The impact of achieving targets set out in Food Harvest 2020 on phosphorus and nitrogen fertilizer usage

Noel Culleton

Maintaining optimum soil fertility – focus on offtake

Stan Lalor, David Wall and Mark Plunkett

Recent technological developments in fertilizer spreading

Emmanuel Piron
**FERTILIZER ASSOCIATION OF IRELAND**

**PRESIDENTS**

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The impact of achieving targets set out in Food Harvest 2020 on phosphorus and nitrogen fertilizer usage

Noel Culleton

Introduction

The objective of this paper is to evaluate the nutrient inputs required to meet the production targets set out by the Food Harvest 2020 Report (referred to as FH 2020 from here on). The FH 2020 Committee Report was published in July 2010. The Report includes a range of specific volume and value growth targets for the different elements of the Irish agriculture, food, and forestry and fishing sectors. A key target in the report is to increase the value of primary output from the agricultural, fishing, and forestry sectors by €1.5 billion.

The FH 2020 report specifies a target increase in dairy production output of 50% relative to the average volume of production over the period 2007 to 2009. No production volume target is set for beef or sheep production, rather a target of increasing the output value of each of these sectors by 20% by 2020 is set relative to the average of the period 2007 to 2009. However, since the publication of the report in 2010, the beef targets have been increased to 40%.

Meeting these targets will obviously involve the extensive use of the major nutrients, nitrogen (N), phosphorus (P) and potassium (K). At the moment, the usage of P and K is declining and there is evidence that reduced fertilizer usage is leading to reductions in soil P and K levels. If Ireland is to increase production in line with FH 2020 targets it will be vital to maintain soil fertility at levels that will ensure that meeting these production targets will not be compromised by low soil fertility status.

This report sets out some basic principles and issues around sustainable fertilizer use in Ireland. Conclusions on what increases in fertilizer usage that might be required to meet targets are drawn and some potential implications of failing to match fertilizer use with production increases are outlined. This paper is confined to N and P as these major nutrients are most sensitive in terms of meeting the FH 2020 targets and their use is controlled by agri-environmental legislation.

Principles and issues around sustainable fertilizer usage in Ireland

Fertilizer types and patterns of usage have evolved in Ireland to suit our soil and climatic conditions and farm management strategies. It is instructive to look at the key factors that influence fertilizer usage before beginning to estimate the possible trends in usage in the future.
Achieving optimum grassland production by having adequate soil fertility:

Grassland based production accounts for 90% of total agricultural output in Ireland, with tillage and intensive livestock (pig and poultry) sectors accounting for most of the balance. The management and fertilizing of grassland is therefore central to future fertilizer use in Ireland.

The dairy, beef and sheep industries constantly face increasing competition as Ireland becomes a more open economy, and it is vital that costs of production are minimised in order to remain economically competitive. Grassland is therefore the single most important agricultural resource in Ireland and it is pivotal to the productivity and profitability of our animal based industries. Successful dairy, beef and sheep farming in Ireland is, to a large extent, due to the efficient conversion of grass to milk and meat. Grass, when grazed efficiently, is by far the cheapest feed available and therefore every effort must be made to provide a supply of nutritious herbage over the entire growing season at low cost.

The farming systems used by many of our European competitors achieve high output per animal, especially dairy cows, by increasing concentrate feeding rate. In Ireland, our competitive advantage lies in maximising the use of grass in situ. Moving towards increased concentrate supplementation to augment output, rather than getting better performance from grass, would mean that we would be in real danger of losing our competitive advantage over our competitors. Maximising output from grass is therefore vital to us. This can be done in many ways but if basic soil fertility is poor the potential yield from grass is significantly diminished (Tunney et al, 2010). If Ireland is to meet its 2020 targets, basic soil fertility and judicious use of nitrogen will be essential, especially if we are to remain dependant on grazed grass rather than on increased concentrate feeding.

Nitrogen also brings many other benefits to a well-managed sward. Nitrogen applied early in spring will facilitate grass growth some six weeks earlier than if no N is applied. Similarly, in autumn, N spread at the appropriate time can extend the grazing season by up to four to six weeks. Nitrogen supplied strategically during the growing season, ensures continuity of supply, on a daily and predictable basis.

**Phosphorus fertilizer strategy**

Phosphorus fertilizer advice for mineral soils is based on increasing the soil P reserves to a level at which the amount of available P supports the production of herbage of optimum quantity and quality (P content should be sufficient to meet not just that required for plant growth but also sufficient to meet the dietary requirements of high yielding dairy cows). The process of establishing the optimum soil P level (Index 3) is referred to as soil P build-up (Coulter and Lalor, 2008). Once this optimum soil P level has been achieved, the objective is to maintain the soil P level by replacing the P removed in animal product, in hay or
silage, or in crops. This is called soil P maintenance. When the soil P is sub-optimal, extra P needs to be added over and above that required for maintenance. When soil P is above optimum, there is increased risk of P loss through overland flow to water bodies, causing potential damage to water quality. In such cases, application should be avoided so that soil P levels can gradually decline to optimum levels and risks of losses are reduced.

Assuming normal soil fertility, a stocking rate of two cows per ha will lead to the removal of approximately 10 kg of P in the milk. This must be replaced if soil fertility is to be maintained. This concept of maintaining a P balance is crucial to the whole debate on sustainable P fertilizer strategy, as, by definition, maintaining a P balance means environmental neutrality, provided good nutrient management practices are adhered to. The concept is also independent of stocking rate. It is possible to have a high stocking rate which will involve the additions of extra P without having an adverse effect on water quality, assuming that the P is applied at the right rates, at the right times and in the right places.

Environmental Considerations

Agriculture, like all industries, has an influence on the environment it operates in. In this country we are fortunate in that the agricultural industry is largely grassland based and approximately 90% of the feed for our livestock is produced on the farm that rears the animals, i.e. the nutrients are recycled directly on the farm and only approximately 10-15% of feed is imported. In practice this means that our grassland based industry is largely based on internal recycling of nutrients, which by definition must be environmentally neutral, provided good nutrient management practices are adhered to. This grassland based industry is also instrumental in helping to create an industry that is based on green, environmentally benign systems of production that are quantifiably sustainable.

Nonetheless, agriculture can have some negative effects in the environment and these negative effects have the potential to become more pronounced as the farming intensity increases to meet FH 2020 targets. In this paper a few brief remarks are confined to nutrient management strategies and the environment.

Increased farming intensity has, in the past, been associated with deteriorating water quality. The reasons for this have now been clarified and have become widely understood over the past decade and it is now possible, using this knowledge and good management practices, to farm intensively with minimal damage to water quality. It is inevitable that more fertilizers will be needed if we are to meet the FH 2020 targets. It is also true that if good nutrient management is followed and farmyard design and management are adequate there need not be any deterioration in water quality at these increased stocking rates.
It is opportune to make one point about water quality and source verification. Over the past decade, farmers have made massive efforts to reduce losses of nutrients to water. Farmyards have been improved; the lack of adequate slurry storage has been rectified on most farms; the efficiency of slurry utilisation has improved significantly and there is a strong appreciation amongst farmers of the risks of water pollution potentially caused by their activities if close attention to nutrient management is not practiced at all times. This begs the question that if water quality is not improving or indeed if it is deteriorating what is causing the deterioration? The farming sector could well argue that the problem is not being caused by them. Unfortunately debate alone will not solve this problem. Sources of pollution need to be identified with scientific certainty in order to answer recurring questions regarding alternative sources of water pollution such as septic tanks and urban waste treatment. Is pollution caused by poor sewage systems in towns and villages? Is it caused by local factories or individual rogue farmers? There is an urgent need to develop scientific methodology that can pinpoint the sources of pollution. If water quality is deteriorating and the farming sector is not the main source of this pollution, then expansion in the dairy and beef sectors should be allowed by the Authorities to proceed at the rapid rate required to meet the FH 2020 targets.

