THE FERTILIZER ASSOCIATION OF IRELAND

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7th February 2012

Horse and Jockey, Thurles, Co Tipperary

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Food Harvest 2020 and the Demand for Fertilizer

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Teagasc

Introduction

This paper examines the likely future requirements for fertilizer in Irish agriculture in the context of the targets that have been set for agriculture in the Food Harvest 2020 (FH2020) Report.

The background and context section of the paper describes how synthetic fertilizer usage has evolved in Ireland over the last ten years, both in aggregate terms and for each of the farm systems recorded in the Teagasc National Farm Survey (NFS). Next the specific targets within FH2020 are discussed and the implications for the level of agricultural production in the period to 2020 are determined.

The methodology underlying the research is briefly described and results are presented which show the projected levels of fertilizer usage that are likely to be required in order to produce the level of agricultural output envisaged under FH2020. The discussion section explores some of the issues which need to be taken into consideration in assessing future levels of fertilizer usage in Ireland.

Background and Context

The FH2020 Committee's Report (DAFF, 2010) was published in July 2020. The report includes a range of specific volume and value growth targets for the different elements of the Irish agriculture, food, forestry and fishing sectors. A key target within the report is to increase the value of primary output from the agriculture, fisheries and forestry sectors by €1.5 billion.

The FH2020 dairy output target is an increase of 50 percent in milk production by 2020 relative to the average *volume* of production over the period 2007-2009. No *volume* target is set for beef or sheep production, rather a target of increasing the output *value* of each of these sectors by 20 percent by 2020 is set relative to the average of the period 2007-2009. In the case of the pig sector the target is to increase output value by 50 percent by 2020. FH2020 targets for forestry and bioenergy crops are not specified, but for the purposes of this analysis an annual growth target for forestry of 7,000 ha per year is used. A target of 4,000 ha per year is specified and for bioenergy crops. No explicit output value targets were set for the tillage sector within the FH2020 report.

Achieving the FH2020 targets for the dairy and beef sectors is likely to result in some change in the intensity of production, in the composition and size of the Irish cattle herd as well as in the relative share of grassland and cropland in the country. Accurately assessing how changing production intensity, herd composition or land use will affect fertilizer usage is not a simple task, since many factors and their interaction have to be taken into consideration. For example, fertilizer requirements per hectare will differ depending on the grassland system in use, i.e. dairy, beef or sheep, and according to the future production intensity of these systems. For livestock the intensity of production can be thought of in terms of both stocking density and yield (milk production per cow or the weight of the animal). Fertilizer usage is likely to increase as cows become more productive (higher milk yields) and stocking density increases. However, fertilizer use depends also on, among other things, the level of fertilizer prices relative to feed prices. To capture the collective impact of these relationships and their complex interaction, a model for the agriculture sector is required that brings together economic and biological relationships. This model, the FAPRI Ireland model, is described briefly in the methodology section.

Historical Trends in Fertilizer Usage in Ireland

Before we consider the prospects for future levels of fertilizer usage in Ireland if the FH2020 target levels of output value and volume are achieved, it is instructive to examine the pattern of fertilizer usage in Ireland in recent years. Figure 1 shows the aggregate level of nitrogen (N), phosphorus (P) and potassium (K) sales in Ireland for each fertilizer year in the period 2000 to 2011.

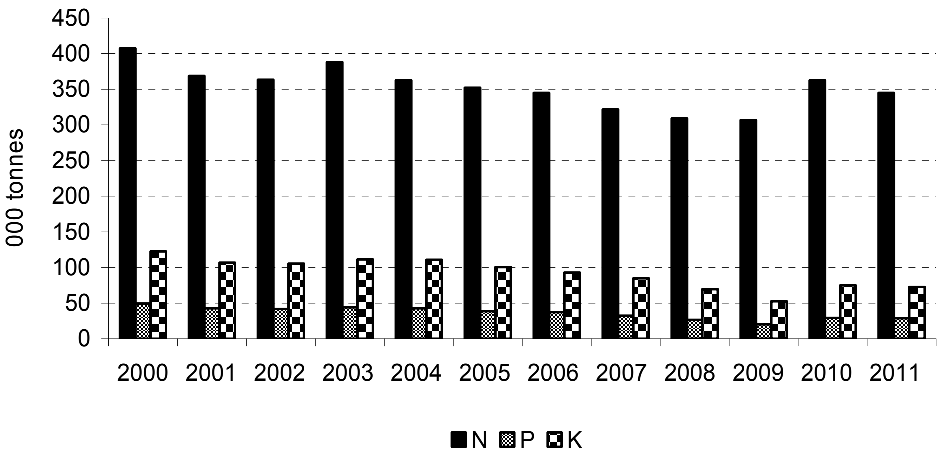

Figure 1. N, P and K Sales by Compounders 2000-2011. Source: DAFM (various years). Note: Figures reflect the fertilizer year (October to September).

For much of the period under examination there was a pronounced downward trend in sales of all three elements, reaching a low point in 2009. In the case of N, the cumulative decrease over the period 2000 to 2009 amounts to close to 100,000 tonnes or about 25 percent. Utilisation levels of P and K exhibited higher rates of decline over the same period with 2009 levels of phosphorous use 59 percent lower and K use 57 percent lower. By 2009 usage of P and K fertilizers were at their lowest levels in 50 years.

Several reasons can be advanced for the observed decline. Some of the decline in use is likely to be due to technical progress in agriculture which has allowed the relatively fixed volume of agricultural production in Ireland to be produced using lower volumes of inputs but this is unlikely to be the entire story. Other factors include:

- better grassland and nutrient management,
- agri-environmental measures (REPS and Nitrates Regulations),
- higher fertilizer prices,
- substitution between the different fertilizer elements due to changes in relative prices for different fertilizer compounds,
- the decline in the area of fertilizer intensive crops such as potatoes and sugar beet,
- contraction in the size of the dairy herd.

Understanding the drivers of reduced fertilizer usage in Ireland is complicated by the increase in aggregate usage levels which has been observed in 2010 and 2011. For a more detailed discussion of the drivers of fertilizer demand see Breen et al (2012).

In Figure 2 Teagasc Fertilizer Use Survey data show that the reduction in fertilizer usage in the period 2003 to 2008 was more severe on grassland than on tillage crops. For example, P usage on grassland fell by 55 percent between 2003 and 2008.

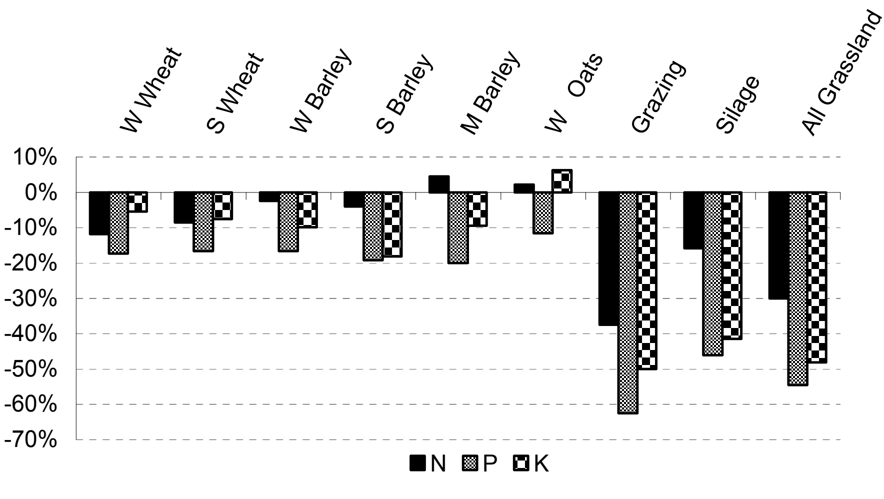

Figure 2. Change in fertilizer usage between 2003 and 2008 for cereal and grassland categories. Source: Teagasc Fertilizer Use Survey.

