This catchment was chosen because of its high concentration of dairy herds (2,000 cows across 15 dairy farms covering 750ha). Projects like this provide the data which the Irish Government needs as evidence in making its case to the EU for keeping a Nitrates Directive national derogation.

Case Study 20: The land-grant universities: University of Wisconsin's Discovery Farms Program

A strength of US agriculture is its land-grant university system. These institutions were designated by individual states using federal funds in the late 1800's to teach practical agriculture, science and engineering. Most became large public universities offering a wide spectrum of different courses and research. Many now have global reputations for the quality of their agricultural teaching and research. Extension services for translating research findings into changed on-farm practice are also a core part of their offering with extension offices spread throughout the states they serve.

One example is the University of Wisconsin. It's Discovery Farms initiative is *'a farmer-led research and outreach programme focussed on the relationship between agriculture and water quality'*. It conducts research on privately owned farms throughout the state and works with the US Geological Survey *'to gather credible and unbiased water quality information from monitored sites'*[28]. Projects are based on a farm for 5 to 7 years at a time and aim to gather as much data as possible on the effects of different farming practices on water quality. Host farms act as a hub for local farmers to visit and discuss the findings. The results are also used by government to inform policy making.

Amber Radatz, Co-Director of the UW Discovery Farms Program with a water quality monitoring station on a farm in the Jersey Valley Lake Watershed of western Wisconsin. Data gathered by this equipment informs local farmers of how and when nutrients are lost from fields.

[28] University of Wisconsin Discovery Farms: www.uwdiscoveryfarms.org/about

Case Study 21: Farmer-funded research: Foundation for Arable Research (FAR), New Zealand

FAR is funded and owned by 30,000 New Zealand arable farmers. Various trials are carried out at their 25ha Northern Crop Research Site near Hamilton, as well as at two sites in the South Island, several of which test practices which can reduce the environmental impact of maize growing. These include a long-term maize establishment trial which has found several benefits for growers from switching from plough and power harrow-based systems to strip-till or no-till planting. Different cover crop species and establishment / destruction techniques are trialled. Undersowing of grass and clover into maize is one of these methods. Drilling of maize into a perennial clover ley is a practice showing potential for reducing nitrogen inputs and soil erosion. Balansa and Gland clover are both proving successful for this purpose.

2016/17: Winter cover crops to reduce herbicide inputs in maize crops

M.R. Trolove and T.K. James

June 2017

REPORT FOR FOUNDATION FOR ARABLE RESEARCH (FAR)

FAR Project Code M16/03

CLIENT REPORT NUMBER: 6675

Left - A perennial clover ley at the FAR Northern Crop Research Site near Hamilton is in the foreground. The clover has had maize drilled straight into it. The clover is knocked back with herbicides in springtime, but not killed, then maize is strip-tilled or direct drilled into it. The clover then grows back once the maize has established. In the background is the control plot with maize drilled into sprayed-off annual ryegrass.

Image credit: *Allister Holmes, FAR.*

Right – an example of a FAR research report.

Appendix 6d. Additional case studies: Country profiles

Case Study 22: Drivers of changing farm practice in New Zealand and Australia

In New Zealand there is increasing pressure on farmers from society and the government to reduce nutrient losses to water. The dairy industry is singled out in the media with phrases like “dirty dairy”, “loss of social licence” and “peak cow” being used to draw attention to environmental issues caused by dairy production. A major focus is on nitrate losses from grazing cow urine deposits. The growth of tourism means it now rivals the dairy industry as an export earner for the country, and clean rivers are a key selling point for NZ tourism.

The regional councils are charged with creating and enforcing water quality rules. Nationally, the decision was taken early on to regulate nutrient loss rather than to impose input controls on farmers. Rules vary by council but in Canterbury most farmers need to ‘hold the line’ by not letting nutrient losses increase above a baseline which they have been set. In nutrient loss hotspots however, farms must reduce nitrate losses by 30%. This scale of reduction may need dairy farmers to reduce stocking rates. The Government’s approach is best summed up by David Parker, NZ Environment Minister in a quote he made in May 2018: *“…in some areas, the number of cows per hectare is higher than the environment can sustain. [Tackling this]… won’t be done through a raw cap on cow numbers; it will be done on nutrient limits, the amount of nutrient that can be lost from a farm to a waterway, because it’s not just a dairy cow issue"*[29].