Projected phosphorus usage in 2020

In a sustainable grassland production system all the P leaving the farm must be replaced by imported feed, slurry/farmyard manure or fertilizer if soil fertility is to be maintained. Central statistics Office data were used to determine milk output, beef and sheep numbers, and area under tillage for the reference years 2007 to 2009. Phosphorus offtakes were calculated from this information (Coulter and Lalor, 2008; DEFRA 2010). For 2020, milk output was taken to increase by 50%. FAPRI data (Donnellan and Hanrahan, 2011) was used to determine beef and tillage data for 2020. FAPRI predicted a slight increase in beef output and a significant decline in the area under tillage. The increase in dairying will result in an increase of 3,007 tonnes of P being removed from dairying; a modest increase of 540 tonnes of extra P being removed from beef farming, and a decrease of 1,348 tonnes of P being removed from tillage operations (Table 1). When these data are collated, a net annual increase of 6.9% in P removals is predicted by 2020. If soil fertility is to be maintained, this P must be replenished in the soil, meaning that the use of nutrient P must therefore increase by 6.9% by 2020.

There are two issues arising from this. The first is the data for the tillage sector. It can be argued that the predictions for this sector are unduly pessimistic, indeed a recent report (Tillage Sector Development Plan, 2012) suggested that there is a potential for an increase in the area under tillage of approximately 64%. It should be pointed out that the area under tillage will have a profound influence on the total amount of P used. A well-stocked dairy farm will lead to the removal of 10-14 kg
ha\(^{-1}\) of P per year; a beef system will result in the removal of 4 to 6 kg ha\(^{-1}\) of P per year. In contrast, one hectare of barley or wheat can lead to the removal of between 30 and 40 kg of P per year.

Table 1. Estimated phosphorus offtake (tonnes per year) in milk, beef and tillage systems in the reference years (2007-2009) and in 2020.

<table>
<thead>
<tr>
<th>Production type</th>
<th>Phosphorus offtake (tonnes per year)</th>
<th>Reference years</th>
<th>2020</th>
<th>Change in P offtakes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillage</td>
<td>8,301</td>
<td>6,953</td>
<td>-1,348</td>
<td></td>
</tr>
<tr>
<td>Meat</td>
<td>10,860</td>
<td>11,400</td>
<td>+540</td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td>4,934</td>
<td>7,401</td>
<td>+2,467</td>
<td></td>
</tr>
<tr>
<td>Total P offtake</td>
<td>24,095</td>
<td>25,754</td>
<td>+1649</td>
<td></td>
</tr>
</tbody>
</table>

% change in P offtake: + 6.9%

The second issue involves soil fertility. In all the estimations to date, no account is taken of soil P fertility, given that only offtakes of P are being considered (i.e. assuming normal soil fertility of Index 3). There has been no account taken of soil P build-up in low fertility situations or, indeed, soil P decline in situations where soils are in P index 4.

There is strong evidence that P fertility has been declining in recent years (Plunkett, 2012). Figure 1 shows soil P levels from 2001 to 2011. These figures were collected from the soil samples sent by farmers and advisors to Teagasc for analysis. The table clearly shows a steady increase in the proportion of Index 1 and Index 2 soils, with a proportionate decrease in Index 3 and Index 4 soils in the period since 2006-2007. The percentage of soils in Index 1 and index 2 have increased from approximately 40% to 55%, while soils at the optimum Index 3 have decreased from approximately 30 to 25%. While a decline in the number of Index 4 soils is desirable from an environmental point of view, an increase in the number of index 1 and 2 soils is highly undesirable where agricultural production is to be maintained and increased. This decline in soil P level is largely due to declining P usage since 2003 according to the Fertilizer Use Survey (Lalor et al, 2010), although this decline in P usage can be seen as far back as 1996 (Tunney et al, 1997).

Another possibility for reduced P status on highly productive farms lies in the Nitrate Directive regulations. The milk yield per cow is taken to be less than 5000 litres of milk per year. There are many dairy farms with cows yielding above this and therefore these farms may be, by definition, in negative balance because more P is being removed than is being replaced and this may be leading to reduced soil P levels over time. This problem can be overcome by frequent soil testing and when soil P levels decline to index 2, build-up as well as maintenance P can be applied.
until adequate soil fertility is restored. The problem with this solution is that frequent soil testing does not always occur, and soil fertility may therefore be declining without being noticed. Tackling this problem by arguing for a change in the rules is problematic, in that the regulations around nutrition in the Directive are quite complex and a change in the regulations in the area of P allowances may have serious implications for other areas in the regulations.

Figure 1. Soil P Index trends from 2001 to 2011 (Plunkett, 2012).

Low soil P in the future will be a serious impediment to crop and livestock production, with mean yield reductions of up to 1.5 t ha\(^{-1}\) yr\(^{-1}\) of grass DM production being estimated where soil P levels are at Index 1 rather than at optimal Index 3 (Teagasc, 2012).

This trend of declining soil fertility is quite serious and, if it were to continue, it could have disastrous economic consequences. Table 2 outlines the state of soil P status by 2020 if fertilizer usage and soil fertility decline trends continue as it is currently. The table assumes a continuation in the rate of decline in soil fertility in the nine years from 2011 to 2020 as has occurred since 2007. It does not take into account any extra off-takes that will occur if FH 2020 targets are to be achieved. While this is a speculative extrapolation of soil P fertility decline, it indicates the potential danger of allowing current trends to continue, and shows that approximately 47% of Irish soils will be in Index 1 and a further 37% will be in Index 2 by 2020. Taking the Teagasc estimate of 1.5 t ha\(^{-1}\) reduction in DM yield due to poor soil fertility, and estimating that an additional 750,000 ha of grassland will revert into Index 1 (increase in Index 1 soils on 23% of the grassland area), this equates to the national grass DM yield being reduced by approximately one
million tonnes compared with current production. If we are to maintain and increase levels of livestock output, this grass DM will have to be provided in the form of concentrate feeds. This is an expensive substitution for grass and will lead us to reducing our competitive advantage.

Table 2. Speculative data on soil P status from 2007-2020, based on estimated data and linearly extrapolated projections based on Figure 1.