Focusing on N use, in Figure 3 it can be seen that the decline in application rates was most acute in the case of the dairy and the dairy other (mixed livestock) systems. For the NFS dairy system (representing approximately 15,500 farms in Ireland) the utilisation rate fell 25 percent from an average of 200 kg per hectare to 150 kg per hectare between 2000 and 2008. In the case of the dairy other system (mixed livestock) which represents approximately 4,500 farms in Ireland, the percentage decrease was even more pronounced with a decline from an average of 150kg to 100kg (33 percent) between 2000 and 2008.

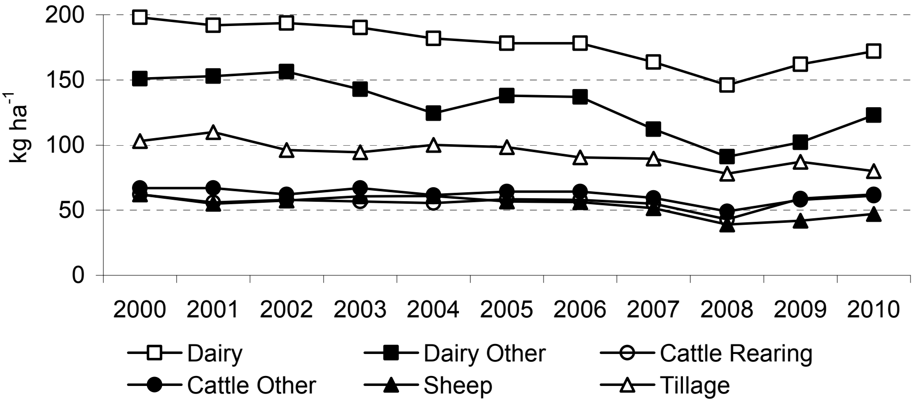

Figure 3. N application per hectare 2000 to 2010. Source: Teagasc National Farm Survey.

For the two NFS beef systems which represent approximately 55,000 farms and account for the bulk of the grassland area in Ireland, the decline is N use in the period 2000 to 2008 is smaller than on the dairy systems both in absolute and percentage terms. This is unsurprising given the minimal level of application in these cattle systems, with an average level of N use of 50 kg to 60 kg per hectare. The decline in N use in the case of the tillage system over the period 2000 to 2008 is less pronounced and is more likely to reflect technical progress in crop production technologies. Across all systems, utilisation bottomed out in the years 2008 and 2009 and the particularly low levels of fertilizer applied in these years is likely to have been a reaction to the extreme spike in fertilizer prices in that period. Figure 4 shows the index of monthly Irish fertilizer prices in the years 2006 to 2011.

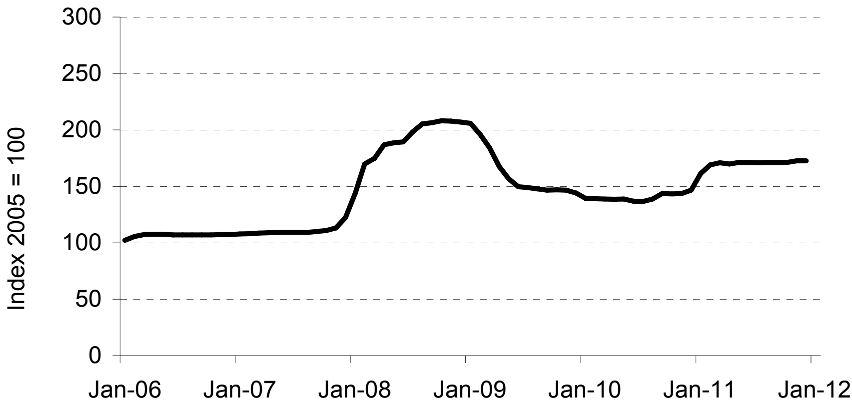

Figure 4. Monthly Index of Irish fertilizer prices 2006 to 2011. Source: Central Statistics Office (Various Years).

Nitrogen use has increased considerably in the period since 2008/09, reversing much of the downward trend in use that was observed in the previous decade and bringing N use back to 2006 levels. This recovery in N usage is all the more notable given that fertilizer prices in 2010 and 2011 were considerably higher than in 2006. Strong fertilizer demand in 2010 and 2011 can be partially explained by the simultaneous rise in commodity prices in 2010 and 2011 and by increases in the price of other agricultural inputs, particularly of purchased animal feeds.

Implications of Changing Fertilizer Usage for Soil fertility

The gradual reduction in fertilizer application observed through the 2000s has had adverse consequences for soil fertility. Analysis of the database of soil results from farmers' samples analysed through Teagasc indicate an emerging trend of decreasing soil P and K fertility in recent years. Figure 5 shows the percentage of soil samples with low fertility levels (Index 1 and 2 soils) from all enterprises (Dairy, Drystock, Tillage and Horticulture) that were analysed for soil test P and K in each year. Soils in Index 1 and 2 are classified as being low soil fertility in the Teagasc Nutrient Advice Manual (The Green Book). The maintenance of soil fertility levels in the target Index 3 range is considered essential for intensive farming systems, as these farms are likely to contribute most to meeting the growth in output that is forecast in the FH2020 report.

There has been a trend towards an increasing percentage of soils with low P and K fertility. Nationally, the percentage of low P fertility soils has increased from 39 percent in 2008 to 53 percent in 2011. The trend has been reasonably consistent across regions. The percentage of low K fertility soils has increased from 40 percent in 2007 to 52 percent in 2011. It is worth noting that while P fertilizer usage was curtailed during this period by environmental regulations, the usage of K had no restrictions, either in application rates or timings.

Figure 5. Percentage of soils with low P and K fertility status (Index 1 and 2) 2006-2011. Source: Teagasc.

Methodology

To assess the impact of achieving the FH2020 output volume and value targets on demand for fertilizer in Ireland, this paper uses an economic model of Irish agriculture known as the FAPRI-Ireland model. Using the FAPRI-Ireland model agricultural output and input prices are adjusted until the target increases in output value and volume set out in the FH2020 report are achieved. Given projected international supply and demand conditions (FAPRI, 2011) and assumptions concerning agricultural policy and the general macroeconomic environment, it is possible using the FAPRI-Ireland model to project the level of input costs and agricultural output prices paid to farmers, the volume of agricultural output and associated agricultural activity levels (area of grassland or crops, number of animals, etc.), and levels of production intensity (yield of crops per hectare and milk per cow for example) as well as input use per hectare (e.g. N per ha of grassland). The FAPRI-Ireland model has been used extensively in the analysis of agricultural and trade policy changes over the last 10 years (Binfield et al., 2000, 2001, 2002, 2003a, 2003b, 2003c, 2006, 2007, 2008).

Fertilizer use in the FAPRI-Ireland model is modelled at the nutrient level (N, P and K) with demand per hectare of grassland distinguished from demand per hectare of cropland. Each of the derived demands for fertilizer per hectare of grassland and cropland are functions of the economic returns from the use of the fertilizer concerned and prices of alternative inputs (e.g. purchased feed). These fertilizer use returns are based on the relative prices of the output produced with that land (milk, beef, cereals, potatoes, etc) and the projected price of the fertilizer element. The aggregate or national demand for fertilizer in tonnes, in a given year, is the product of demand per hectare on grassland or cropland and the total number of hectares of grassland and cropland farmed in that year. The projected prices of fertilizers in the future are function of projected energy prices which are obtained from the ESRI.

As noted earlier some of the targets set out in FH2020 are value targets (sheep, cattle and pigs) while some are volume targets (milk production). A value target can be achieved without any change in the volume of production if output prices changes are sufficiently large. In our FH2020 scenario a large proportion of the change in the value of output from the cattle and sheep sectors are as a result of projected increases in output prices rather than increases in the volume of production. In contrast the achievement of the volume target set for milk will require a large increase in output volume. This increase will be achieved both through increases in the number of dairy cows and increases in milk yields per cow. Both of these factors (intensity of production and number of cows) will increase demand for grassland and for grassland inputs, most obviously, fertilizer.

Results

Figure 6 shows how the intensity of N usage per hectare of grassland would be projected to evolve under FH2020. In particular the increased intensity of dairy production under the FH2020 scenario causes some increase in N use, but this is partially offset by projected reductions in the suckler herd. The net result is that achievement of FH2020 would require a projected 17 percent increase in N usage per hectare of grassland by 2020 relative to the level in the FH2020 reference period of 2007-2009. It should be noted that N use in this reference period was at a 50 year low, so this increase is not spectacular when placed in the context of average usage levels in the 2000s.

