The role of balanced nutrition in sustainable agriculture

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Introduction

Sustainable agriculture requires farmers to be profitable so they can concurrently produce food and enhance the environment. The inextricable linkage between productive, profitable farming and environmental enhancement needs to be reflected in policy and practice if the sector is to meet its multi-faceted societal demands in both the short and longer terms.

Nutrients from all sources including soils, organic manures and mineral fertilisers are a pivot point in striking the balance between productive agriculture and environmental enhancement. We need nutrients to grow sufficient, nutritious food for an increasing global population. However, nutrients in excess – particularly nitrogen and phosphorus – can have a significant detrimental impact on climate change and soil, air and water quality. The potential environmental impacts of excess nutrients are increasingly reflected in policy and regulations at global, EU and national levels, although it is debatable whether there is sufficient linkage with profitable, productive farming.

Given the pivotal role of nutrients in sustainable agriculture, there is an inherent responsibility on the fertiliser industry to provide products and services that enable farmers to be productive and protect the environment when using fertilisers. In accepting this responsibility, the industry needs to reflect on current practice, to understand the challenges and to improve what we do. The status quo is not an option.

Managing nutrients efficiently is complex, involving multiple biological, chemical and physical interactions between soils, crops, livestock and humans, and also uncontrollable variables such as climate. There is a lot talked and written about improving nutrient management planning and increasing nitrogen use efficiency. The challenge is to take this off the page and put it into practice which will inevitably mean taking a more complex approach to fertilisers than is currently the case.

The authors contend that a balanced, prescriptive approach to nutrition is the most significant contribution the fertiliser industry can make to sustainable agriculture. The paper will outline the drivers behind balanced, prescription nutrition and give an insight into recent and ongoing trial work.

The need for balanced nutrition

Although there are six macro-nutrients (nitrogen, phosphorus, potassium, sulphur, calcium magnesium) and at least seven micro-nutrients (boron, chloride, copper, iron, manganese, molybdenum and zinc) considered essential for plant life, the fertiliser industry has traditionally focussed on nitrogen, phosphorus and potassium and, more recently, sulphur. Micro-nutrients have largely been managed independently of macro-nutrients for grassland and tillage by the animal feed and crop protection sectors respectively.

Balanced nutrition implies extending the focus beyond N, P and K through an integrated approach to nutrient management planning to determine the specific nutrient requirements at crop or individual field level, and then matching them through prescription fertiliser formulations. Prescription nutrition is already well-established practice in the UK, USA, New Zealand and throughout Northern Europe, is emerging in many more countries and is likely to continue to grow as more farmers and advisors realise the agronomic, economic and environmental benefits.

Figure 1 shows the rate of increase in unique fertiliser analyses from one blender in Great Britain whose product catalogue has grown from 250 individual products in 2011 to nearly 18,000 in 2023, with new analyses added daily. The split between tillage and arable is c. 70% / 30%. Not only is the number of grades increasing but the number of nutrients that can be included has increased from 5 or 6 a decade ago to 15 now, as well as additives such as urease and nitrification inhibitors. This represents a significant level of complexity in terms of both nutrition agronomy and fertiliser production, which in turn reflects the complexity of efficient nutrient management referred to above.

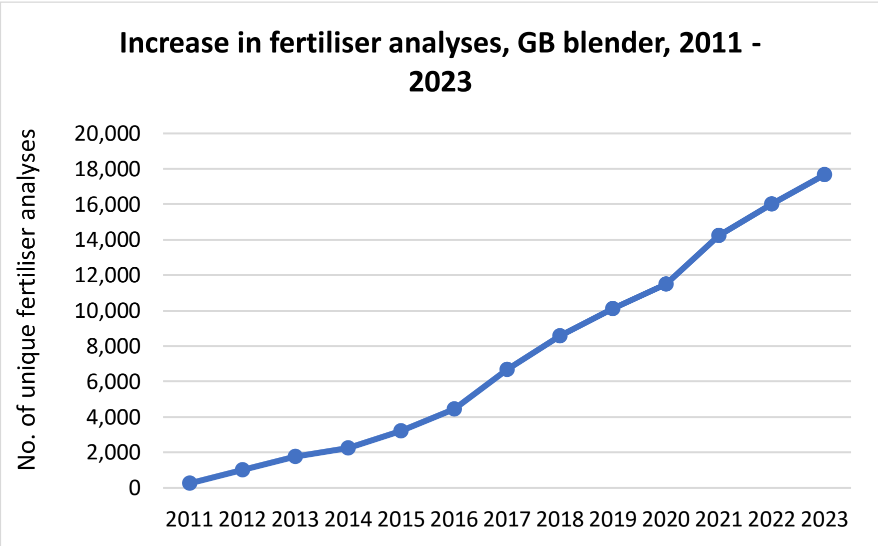


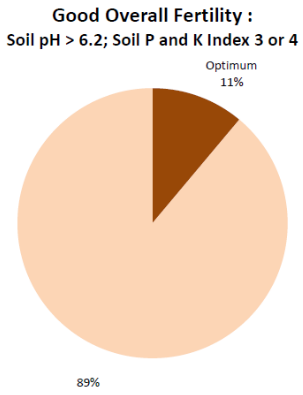
Figure 1: Number of unique fertiliser analyses over time from one GB blender

Several factors are driving the increasing demand for balanced, prescription nutrition including addressing imbalances in soil fertility, improving crop yield and quality and environmental policy, as discussed below.

