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Sustainable Farming Scheme Evidence Review Technical Annex

Annex 1: Soil nutrient management for improved land

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Contents

1 Introduction & background

The Brief: *Establish intervention logic for Soil Nutrient Management (SNM) plans across all improved agricultural land. Establish the environmental benefits including GHG emissions reduction, biodiversity, water quality and air quality which will be secured through the universal uptake of SNM plans. Identify the contribution that better SNM will make to the economic resilience and sustainability of Welsh agriculture.*

Annual nutrient losses from Welsh agriculture are estimated at around 37,000 tonnes of nitrate-N and 700 tonnes of phosphorus to water, and 20,000 tonnes of ammonia and 8,000 tonnes of nitrous oxide to air (Anthony *et al.,* 2012; Anthony *et al,* 2019). Poorly managed applications of manufactured fertilisers and organic materials represent a significant risk to water and air quality as well as impacting on farm business performance.

1.1 Crop nutrients and soil pH

In addition to carbon, hydrogen and oxygen, thirteen elements are essential for plant growth. The nutrients are typically classified depending on how much plants need. Macronutrients that are needed in relatively large amounts include nitrogen, phosphorus, potassium, calcium magnesium and sulphur. Micronutrients which are needed in smaller amounts include iron, copper, manganese, zinc, boron, molybdenum and chlorine (Archer, 1984).

Deficiency of any one of the elements is likely to limit plant growth and reduce yield. Sub-optimal supply of any of the nutrients will also reduce the uptake of other nutrients, which may increase the risks of losses to the environment. Elements such as cobalt, nickel and selenium are not essential for plant growth but are important for animal nutrition. Managing nutrient applications to optimise nitrogen and phosphorus supply is important to minimise losses to the environment

The pH of a soil affects the bioavailability of plant nutrients, which will also impact on plant growth. The optimum availability of most plant nutrients occur over a small range of soil pH values (Table 1.1.1). The range for each nutrient is not the same, but recommendation systems suggest target soil pH values which provide a compromise for different cropping systems and soil types (Table 1.1.2) (AHDB, 2017)

Nutrient	N	P	K &S	Ca & Mg	Fe	Mn	B, Cu & Zn	Mo
Optimum pH range	6-8	6.5-7.5	>6	7-8.5	<6	5-6.5	5-7	>7

Table 1.1.1. Optimum soil pH values for the availability of major and most important micronutrients (Goulding, 2015 and Foth, 1990)

	Optimum pH	
Cropping system	Mineral soils	Peaty soils
Continuous arable	6.5	5.8
Grass with occasional barley	6.2	5.5
Grass with occasional wheat or oats	6.0	5.3
Continuous grass or grass/clover swards	6.0	5.3

Table 1.1.2. Optimum soil pH for different cropping systems and soil types (AHDB, 2017)

1.2 Nutrient Management Planning

AHDB's Nutrient Management Guide (RB209) is recognised as the industry standard fertiliser recommendation system for supporting nutrient management planning in Wales. The fertiliser recommendations were first published in the 1970s and the latest version was published in 2017 based on a review led by ADAS in 2016 (e.g. Newell Price *et al,* 2016b).

The Nutrient Management Guide includes a section on organic materials which provides information on the crop available nutrient supply from organic materials based on outputs from the MANNER-*NPK* manure decision support system (Nicholson *et al.,* 2013). The importance of factors that affect manure nutrient content such as the dry matter content of livestock manures and the source of feedstock for anaerobic digestate are also highlighted. The approach of integrating fertiliser and manure nutrients to provide optimum levels for plant growth is also used in computer based nutrient management systems such as PLANET (www.planet4farmers.co.uk) and other software tools produced by commercial software companies such as FarmPlan and Muddyboots.

There are four key stages which should be followed to maximise nutrient use efficiency and minimise the potential risk of nutrient losses to the environment:

1.2.1 Quantifying crop nutrient requirement

Fertiliser recommendation systems such as AHDB's Nutrient Management Guide (RB209) provide comprehensive guidance on the nutrients required for economic optimum crop production. The crop requirements vary with species (and sometimes variety of crop) and reflect soil nutrient supply, soil type and over winter rainfall.

1.2.2 Quantifying soil nutrient supply

In most situations soil nitrogen supply can be assessed using information relating to soil type, typical over winter rainfall (to assess leaching losses), nitrogen released from crop residues and previous fertiliser N and manure use. In circumstances where previous management has been atypical, soil sampling to 90 cm may be more effective to quantify the soil nitrogen supply on arable fields

Soil analysis is recognised as the most effective method of quantifying soil pH status and extractable phosphorus, potassium and magnesium contents. Soil pH, phosphate, potash and magnesium are usually managed for a rotation rather than an individual crop so soil analysis is recommended every 3 -5 years.