<table>
<thead>
<tr>
<th>Soil Index</th>
<th>2007</th>
<th>2011</th>
<th>Estimated Δ per annum</th>
<th>Projected %’s in 2020</th>
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<tr>
<td>1</td>
<td>14%</td>
<td>24%</td>
<td>+ 2.5%</td>
<td>47%</td>
</tr>
<tr>
<td>2</td>
<td>27%</td>
<td>30%</td>
<td>+ 0.8%</td>
<td>37%</td>
</tr>
<tr>
<td>3</td>
<td>29%</td>
<td>24%</td>
<td>- 1.3%</td>
<td>13%</td>
</tr>
<tr>
<td>4</td>
<td>30%</td>
<td>22%</td>
<td>- 2.0%</td>
<td>4%</td>
</tr>
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</table>

The problem does not really stop here. If poor soil P status is to be reversed, maintenance dressings must be supplemented with additional P from soil fertility build-up. Teagasc results have shown that it requires approximately 50 to 60 kg ha\(^{-1}\) of fertilizer P to increase soil test P by 1 mg L\(^{-1}\). This suggests that it will take approximately 150 kg ha\(^{-1}\) to increase a soil Index 1 or 2 to a soil Index 2 or 3, respectively. Using Teagasc figures for 2011 where some 55% of soil samples are in Index 1 or 2, it would mean that there would be an additional 300,000 tonnes of P required to build all of the Index 1 and 2 soils by one index by 2020.

Against a background of the fact that P is a finite resource there is some evidence that world supplies are becoming scarcer (Cordell et al 2009). It is therefore inevitable that P will become more expensive in the coming years. It does appear short-sighted that the country is running down its reserves of soil P rather than conserving and increasing it. It is appreciated that when P is spread at the wrong rates, or at the wrong times, or in the wrong places that it poses a serious threat to the environment. Nonetheless, using it at inadequate rates at a national level poses a serious threat to the competitiveness of the industry.

It is time that an accommodation is reached between agricultural interests and environmental concerns. The following issues need to be addressed:

1) From a farming perspective, use of P needs to be on a sustainable basis. It will not be possible to continue intensive and competitive agricultural activity against a background of declining soil fertility. Farming in low fertility soils leads to a reduction in grass yields and if output is to be maintained, it can only be done by the purchase of expensive concentrate feeds.

2) In order to achieve FH 2020 targets use of P will need to increase significantly. Increased P use will lead to increased risk of overland flow to water. Therefore,
care will be needed to ensure that risks are minimised by ensuring that P is spread at the right rates at the right times and in the right places.

3) Good water quality is vital to our national interests. It is therefore vital that every effort is made to ensure that P does not escape from the land to water. Measures like riparian zones, constructed wetlands and catchment/community approaches to water quality improvement all need to be fully explored and developed.

4) The scientific community needs to throw their weight behind efforts to achieve sustainable P fertilizer use. The areas that warrant research include the following:

- Verification of sources of pollution.

- Soil P chemistry: more information is needed on mechanisms governing P release in soils and rate of P decline in differing soil types with a view to developing more precise recommendations for differing soil types.

- Phosphorus recycling in all its aspects.

- The main reason why P is lost from grassland soils is that it remains on the surface of grassland soils rather than being incorporated into the soils. This leaves the P vulnerable to run-off. Research is needed to explore biological, chemical or mechanical means of incorporating P into the top 5-10 cm of soil, thereby reducing the risk of overland flow to water bodies.

**Projected nitrogen usage in 2020**

The projections for N usage in the event of achieving FH 2020 targets are more difficult to predict and therefore the predictions outlined in this paper will be more speculative than those made for P. Nitrogen use in tillage systems is based on crop type and the crops place in a rotation. Therefore, the overall N usage therefore is largely dependent on land area devoted to tillage. For grassland, N usage is largely dependent on stocking rate and animal type. Other factors that influence N usage in grassland are efficiency of slurry usage, reseeding and most importantly climatic factors in any one year. Stock numbers, stock type and stocking rates are the three variables that must be examined if we are to arrive at a reasonable estimate of future N usage in the grassland sector.

**Predicted livestock numbers by 2020**

Table 3 shows that the annual livestock numbers for grazing animals in the reference years (2007-2009) calculated from CSO data. Projected annual livestock numbers for grazing in 2020 are estimated as per the projections or the FAPRI model published by Donnellan and Hanrahan, (2011).
Table 3. Predicted grazing livestock numbers ('000 head) under FH 2020 based on FAPRI-Ireland predictions (Donnellan & Hanrahan, 2011).

<table>
<thead>
<tr>
<th>Reference Years 2007-2009</th>
<th>FH 2020</th>
<th>% Change</th>
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<tbody>
<tr>
<td>Total cattle</td>
<td>6487.2</td>
<td>5714.9</td>
</tr>
<tr>
<td>Dairy cows</td>
<td>1065.3</td>
<td>1380.8</td>
</tr>
<tr>
<td>Other cows</td>
<td>1164.9</td>
<td>925.1</td>
</tr>
<tr>
<td>Total sheep</td>
<td>4249.5</td>
<td>5020.2</td>
</tr>
<tr>
<td>Breeding sheep</td>
<td>2658.7</td>
<td>2484.9</td>
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The FAPRI-Ireland model predicts that total cattle numbers will decline by 12% in 2020 compared to the reference years. The abolition of quotas and therefore the production of milk are the principal drivers of change in agricultural output within the FH 2020 scenario. The 50% increase in milk output will come from both increased milk per cow and increased dairy cow numbers. FAPRI-Ireland predicts that cow numbers will increase by 30% by 2020. However, the FAPRI model also predicts that this increase in dairy cow numbers will be somewhat moderated by a decline of 21% in numbers of other cows, comprising mostly of suckler cows. Overall this translates into an increase in breeding cow (dairy and beef) numbers of approximately 3% (i.e. 3% more calves born per year). This means that the decline in beef calves born to suckler cows will be fully offset by an increase (approx. 30%) in dairy to beef calves as a result of the larger dairy cow herd. With increased efficiency and shorter beef animal finishing durations, a modest increase in overall beef (meat) production in 2020 is predicted. The total number of sheep is predicted to increase by 18%, although this is within a background of declining breeding sheep numbers (-17%). By 2020, dairy cows will be the largest group within the entire livestock grouping. A 30% increase in cow numbers is a quite a conservative estimate. A recent study conducted for Ulster Bank suggested that there could be an increase of over 42% in cow numbers (Bogue, 2012). With the abolition of quotas and an improvement in the genetic merit of cows it is felt that there is huge potential for vastly improved output per cow. Hence, it is felt that a 30% increase in numbers will give the necessary increase in milk yield to achieve FH 2020 targets.

In terms of livestock production systems, dairy systems are by far the biggest users of nitrogenous fertilizers. As farmers increase output of milk to meet FH 2020 targets, more grazed grass will be required to feed the national dairy herd. In turn more nitrogenous fertilizer will be required to grow grass to meet the demand from these grazing animals. If more grass is not grown the extra feed can only be acquired from purchasing additional concentrates.
The decline in overall beef cattle numbers is considered in terms of the land made available for (or transferred to) dairy production systems and the moderation in dairy stocking rates accrued from this increased dairy land base. Changes in sheep numbers are not considered due to the relatively low increase in land needed to carry the predicted increase in sheep numbers and the relatively low fertilizer rates used in sheep production systems.

**Predicted land use changes by 2020**

The next stage in this analysis was to predict the changes in agricultural land use for the differing agricultural sectors. The percentage distribution of Irish farms according to farm systems and size was calculated for the 2007-2009 reference years from the NFS data and was reported in The Fertilizer Use Survey (Lalor et al., 2010). Land used for forestry and other uses were not included in these calculations and, for this study, it is assumed that none of the agricultural land made available through changing land use went into these alternative systems. This may be an over simplification but unless major changes in our farming systems were to occur (which history would suggest that such a rapid change is unlikely), for the purposes if these estimates, the assumption is reasonably valid.