Soil fertility

The Fertilizer Association of Ireland, Teagasc and others have published several papers and reports on soil fertility, so the topic is not covered in detail here other than in the context of how it relates to balanced, prescription nutrition.

There is broad understanding and consensus on the importance of soil fertility to agricultural productivity and mitigation of environmental impacts, particularly in relation to optimising nitrogen use efficiency and minimising nutrient losses to air and water. For example, we know the risk of nitrous oxide emissions are reduced from soils with optimal pH and that available P and K are important factors in maximising nitrogen use efficiency. It is therefore encouraging to note the improvements in overall soil fertility in Ireland in recent years, with 19% of all soils analysed by Teagasc in 2022 at 'good overall fertility' – i.e. pH > 6.2; P and K index 3 or 4 – compared to 11% for the same parameter in 2014 (Teagasc, 2023 and Teagasc, 2014). That said, there is still self evidently a lot to do given 81% of all soils tested were suboptimal in relation to 'good overall fertility'.



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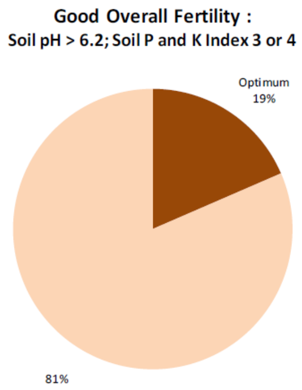

2022

Figure 2. Percentage of all soils tested with good overall fertility, 2014 and 2022 (Source: Teagasc Soil Atlas 2014 and Teagasc Soil Report 2022)

Although an encouraging trend, it is important to look behind national data and focus on farm and individual field scale if we are to effect significant change in soil fertility. There is a lot of variability in soil fertility between fields within individual farms. The data in Figure 2 is from a total of 36,336 soil tests in 2014 and 38,134 tests in 2022. We need to consider whether the inherent complexity within this data is properly reflected in fertiliser practice and manure management at individual field level. In other words, are we using soil test data to effect changes in fertiliser practice? A blanket approach to fertiliser planning across all fields is unlikely to achieve the outcomes we want (Wall, 2019).

Current fertiliser practice

There were 655,292mt of compound fertilisers sold nationally in 2022-23 (1st October 2022 – 30th September 2023), (DAFM, 2023). The total compound market was supplied with fewer than 100 different analyses and five products accounted for 71.7%, namely 18-6-12 (25.1%); 27-2.5-5 (17.4%); 24-2.5-10 (14.6%); 10-10-20 (7.7%) and 24-2.2-4.5 (6.9%). The average nutrient content of all compounds was 19.65% N – 4.78% P – 11.86% K, which is unsurprising given that 18-6-12 accounts for 25% of the total compound market.

It is unlikely this compound fertiliser practice fully reflects the variability in soil fertility within and between farms, the information obtained from 38,000 soil tests and the appropriate balance between nutrients from organic manures and mineral fertilisers. Analysis of compound fertiliser sales indicates a commoditised market with a largely blanket approach to selection of analyses and, arguably, a need for greater innovation and product development beyond N, P and K.

Forage quality

Livestock farming in temperate grasslands is a sector that is perfectly positioned to adopt and take advantage of balanced, prescription nutrition. Forage is largely grown for consumption on the farm, i.e. an 'internal market' where the farmer can determine their own crop 'specification' in terms of nutritional value and mineral composition. Nutrients can play a key role in influencing the nutritional value, mineral composition and intake of forage, particularly if a prescriptive approach is taken.

Table 1. Typical concentrations of N, P, K and S in a tonne of grass DM, and the uptake of each nutrient in a full year by swards growing 16t/ha of grass DM (source: Wall, 2019)

Nutrient	Typical nutrient concentration in grass (kg/t DM)	Total uptake required for 16t/ha DM (kg/ha)
N	34.9	558
P	4.1	67
K	29.7	475
S	2.9	46

Table 1. shows the nutrient concentration for N, P, K and S in grass on a dry matter basis and the total uptake of each nutrient across the growing season based on a dry matter yield of 16 tonnes per ha. Understanding the amount of each nutrient required per tonne of dry matter is essential in improving nutrient management. However, we need to take this a stage further to include a wider spectrum of nutrients and consider the relationships between the mineral content of forage and its feed value.

For example, there is a well-established relationship between the ratio of nitrogen and sulphur in forage and protein content, with the optimal N:S being ≤ 15:1 and a minimum critical sulphur content of 2.0kg S per t DM, or 0.2% S (Wall, Plunkett, 2020). The N:S ratio shown in Table 1. is 12:1 so is optimal. However, in situations where the N:S ratio is higher than 15:1 then additional S is required to avoid deficiency.

The ratio of potassium to both magnesium and sodium has a direct influence of the risk of hypomagnesaemia with the risk being considerably reduced when K:Mg and K:Na and less than 20:1, and ideally < 10:1. Therefore, forage containing 29.7kg K per tonne DM should contain a minimum of 1.5kg/t DM of both magnesium and sodium and, ideally, 3.0kg/t DM.

This approach can also be applied to micro-nutrients. The average level of selenium in forage is < 0.07mg/kg DM, well below the optimum dietary level for cattle of 0.3mg Se/kg DM (NRC, 2001). Rather than treating the animal, it makes sense to fertilise grass with selenium to bring the cornerstone of the diet up to optimum levels. There has been a lot of work done in Ireland on the benefits of selenium fertilisation and several compounds are available containing selenium. Perhaps we need to expand this now to include other micro-nutrients such as copper, cobalt, iodine and zinc?