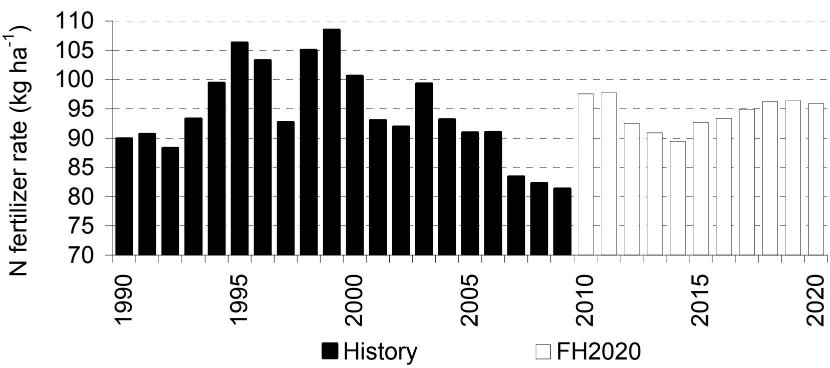

Figure 6. Intensity of N usage on grassland in Ireland: Historical data and projections under FH2020. Source: FAPRI-Ireland (2011).

Simply put, if FH2020 is achieved it will mean that grassland agriculture and associated fertilizer use in Ireland will be increasingly driven by the evolution of the dairy herd. Figure 7 shows both the historic and projected ratio of dairy cow to beef (suckler) cow numbers. Over the last 20 years, the number of dairy cows in Ireland fell as yields increased in the presence of the fixed milk quota. Over the same period the number of suckler cows increased, in reaction to the incentives created by the coupled payment system. Accordingly the ratio of dairy cows to beef cows fell sharply.

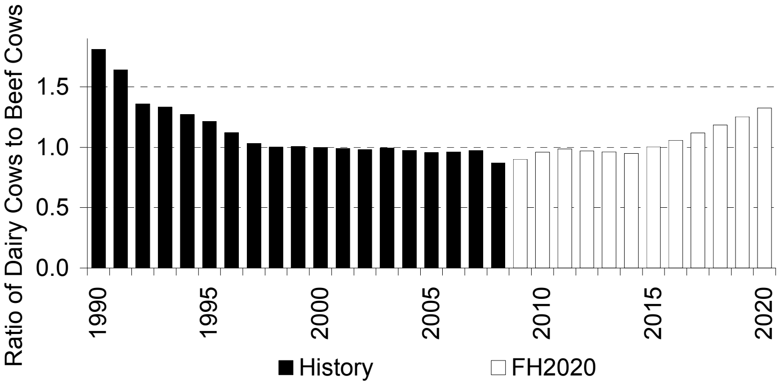

Figure 7. Ratio of Dairy Cows to Beef Cows in the Irish Cattle Herd: Historical data and Projections under FH2020. Source: FAPRI-Ireland (2011)

In contrast the ratio is projected to increase if the FH2020 targets are achieved. The achievement of FH2020 targets would see an increase in the number of dairy cows (and milk yields) to provide the targeted growth in Irish milk production. Despite the FH2020 growth target for beef, a fall in the number of suckler cows under FH2020 is projected. Hence the ratio of dairy to suckler cows is projected to return to levels last seen in the early 1990's. In aggregate the total cow population is projected to increases, as is the number of calves born and the population of other cattle. Ultimately, the achievement of the FH2020 targets will have consequences for the intensity of grassland use, with the average stocking density of cattle per hectare projected to increase and the use of fertilizer per hectare also projected to rise, particularly on dairy farms.

Importantly, the decline in suckler cow numbers does not imply that total production of beef declines in Ireland. The increase in the number of dairy cows and associated progeny more than offsets the projected decline in the number of suckler cows and their offspring. The volume of Irish beef production actually increases; this increase in beef production is entirely due to the drive to achieve the FH2020 milk target. Admittedly, with the changing composition of the total cow herd, slaughter weights are projected to decline, but overall beef production in aggregate is projected by 2020 to be almost 9 percent higher than in the FH2020 reference period of 2007-2009.

Associated with the increase in milk and meat production with the achievement of the FH2020 targets, total purchased feed use is projected to increase by 27 percent. Over half of the projected increase in feed use under FH2020 arises from the dairy sector, where feed use per dairy cow is projected to increase by 22 percent.

Under FH2020 as the dairy sector expands the share of Irish agricultural area accounted for by tillage crops is projected to decline by 8 percent (the FH2020 report does not set an explicit growth target for cereals output). Over the period to 2020 total cereal production is projected to decline, though the decline in area is partially offset by projected increases in yields. Under FH2020, the volume of Irish grain production is projected to be 5 percent lower by 2020 than in the period 2007-2009.

Discussion

The results presented are subject to several caveats which readers should carefully consider.

Grassland Management and Land Use

One important consideration is how grassland agricultural practices develop in the current decade. On the dairy side much emphasis is placed in Ireland on displacing concentrate feed usage by grass and silage. To the extent that a trend in this direction emerges, this will lead to higher levels of fertilizer application on land used in dairy, even in the absence of any growth in the volume of milk production. If one then further considers the 50 percent increase in milk production required under FH2020, this is likely to lead to a further intensification of dairy production, further boosting applications per hectare.

The story on the beef and sheep side is somewhat different. The targets set for these sectors can be met as least partially through higher output prices. Given that these two sectors are considerably less profitable than the dairy sector, and more reliant on subsidy payments, expectations of dramatic increases in the volume of beef or lamb produced in Ireland should be tempered. The low levels of profitability in drystock production mean that the gains in farm income that can be achieved through changing grassland management practices are likely to be less lucrative than in dairy production and this may reduce the extent to which such measures are adopted. It follows that fertilizer utilisation per hectare in the beef and sheep sectors is unlikely to change to any great extent, even in the context of the FH2020 targets being achieved. While Irish cereal farmers achieve amongst the highest yields per hectare in the world, the international competitiveness of Irish cereal production is constrained by farm scale and the limited area of land in

Ireland that is well suited to cereal production. In the period to 2020, this situation is unlikely to change. The area in Irish cereal production is likely to decline and hence it is projected that the cereal sector will not exert a positive influence on future levels of fertilizer demand in Ireland in the medium term.

Fertilizer versus Feed Use

Another factor that will affect the choice between feed and fertilizer will be the price of these two inputs. Economists refer to these two inputs as imperfect substitutes in production, meaning that a farmer can alternate to some degree his utilisation of the two inputs in response to changes in their relative prices. For example, if fertilizer prices rise at a faster rate than feed prices, this is likely to reduce the demand for fertilizer. Importantly, we would argue that were fertilizer prices to fall in the future, it may not necessarily boost demand for fertilizer if feed and other input prices are also falling.

Across the grassland enterprises, output prices have increased considerably in the period since 2006. This would be expected to have created incentives to increase production and increased levels of feed and/or fertilizer usage. However, it must be kept in mind that there has also been a substantial increase in the overall cost of production in recent years. The increase in margins earned in Irish agriculture has been less impressive than the rise in output prices might initially suggest, and accordingly there has been no significant change in the volume of agricultural output. So long as increases in output prices are matched or exceeded by increases in input prices, significant changes in output volumes are unlikely except where other policies (e.g. the milk quota system) have been a constraint on production.

Live Trade

While highly variable from year to year, live cattle exports have remained a feature of Irish cattle disposals, typically representing 10 to 15 percent of total disposals in any given year. Dairy expansion would require more replacement animals and would reduce the number of female calves available for fattening. On the other hand the volume of dairy bull calves is likely to increase due to dairy expansion. Whether these animals are reared in Ireland will depend on the level of future beef prices and the costs of rearing these animals to slaughter. If these animals are exported as calves rather than being raised in Ireland, the extent of the increase in the total Irish cattle population will be smaller and there would be less pressure for increased fertilizer usage nationally.