It is assumed that the agricultural area used for sheep production will remain more or less constant and that farm stocking rates will increase in line with the increases in total sheep numbers predicted by FH 2020 (coming primarily from seasonal increases in lamb numbers). The decline in area devoted to tillage will lead to more land being made available to dairy systems. The decline in beef cattle numbers will lead to a reduction in land used for beef production, if we assume a constant beef cattle stocking rate. The increase in land used for dairy systems was calculated by difference in the other systems, assuming the direct transfer of land to dairying from these systems.

**Table 4. Predicted change in agricultural land use in 2020.**

<table>
<thead>
<tr>
<th></th>
<th>2007-09 Proportion of Agricultural Land-use</th>
<th>FH 2020 Proportion of Agricultural Land-use</th>
<th>% Change in Agricultural Land use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy</td>
<td>30.1</td>
<td>35.5</td>
<td>18</td>
</tr>
<tr>
<td>Cattle</td>
<td>46.7</td>
<td>43.0</td>
<td>-8</td>
</tr>
<tr>
<td>Sheep</td>
<td>13.8</td>
<td>13.8</td>
<td>0</td>
</tr>
<tr>
<td>Tillage</td>
<td>9.4</td>
<td>7.7</td>
<td>-18</td>
</tr>
</tbody>
</table>

Table 4 shows that by 2020 the land devoted to dairying will increase from 30.1% to 35.5%, an increase of 18%. The area devoted to cattle production will have declined by about 8%. The area devoted to sheep, as suggested in the methodology, will remain static. Finally the area devoted to tillage will have declined by 18%.
This study therefore suggests that there will be a shift towards our most profitable sector (i.e. dairying) over the next eight years.

**Predicted fertilizer nitrogen usage by 2020**

The mean number of dairy cows was calculated from CSO data (www.cso.ie) for the reference period (2007-2009). The proportion of the total national dairy herd in a range of stocking rates was determined using National Farm Survey and Fertilizer Use Survey data (Lalor et. al., 2010). These results are presented in Table 5. There were 53,319 cows at a stocking rate of less than 100 kg ha\(^{-1}\) of organic N during the reference years. The N fertilizer usage recommended for an average stocking rate of 90 kg ha\(^{-1}\) of organic N is, according to Teagasc, 40 kg ha\(^{-1}\), while the actual N usage, according to the Fertilizer Use Survey, was 35 kg ha\(^{-1}\). Similarly, at a stocking rate of 130-170 kg ha\(^{-1}\) of organic N, there were 494,280 cows. The fertilizer N advice for a mean stocking rate of 150 kg ha\(^{-1}\) of organic N is 141 kg ha\(^{-1}\) of N, while the rate spread at this stocking rate was 106 kg ha\(^{-1}\). Table 5 outlines the number of cows at stocking rates up to and beyond 250 kg ha\(^{-1}\) of organic N, as well as the suggested fertilizer N rate and the actual amount of fertilizer spread at each stocking rate. Approximately 63% of the national dairy herd was being farmed at stocking rates less than 170 kg ha\(^{-1}\) of organic N, with 17% at low stocking rates (< 130 kg ha\(^{-1}\) of organic N). This shows the scope to increase cow numbers on land currently being used for dairy production while remaining compliant with the maximum stocking rate levels under the Nitrates Directive.

The FAPRI model prediction for the increase in cow numbers is 30%. The area of land devoted to dairying has been calculated as increasing to 35%. In the calculation of stocking rates in 2020, the increase in stocking rates is assumed to be somewhat mitigated by the extra land that will become available to dairy farmers from the reduction in area devoted to other enterprises (primarily from beef farming and the reduction in the tillage area, see Table 4). Table 5 enumerates the number of cows at each of the newly calculated stocking rates in 2020 assuming a pro rata increase in cow numbers by 30% across all stocking rate groupings. It is predicted in 2020 there will be 1,381,000 cows in total. At a mean stocking rate of 165 kg ha\(^{-1}\) of organic N, it is predicted that there will be 640,739 cows. The new N advice calculated for each new mean stocking rate in 2020 is also calculated. These N fertilizer advice calculations are based on the grass requirement for each whole farm stocking rate and assume that grazed grass remains the dominant feed for cows. The predicted increase in N fertilizer use in 2020 is based on the % increase in N fertilizer advice calculated for each stocking rate and ranges from zero at the high stocking rates (> 210 kg ha\(^{-1}\) of organic N) to between 10-24% at lower stocking rates (< 210 kg ha\(^{-1}\) of organic N). The average increase in overall mean N fertilizer use will be similar to the increase in average mean fertilizer advice. For the 130-170 kg ha\(^{-1}\) of organic N stocking rate grouping, a 24% increase in N
fertilizer use is predicted over that used for this stocking rate grouping during the reference years. Using this methodology it is calculated that total N fertilizer usage for dairying will increase by 18%.

Table 5. Nitrogen fertilizer use on the dairy grazing platform under FH 2020 scenario*.

<table>
<thead>
<tr>
<th>Farm Stocking Rate Grouping kg ha⁻¹ organic N</th>
<th>Reference farm profile 2007-2009</th>
<th>FAPRI-Ireland FH 2020 Scenario (Increase in dairy cow numbers by 30%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Stocking Rate kg ha⁻¹ organic N</td>
<td>Number of Dairy cows#</td>
</tr>
<tr>
<td>&lt;100</td>
<td>90</td>
<td>53,319</td>
</tr>
<tr>
<td>100-130</td>
<td>115</td>
<td>122,715</td>
</tr>
<tr>
<td>130-170</td>
<td>150</td>
<td>494,280</td>
</tr>
<tr>
<td>170-210</td>
<td>190</td>
<td>290,558</td>
</tr>
<tr>
<td>210-250</td>
<td>230</td>
<td>79,141</td>
</tr>
<tr>
<td>&gt;250</td>
<td>270</td>
<td>25,320</td>
</tr>
</tbody>
</table>

Overall Change in N fertilizer use (weighted average) 118%

Total Cow Numbers 1,065,333§ 1,381,000*

* Number of dairy cows per stocking-rate band calculated from Fertilizer Use Survey data (Lalor et al., 2010)
§ Mean number of dairy cows in reference years was calculated from CSO data (www.cso.ie)
* FAPRI-Ireland dairy cow number predictions (Donnellan & Hanrahan, 2011)

In summary, almost 50% of dairy farms were stocked between 130 - 175 kg organic N ha⁻¹ in the reference years and these farms contained approximately 50% of the national dairy herd (494,000). By 2020 the number of cows in this grouping will have risen to 640,739. The average stocking rate in this grouping will also have risen, resulting in an increase of 24% in N usage to grow the grass necessary to maintain this level of production. There may be more scope for lowly stocked farms (<170 kg ha⁻¹ of organic N) to increase cow numbers compared to highly stocked farms due to land availability and Nitrates Directive restrictions. There are also significant increases predicted in the numbers of cows at the high stocking rates, for which derogations will be necessary. The maintenance of the derogation facility and acquiring permission for many more farmers to avail of it will be vital to the expansion of the dairy sector to meet the FH 2020 targets. Overall N fertilizer use on grassland for grazing on dairy farms will increase by approximately 18%.
Predicted nitrogen use in tillage farming systems

As already stated the overall area of land devoted to tillage crop production is predicted to decline by 18%, according to the FAPRI model predictions. Overall the N fertilizer usage on tillage crops is predicted to decline by approximately 17% by 2020. As already stated this prediction may be unduly pessimistic and as N use in tillage is directly related to area of land under tillage. It follows that if the tillage area remains static or increases, then higher N usage will follow.