Although we understand the typical amount of each nutrient per tonne of forage dry matter, there is a knowledge gap in the temporal variation of the mineral content of forage throughout the growing season, which makes interpretation of fresh forage analysis difficult. Origin Fertilisers has funded broad-spectrum mineral analysis of forage samples from the GrassCheck NI and GrassCheckGB grass monitoring projects throughout the growing seasons of 2021, 2022 and 2023. Sixteen nutrients were analysed in every sample: N, P, K, S, Ca, Mg, Na, B, Co, Cu, Fe, I, Mn, Mo, Se and Zn.

The project has generated multiple data points of forage mineral content from March to October over three growing seasons throughout the UK. The mineral data is also being overlaid with the nutritional analyses to better understand correlations between them. The data is currently being analysed with a view to informing temporal variation in forage mineral content and improving the interpretation of fresh grass analysis, which could be a useful diagnostic tool in fine-tuning prescription fertiliser programmes and their role in producing high quality, nutritious forage.

There is further information on the role of prescription nutrition on forage yield and quality in the sections on trial work below.

Environmental policy

Mineral nitrogen fertilisers account for c. 40% of nitrous oxide emissions from the agricultural sector (DAFM, 2020), 8.9% of total national ammonia emissions (EPA, 2023) and are a significant contributor to nitrate levels in water. The 'Farm to Fork Strategy' is at the heart of the EU Green Deal and calls for a 20% reduction in use of mineral nitrogen fertilisers within Member States by 2030 to meet environmental targets (EU, 2020). Ireland has gone further than this with the Climate Action Plan 2024 committing to a reduction in mineral nitrogen of 19.1% by 2025 and 26.5% by 2030 from a base of 408,000mt mineral N in 2018 (Irish Govt., 2023).

Table 2. Required changes in fertiliser formulation and practice to reduce nitrous oxide emissions (source: Climate Action Plan 2024, Irish Govt., 2023)

Theme	2025 KPI	2025 abatement (vs 2018) $MtCO_2eq.$	2030 KPI	2030 abatement (vs 2025) $MtCO_2$ eq.	2031-2035 measures
Reducing Chemical N Use	Maximum usage of 330,000 tonnes	0.4 – 0.45	Maximum usage of 300,000 tonnes	0.1 – 0.2	Ensure that new mitigation technologies and innovations are adopted as they become available through incorporation in agri-food strategy and policy
Increased Adoption of Inhibited Urea	Target 80%-90% replacement of CAN with Inhibited urea	0.35 – 0.45	Target 90-100% replacement of CAN with Inhibited urea	0.08 – 0.12	

The challenge for Irish agriculture is to implement this reduction in mineral nitrogen use whilst maintaining productivity. There are a wide variety of potential mitigation measures proposed within AgClimatise 2020 (DAFM, 2020) and Pathway 2 of the Teagasc Marginal Abatement Cost Curve (MACC) 2023 (Teagasc, 2023), including:

- Increasing lime applications to 2.0Mtpa by 2030
- Increased use of clovers and other legumes
- Low emission slurry spreading
- Switching 100% of straight urea and 95% of CAN to protected urea – refer to Table 2. above
- Switching 65% of compounds from nitrate-based to ammonium-based – refer to Table 2. above
- Reducing the average age of finishing prime beef cattle by 3 months

It is beyond the scope of this paper to fully evaluate environmental policy in relation to nutrients. Rather the focus is on what role balanced, prescription nutrition can play in implementing some of the above measures aimed at mitigating the effects of reduced mineral nitrogen fertiliser on productivity.

Balanced, prescription nutrition in practice

Balanced nutrition implies extending the focus beyond N, P and K through an integrated approach to nutrient management planning to determine the specific nutrient requirements at crop or individual field level. Prescription fertilisers can then be formulated to provide an exact match with these specific nutrient requirements as shown in Tables 3. and 4. below.

Table 3. Nutrient requirements for an individual field of grass silage, Scotland, 2023

Nutrient requirement (kg/ha)						g/ha
N	P	K	S	Mg	Na	Se
90	10	80	8	5	7.5	5

Table 4. Prescription fertiliser to match nutrient requirements in Table 1

Prescription fertiliser, nutrient analysis % by weight						
N	P	K	S	Mg	Na	Se
15.9	1.8	14.2	1.4	0.9	1.3	0.001

The nutrient requirements in Table 3. for an individual field of grass silage in Ayrshire, Scotland were established by the farmer's advisor taking account of broad-spectrum soil analysis and mineral analysis of a previous silage crop from the same field. The farmers fertiliser supplier formulated an analysis to provide an exact match for each of the seven nutrient requirements when the fertiliser is applied at 565kg/ha, Table 4.

CAN and protected urea-based prescription compound fertilisers

The small plot replicated trial described below was conducted by the National University of Ireland, Galway (NUI) in 2019. It compares standard analysis compounds – one complex, one blended – against two prescription compounds – one CAN-based and one protected urea-based (PU). The analysis of the prescription fertilisers was based on a broad-spectrum soil analysis of the trial site. The hypothesis of the trial was to assess whether prescription blended compounds – either CAN or protected urea based – could increase grass yield and quality compared to a *'standard analysis'* compound. The trial was based on a 2 cut-system (1st cut 1st June; 2nd cut 14th August) with fertiliser treatments applied 6 weeks before each cut. Each treatment was replicated four times using a random block design.