CAP Reform

The possible implications of CAP reform were explicitly not considered in the formulation of the FH2020 recommendations. At the time of writing (January 2012) the CAP reform debate is centred around proposals to flatten the subsidy per hectare currently received via the historical Single Payment System (SPS) model used in Ireland, by moving to a national or regional flat rate average direct income support payment. Teagasc research (Shrestha et al., 2007) has already shown that such flattening would disadvantage particular (largely more production intensive) farm systems and favour other (less intensive) production systems. The European Commission has long argued that the SFP is fully decoupled from production and if this is the case, then the flattening of payments would not be expected to have negative consequences for production. However, if production is linked to some degree to receipt of "decoupled" direct income support receipts, then any reallocation of this support between farmers may have negative production consequences, which in turn would adversely impact on fertilizer demand.

Environmental and Climate Change Concerns

Nitrogen is a key consideration in relation to greenhouse gas emissions (GHG) from Irish agriculture. GHG emission from agriculture in Ireland in 2010 would have fallen were it not for the increase in N sales that year, a point recently noted by the Environmental Protection Agency in their presentation of the GHG inventory for 2010 (Duffy et al., 2011). While a GHG constraint has not been established for Irish agriculture, the Irish Government still faces a difficult decision in how it manages GHG emissions in the non-Emissions Trading sector (non-ETS) element of the GHG inventory and how it achieves the required reduction of 20 percent by 2020. Aside from agriculture, the only other significant sector in the non-ETS sector is transport, and while transport emissions in Ireland are now in decline, a return to growth in the Irish economy would reverse that trend. Internationally, the debate on reducing GHG emissions from food production has given rise to suggestions for measures such as a fertilizer tax or a system of GHG emission quotas for agriculture. The results presented in this paper projected that the net result of FH2020 would be a 17 percent increase in N usage per hectare of grassland by 2020 relative to the reference period of 2007-2009. Other things being equal, this projected increase in N usage would have adverse consequences in terms of reducing GHG emissions from Irish agriculture.

Were a constraint on GHG emissions from agriculture to be imposed under some future Climate Change Bill in the Oireachtas, such a constraint would probably negatively impact on the volume of agricultural activity in Ireland and in turn negatively affect the demand for N fertilizer by Irish agriculture. Teagasc is actively researching the potential of technologies and novel farming practices to reduce the GHG emissions associated with fertilizer use. Improving the efficiency of N usage in grassland and crops, and increasing the N fertilizer value of organic fertilizers and clover in the sward are amongst the most successful technologies available to date.

Other environmental concerns regarding fertilizer use include potential adverse impacts on water quality. Much of the projected increase in output will depend on the maintenance of our Nitrates derogation to allow higher farm stocking rates and fertilizer application rates than would otherwise be permitted. The cessation of the current derogation conditions would require a re-evaluation of the projected changes in farming activity and fertilizer use.

A key aspect of the FH2020 report is that increases in agricultural activity must be achieved in an environmentally sustainable manner. Therefore, while fertilizer inputs will be a central requirement to achieving increased output targets, the sustainable use of fertilizer inputs will be critical. Improving the efficiency of N and P usage as well as ensuring that associated factors influencing fertilizer efficiency such as lime usage and balanced nutrient supply will be critical to this.

Conclusion

In this paper we estimate the growth in the volume of agricultural production that would be required to meet the targets set out in the FH2020 report. The main source of increased production volume is likely to be from increased milk production and the additional dairy cows and associated replacements and surplus dairy progeny reared for beef. This increase in milk and beef production will generate some additional demand for fertilizer application, particularly where the intensity of production on grassland is increased. Changing grassland management practices which favour the use of fertilizer over concentrate feed may also boost fertilizer demand. Several caveats are identified in the paper which should be considered in any assessment of the future level of fertilizer demand. Responsible and efficient use of fertilizers remains critical for sustainability of the sector and the environment.

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The Importance of Sulphur in a Balanced Fertilizer Strategy

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Historically, the use of sulphur (S) as a fertilizer in Ireland was quite variable. Sulphur deposition levels from the atmosphere, mainly from industry, have always been a significant contributor to S requirements of tillage crops and grass. Also, ammonium sulphate and triple super phosphate were more commonly used as sources of nitrogen (N) and phosphorus (P) fertilizer, which also happened to supply significant quantities of S. More recently however, S emissions (and therefore deposition onto farmland) from industry have been reduced and CAN and urea have largely replaced ammonium sulphate as the main nitrogen fertilizers. As yields have increased leading to higher annual nutrient offtakes, and with reduced S from deposition and N and P fertilizers, the need to carefully consider S when planning fertilizer requirements continues to increase.

Two papers on the subject of sulphur have been published in previous Fertilizer Association of Ireland proceedings, the first in 1991 and the second in 2000 (Murphy, 1991, 2000). Given this seemingly ten year trend, and the recent changes in cropping, deposition and application, it is appropriate to revisit the subject of S fertilization.

Rather than covering all of the previous information on the general information on S nutrition, this paper attempts only to highlight and quantify recent advances made on this important nutrient in the context of modern Irish agriculture and to ensure that a shortage of an important secondary nutrient does not slow the recent advances made in both yield and quality of Irish agricultural production.

Atmospheric sulphur depositions

Atmospheric S is derived principally from the combustion of fossil fuels for electricity generation and it is now widely accepted that deposition to land from atmospheric sources has reduced. What is less known however is the speed and the extent of this decline which has been dramatic. Drennan (2000) outlined the pattern of emissions and deposition of transboundary pollutants including |S. Throughout Europe, cleaner air policies have been extraordinarily successful to the benefit of society in general but possibly to the detriment of the fertilizer conscious farmer!

The emissions and deposition of sulphur (total S) in Ireland over the past 20 years is shown in Figure 1.

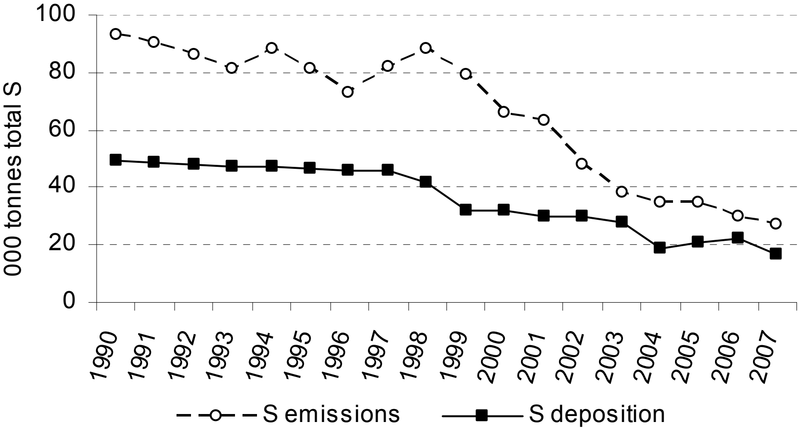

Figure 1. Total S deposition and emissions in Ireland for the period 1990-2007. Source: Norwegian Meteorological Institute, 2009.

Even by 1990, Sulphur deposition had already significantly declined to a 'low' deposition figure of around 10 kg/ha of S in 1969 (Gallagher, 1969). Sulphur deposition in Ireland has always been lower than the UK and is higher on the Eastern side, particularly close to major sources of industry (Figure 2).

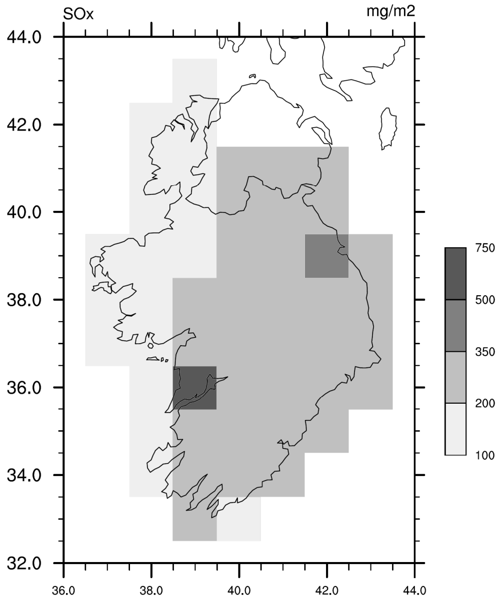

Figure 2. Total oxidised S deposition Ireland 2007. Source: Norweigan Meteorological Institute, 2009. (Note the units in mg/m2 of S equates to total oxidised sulphur deposition for much of Ireland now amounts to between 1-3.5 kg/ha/yr of S.)