Table 6 draws all these facts together into one table. In dairying, mean N fertilizer usage will go from 112 kg N ha\(^{-1}\) to 132 kg N ha\(^{-1}\), an increase of 18%. The percentage of total N fertilizer spread in the dairying sector as a percentage of total fertilizer used will increase from 53% to 64%. The N usage on the beef sector will remain static, suggesting that the N usage in the sector expressed as a percentage of total N usage will decline from 21% to 16%. A similar picture emerges for the sheep sector, in that the mean N usage is predicted to remain relatively static, indicating that when N usage in the sector is expressed as a percentage of total N spread, the figure falls to 6% of the total. While it is assumed that mean N usage per hectare in the tillage sector remains the same, the area devoted to tillage is predicted to fall, and therefore N usage in tillage as expressed as a percentage of total N usage will fall from 20% in the reference years to 14% in 2020. The weighted mean N fertilizer usage is estimated to increase from 95 kg ha\(^{-1}\) to 110 kg ha\(^{-1}\). This represents an increase of 16%.


<table>
<thead>
<tr>
<th></th>
<th>2007-09 Average N fertilizer use*</th>
<th>2007-09 Distribution of total N fertilizer use</th>
<th>FH 2020 Average N fertilizer use*</th>
<th>FH 2020 Change in N fertilizer use/ha</th>
<th>FH 2020 Distribution of total N fertilizer use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg/ha</td>
<td>%</td>
<td>kg/ha</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Dairy</td>
<td>112</td>
<td>53</td>
<td>132</td>
<td>118</td>
<td>64</td>
</tr>
<tr>
<td>Cattle</td>
<td>28</td>
<td>21</td>
<td>28</td>
<td>100</td>
<td>16</td>
</tr>
<tr>
<td>Sheep</td>
<td>30</td>
<td>7</td>
<td>30</td>
<td>100</td>
<td>6</td>
</tr>
<tr>
<td>Tillage</td>
<td>137</td>
<td>20</td>
<td>137</td>
<td>100</td>
<td>14</td>
</tr>
<tr>
<td>Weighted mean</td>
<td>95</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*2020 (FH) total N fertilizer use 110

*N fertilizer use data for livestock based on rates applied to grazing only
Summary and conclusions

- The impact of reaching the targets set out in FH 2020 on N and P usage is assessed.

- The major change in land-use, and therefore in fertilizer usage, is in the dairying sector. There will be 2,467 extra tonnes of P removed off farms in milk, assuming the 50% increase in milk production is achieved. If soil fertility is to be maintained this P must be replaced.

- Because of the reduced area in tillage predicted by FAPRI, P usage will have declined significantly by 2020. It is predicted that P off-takes will be reduced by 1,348 tonnes. It follows therefore that P usage can decline by this amount without reducing soil fertility any further in this sector. It is possible that the prediction of this reduction in the area under tillage is unduly pessimistic. It is noted that even though the area of land under tillage is less than 10%, the total land, the total impact of changes in area devoted to tillage on total P usage and off-takes will be significant given that approximately 25-35% of the total P fertilizer usage is applied to tillage crops.

- It is predicted that there will be modest increase in P off-takes in beef production, amounting to some 540 tonnes. To maintain soil fertility, this P must be replaced.

- Taking the industry as a whole, P off-takes are predicted to increase by 6.9%, suggesting that in order to maintain soil fertility nutrient P inputs should increase by 6.9%.

- There is strong evidence that soil P levels have been declining quite rapidly in the past few years. If the current trend of declining soil P were to continue until 2020 there will be 47% and 37% of soils in index1 and index 2, respectively. If we were to assume that this led to a potential drop in production of 1.5 t ha\(^{-1}\) yr\(^{-1}\) of DM due to poor soil fertility, this, in turn, would mean that the national dry matter yield of grass would decline by approximately one million tonnes per annum compared to current production. If production levels are to be maintained, extra concentrates will be required to replace the shortfall in grass supply.

- If the current trend of declining fertilizer usage continues and soil fertility continues to decline, it will be difficult, if not impossible, to meet FH 2020 targets without a significant increase in the usage of concentrates to compensate for grass dry matter yields not reaching their potential. This will result in a loss of competitiveness.

- There is need for a strong awareness campaign to highlight the importance of P to maintain competitiveness in food production. This campaign will
also have to highlight the fact that, if good farming practice is adhered to, there need not necessarily be deterioration in water quality.

- Trends in N use are more difficult to predict because of changing patterns in animal numbers.

- Assuming that the 2020 target of a 50% increase in milk production is achieved by a 30% increase in cow numbers, an 18% increase in N usage in the dairying sector is predicted.

- There are very little changes in the predicted N usage in the beef and sheep sectors.

- Because of the predicted decline in the area devoted to tillage, N usage is predicted to decline by approximately 17%. This may change if this rather pessimistic projection is wrong and nitrogen usage will rise in tandem with any increases in the area devoted to tillage.

- Taken as a whole, it is predicted that N usage in the agricultural sector will increase by approximately 16%.

- The major change will be in the dairying sector. In the reference years (2007-2009) of the N usage in agriculture, dairying consumes some 53% of the total. By 2020 dairying will consume some 64% of the total N used.

- The increases in the fertilizer usage projected in this paper can be achieved within the Nitrate Directive Regulations. The P increases are due to increased output and maintaining P balances. The N is accounted for the extra N needed to maintain the increased stocking rates that are well within the organic nitrogen thresholds outlined in the Nitrates Directive.

References


Introduction

Only approximately 25% of soil samples analysed through Teagasc in 2012 had soil P and K levels in the optimum soil fertility range, commonly referred to as Index 3. This means that 75% of the soils analysed were outside the range of what is desirable in an agronomic and environmental sense.

Productive soils are the foundation of any successful farm system. The increasing demand for high grass growth rates and crop yields represents an increasing demand on soil fertility levels. The ability of soils to maintain a temporal supply of nutrients in the appropriate quantities for crop growth is a key determining factor of how productive a field or farm can be. Therefore, the management of soil fertility levels should be a primary objective on any farm.

Fertilizers account for a significant proportion of direct production costs on farms, but fertilizer costs represent good value for money when used correctly. However, fertilizer application rates that are either too low, too high, or not in balance with other soil fertility factors will yield lower returns on investment. With fertilizers becoming more expensive, it is vital that fertilizer is managed as efficiently as possible with maximum return in farm produce.

The objective of this paper is to focus on the impact of this diversity in soil fertility levels on the fertilizer application rates of different crops and grassland systems. The paper highlights the importance of balancing nutrient inputs against nutrient offtakes. The paper also describes a new ‘Nutrient Calculator Wheel’ that can assist in formulating fertilizer recommendations that take nutrient offtakes into account.

Soil fertility management

Managing soil fertility is about focussing on the key aspects of soil and nutrient applications, and setting targets for the farm. Plunkett (2012) outlined 5 steps that should be followed to manage soil fertility.