Table 5. Soil analysis of the NUI trial site for complex vs. prescription blend trial

Analysis	**Result**	**Guideline**	**Interpretation / comments**
pH	6.8	6.5	Higher than optimum for grass
Phosphorus (mg/l) Morgans	5.7	5.1 – 8.0	Teagasc index 3 (medium)
Potassium (mg/l) Morgans	73	101 – 150	Teagasc index 2 (low)
Magnesium (mg/l) Morgans	129	51 – 100	Teagasc index 4 (sufficient / excess)
Sulphur (mg/l)	6	10	Low; apply S for optimal growth
Sodium (mg/l)	39	90	Very low; soil applied sodium can improve palatability
Selenium (mg/l)	0.23	1.5	Very low; priority for animal health

From the soil analysis in Table 5., the 'best fit' analysis of commercially available 'standard' compounds was 24-2.5-10. This analysis was used as the control, treatment no. 1. Treatment no. 2 was a high-quality blend made in accordance with the European Fertiliser Manufacturers Association Handbook, (EFBA) and the same analysis as treatment no. 1, i.e. 24-2.5-10. Treatments no. 3 and no. 4 were prescription blended compounds, the analysis of which took account of the low soil levels of potassium, sulphur, sodium and selenium. Treatment no. 3 was CAN-based and treatment no. 4 was protected urea based. The fertiliser analyses, total application rates across two applications and the amounts of nutrient applied are summarised for each treatment in Table 6. below.

Table 6. Treatment list for NUI trial comparing complex compound and prescription blend

Trt. no.	Product type	Fertiliser analysis	kg/ha	Nutrient applied (kg/ha
1	Complex compound	24-2.5-10	500	120-12.5-50
2	Blended compound	24-2.5-10	500	120-12.5-50
3	Prescription blended compound (CAN-based)	19-2-9 + 2.5 S, 3.0 Na, 0.001% Se	633	120-12.5-57 + 15.8 S + 19 Na + 6.33g/ha Se
4	Prescription blended compound (PU-based)	24-2.5-11.3 + 3.1 S, 3.7 Na, 0.00125% Se	500	120-12.5-57 + 15.8 S + 19 Na + 6.33g/ha Se

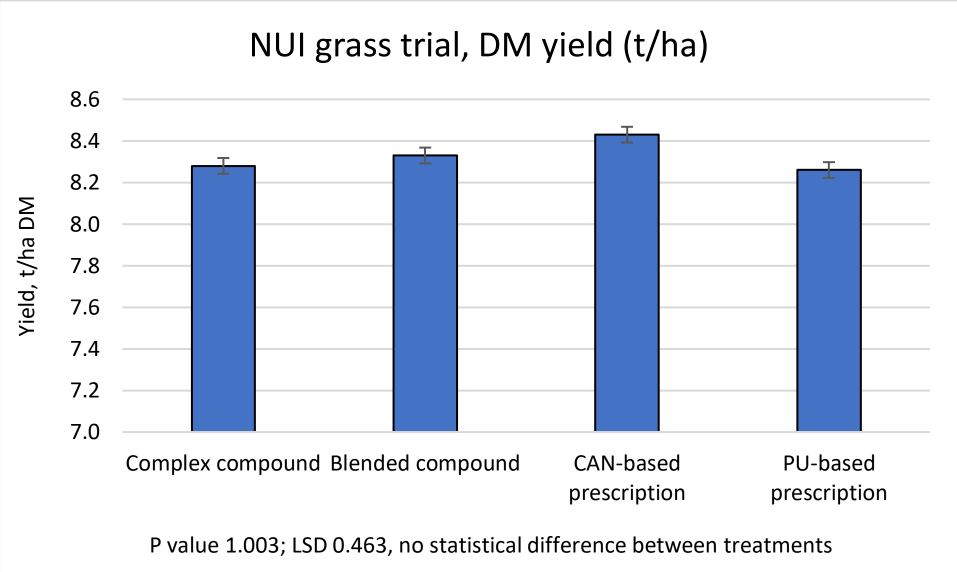

Figure 3. Dry matter yield across 2 cuts from different fertiliser treatments

Figure 3. above shows there were no statistical differences between treatments for total dry matter (DM) yield. However, Table 7. below shows that both prescription compounds improved forage nutritional quality compared to the *'standard'* compounds with higher levels of crude protein and energy from the CAN-based prescription treatment and higher levels of water-soluble carbohydrate from both the CAN-based and PU-based prescription compounds.

Table 7. Forage quality measurements from different fertiliser treatment

Trt. no.	Product type	Crude protein	Energy	WSC	D-value
		kg/ha	KJ/ha	kg/ha	
1	Complex compound	1,937	84,870	429.7	65.54
2	Blended compound	1,835	86,215	430.7	65.87
3	Prescription comp (CAN-based)	2,082	88,009	529.4	66.15
4	Prescription comp (PU based)	1,882	86,234	523.7	66.54

Table 8. below shows that the additional sulphur (S), sodium (Na) and selenium (Se) applied in both the CAN-based and PU-based prescription blended compounds led directly to higher levels of each nutrient within the forage. Although not analysed, it is probable that the higher S levels and lower N:S ratios in both the prescription treatments compared to the *'standard'* treatments will have led to higher levels of amino acids, or true protein. Similarly, there is a probable correlation between the increased sodium concentrations and the higher water-soluble carbohydrate levels in both prescription treatments compared to the *'standard'* treatments. The selenium level in the forage from treatments nos. 1 and 2 is critically low, whereas the level in treatments no. 3 and no. 4 is at the minimum dietary recommendation for cattle (0.1mg/kg Se).