The likelihood of sulphur deficiency can be assessed based on soil type and rainfall. Most micronutrients are present in sufficient quantity in UK soils and deficiency is most common on soils with high pH. The most common micronutrient deficiencies in field crops include manganese, boron and copper. Soil analysis can be effective at assessing the risk of boron and copper analysis and leaf analysis is most reliable for assessing manganese deficiency.

1.2.3 Quantifying the nutrient supply from organic materials

Understanding the nutrient content of organic materials and quantifying application rates are crucial for making best use of manure nutrients. The nutrient content of organic materials will depend on a number of factors. For livestock manures the main determining factors include livestock type, feeding regime, diet, the amount of rainwater dilution that occurs during storage and the amount of bedding used. For digestates and composts the source of the feedstock material and for biosolids the treatment processes are important factors.

Typical figures for the nutrient content of organic materials are available in AHDB's Nutrient Management Guide (2017). However laboratory analysis can give a more accurate assessment of the nutrient content of organic materials for an individual source.

Nutrients in organic materials are present in two forms: (i) readily available soluble forms, which are immediately available to the crop and most at risk of loss to the environment and (ii) organic forms, which will only become available overtime following the mineralisation of organic matter in the soil. It is important to manage applications to maximise the crop available nutrient supply and utilisation.

Manure type	Application rate T FW*/ha	Crop available N** (kg/ha)	Total phosphate (kg/ha)	Total potash (kg/ha)
Cattle slurry	35	32	48	88
Cattle FYM	40	24	128	376
Poultry manure	8	67	136	168
Whole digestate	25	72	53	43

* Fresh Weight
** Assumes spring broadcast application timing

Table 1.2.3.1. Crop available nutrient supply from typical organic material applications

1.2.3.1 Nitrogen

For manures with a high proportion of total nitrogen in the readily available form (e.g. slurries, poultry manures and digestates) applying organic materials at times when crops are actively growing will increase the nitrogen use efficiency by reducing the risk of nitrate leaching.

Spreading liquid manures containing concentrations of high readily available N with precision application techniques such as bandspreaders and shallow injectors instead of conventional surface broadcast applications will reduce the risk of ammonia emission, odour nuisance and crop contamination. Precision application techniques also allow the liquid manures to be spread evenly across known bout widths (Chambers *et al.,* 2001). Applications of solid manure on tillage land should be incorporated within a few hours of application to reduce ammonia emissions.

1.2.3.2 Phosphate and potash

Applications of solid manure typically apply more phosphate (P2O5) and potash (K2O) than is taken off by a crop in a single harvest year (Table 1.2.3.1). For example a 40t/ha application of cattle FYM will supply around 130 kg/ha of P2O5 and 376 kg/ha of K2O. In comparison, 40t/ha of grass at 25% dry matter (i.e. 10 t/ha of grass dry matter) will remove 68 kg/ha of P2O5 and 240 kg/ha K2O. Consequently, it is important to target solid manure applications to fields with low P and K status to maximise their nutrient value and reduce the risk of excessive soil P levels, which increase the risk of P losses to water (Figure 4.1.1.2.1).

1.2.4 Accounting for manure nutrients when planning manufactured fertiliser applications.

Crop available nutrient supply from contrasting manure application timings and methods can be calculated by using the MANNER-*NPK* decision support tool or by reference to AHDB's Nutrient Management Guide, which is also available via the CrapApp (www.swarmhub.co.uk). It is important that the nutrients supplied by the manures are accounted when calculating manufactured fertiliser application rates to ensure that crop nutrient requirements are not exceeded and the risks of nutrient losses to the environment are not increased.

2 Outcomes

Efficient nutrient management is fundamental to the support of sustainable farming systems by encouraging efficient food production whilst minimising diffuse air and water pollution from agricultural systems.

Nutrient management planning has the potential to maximise nutrient use efficiency by ensuring crop available nutrient supply is sufficient for optimum crop growth.

Where excess nutrients are applied it is likely that nutrient management planning will reduce manufactured fertiliser applications leading to cost savings and a reduction to the risks of air and water pollution.

Where insufficient nutrients have been applied to support optimum crop yields, nutrient applications from fertilisers and manures may increase leading to enhanced crop yields. Under this scenario it is likely that the environmental losses per unit of production will reduce, however the total nutrient losses (e.g. nitrous oxide emissions to air following elevated fertiliser N applications) may increase.