1) Soil samples

Have soil samples taken for the whole farm. Unless you know what is already in the soil, it is impossible to know how much fertilizer it needs. Therefore, by taking soil analysis and putting the results into practice, the fertilizer programme can be
tailored to the needs of the soil and the crop. Repeating soil analysis over time is also critical to monitor the effectiveness of the fertilizer strategy.

2) *Lime*

Apply lime as required to increase soil pH up to target pH for the crop. Soil pH should be the first thing to get right where soil test results indicate that lime is required. Lime should be applied to neutralise acidity and raise the pH. For mineral soils, a pH of 6.3 is recommended for grassland. The soil pH should be slightly higher for tillage crops. Acid soils will result in reduced nutrient release from soil, and poorer response to fertilizers. Apply lime as a priority in line with the lime advice.

3) *Target Index 3*

Aim to have optimum soil P and K fertility levels in all fields. At optimum fertility levels, nutrients being removed in products need to be replaced. High fertility soils are a resource and should be exploited. Low fertility soils need to be nurtured. For soils in Index 3 the fertilizer program should be designed to replace the nutrients being removed, thus maintaining the soil fertility level. Index 1 and 2 soils are low, and require additional nutrients to increase the fertility levels. Index 4 soils are high, and present an opportunity to save money on fertilizer inputs by harvesting the resources in the soil.

4) *Slurry and manures*

While slurry can be more difficult to manage than chemical fertilizer, it can be a very cost effective resource to increase fertility levels. Use slurry on the farm as efficiently as possible, and top up with fertilizer as required. Aim to apply slurry and manures to fields that have high P and K requirements. Apply in cool and moist weather conditions to maximise N recovery.

5) *Balanced nutrient supply*

If one nutrient is deficient, no amount of another nutrient will overcome this. For example, if a field is deficient in K, then excess N application will not be fully utilised. Make sure the fertilizer compound is supplying nutrients in the correct balance for the crop, the soil, and to complement other fertilizers being applied. Other nutrients such as Sulphur can play a very important role in a balanced fertilizer programme and should also be applied where necessary.

**Soil analysis**

In this paper, we discuss step 3 of soil fertility management (target Index 3) in more detail. Aiming to have as much of the farm as possible in soil Index 3
requires an understanding of the soil Index system and what the different indexes mean for fertilizer application. Understanding how much nutrients are being removed in different crops is also important.

**Soil Index system**

To simplify nutrient advice, the soil Index system was developed to allow soils to be categorised for each nutrient tested based on the soil test result. The Index system used in Ireland places soils into one of four categories for each nutrient. The range in soil test results corresponding to each Index varies with each nutrient. The Index ranges for phosphorus (P), potassium (K) and magnesium (Mg) are shown in (Table 1). The nutrients P and K usually receive most attention in Ireland. The advice for soils low in Mg is to use a lime source that contains Mg.

**Table 1. The soil Index system used in Ireland for P, K and Mg (Coulter and Lalor, 2008).**

<table>
<thead>
<tr>
<th>Soil Index</th>
<th>Response to fertilizers</th>
<th>P (mg L$^{-1}$)</th>
<th>K (mg L$^{-1}$)</th>
<th>Mg (mg L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Grassland</td>
<td>Tillage</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Definite</td>
<td>0 – 3.0</td>
<td>0 – 3.0</td>
<td>0 – 50</td>
</tr>
<tr>
<td>2</td>
<td>Likely</td>
<td>3.1 – 5.0</td>
<td>3.1 – 6.0</td>
<td>51 – 100</td>
</tr>
<tr>
<td>3</td>
<td>Unlikely / tenuous</td>
<td>5.0 – 8.0</td>
<td>6.1 – 10.0</td>
<td>101 – 150</td>
</tr>
<tr>
<td>4</td>
<td>None</td>
<td>&gt;8.0</td>
<td>&gt;10.0</td>
<td>&gt;150</td>
</tr>
</tbody>
</table>

The P and K advice is based around maintaining soils at Index 3. This is the soil Index where the soil has sufficient nutrients to meet the nutrient uptake demands of the crop. For P, which can cause issues with water quality, Index 1, 2 and 3 are also considered to be lower risk for losses to water. The objective of the fertilizer strategy should therefore be to move as many soils into Index 3 as possible, and maintain them in Index 3 after that.

Advice for P and K in Index 3 is to apply annually to maintain soil reserves. 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.

Index 1 and 2 soils are very responsive to applied P and K. These soils have a higher P and K requirement as 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). The aim should be to build soil fertility levels from Index 1 and 2 up to Index 3 over a number of years. The application rate required for 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 results
A review of soil samples taken on farms and analysed through Teagasc indicates a large diversity in soil fertility levels on farms. The results of samples analysed in 2012 over all farm systems is shown in Figure 1. The results indicate that a relatively small proportion (only approximately 25%) of the soil analysed are in the optimum soil fertility range of Index 3. Plunkett (2012) identified an increasing trend in the proportion of these soils analysed with low fertility (Index 1 and 2) for P and K in recent years.

**Figure 1.** Proportions of soil samples analysed through Teagasc in 2012 (n= c. 35,000) with very low (Index 1), low (Index 2), optimum (Index 3) and high (Index 4) soil fertility levels for P and K. (Source: Teagasc).
These results indicate how important it is to have soil analysis results for a farm. In many cases, advice for Index 3 soils is assumed where soil test results are not available. These results highlight the danger of this strategy, and show that where standard Index 3 advice based on average offtake is given in the absence of a soil test result, the advice is likely to be incorrect in 75% of cases.

Another important message in these results is that there is a need to consider each nutrient separately. A soil that is low in P is not necessarily low in K, and vice versa. A lot of the commentary on nutrient management and fertilizers focus on P, while neglecting to consider other nutrients as being equally critical. The GAP (Nitrates) Regulations (Anon, 2010) are an explanation for this given that they focus exclusively on P from a soil testing perspective. However, giving all nutrients in the fertilizer blend equal consideration is a very important component of soil fertility management, and should not be forgotten. In many cases, this may mean a requirement for more diversity in the mix of NPK fertilizer blends available, or a move at farm level to greater adoption of straight P or K products or zero P and zero K blends.

**Replacing offtake**

Knowing how much nutrients are leaving the farm in produce is the key step to knowing how much fertilizer needs to be applied. In a tillage context, the level of offtake varies between crops and between years (mainly through yield variation). Factors such as straw removal also affect the offtake of nutrients, particularly K. In a grassland system, the offtake will depend on the farm system (e.g. dairy will be different to drystock) and the stocking rate. In some cases, such as with P in concentrate feeds fed to grazing animals, inputs into the farm can help offset the nutrient removal.

To assist in combining these factors when devising a fertilizer programme for a crop, The Fertilizer Association of Ireland, in collaboration with Teagasc and K+S UK & Eire Ltd, has published a ‘Nutrient Calculator Wheel’. This ready reckoner can be used in the field to estimate P and K offtakes for grassland and tillage crops. The P and K offtakes assumed in the wheel are based on a combination of existing advice in Ireland (Coulter and Lalor, 2008) and the UK (DEFRA, 2010).