Table 8. Forage mineral content and nitrogen to sulphur ratio (DM basis)

Trt. no.	**Product type**	**Forage mineral content (%)**					Se (mg/kg)	N:S ratio
		N	P	K	S	Na		
1	Complex compound	3.74	0.268	1.644	0.197	0.275	0.036	19:1
2	Blended compound	3.52	0.274	1.473	0.192	0.281	0.033	18:1
3	Prescription comp (CAN based)	3.95	0.236	1.684	0.308	0.428	0.109	13:1
4	Prescription comp (PU based)	3.64	0.289	1.630	0.308	0.440	0.108	12:1

With the benefit of hindsight, Table 8. also highlights 'errors' made in determining the nutrient analysis of the prescription blended compound, e.g. the potassium (K) level should have been higher as it is sub-optimal in the forage, probably due to a combination of low soil K levels initially, high summer rainfall and a free-draining sandy loam soil type. However, the data shows sufficient evidence to conclude that the prescription fertilisers increased the nutritive value and mineral content of the forage compared to the *'standard'* treatments.

Prescription compounds at reduced nitrogen inputs

If we were to repeat the above trial now, we would look at reducing the nitrogen inputs in the prescription treatments to see if balanced nutrition could mitigate a lower N input. To test the hypothesis of prescription nutrition mitigating lower N inputs, a trial was conducted by Eurofins near Mountrath, Co. Laois in 2023. The trial was designed to compare the effect on grass yield over 2 cuts between a *'standard'* compound fertiliser (treatment no. 1) and a prescription fertiliser (treatment no. 2) at 15.9% less nitrogen, see Table 9. below.

Table 9. Treatment list for Eurofins trial comparing complex compound and prescription blend

Trt. no.	**Product type**	**Fertiliser analysis**	**kg/ha**	**Nutrient applied (kg/ha) per application**
1	*'Standard'* compound	27-2.5-5	370	100-9-18.5
3	Prescription compound	22.7-2.5-5 + 3 S + Mg, Cu, Mn & Zn	370	84-9-18.5 + 11 S + Mg, Cu, Mn & Zn

The first cut was on 18 May followed by a second cut on 10th August. Each fertiliser treatment was applied at 370kg/ha c. 50 days before cutting. The amount of nutrient applied in each application is shown in table x above. Despite applying 15.9% less nitrogen, the dry matter yield across 2 cuts was

25.2% higher in the prescription fertiliser compared to the *'standard'* treatment. Nutritional and mineral data indicate improvements in dry matter, protein, energy, and nutrient content in the prescription compound which has more than mitigated the 15.9% reduction in N inputs.

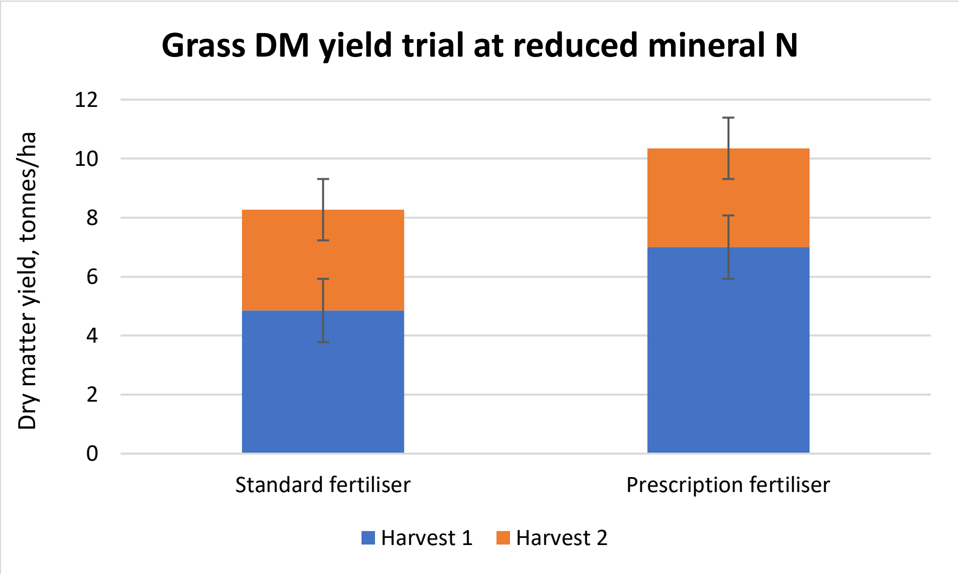

Figure 4. Grass DM yield (t/ha) from 2 cuts comparing standard and prescription fertilisers
Source: Eurofins

Prescription nutrition to increase liveweight gain

With a focus on improving forage quality, particularly the nutritional value and nutrient density, there is potential for prescription fertilisers to play a role in increasing the rate of liveweight gain in livestock. One of the mitigation measures outlined in Pathway 2 of the Teagasc MACC (Teagasc, 2023) is to reduce the average age of finishing prime beef cattle by 3 months.