Taking account of nutrients supplied by organic materials is crucial to minimise nutrient losses to water and air from agricultural systems. Manure nutrient use efficiency can be improved by ensuring manures are applied at application rates that do not supply nutrients in excess of crop demand. Targeting manure applications to soils that require phosphate applications to maintain soil fertility will reduce the risks of phosphate losses to water.

On many farms, investment in farm infrastructure will be required to maximise the nutrient value of manure applications. The investments include increasing storage capacity for liquid manures (i.e. slurry and digestate) so that they can be applied at times of the year and under soil/weather conditions where nutrient losses can be minimised. Also, covering liquid manures stores combined with the use of precision application technologies for spreading liquid manures will reduce ammonia emissions. Precision slurry spreading also ensures even application across known bout widths, reduces crop contamination and minimises odour emissions following application.

3 Policy Relevance and Policy Outcomes

Nutrient management planning is important to support the delivery of policies to mitigate diffuse pollution from agricultural systems which is important to achieve the UN's sustainability goals i.e.:

- Good health and well-being (e.g. reductions in ammonia emissions to air)
- Clean water (i.e. reductions in nitrate and phosphorus losses to water)
- Industry innovation and infrastructure (e.g. improvements in manure management infrastructure)
- Responsible consumption and production (e.g. minimising manufactured fertiliser inputs and maximising manure nutrient use efficiency)
- Climate Action (e.g. optimising N inputs from manufactured fertilisers and organic materials use will reduce GHG emissions from fertiliser production and minimise direct and indirect nitrous oxide emissions from agricultural systems)

4 Intervention

4.1 Soil nutrient management planning

4.1.1 Causality

Nutrient management plans use fertiliser recommendation systems to ensure that the total supply of nutrients from all sources meet, but do not exceed, crop requirement. Maintaining an appropriate balance between different nutrients is also important to maximise the efficient uptake of all nutrients and reduce environmental losses to a minimum.

4.1.1.1 Nitrogen

Most agricultural soils require applications of nitrogen from fertiliser and/or organic materials on an annual basis to ensure optimum crop growth. Most of the mineral nitrogen in the soil is present as nitrate, which is mobile in the soil. Any nitrate that is present in the soil at the start of the winter is unlikely to be taken up by crops as growth slows due to cold temperatures and reduced light intensity. When excess winter rainfall occurs, and water drains through the soil the nitrate is at risk of being lost from the soil by leaching.

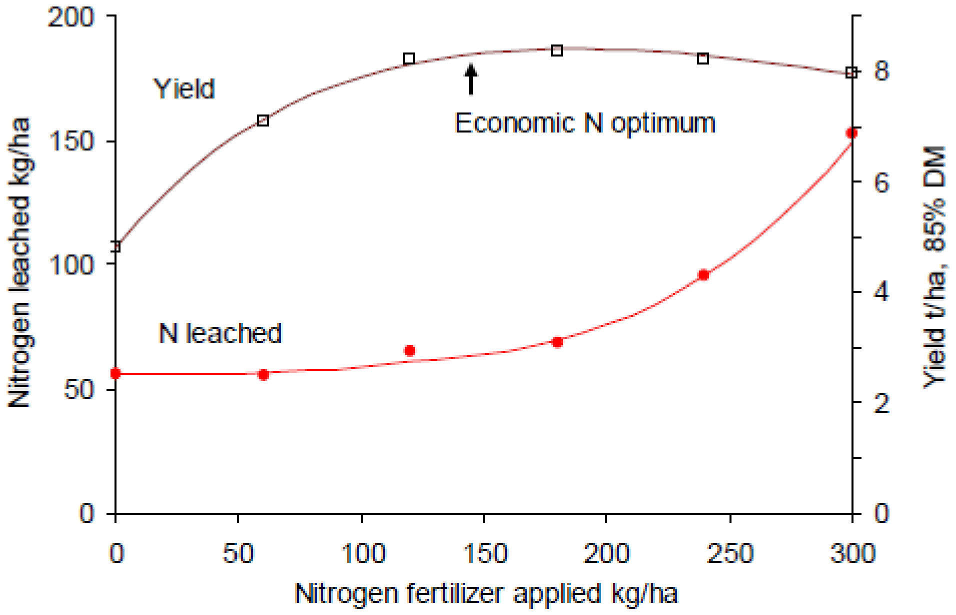

Figure 4.1.1.1.1. Impact of manufactured fertiliser nitrogen applications on winter wheat yields and nitrate leaching losses (Lord and Mitchell, 1998)

Nitrogen applications to arable crops that supply less than economic optimum will result in sub-optimal crop yields and quality whilst applications that exceed crop requirement will increase the risk of nitrate leaching (Figure 4.1.1.1.1; Lord and Mitchell, 1998). For grassland, nitrogen applications are important for increasing grass dry matter yields (Figure 4.1.1.1.2, Newell Price *et al.,* 2016a), however the risks of nitrate leaching increase with increased fertiliser nitrogen applications (Figure 4.1.1.1.3; Johnson *et al.,* 2011).