**Offtakes in grassland systems**

The offtakes of P and K in grassland farming systems depend principally on the farm system and the stocking rate. Offtakes are normally calculated on the basis of whole farm nutrient balancers that estimate the net nutrient removal counting in the P and K removed in milk or meat. Inputs are also included; most notably the P contained in concentrate feeds. The standard P and K offtakes from dairy, grazing and drystock are shown in Table 2.
Table 2. Typical fertilizer P and K advice (kg ha\(^{-1}\)) for soil fertility maintenance in grazing systems on Index 3 soils (Coulter and Lalor, 2008). (Rates shown for P should be reduced by 5 kg ha\(^{-1}\) for every 1 t ha\(^{-1}\) of concentrate feed used).

<table>
<thead>
<tr>
<th>Stocking Rate (kg ha(^{-1}) organic N)</th>
<th>&lt;100</th>
<th>101-130</th>
<th>131-170</th>
<th>171-210</th>
<th>211-250</th>
<th>&gt;250</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy</td>
<td>P</td>
<td>6</td>
<td>10</td>
<td>14</td>
<td>19</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td>Drystock</td>
<td>P</td>
<td>4</td>
<td>7</td>
<td>10</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
</tr>
</tbody>
</table>

It should be noted that the rates shown for P should be reduced where concentrate feeds are used on the farm. The simplest way of adjusting for concentrate feeds is to calculate the tonnes of concentrates used on the farm per hectare using the following equation:

\[
P_{in\ Concentrate\ feed\ (kg\ ha^{-1})} = \frac{Total\ concentrate\ feed\ used\ (tonnes) \times 5\ (kg\ t^{-1}\ of\ P)}{Total\ grassland\ area\ (ha)}
\]

This equation assumes an average P content in concentrate feeds of 5 kg t\(^{-1}\). However, many straight or compound feeds may differ from this default value. True P contents of individual feeds should be used where they are known. In many cases, it can happen that the P in the concentrate feed will balance the full P offtake; hence the P fertilizer advice can be reduced to 0 kg ha\(^{-1}\) in these cases.

**Offtakes in silage**

The P and K offtakes of a grass silage field can be estimated from the dry matter (DM) yield of silage removed. The standard P and K advice for silage in Ireland assumes a crop yield of 5 t ha\(^{-1}\) of DM, and a P and K offtake of 20 kg ha\(^{-1}\) of P, and 125 kg ha\(^{-1}\) of K (Coulter and Lalor, 2008). However, the P and K offtake of any grass silage crop can be estimated based on the DM yield and by assuming P offtake of 4 kg t\(^{-1}\) of DM, and K offtake of 25 kg t\(^{-1}\) of DM.

The P and K offtake maize silage crop can be estimated based on assuming P offtake of 2.7 kg t\(^{-1}\) of DM, and K offtake of 12.7 kg t\(^{-1}\) of DM.

**Offtakes in Tillage crops**

The offtakes of P and K in tillage crops can also be estimated based on the yield of the crop. Typical offtakes of P and K from a range of tillage crops are shown in Table 3. Aside from harvested yield, the choice to remove straw as well as grain can have an impact on the total offtake. This is particularly true of K in cereal crops, where the straw represents a greater proportion of the K than the grain does. However, the effect of straw removal on P offtake is minimal, as most of the P in a
cereal crop is in the grain. Also of note in Table 3 is that the offtake of P and K per
tonne of beet or potatoes is very low. This is mainly due to the high water content
in the harvested yield of these crops relative to cereals, oilseeds or pulses, and
hence the higher overall yield of fresh material.

Table 3. Typical P and K offtakes in tillage crops, expressed as kg of P and K removed
per tonne of harvested yield. (Coulter and Lalor, 2008; DEFRA, 2010).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Offtake (kg t⁻¹ yield)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P</td>
</tr>
<tr>
<td>Winter Wheat / Winter Barley</td>
<td>3.8</td>
</tr>
<tr>
<td>Spring Wheat / Spring Barley</td>
<td>3.8</td>
</tr>
<tr>
<td>Oats</td>
<td>3.8</td>
</tr>
<tr>
<td>All Cereals</td>
<td>3.4</td>
</tr>
<tr>
<td>Oilseed Rape</td>
<td>Straw removed</td>
</tr>
<tr>
<td></td>
<td>Straw not removed</td>
</tr>
<tr>
<td>Peas</td>
<td>3.8</td>
</tr>
<tr>
<td>Beans</td>
<td>4.8</td>
</tr>
<tr>
<td>Beet</td>
<td>0.35</td>
</tr>
<tr>
<td>Potatoes (maincrop)</td>
<td>0.44</td>
</tr>
</tbody>
</table>

Converting offtake to a fertilizer recommendation

Generating a fertilizer programme requires combining the offtake and the soil test
result. Linking the soil test result to the offtake of the crop allows the nutrient
application rate to be adjusted for additional requirements for build-up if in Index 1
or 2, and for reduced application rates in high fertility Index 4 soils. The fertilizer
programme should also take into account nutrient sources that may be available in
the form of organic manures.

Nutrient Calculator Wheel

The nutrient calculator wheel (Figure 2) can be used for estimating P and K offtake
and formulating fertilizer advice based on soil test results. The wheel shows the P
and K offtake for a given grassland system based on the criteria of stocking rate,
system and concentrate feed input as outlined in Table 2. The wheel also estimates
the P and K offtake of silage, cereal and other tillage crops based in crop yield.

How it works

The wheel is worked by dialling the yield or stocking rate of the crop or grassland
and reading off the P and K offtake from the column of numbers revealed. This
offtake is referred to as the maintenance rate (M) in the wheel. The maintenance
rate can then be compared to the P and K application rate tables that indicate the correction of the maintenance rate for the soil test results. At Index 1 and 2, the advice is to apply ‘M’ plus and additional rate of P or K for soil build up. The build up rate to apply depends on the crop type. At soil Index 4, the advice is usually to apply either no P or K. Some crops (root crops and maize) recommend a lower rate of M, but still recommend some fertilizer at Index 4.

Figure 2. Nutrient calculator wheel: a ready reckoner that can be used in the field to estimate P and K offtakes for grassland and tillage crops

Applying the nutrients

When the required application rate, corrected for soil Index, has been calculated, the decision remains as to how to supply these nutrients. One option is to apply an organic fertilizer to supply all or part of some of the nutrients. Grassland or mixed farms will have organic manures available on the farm. Other farms may have the option of importing organic fertilizers. Either way, organic fertilizers can be a very cost effective source of nutrients, particularly where low fertility soils require additional nutrients for soil build up over and above the maintenance rates.

The right fertilizer product

The final step in the fertilizer recommendation is to select a fertilizer product (or mix of products) that supply the required application rates in the correct balance. Standard products may not suit all situations, so mixes of NP and straight K products may help in allowing sufficient scope for variation of P and K application between fields. The fertilizer selection should also complement any organic fertilizers that are applied to the crop.

Soil pH, lime, Sulphur (S) and Mg are also critical to an overall balanced approach to soil fertility, as are trace elements, particularly in tillage crops. A significant proportion of Irish soils will show a response to applied S. There is no reliable soil test for S, but responses are most likely on light textured soils with low organic matter content. Apply the following rates to crops grown on soils responsive to S:
grazed grass 20 kg ha\(^{-1}\) per year; grass silage 20 kg ha\(^{-1}\) per cut; cereals 15 kg ha\(^{-1}\) per year; and oilseed rape 25 kg ha\(^{-1}\) per year.