Although the trial outlined below was conducted on lambs, the same principles could be applied to finishing prime beef. An on-farm trial was conducted in Northumberland in 2021 comparing a prescription fertiliser against straight nitrogen in the context of rearing lambs on grazed grass. As part of the trial, the amount of nitrogen applied by the prescription fertiliser was reduced by 15% compared to the straight nitrogen comparison. The hypothesis of the trial was: *'Can liveweight gain of grass reared lambs be maintained or increased from birth to weaning at 16 weeks with 15% less nitrogen by using a prescription blended compound rather than applying straight nitrogen?'*

The trial was conducted on an 8.4ha field which was split into 2 x 4.2ha blocks. Straight nitrogen was applied at 120kg/ha to Block 1 and Block 2 was treated with a prescription fertiliser which was formulated to apply a total of 101kg/ha N, i.e. 15.8% less nitrogen than Block 1. The nutrient analysis of the prescription fertiliser was based on broad-spectrum soil and forage mineral analyses taken pre-trial in March which highlighted deficiencies in phosphorus, sulphur, sodium, selenium and zinc. The total nutrient applied to each block is summarised in Table 9. below.

Table 9. Nutrient applied to Block 1 (straight N) and Block 2 (prescription compound)

Nutrient applied	**Block 1 (straight N)**	**Block 2 (prescription blended compound)**
Nitrogen (N), kg/ha	120	101
Phosphorus (P), kg/ha		21
Sulphur (S), kg/ha		16
Sodium (Na), kg/ha		26
Selenium (Se), g/ha		6.6
Zinc (Zn), g/ha		132
Total nutrient applied (kg/ha)	120	164.139

Grass cover (kg/ha DM) was measured in each block using a plate meter directly before ewes and lambs were put into the field and at regular intervals throughout the 16-week period of the trial. The grass cover in Block 2 (prescription fertiliser) was higher than in Block 1 (straight N) at the start of the trial; 2,180kg/ha DM cf. 1,905kg/ha DM. Despite supplying 15.8% less N, the prescription fertiliser maintained a higher level of grass cover throughout the trial, Figure 5. below.

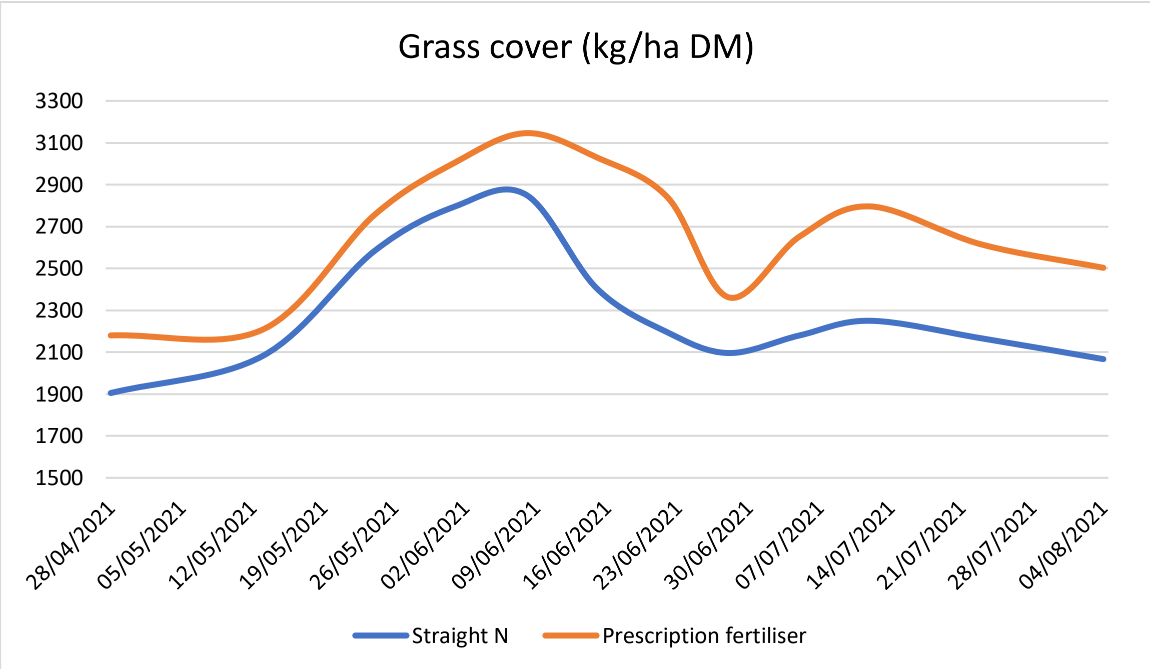

Figure 5. Grass cover (kg/ha DM) for each of the fertiliser treatments

Grass samples were taken from both blocks at regular intervals throughout the trial and analysed for nutritional value and mineral content. Some of the key data from these analyses are detailed in Table 10. Below. The values are the average of all sampling points and dates.

Table 10. Grass analyses for Block 1 (straight N) and Block 2 (prescription blended fertiliser)

Parameter	**Block 1 (straight N)**	**Block 2 (prescription fertiliser)**
Nitrogen (%)	2.46	3.28
Sulphur (%)	0.160	0.293
N:S ratio	15.4:1	11.2:1
Crude protein (%)	15.38%	20.50%

The average N level in Block 2 (prescription fertiliser) was 33.3% higher than Block 1 (straight N) despite applying 15.8% less N. Sulphur was sub-optimal in Block 1 at 0.16% and below the critical level for grass of 0.25%, (RB209, 2022) which is likely to have limited the uptake of nitrogen and the formation of protein. Conversely, the application of sulphur in Block 2 is believed to have stimulated nitrogen uptake and a subsequent increase in protein of 7.57% compared to Block 1.