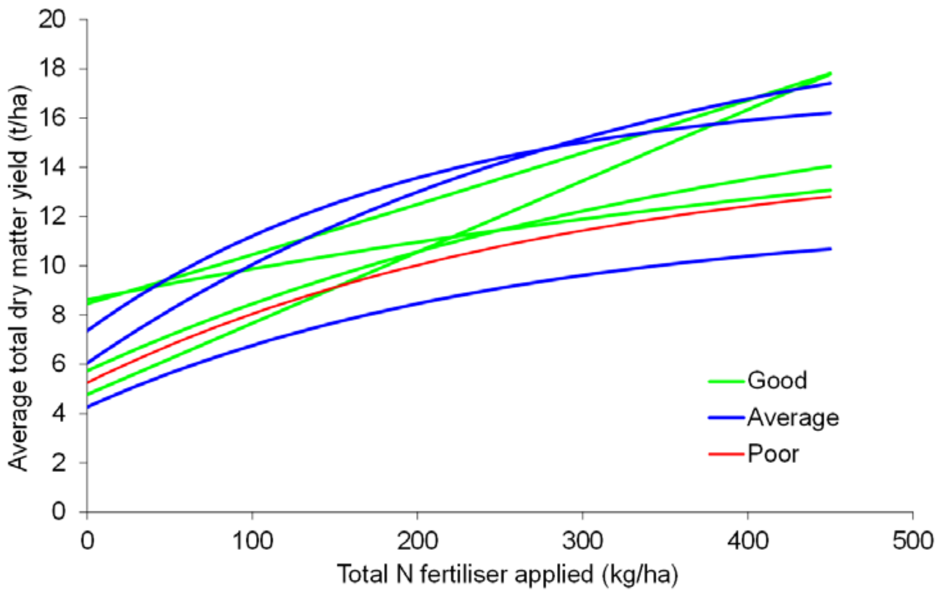

Figure 4.1.1.1.2. Effect of fertiliser nitrogen application on grass dry matter yields at sites with contrasting grass growth potential (Newell Price *et al.,* 2016a)

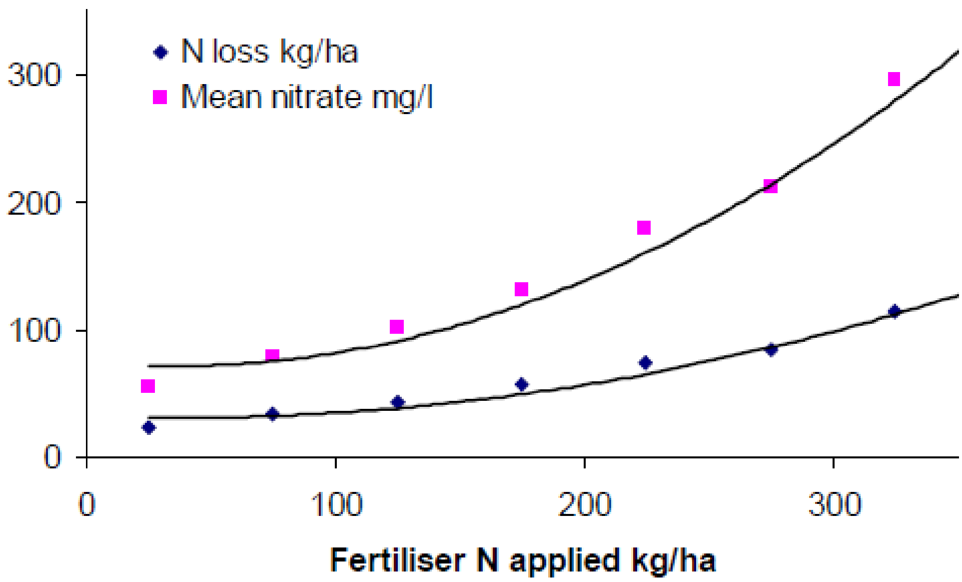

Figure 4.1.1.1.3. The effect of nitrogen fertiliser applications on drainage water nitrate concentrations and nitrate leaching losses (Johnson *et al.,* 2011)

Nitrous oxide emissions occur from soils as a result of the microbially mediated processes of nitrification and denitrification. Factors that affect nitrous oxide emissions include soil moisture content, temperature and mineral nitrogen content. Generally nitrous oxide emissions are related to nitrogen inputs from manures and fertilisers with elevated emissions where nitrogen supply exceeds crop requirement (Figure 4.1.1.1.4; Cardenas *et al.,* 2010).