The emissions of S in the UK up to 2010 shows a further decreasing trend and is thought to be indicative of emission levels in Western Europe (Figure 3).

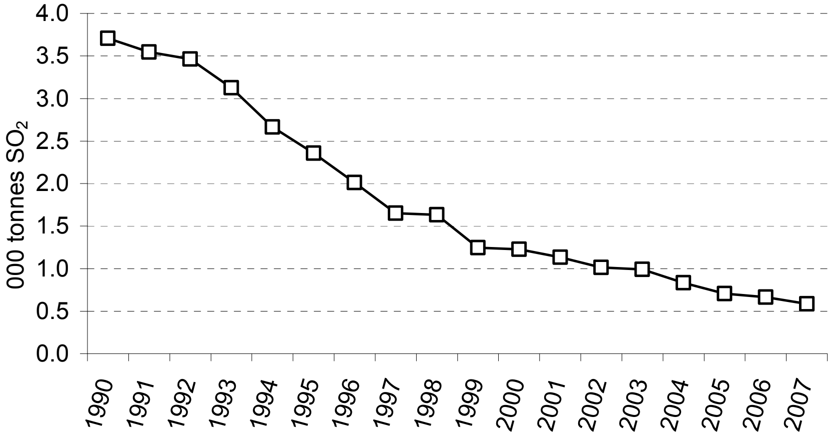

Figure 3. Sulphur dioxide (SO_2) emissions in the UK for the period 1990-2010. Source: National Air Emissions Inventory, 2011.

Sulphur from fertilizers

In the past, a significant quantity of S was coming, often by chance, from raw materials used in the fertilizer industry. Ammonium sulphate and (Triple super phosphate) were both major sources of S and at one time were the principal sources of N and P used respectively. Sulphur derived from fertilizers amounted to approximately 5 kg/ha in 1952 and approximately 15 kg/ha by 1963. High purity fertilizers then began to dominate with urea and CAN increasing in usage together with a shift from TSP to di-ammonium phosphate (DAP) as a P source. None of these raw materials contained sulphur and as a consequence, S applications to agricultural land fell dramatically.

Based on recent response work, sulphur is now added to fertilizers purposefully and has a value itself. Ammonium sulphate nitrate (13% S) and Kieserite (20% S) are now commonly used in blended fertilizers as plant available sources of sulphur.

Modern Sulphur requirements

Given that for much of Ireland, S deposition is now negligible (between 1-3.5 kg S/ha) and that S now doesn't now come by default in NPK fertilizers, additional S is required to make up the balance between crop demand and supply to the crop. This demand can be met through mineralised S on soils that have a medium to high content of organic matter or from fertilizer S which can be stipulated in both true compound and blended material.

Typical removal (offtake) rates of S in harvested and non-harvested / residual fractions (eg. Straw, haulm etc.) for a range of crops are shown in Table 1.

Table 1. Sulphur offtake rates for a range of crops. **Source: LFL, 2010, Germany.**

Crop	S offtake (kg per tonne yield)	
	Harvested part	Crop residue / straw*
Silage grass	2.0 (/t DM)	
Winter wheat	1.2	1.5
Spring barley	1.1	1.6
Fodder Beet	0.3	0.4
Oilseed rape	5.5	7
Potatoes	0.3	0.1

*Crop residue figures are residue associated with a tonne harvested yield and not a tonne of residue itself.

Experimental trials work on sulphur

Little response work has been done on sulphur in Ireland in the past decade but a significant number of field trials have been conducted in the UK (where depositions levels are higher). In general, it is light soil types and higher rainfall areas which show the greatest yield responses to sulphur.

Grassland

Much of the experimental work done on sulphur In Ireland has been on grassland and an extensive dataset was built up from 1970 to 2002. Of 140 trials conducted, a significant response was recorded on exactly half of the trials and the yield at these sites was increased by an average of 15% (Murphy, 2000). More recently trials conducted at IBERS (Aberystwyth University, Wales) revealed an increase in silage yield of 35% on sandy loam soil, and 11% on clay loam soil, from an application of 15 kg/ha of S, with increases in true protein and soluble sugar levels also reported

Higher responses to S are more common in second and subsequent silage cuts when mineralised S from soil reserves is often more depleted. Responses to S are also greater at higher rates of N application.

Tillage

Most of the recent experimental work on tillage crops has been conducted in the UK. In particular a major study was undertaken by the HGCA to determine recommendations for cereals. In summary the project concluded that the three greatest factors determining responsiveness were winter rainfall, soil texture and atmospheric deposition. Of all 88 wheat trials reported, a mean response of 6% yield increase was recorded. The response to S was significant at 26% of the sites used. The mean yield response at these responsive sites was 27%. An HGCA study on malting barley in 2004 reported a yield increase of 0.2-1.2 t/ha from 8 trials conducted (significant on 5 of the 8 sites).

Conclusions

- A satisfactory supply of S is essential for high yielding, quality tillage crops and grass grown in Ireland.
- Atmospheric S deposition has reduced significantly and continues to do so.
- The contribution to crop demand from deposition is now minimal and likely to equate to between 5-10% of crop demand.
- Increased yields have a corresponding increased demand for S.
- Increased S demand can be met from mineralisation of organic S sources or by way of fertilizers with an S component.

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Using Soil Test Results for Soil Fertility Management

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Introduction

Soil testing is an effective tool for good nutrient management planning. Soil results will provide up to date information of the soil fertility status of the farm on a field by field basis. This information is critical when making nutrient application and fertilizer decisions. Soil testing represents a small annual cost when considered in parallel to the potential to make both short terms benefits in maximising the return from each kg of nutrient applied, and long term benefits of maintaining the correct soil fertility ranges for optimising farm productivity.

A review of soil samples taken on farms and analysed through Teagasc indicates a decline in soil phosphorus (P) and potassium (K) fertility levels. This decline in soil P and K levels is most notable in the last three to four years. For example the percentage of soils in Index 1 and 2 (very low to low fertility) have increased from approximately 40% to 55%, while soils at the optimum Index 3 decreased from approximately 30 to 25% (Figures 1 and 2). This decline in soil fertility can be associated with a corresponding decrease in fertilizer P and K usage over the last decade. Where soil fertility continues to decline and go unnoticed at farm level, soil productivity will slowly be reduced over time.

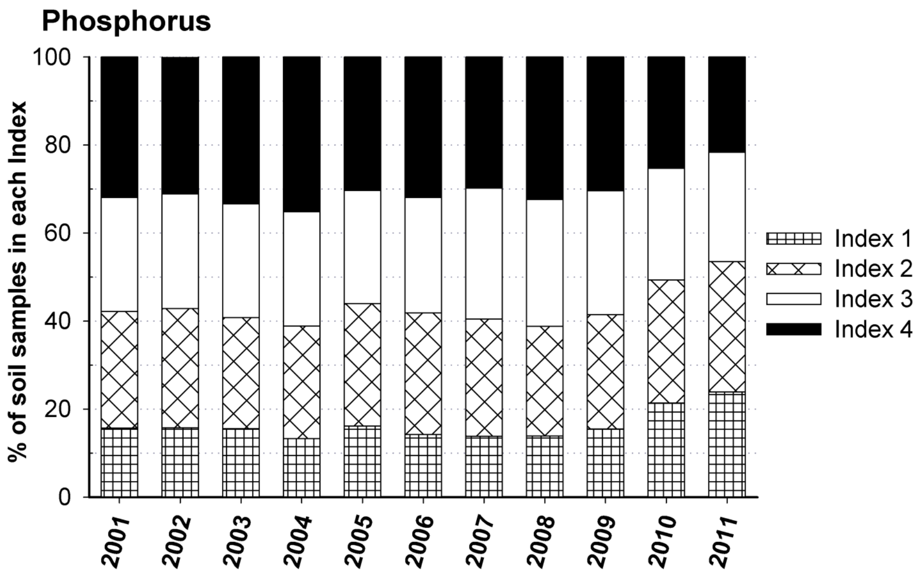

Figure 1. % of soils in each soil P Index from 2001 to 2011. (Source: Teagasc).