Each 4.2ha block was stocked with 53 ewes, each of whom had new-born twin lambs (25.2 lambs per ha). The lambs were weighed at birth and again at 8 and 16 weeks and the cumulative weights across the 16 weeks are recorded in Figure 6. below.

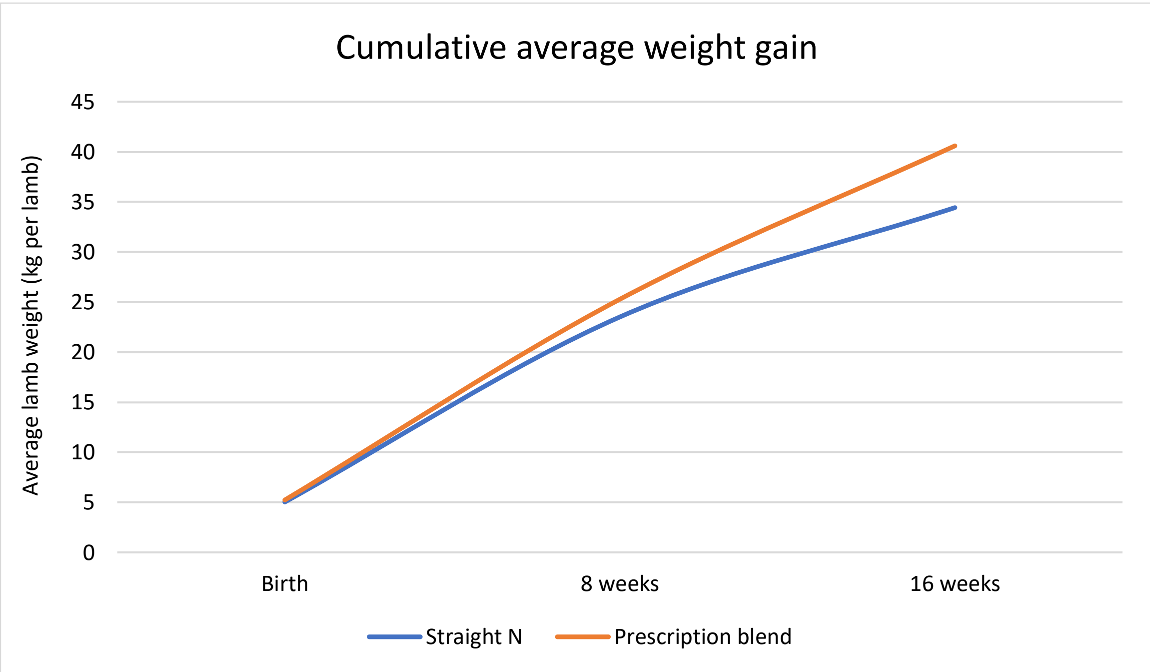

Figure 6. Cumulative average weight gain by fertiliser treatment

The difference in weight gain from birth to 16 weeks was 20.3% higher in the lambs grazed on Block 2, the prescription fertiliser treatment, compared to the lambs grazed on Block 1 which was treated with straight nitrogen. This correlates with the higher levels of grass growth and improved forage quality in Block 2 compared to Block 1 highlighted above.

Although only one trial, the output data from this practical on-farm study summarised in Table 11. below is potentially significant in helping livestock farmers improve their efficiencies and reduce their environmental footprint by matching fertiliser inputs to match specific nutrient requirement.

Table 11. Lamb liveweight gain (LWG) per hectare and per kg of applied N

Parameter	Block 1 (straight N)	Block 2 – prescription fertiliser	Difference +/- %
Inorganic N applied, kg/ha	120	101	- 15.8%
LWG, kg/ha	735	884	+ 20.3%
LWG per kg N	6.13	8.75	+ 42.7%

The increase of 42.7% in LWG per kg of N applied from the prescription blended compound is a potentially significant metric, showing that balanced nutrition can offset a reduction in applied inorganic nitrogen.

From the farmers immediate perspective, a key question was whether there was a positive return on investment (ROI). Based on fertiliser and lamb prices at the time of the trial (spring / summer 2021), the return on investment of the extra cost of the prescription blended compound compared to the straight nitrogen was 4.86:1, i.e. for each additional £1 spent on fertiliser, the additional value of the lamb produced was £4.86.

Switching fertiliser formulations

A key component of AgClimatise and the Teagasc MACC is to switch 100% of straight urea to protected urea and 95% (Pathway 2) of CAN to protected urea. Protected urea as a nitrogen component within prescription compounds could also play a role in reducing nitrous oxide and ammonia emissions and, at the same time, improving forage quality – as seen in the NUI trial above.

The MACC also refers to switching from nitrate-based to ammonium-based compound fertilisers. Teagasc conducted a field trial at Johnstown Castle in 2021 on grass which showed that compounds with a high proportion of ammonium-N to nitrate-N had lower emissions of nitrous oxide compared to those with a higher proportionally higher levels of nitrate-N over two cuts of grass in the June – August period, Table 12. below. The reduction in nitrous oxide emissions was associated with higher N uptake and nitrogen use efficiency in the higher ammonium-N compounds and a reduced risk of denitrification, particularly in relation to the second fertiliser application when conditions were wetter and water-filled pore space (WFPS) was > 70%.