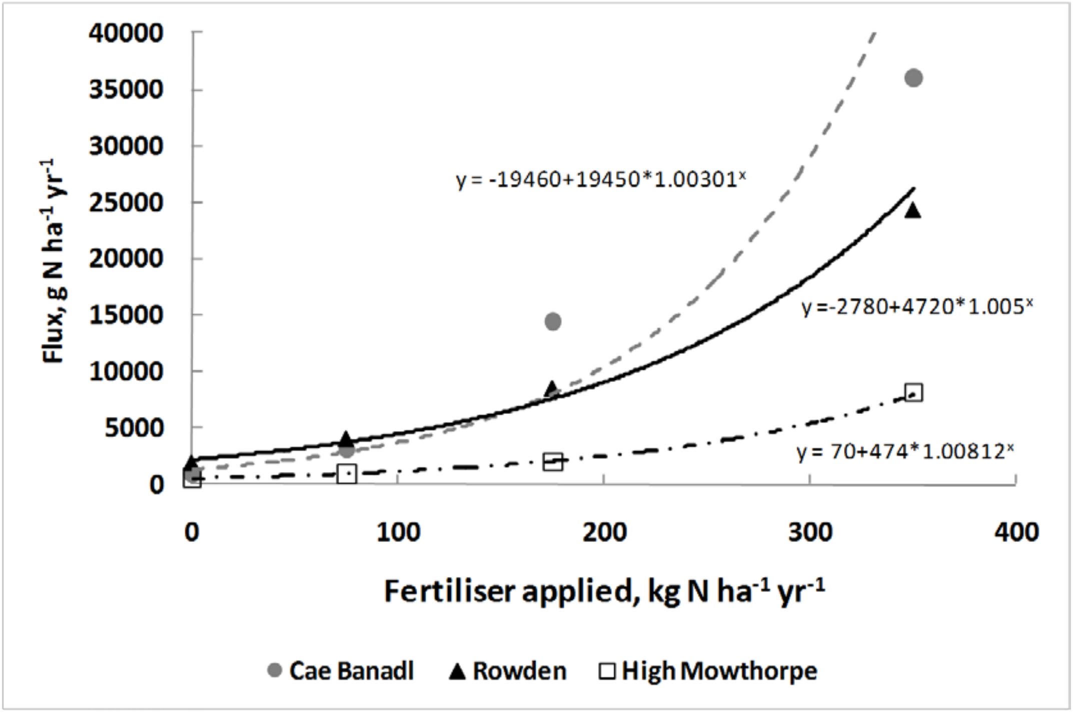

Figure 4.1.1.1.4. The effect of manufactured fertiliser nitrogen application rate on nitrous oxide emissions at 3 contrasting grassland sites (Cardenas *et al.,* 2010).

4.1.1.2 Phosphorus

A large proportion of phosphorus (P) in soils is bound in forms that are not readily available to the plant or at risk of leaching to water (i.e. fixed or residual P), because of the strong affinity that some soil substances (clays, iron-Fe/aluminium-Al/calcium-Ca) have for P (Holford, 1997). Consequently, managing crop available P supply is based on maintaining sufficient amounts in the soil for the needs of a crop rotation rather than an individual crop.

AHDB's Nutrient Management Guide (RB209) uses a soil P index system (based on the Olsen extractable P levels in topsoil) to provide guidance on P supply from manufactured fertilisers and organic materials. For grassland and most arable crops the target soil P index is 2 (16-25 mg/l Olsen P – marked with a green vertical bar on Figure 4.1.1.2.1). For soils below the target index it is recommended to apply P at rates that exceed crop offtake to ensure optimum crop yields and to build up soil reserves. Where soils are at target index, fertiliser rates should match crop offtake to maintain soil fertility at optimum levels and where soil P levels are above target index, P fertiliser applications are not recommended as they represent an unnecessary cost and increase the risk of P losses to water (Figure 4.1.1.2.1; Poulton *et al.,* 2013, Heckrath *et al.,* 1995 Withers *et al.,* 2017).