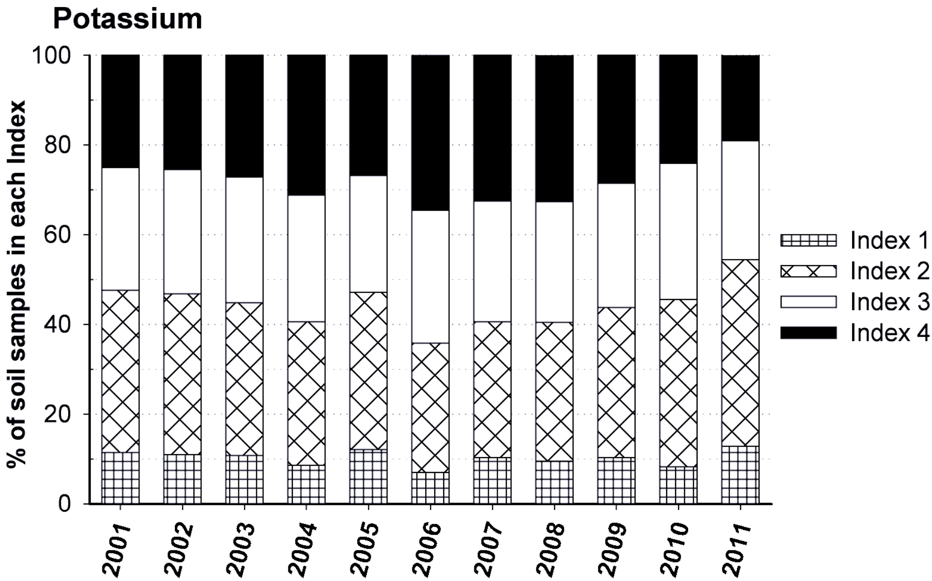

Figure 2. % of soils in each soil K Index from 2001 to 2011. (Source: Teagasc).

Soil pH is a critical property that must be considered when managing soil fertility. While there has not been an obvious trend in soil pH over time as seen with declining P and K levels in the soil, the percentage of soils in a range of soil pH categories shows that a significant proportion of soils in Ireland would benefit from lime application (Figure 3).

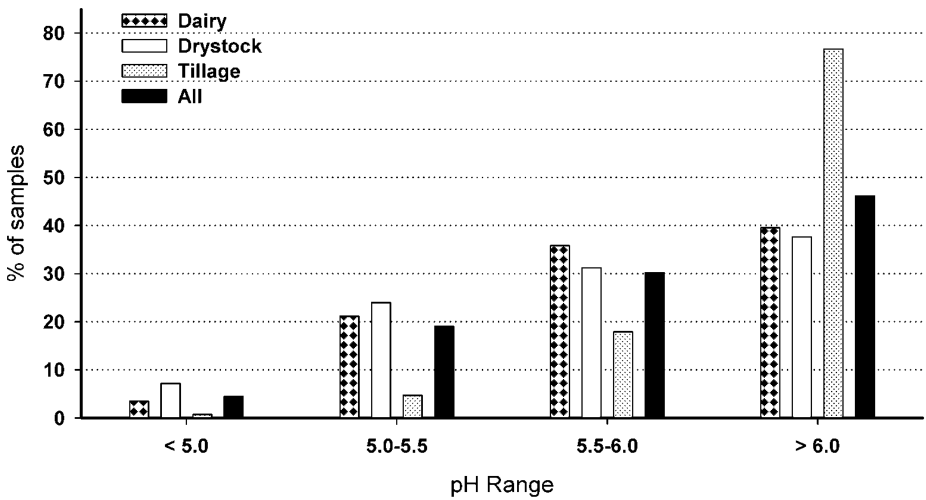

Figure 3. % of soil samples in soil pH categories for dairy, drystock, tillage, and all enterprises combined in 2010. (Source: Teagasc)

The proportion of tillage soils with soil pH greater than 6.0 is higher than grassland soils. This is due to the higher lime requirements for tillage crops such as barley or beet compared to grassland. Currently, over 60% of grassland samples tested below soil pH of 6.0, with 25% below a soil pH 5.5. Given that the optimum soil pH for grassland is 6.2-6.3, this data indicates the potential benefits of lime application to increase productivity on many grassland farms in Ireland.

Over the last decade there has been a steady decline in fertilizer usage from 1.7 million tonnes in 2000 to 1.3 million in 2011. While declining fertilizer usage has benefits from both financial and environmental perspectives, it is still critical that our productive soils are maintained at the optimum soil Index 3 to meet annual crop nutrient requirements and avoid soil fertility levels falling below optimum levels.

The objective of this paper is to consider how nutrient management could be improved on farms in a way that would curtail the decline in soil fertility and ensure production levels are optimised in the future in an environmentally and economically sustainable manner. Much of the information outlined is taken directly from Teagasc Nutrient Advice, as outlined in the 'Green Book' (Coulter and Lalor, 2008). The paper proposes 5 key steps to soil fertility management.

1. Have soil analysis results for the whole farm.
2. Apply lime as required to achieve the target pH for the crop.
3. Aim to have soil test P and K in the target Index 3 in all fields.
4. Use organic fertilizers as efficiently as possible.
5. Make sure the fertilizers used are properly balanced.

Each step is discussed in turn.

1) Have soil analysis results for the whole farm

Soil analysis is an essential tool in determining available soil nutrients such as soil pH, P, K and magnesium (Mg) on your farm. It is a small annual cost and will provide sound information to plan fertilizer and manure applications for the next 5 years. Soil test results can be used for 3 to 5 years and are a good starting point each year for fertilizer planning.

While soil sampling may be a small annual cost per hectare over the long term, it may still be a significantly high cost in the year of sampling, particularly if most or all of the farm is being sampled at the same time. Therefore, it is critical to ensure that the samples are taken correctly so that the results are accurate and usable. Attention to detail with the following factors is important to ensure that soil samples are taken correctly and that laboratory results are reliable and usable.

Area- Sample areas should reflect practical management units of the farm. There is no point taking samples from different areas if they will not or cannot be managed differently based on the results. Therefore, be practical. As a guide, take one sample for every 2 to 4 ha. The Nitrates rules specify a maximum area per soil sample of 8 ha. Nitrates derogation rules require that the area represented by each sample is not greater than 5 hectares (Anon, 2010). Sample areas should be as uniform as possible regarding soil type; slope; drainage; and cropping history.

Sampling pattern- Take a representative sample from the entire field, following a 'W' sampling pattern (Figure 4). Avoid unusual spots such as gateways; sites of feeders or manure heaps; old fences or ditches; and dung or urine patches. Take a minimum of 20 soil cores per sample. Samples should be thoroughly mixed and sub-sampled if necessary to get a suitable quantity of sample for dispatch to the laboratory.

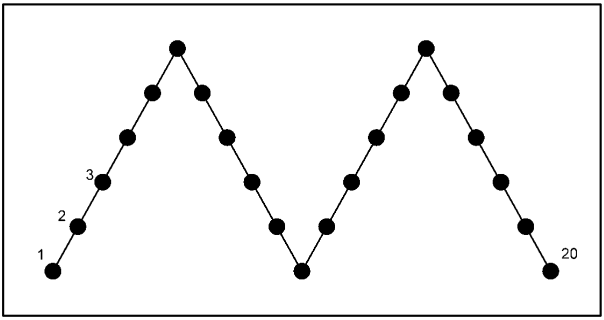

Figure 4. Soils should be sampled by taking cores from a 'W' pattern in the field.

Timing- Allow 3 to 6 months after previous P, K or manure application. Allow 2 years after lime application for accurate lime requirement assessment. For comparison, sample at the same time of year as previous sampling. Avoid dry or wet extremes of weather.