The nutrient loss model which is used to establish a nitrogen reference point for each farm is called Overseer. This model is used by farm advisors to show farmers what the impact of changing certain farming practices would have on nitrogen losses. Improving water quality is a key priority for all farming sectors and 67,000km of water courses have been fenced to exclude grazing livestock[30]. Investments that dairy farmers are making to improve nutrient and soil management include feed-pads, stand-off pads and effluent ponds. Researchers are also working hard on solutions like better livestock outwintering systems and plant and animal breeding programmes for improving NUE. The supply chain is also part of the solution with major dairy processors like Fonterra and Synlait supporting and encouraging producers to reduce nutrient loss. There is no government funding available for NZ farmers to do any of this, so the main drivers of change are regulation, customer demand and the productivity gains from better NUE.

NZ contrasts sharply with Australia where the farm regulatory regime for water quality is more relaxed. The main priority in most Australian states is prevention of point-source pollution incidents such as effluent ponds discharging into a watercourse. In both countries there are examples of payment-for-ecosystem-services schemes such as nutrient trading in the Lake Taupo catchment of NZ and the Emissions Reduction Fund in Australia. A key driver for uptake of conservation agriculture techniques in Australia is the need to improve resilience to extreme weather, especially drought. Cover crops and no-till are both becoming more popular there because of the way they help retain moisture in soils.

[29] **Source:** Transcript of TVNZ interview 6th May 2018: http://www.scoop.co.nz/stories/PO1805/S00065/qa-minister-david-parker-interviewed-by-corin-dann.htm
[30] **Source:** NZ Ministry of Primary Industries National Stock Exclusion Study, July 2016: www.mpi.govt.nz/dmsdocument/16513/send

Appendix 6e. Additional case studies: Industry initiatives

Case Study 23: Resource efficiency for increased profit: Smart Farming in Ireland

Smart Farming is a voluntary resource efficiency programme led by the Irish Farmers Association, in conjunction with the Environmental Protection Agency. The programme uses extensive research carried out by research and advisory organisations such as Teagasc. This knowledge is communicated in a targeted way to achieve the double dividend of increased profitability and reduced environmental emissions. Participating farmers receive a resource efficiency assessment of their farm which is also called a cost-saving study. The agronomist who carries out this study recommends actions which the farmer can implement. Focus areas are soil fertility, energy, machinery, time management, water, inputs and waste, grassland management and feed efficiency. There is a strong focus on nutrient management planning within the process. In 2017 the average savings identified on participating farms totalled €8,700 which would lead to a 10% reduction in greenhouse gas emissions and reduced risk of loss of nutrients to water. Greatest savings came from improving soil fertility as 87% of all soil samples were at sub-optimal fertility levels. Grassland management and feed use efficiency were other areas which offered significant cost saving and environmental improvement opportunities[31].

A new trailed fertiliser spreader on Owen Brodie's dairy farm in County Cavan. More accurate spreading of fertiliser is a key element of the Smart Farming programme, and having a trailed machine allows Owen to adopt a 'little-and-often' approach to applying nitrogen.

[31] **Source:** Smart Farming Progress Report 2017: www.smartfarming.ie/progress-report-2017/

Case Study 24: Farmer-led research: Practical Farmers of Iowa (PFI)

PFI was formed in 1985 to help its farmer members practice an agriculture that benefits both land and people. Through farmer-led investigation and information sharing PFI helps farmers to conduct randomised and replicated on-farm research to improve their profitability, efficiency and environmental stewardship. They have 3,300 members, of which approximately 500 actively participate by conducting their own field trials or by sharing their observations at more than 200 field days and workshops annually. The reach of PFI is wider than its membership with a total of 9,000 people attending various PFI events annually. PFI staff support members with field trial procedures to make the results as useful as possible. Farmers are also coached in presentation skills so that they can share the results. Trial ideas come from farmers. PFI can help farmers who host trials with some of the costs of running a trial and running a field day to share its findings. Funding comes from the PFI membership, government and the private or charitable sectors. Areas of focus are cover crops, interseeding and use of perennial cover such as clover and alfalfa coupled with small grain production. A key aim is to improve farm profitability so opportunities to reduce input costs are common trial themes.

Sarah Carlson, PFI Strategic Initiatives Director and PFI member, Aaron Lehman standing in a field of red clover on Aaron's farm near Polk City, Central Iowa in October 2017. Oats and clover were sown together and the oats harvested in July, leaving the clover to regrow. Maize was due to be planted in this field in spring 2018. Maize which has been interseeded with radish and cereal rye is shown on the right. Aaron is undertaking a phased organic conversion on his farm. With the support of PFI, Aaron has been gradually adopting various conservation agriculture techniques such as aerial seeding of cover crops into standing maize, non-chemical weed control and use of legumes to reduce nitrogen fertiliser use.

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