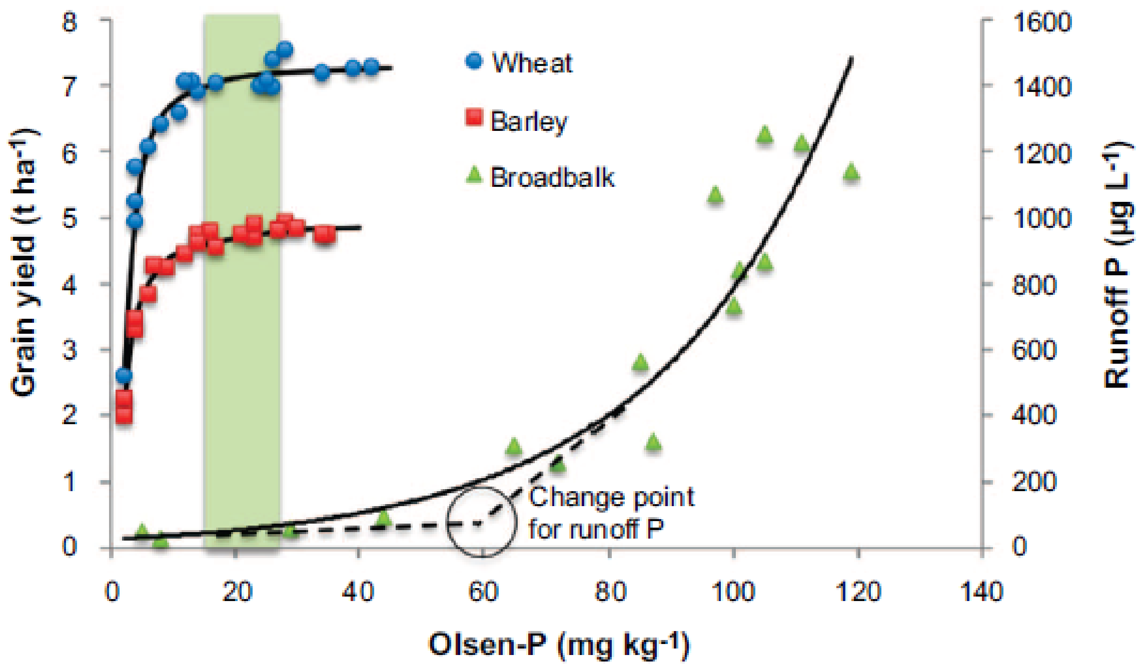

Figure 4.1.1.2.1. The impact of Olsen extractable P levels on crop yields and soluble P losses to water (Poulton *et al*., 2013, Heckrath *et al.,* 1995). Graph taken from Withers *et al.,* (2017).

The extent to which soil is saturated with P will influence the risk of P losses to water. The soil saturation capacity depends on the quantities and forms of Fe, Al and Ca present in the soil and P is more strongly bound in the order Fe>Al>Ca (Withers, 2011). Risks of P loss to water have been reported to greatly increase once P saturation exceeds a threshold of 20-30% (Heckrath *et al*., 1999, Kleinman *et al*., 2000; Nair *et al*., 2004). P saturation threshold broadly equates to Olsen soil P indices of 3, 4 and 5 for sand, loam and clay soils, respectively. Consequently, soils with P indices above these levels represent an increased risk of P losses to water.

4.1.2 Co-benefits and trade-offs

Savings in fertiliser use, as a result of identifying excess nutrient applications, will improve farm profitability by reducing inputs and potentially by increasing crop yields and quality. Where insufficient nutrients have been applied for optimal crop growth, increased fertiliser use will increase crop yields. However, the increased use of nutrients may lead to greater losses to the environment (e.g. elevated nitrous oxide emissions from higher N rates) although under this scenario it is likely that the environmental losses per unit of production will reduce.

On livestock farms matching nutrient supply in animal feeds to achieve optimal livestock production (i.e. not over-feeding protein, which is degraded into nitrogenous compounds in livestock excreta) may lead to reduced feed costs and nutrient loadings on farm.

4.1.3 Magnitude

Understanding to what extent nutrient management planning is currently undertaken will be important in assessing the likely impact of introducing the policy on farm productivity and air and water quality. Information from the Wales Farm Practice Survey in 2012 suggest that 43% of farmers have a soil nutrient plan (Anthony *et al.,* 2012). Other survey data carried out as part of Defra project IF01121 suggested that

30% of grassland farmers had a formal nutrient management plan. The survey also suggested that 30% of grassland farmers had no plan or applied the same amount of fertiliser each year (Newell Price *et al.,* 2016a).