Depth- This is particularly critical for P analysis, as P tends to accumulate in the top few cm of grassland soils. Samples not taken from the full depth of 10 cm will usually overestimate the soil P level. Wear on the end of the soil corer and soil moisture conditions at sampling can have an impact on sampling depth. Where grassland is being ploughed, soil at the surface that is high in P can be moved to deeper in the soil, and replaced at the surface by soil with lower P content. Therefore, it is advised to soil test after ploughing.

In practice it is best to take soil samples from September to February and have results in place to plan spring applications of manure and fertilizer. When testing tillage soils it is also useful to check soil minor nutrients such as manganese (Mn), copper (Cu) and zinc (Zn). This will provide knowledge of the soils minor nutrient status. Based on this information nutrient deficiencies can be anticipated and treated appropriately.

Soil test results are also essential for comparing soil test results from the same field over time. This exercise can provide information for the soils on your farm in relation to the rate of change soil nutrient levels over time. This will also show how effective and appropriate the previous fertilizer and manure programmes have been. This information is invaluable for slurry management and for selecting the most suitable fertilizer P:K ratio to meet the nutrient requirements of the soils and crops on the farm.

2) Apply lime as required to achieve the target pH for the crop

Soil pH plays a key role in soil fertility. Maintaining the soil pH at the optimum level will increase the microbiological activity of the soil, and result in better soil nutrient recycling and release. Soil pH is also critical for maximising the availability of nutrients applied in organic and chemical fertilizers.

Lime is continually being lost from the soil and needs to be replaced as part of a nutrient management programme. For example drainage water can remove approximately 250-625 kg ha^{-1}, depending on the soil type, of lime equivalent each year. Light free draining soils will lose lime more quickly than heavier soils. Therefore light land may need extra attention; particularly in areas limestone is not present in soil parent material or bedrock. Crops and livestock also remove lime. For example, a crop of first cut grass silage removes approximately 190 kg ha^{-1}kg yr^{-1} of lime equivalent. Nitrogen fertilizers also have an acidifying effect. Each 1 kg of N applied as CAN or Urea will generate acidity that will require approximately 2 kg of lime to neutralise.

The target soil pH for a range of crops is shown in Table 1. Aim to maintain soil pH close to the target level and apply lime as recommended on the soil test report.

Table 1. Optimum soil pH for a range of crops (Source: Teagasc)

Crop	Optimum pH
Beet, beans, peas and oilseeds	7.0
Cereals and Maize	6.5
Grassland	6.3
Grassland (High Molybdenum)	6.2
Potatoes	6.0

The lime requirement is calculated in the laboratory based on a test that measures the buffering capacity of the soil. Buffering capacity is a measure of how much lime it takes to change the soil pH. Therefore, soils that are returned with the same soil pH may be shown to have different lime requirements. This is because the soils have different buffering capacities require more lime to achieve the same increase in pH. Soils that are heavier textured or higher organic matter contents tend to have higher buffering capacities and higher lime requirements as a result. However, while these soils may require more lime following the soil test, the higher buffering capacity should result in the soil retaining lime better in the future once it has been applied.

Calcium limestone is the most common form of ground limestone available. Magnesium limestone (also called dolomitic limestone) can also be used, and are recommended where soil test Mg levels are less than 50 mg L^{-1}.

Liming grassland soils

Soils maintained close to the target pH will have benefits of increased grass yields; more efficient utilisation of applied fertilizers and manures; and better persistence of more productive species in the sward such as perennial ryegrass and clover. Limed soils also tend to release more N from the soil organic matter. It has been estimated that grassland soils that receive lime will release approximately 50-70 kg ha^{-1} more N per year than unlimed soils (Culleton *et al.*, 1999). This is worth approx. €60-85 ha^{-1} based on current fertilizer prices.

Aim to maintain the soil pH for grassland at or above pH 6.3. To achieve this, the advice is to apply lime to increase the soil pH to approximately 6.5. This allows for the soil pH changes that occur after liming and the gradual lime loss after the target soil pH has been reached. Liming up to pH 6.5 means that liming need not be done each year. Where lime advice exceeds 7.5 t ha^{-1}, it is recommended to split the application and apply 7.5 t ha^{-1} in the first application, and the remainder after two years. This approach will help avoid trace element imbalances occurring due to high lime application rates and excessive and rapid changes in soil pH.

In grassland soils that are high in molybdenum (Mo), it is recommended to maintain the soil pH at or below a pH 6.2. Increasing the soil pH above 6.2 increases the availability of Mo which reduces the availability of Cu in bovines. Where there is either a history or a risk of soils or herbage being high in Mo, it is recommended to reduce the lime recommendation by 5 t ha^{-1}. However, this is a crude estimation, and can be tailored for each situation depending on pervious experience. Problems with high Mo tend by more common on wetter soils (or in wetter years); in swards with low ryegrass and/or high clover content; and where annual rates of N fertilizer application are low. Where high Mo is an issue, it is best to apply lime on a rotational basis for example 20% of the farm each year rather than the whole farm. Therefore, elevated Mo in herbage in a section of the farm due to lime may be somewhat diluted across the whole farm.

Liming tillage soils

The optimum soil pH is 6.5 for cereals and maize, and pH 7.0 for beet, peas and beans. Potatoes and oats are more tolerant of low pH and pH 6.0 is adequate to produce a good crop. Lime should be applied to tillage soils based on the most sensitive crop to lime in the rotation. Where potatoes are grown in rotation it is best to apply lime after the potato crop, as the risk of common scab is increased where lime is applied within the previous two years.

Timing of lime application

Lime can be applied at any convenient time of the year. For lime sensitive crops such as beet, cereals, maize, apply lime 2 years before sowing. If lime has not been applied it should be spread after spring ploughing so that it can react with the soil and be thoroughly mixed with soils during spring cultivations.

For grassland, it is preferable to apply to fields with very little grass cover, and to avoid grazing or cutting until sufficient rainfall has occurred to wash the lime off the herbage. For silage swards, apply lime before mid-march for first cut or within one week after cutting on land being closed for a second cut. Applying lime to heavy covers of grass intended for silage can reduce the silage quality if the lime is not washed off the grass by rain.

3) Aim to have soil test P and K in the target Index 3 in all fields

The aim of P and K nutrient advice is to maintain all fields at the optimum soil fertility level. The soil test measures the plant available P and K in mg L^{-1} of soil. For simplicity, this result is categorised into a soil Index for each nutrient. The soil Index system divides soils into one of four soil Index levels based on the soil test result. The soil Index system and the corresponding soil test P and K ranges for each Index are shown in Table 1. The soil Index indicates the expected response to nutrients applied. For example Index 1 soils are very responsive while Index 4 soils have sufficient soil nutrient reserves and do not respond to fresh P and K applications.

Table 2. Soil nutrient Index, response to fertilizers and soil test range for P, K and Mg. (Source: Teagasc)

Soil Index	Response to fertilizers	P (mg L^{-1})		K (mg L^{-1})	Mg (mg L^{-1})
		Grassland	Tillage		
1	Definite	0 – 3.0	0 – 3.0	0 – 50	0 – 25
2	Likely	3.1 – 5.0	3.1 – 6.0	51 – 100	26 – 50
3	Unlikely / tenuous	5.0 – 8.0	6.1 – 10.0	101 – 150	51 – 100
4	None	>8.0	>10.0	>150	> 100

Index 1 and 2 soils are very responsive to applied P and K. These soils have a higher P and K requirement due the fact that the P and K applied should be sufficient to build up soil reserves to the optimum soil Index in addition to replacing the P and K removed in product (grain, straw, meat, milk, etc). Soil Index 3 is the optimum Index for production, as it is in this range that the soil fertility level is considered sufficient to feed the crop. Therefore, in order to maintain the soil in this optimum range, the P and K application should replace the P and K removed. The aim is to build soil fertility levels at Index 1 and 2 up to Index 3 over a number of years. The rate of soil build up will depend on a number of factors such as soil type, nutrient application rate, and the amount of nutrient removed. Building soil fertility usually takes a number of years, so application of build up rates in addition to maintenance rates should continue for a number of years after the soil sample is taken.