Table 12. Reductions in nitrous oxide emissions cf. CAN from compounds with varying nitrate : ammonium ratios (source: Gebrelmichael *et al*., 2021)

Compound	Ammonium-N % NH_4^+	Nitrate-N % NO_3^-	NO_3^- : NH_4^+	N_2O reduction cf. CAN
18-6-12	11.8	6.2	0.53	44%
10-10-20	9.5	0.5	0.05	43%
24-2.2-4.5	12.8	11.2	0.88	37%
27-2.5-5	15.0	12.0	0.80	31%

Although a limited data set, if a move towards compounds with a higher proportion of ammonium-N is beneficial then it makes sense for all parties to work together to put it into practice. One immediate thought would be to include sulphur from ammonium sulphate within more compounds. An inclusion of 3% S would significantly reduce the nitrate : ammonium ratios in compounds. There should arguably be a greater use of sulphur within compounds and straight N from an agronomic perspective in any case in terms of yield and crop quality response, (Aspell, 2023).

Major UK research project on legumes

One of the mitigation measures outlined in AgClimatise and the MACC is to increase the use of legumes within forage production to reduce reliance on mineral nitrogen fertiliser. The UK Department of the Environment, Food and Rural Affairs (DEFRA) has recently (December 2023) awarded £3.3million in funding to a major on-farm trial and research project that seeks to reduce the dependence of UK grassland farming on applied nitrogen fertilisers.

The project is called Project NUE-Leg (nitrogen use efficiency – legumes) and the objective is to create the conditions in commercial farm settings that will enable clover to fix up to 300 kg of nitrogen per hectare per year, a large portion of which will be available for grass growth. At these levels, additional mineral nitrogen fertilisers needed for grass growth can largely be eliminated.

Project 'NUE-Leg' will exploit major innovations in plant breeding, soil microbiology, nutrition and grassland management to achieve improvements in the capacities of legumes, such as white and red clovers, in combination with soil microbes, to fix atmospheric nitrogen and make this available to grass. New proprietary legume varieties have also been developed by Germinal and Aberystwyth University that improve the efficiency of protein uptake by cattle from grassland thereby reducing emissions of ammonia. Other varieties have been developed which contain tannins that reduce methane emissions by cattle.

The project consortium draws together scientific expertise and global leaders in plant breeding and soil microbiology, agronomy, carbon emissions and the farming and food supply chain. Project partners include Aberystwyth University, Germinal, Origin Enterprises, the James Hutton Institute, Agrecalc, Linking Environment and Farming (LEAF), Dovecote Farm, Pilgrim's Pride, Müller UK & Ireland and the CIEL Innovation Centre.

Project 'NUE-Leg' will deploy a new approach to fertilising and managing grasslands. At the heart of the project are new legumes bred by Germinal Horizon at the Institute of Biological, Environmental and Rural Sciences (IBERS), which is part of Aberystwyth University. Strains of rhizobia have been selected and will be matched with the new legume varieties to help maximise their nitrogen fixing capacity. These innovations will be further enhanced with prescription nutritional packages. Origin Fertilisers will be conducting replicated and farm trials to identify the specific nutritional requirements of these new legume varieties and evaluating whether metallo-catalyst fertiliser coatings can increase nitrogen fixation.

Although NUE-Leg is a UK-based project, it is anticipated the findings will be practically applicable across temperate grasslands in the northern and southern hemispheres.

Conclusions

There is an increasing demand for prescription fertilisers in many countries as agronomist, advisors and farmers aim to match soil, crop and livestock nutrient requirements with inputs as closely as possible to optimise productivity and financial returns. This precision approach to fertiliser inputs could also play a role in helping agriculture achieve a balance between profitable productivity and enhancing the environment by driving improvements in soil fertility, crop yields and quality, nitrogen use efficiency and reduced nutrient losses to air and water.

Balanced, prescription nutrition places a firm focus on determining specific nutrient requirements at individual field level based on broad-spectrum integrated analyses of soils, growing and harvested crops and, when practical, organic inputs. This inevitably involves a more time consuming and complex approach to nutrient management planning. However, nutrient management is an inherently complicated process, and it is reasonable to expect this is reflected as accurately as possible in the nutrients applied as mineral fertilisers, particularly when considered through the lens of environmental impact. Integrated nutrient management and balanced, prescription nutrition could be proactively developed by the industry to create a future 'licence to operate' for the use of fertilisers.

The additional costs and complexities of prescription nutrition will be repaid by a positive return on investment. Whilst this approach may reduce or increase spend on fertiliser at individual farm level, it will ensure the right fertiliser, amount, time and place. With fertiliser prices likely to remain higher than historic levels, it is important to remember that the most expensive fertiliser is the wrong fertiliser. The days of using 18.6.12 because that's what we've always used belong in the past. We should ask ourselves: 'what comes first: the soil analysis or the fertiliser analysis?'

The trial data presented in this paper is a brief overview of a much wider ongoing research programme into balanced, multi-nutrient prescription fertiliser on a range of arable and forage crops. Much has been learned and there is still much to do. To realise the full potential of prescription nutrition will require the fertiliser industry, researchers, knowledge transfer, policy makers, merchants and co-ops and farmers to work much more collaboratively. However, the authors believe the onus is firmly on the fertiliser industry to be proactive, show leadership and drive the innovation towards prescription nutrition. If we don't take ownership there is a risk that we miss the opportunity to shape a future in which balanced nutrition is part of the sustainability solution.

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