Newell Price *et al.,* (2011) suggested that the use of fertiliser recommendation systems had the potential to reduce nitrogen and phosphorus losses to water and ammonia and nitrous oxide emissions to air by c.5%. The impact would depend on the current level of nutrient use and the extent to which manure nutrients were being accounted for when planning manufactured fertiliser applications.

Data from the British Survey of Fertiliser Practice (2018) indicate 88% of tillage land and 52% of grassland in England and Wales received applications of manufactured fertiliser nitrogen in 2017. Average field rates for tillage land were 159 kg/ha N compared with 98 kg/ha on grass. Fertiliser phosphate was applied to 44% of tillage land and 30% of grassland in England and Wales with average field rates of 59 kg/ha P_2O_5 on tillage land and 22 kg/ha P_2O_5 on grassland, respectively. An estimated 34% of grassland and 22% of tillage land in England and Wales received applications of organic manure in 2017. Others have found that the extensive systems that typify much of the low-input livestock farms in Wales are often under-applying nutrients (Gibbons et al., 2014). This inevitably restricts yield potential, leading to higher economic (and possibly environmental) costs of increased supplementary feeding with concentrates. These studies suggest that the scope for reducing nutrient inputs in Wales is limited to those farms with high levels of fertiliser and manure use.

4.1.4 Timescale

A programme of nutrient management planning could be introduced across Wales within 5 years. An education/ demonstration programme is likely to be required to provide sufficient information for farmers not actively managing nutrient inputs to implement nutrient management plans. An on-going programme of knowledge exchange would be required in order to update farmers and maintain good practice. Such a programme should build on the existing programme of advisory visits and support provided by Farming Connect https://businesswales.gov.wales/farmingconnect/advisory-service.

4.1.5 Spatial issues

Nutrient management planning will be most effective on all farms where manufactured fertilisers and organic materials are applied to land regularly to support crop yields. These farms are likely to include dairy, specialist beef, specialist sheep, arable and horticulture production systems, which cover 750,000 ha - equivalent to c.40% of agricultural land in Wales. In high output systems, effective nutrient management is essential to underpin economic performance. In these systems, replacing nutrients taken off by crops with manufactured fertiliser or applications of organic materials (e.g. livestock manures, biosolids, compost, digestate etc.) is essential to maintain optimum crop yields and quality.

In extensive systems (e.g. upland beef and sheep enterprises) and on land where yield potentials are limited by factors such as climate, soil depth and topography (e.g. ALC groups 4 and 5), detailed nutrient management planning will be less important to farm productivity.

4.1.6 Displacement

Improving utilisation of manure nutrients will reduce the need for manufactured fertiliser inputs to optimise crop available nutrient supply. Reductions in fertiliser N use will reduce the need for energy intensive fertiliser production and reductions in fertiliser P use will reduce the need for imports of phosphate fertilisers produced from finite resources of rock phosphate.

Optimising production in Wales, including improving nutrient use efficiency, reduces the need to import food from parts of the world where the environmental impact of food production may be greater. It will also help spare land from habitat loss in other parts of the world (e.g. Loos *et al*., 2018).

4.1.7 Climate interactions

Climate change may lead to changes in growing season, yield potentials and cropping patterns etc. It will be important to update recommendation systems to adapt to changing growing conditions.

4.1.8 Social and economic barriers

Nutrient management planning will inevitably require access to decision support systems that provide guidance on crop nutrient requirement, fertiliser application rates based on soil analysis and information on the crop available nutrient supply from manure applications. Lobley (2015) suggested that farmers with formal nutrient management plans tended to have an agricultural qualification and worked on larger farms, particularly dairy.

A number of reviews have suggested that decision support systems are often not used by farmers reflecting concerns over complexity, usability and cost-effectiveness (Rose *et al.,* 2016; Williams *et al.,* 2017). Consequently there is a need to provide technical support and guidance to farmers to support the implementation of nutrient management plans. Agronomists and advisers represent trusted and credible sources of nutrient management advice on farms (AIC, 2013) and play an important role in translating research findings into practical messages that can be easily applied by farmers.