Soils at Index 4 are very fertile soils and soil reserves will supply sufficient P or K to meet crop nutrient requirements throughout the growing season. It is recommended to omit P or K applications with the exception of certain crops such as potatoes, beet, and some horticultural crops. Where grass and tillage crops are grown on Index 4 soils it is recommended to omit P for a number of years and then re-sample to monitor changes over time. For K it is recommended to omit K applications for one year and then revert back to Index 3 advice in subsequent years. Index 4 soils tend to be fields on the farm that receive frequent dressings of organic manures such as cattle or pig slurry or farmyard manure. These fields offer an opportunity to reduce fertilizer costs and to target other areas of the farm that would benefit from organic manure applications. The speed of P and K decline on Index 4 soils will depend on the soil type, the level of P or K in the soil, and the removals on an annual basis. Regular soil testing is essential to monitor changes.

Soil analysis will identify the low fertility fields which are most deserving of organic manures. These fields will have high nutrient requirements and organic manures are the most cost effective route to controlling costs in these fields. For example on grassland farms silage fields will usually have higher P and K requirements than the grazed areas. Cattle slurry is usually more suitable fertilizer for silage than for grazing, as slurry contains high levels of K which is essential for high yielding grass silage crops. However, this is not always the case, and will depend on the soil results.

On tillage farms the main source of P and K applied to crops is chemical fertilizers. It is essential to match crop P and K requirements with a fertilizer with the correct ratio of P : K. For example take a 7.5 t ha^{-1} spring barley crop grown on a soil P and K Index 3. This crop will remove approximately 28 kg ha^{-1} of P and 86 kg ha^{-1} of K (grain and straw) at harvest time. To maintain soil fertility these nutrients must be returned to the soil as either organic manure or fertilizers.

With high fertilizer prices at present, one may ask if P and K application rates should be reduced. The P and K advice is based around maintaining soils at Index 3 for optimum productivity. The P and K is applied annually to maintain soil reserves at the correct level of nutrients to ensure optimum yields and effective use of all other inputs, especially N. This is the main reason why one may not see a response to P and K applied annually if the soil reserves are sufficiently high. However, reducing or skipping P or K applications will mean that the nutrients will have to be replaced at some stage if soil fertility is to be maintained. With restrictions in P fertilizer use based on annual allowances, it may not be possible to apply extra in subsequent years.

4) Use organic fertilizers as efficiently as possible.

Organic fertilizers are a valuable source of N, P and K. Cattle slurry is by far the most common form of organic fertilizer applied in Ireland. Over the last number of years there has been a major drive on Irish farms to improve the utilization of slurry and reduce fertilizer costs. This has been achieved on farm by better facilities for the management of slurry during the winter and more slurry been applied on grassland in early spring when N utilisation is highest.

One of the biggest problems with using slurry within a nutrient management plan is the variability in the dry matter (DM) and nutrient contents. Up to tenfold variation has been found in the DM, and total N P and K contents of different cattle slurry samples. Although factors such as animal type, production system and diet will affect the slurry, the variability is mainly attributable to varying DM content caused by the dilution of slurry with water from dairy parlour washings or rainfall collected on open yards. Where slurry is diluted with water, the nutrient content will be lower. The degree of slurry dilution with water sources can be used as a guide to estimate the nutrient content of slurry. On average, slurry in Ireland is approximately 7% DM. However, the variation in slurries, even between two tanks in the same shed or yard, can be quite considerable.

To make best use of any organic manure it is important to know the actual nutrient content (N, P and K). Laboratory analysis is the most accurate way to determine the dry matter and nutrient content of the slurry. However, the farmer needs to know the nutrient content of the slurry on the day of application. This can be difficult as a representative sample of slurry, usually only obtained after agitation, is needed weeks in advance of the day of spreading in order to have results back from the laboratory. Since cattle slurry is generally agitated and spread on the same day, the usefulness of laboratory analysis when making decisions about applications is limited. However, occasional analysis of slurry, even if not every year, can still be a good guide to the nutrient content that one might expect from similar animals on similar diets in the same sheds.

In order to get more rapid information on the day of application, there are a number on farm measurement tools to estimate the nutrient content of slurry. The slurry hydrometer is the simplest and most effective on farm tool which estimates the slurry DM content. Since, the DM content of the slurry is closely related to the N, P and K content, this can be a very useful tool to estimate nutrient contents in slurry easily and cheaply on the day of slurry application. This will allow adjustment of slurry application rates based on the slurry nutrient content.

The extent to which slurry can vary in its fertilizer value based on dilution is shown Table 3. For example take silage ground receiving 33m^3/ha of slurry at 7% DM will supply 20kg P and 142kg K compared to 4% DM will supply 13 kg of P and 83 kg K. Incorrect estimation of nutrient value based on average values can lead to significant under- and over-supply of nutrients. Therefore a tool like the hydrometer that can help estimate nutrient content quickly and cheaply on farm would be beneficial.

Table 3. Typical N, P and K fertilizer value of cattle slurry and soiled water.

	Dry Matter %	Fertilizer Value (kg m^{-3})*		
		N**	P	K
Cattle Slurry	7%	0.7 (6)	0.6 (5)	4.3 (38)
½ slurry; ½ soiled water	4%	0.6 (5)	0.4 (3)	2.5 (22)
Soiled Water	1%	0.5 (4)	0.1 (0.7)	0.6 (5)

* units per acre are shown in brackets

** N fertilizer value assumes spring application with splashplate

Organic fertilizers on tillage crops

It is even more important where organic fertilizers are applied to tillage crops that the first load is of similar nutrient content to the last load. Organic fertilizers need to be applied at a consistent rate and evenness to ensure consistent nutrient supply across the field. Immediate incorporation of slurry will significantly increase N recovery. On tillage farms organic fertilizers should also be targeted to fields that are the longest in tillage, particularly those with low organic matter contents. As well as supplying N, P and K, organic manures also supply organic matter plus a range of secondary and micro nutrients such as Mg, sulphur (S), Mn, Cu and Zn.

5) Make sure the fertilizers used are properly balanced

The final step in the soil fertility management is to select a fertilizer that will deliver sufficient N, P and K in a cost effective way. Nutrients need to be applied in the correct balance. Over-supplying one nutrient will be money wasted if the output is being limited by another nutrient that is in short supply. The fertilizer products selected should complement the remaining N, P and K required after soil test results, production potential and earlier organic and chemical fertilizer applications have been accounted for.

On grassland farms nutrient advice, has to be adjusted for the nutrients supplied in slurry and the P coming onto the farm in concentrate feeds. On many intensively stocked livestock farms, chemical P rates are either very low or are not permitted. In this case, the main source of P on the farm is cattle slurry. It is therefore critical to target slurry applications to fields with a P requirement.

The reduction in P fertilizer application rates has resulted in a reduction in K fertilizer, as P and K application are usually applied together in NPK or PK compounds. This has resulted in an increase in the application of straight N products as the main fertilizer and forgetting about the K requirements on the farm. Potassium has a key role in the efficient use of N. Where K is limiting, it will reduce grass yield potential and reduce N efficiency.

On tillage farms the yield potential of cereal crops have increased significantly over the last 25 years resulting in higher P and K requirements. Therefore it is critical to select a fertilizer that will deliver the correct balance of P and K for the crop been grown. This is essential to maximise crop yield potential and secondly to prevent the decline of soil fertility levels.

Conclusions

Soil testing is the starting point to managing soil fertility. Knowledge of the nutrient status of each field on the farm is essential to making appropriate and cost effective decisions on fertilizer applications and organic fertilizer distribution around the farm. Soil pH is the first thing to get right. The efficiency of all other nutrient inputs will depend on it. Aim to maintain a soil pH 6.3 for the grassland farms and pH 6.5 for tillage crop rotations to maximise the availability and utilisation of applied N, P and K.

Soil fertility needs be managed on a long term basis with the aim to maintaining soils at P and K Index 3 for optimum production. It is very worthwhile to compare soil test results from the same fields over time. This will provide a sound basis for tailoring a fertilizer plan for the soils on your farm. It will also help identify fields that need extra nutrients in the form of slurry or FYM which is a cost effective way of replenishing soil fertility levels. Soil fertility changes very slowly over time so a small annual investment in lime, P and K now will pay long term dividends in the future.

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