The need for valued and trusted advice, including clear explanation of demonstrable benefits and ease of implementation (Kuehne *et al*, 2011; Defra 2013) is especially important to encourage changes in farm practice which may involve investment in farm infrastructure (e.g. investment in application equipment and slurry storage facilities). The requirement to keep records, take soil samples and use decision support tools to draft nutrient management plans will inevitably add direct and staff costs to farm businesses.

There is a need to ensure that advisers are well trained and competent to provide advice. The Fertiliser Advisers Certification and Training Scheme (FACTS) sets standards and provides training and accreditation for crop nutrient management advisers in the UK.

Where farm biodiversity is of value, advisors may need to tailor advice to maintain (and enhance) biodiversity, as opposed to tailoring advice for yield growth.

A significant potential economic barrier is the ability of many farmers to act on the advice provided by the soil nutrient management plan. For instance, it is known that many livestock farms are deficient in lime, but anecdotally, although they would wish to act on the advice to apply lime, they do not possess the working capital to be able to do so. This may at least partially explain why the intentions of soil nutrient management plans are commendable, their value in delivering change might be impeded by other factors.

4.1.9 Metrics and verification

The following metrics would help quantify overall nutrient use efficiency

- At a national level; statistics on fertiliser use and agricultural production productivity (e.g. British Survey of Fertiliser Practice, June census data etc.)
- At a farm level; benchmarking farm performance by assessing productivity compared to nutrient inputs.
- Changes in water quality identified from local, regional and national monitoring programmes over time.

Information from farm practice surveys on nutrient management practices including slurry storage capacities, method and timing of manure application, would also be useful to inform models used to quantify the impact of measures to improve nutrient use efficiency on diffuse pollution at farm, catchment, regional and national scales.

5 Evidence Gaps

There is a need to collect farm activity data to inform models to establish a robust baseline of diffuse pollution from Welsh agriculture. Information collected should include the extent to which nutrient management planning is used on farms, as well as information on key farm infrastructure such as slurry storage capacities and the use of precision slurry application technologies and other diffuse pollution mitigation practices. The surveys should be repeated periodically to quantify the impacts that changes to nutrient management practice resulting from the implementation of supportive and regulatory measures have on nutrient use efficiency and diffuse air and water pollution.

There is a need to ensure that decision support tools are maintained and available to farmers in formats that are easily accessible and simple to use.

The impacts of the relative importance of good soil physical health (e.g. compaction) can impact on nutrient use efficiency should be determined, and the findings conveyed to industry that such factors must be remedied before nutrient applications are altered. Similarly, how soil type and other geographical factors (e.g. rainfall, elevation) are considered within soil nutrient management plans needs to be evident.

There is a need to determine how nutrient demands vary between different species mixtures. For instance, much of the nutrient application advice for grassland will be based on the demands of a productive grass sward, dominated by perennial ryegrass (*Lolium perenne*). Many permanent pastures are far-removed from such swards and less responsive to nutrient applications, therefore there is risk that advice given may be erroneous. In the same vein, there is increasing interest in growing mixed-species leys (e.g. inclusion of deep-rooting species such as chicory and plantain). The nutrient demands of such leys (taking into account, for instance, nitrogen supply by the inclusion of clover) needs consideration.

6 Summary

A high level summary of our conclusions is presented in Table 6.1.

Confidence	Intervention name	Key Outcomes	Key Benefits	Any critical concerns
Blue	Use of soil nutrient management plans on improved agricultural land	Sustainable nutrient use Improved manure nutrient use efficiency Reductions in diffuse air and water pollution	Enhanced farm profitability Reduced risks of: Nitrate and phosphorus losses to water Direct and indirect nitrous oxide emissions Ammonia emissions	Only effective on high output grassland, arable and horticultural systems. Difficult to quantify the impact without the collection of farm practice activity data.

Table 6.1: Key outcomes, benefits and critical concerns associated with supporting the uptake of Soil Nutrient Management Plans.

Colour Key:

- Blue = well tested at multiple sites with outcomes consistent with accepted logic chain. No reasonable dis-benefits or practical limitations relating to successful implementation.
- Amber = agreement in the expert community there is an intervention logic chain which can be supported but either evidence is currently limited and/or there are some trade-offs or dis-benefits which WG need to consider.
- Pink = either expert judgement does not support logic chain and/or whilst logic chain would suggest it should work there is evidence of one or more of the following:
    - its practical potential is limited due to a range of issues (e.g. beyond reasonable expectation of advisory support which can be supplied and/or highly variable outcome beyond current understanding or ability to target),
    - the outcome/benefit is so small in magnitude with few co-benefits that it may not be worth the administration costs,
    - there are significant trade-offs.

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