**GAP (Nitrates) cross compliance**

The formulation of fertilizer programmes for individual fields based on individual crop offtakes and soil test results being recommended in this paper needs to be cross-checked against the total N and P allowance on the farm in compliance with the GAP (Nitrates) Regulations. Adjustments to the fertilizer programme may be required where the N and P application rates need to adjusted to comply with the regulations. However, it is also important to highlight that it is only N and P that are controlled by the regulations. The farmer has freedom of choice in how to manage other nutrients such as lime, K and S. Therefore, it is important not to let the regulations in place be a reason for neglecting to focus attention on these nutrients in the soil and in the crop.

**Conclusions**

Managing soil fertility on farms is a critical factor in having a productive and profitable farm. Given the diversity of soil fertility levels in Irish soils, it is essential to know how fertile the soils on your farm are by soil testing. Fertilizer programmes should then be tailored to the soil test results and the offtake of the crops and systems on the farm. Balanced fertilizer inputs based on this information is the key to maintaining soil fertility over time. Tools such as the nutrient wheel can make the process simpler and easier to understand and implement.

**References**


Recent technological developments in fertilizer spreading

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Introduction

Generally, mineral fertilizer spreading is an agricultural operation carried out using centrifugal spreaders. As well as being relatively small, simple, easy to use and cheap, they are also attractive because of their capacity to reach high spreading efficiency due to factors such as wide working widths and high tractor speeds. Nevertheless, spreading uniformity depends on numerous variables such as the settings chosen on the spreader and the physical fertilizer properties. The latest technological developments which were developed by spreader manufacturers lead to an increase in working width performance up to a new maximum of 48 m but which are reliant on projection of the fertilizer granules over distances in excess of 35 m. Knowledge about the behaviour of fertilizer granules during the spreading process (i.e. from the hopper to the ground, passing through the vane’s acceleration) is important. However, it is relatively complex to model. Precise test benches are used by technicians in order to develop accurate technologies.

Tests were commonly performed using traditional transverse test benches and analysed using transverse curves. New test benches allow the real fertilizer spread pattern to be measured, including an increased knowledge of the 3D distribution. New information which is available from analysis of the 3D spread pattern is of great interest in isolating and better understanding the successive steps of centrifugal spreading. In particular, both main steps of centrifugal spreading can be analysed: acceleration along the vanes, and the ballistics of the fertilizer granules.

The first part of this paper gives some basic information about the centrifugal spreading process, leading to specific criteria such as the coefficient of variation (CV) which is an indicator of the robustness of the spread pattern. These criteria are explained using 3D spread pattern information. The paper also discusses the specific fertilizer physical properties that influence spreading, and suggests some ways to improve spreading performance by optimising some characteristics such as granulometry.

Physical principles of centrifugal spreading

Modern fertilizer spreaders are almost all based on the centrifugal spreading process which generally uses two different spinning discs which rotate in opposite
directions (divergent and convergent directions are both used by different manufacturers). Fertilizer flow from the hopper to each of the two discs is determined and controlled by gravity and the aperture size of the opening gate. This point is not a major issue nowadays since reliable technological devices are available to maintain the required flow rate relative to actual tractor speed.

Fertilizers arrive from the hopper to the disc in a continuous flow, and particles are then accelerated by the vanes (variable number between two to six or more). Regarding the flow value, each vane accelerates a variable quantity of fertilizer granules (between 30 and 3000 particles) and the granules leave the vane with a final speed which depends on the disc angular velocity, the length of the vane, and the physical properties of the fertilizer (e.g. angular shapes result in a lower final velocity than spherical ones). The total angular sector covered by each vane rotation is between 160° and 240°, with a particle distribution which follows a Gaussian law (the maximum density at the middle angle, and regular decreasing quantities on each side).

The acquired velocity allows the granules to start a ballistic flight in the air and to reach the ground at a distance called the projection distance.

![Figure 2. 3D spread pattern obtained using 2 discs, and field distribution induced after many parallel passes of the spreader. (Representation of the transverse curve for each successive run, and after overlapping.)](image)
The sum of the fertilizer quantities distributed on the ground is called the 3D spread pattern (Figure 2). It looks like an arc, with variable density distribution, and so the transverse curve it produces when the spreader moves along its travel axis is not regular. Generally a maximum quantity is distributed in the middle of the run, with decreasing quantities on either side. Overlapping between the successive runs is necessary in order to obtain a final rate that is consistent and as close to the desired rate as possible (Figure 2). Achieving a good spreading distribution in the field is a complex process, with a lot of interaction between transverse and longitudinal distribution. The variable distance between successive tramlines in the field can be an additional difficulty.

When correctly designed and set, each disc of a twin-disc spreader delivers a spatial distribution which is the mirror of the other regarding the spreader displacement axis (Figure 3). The non-regular transverse curve it produces is used to calculate the CV curve, which is a measure of the evenness of fertilizer distribution across the working width.

![Figure 3. Distribution obtained using a twin-disc: the CV curve is produced from the 3D spread pattern and the transverse curve.](image)

Optimal working width for each configuration of fertilizer and spreader settings is obtained when the CV value is minimal on the hollow of the CV curve (approximately 24 m in Figure 3). The CV value at this point represents the spreading heterogeneity which should be achieved if working with these configurations and working width. The CV values are considered as excellent if lower than 5%, as good between 5 and 10%, and poor if higher than 15%.
Spread pattern characteristics and spreading quality

In addition to the CV value, the robustness of the transverse curve must also be taken into account. Figure 4 shows the same field fertilizer application configuration where the tramlines are irregularly spaced (between 20 m and 30 m). Ideally set to work both at 24 m, the spreading pattern obtained on the left of Figure 3 presents very little under and over-applications compared to the right of Figure 3 where the application is more uneven (and induces potential agronomic or environmental problems). The difference between these two configurations is the transverse curve shape, which is “triangular” on the left, and “trapezoidal” on the right.

![Robust spreading](image1.png)

![Non robust spreading](image2.png)

Figure 4. Example of default applications in the field when tramlines are not regularly spaced, and regarding two different application parameters.

Examples of triangular and trapezoidal configuration in two dimensions from spatial and transverse points of view are shown in Figure 5. The CV graphs show identical performances of both spreading configurations when working on 32 m spaced tramlines (CV < 5%). They also show that heterogeneity becomes very important at higher or lower working widths when using trapezoidal configuration (right curves). The triangular configuration (left curves) allows the CV to remain very good at working widths between 20 and 35 m. This triangular shape is also considered to be more robust and adaptive to tramline variations in the field. The following ratio can be used to evaluate this ability of the curves:

\[ \frac{2W_w}{T_w} \]

(where \( W_w \) is the working width and \( T_w \) is the throwing width). When this ratio is equal to 1, the distribution area is in keeping with the required working width. When the value is greater than 1, it introduces some significant risks of under and over application where variations in tramline width occur.
Figure 5. Example of triangular and trapezoidal configurations.

**Trapezoidal or triangular shape: the determinant**

As already outlined, the shape of the final transverse curve comes from the spatial distribution of the fertilizer. The more important parameters of the 3D spread pattern (Figure 6) are the angular distribution (mean and standard deviation) and the projection distance distribution (mean and standard deviation).

For a given fertilizer projection distance, a triangular curve will be obtained when the fertilizer is distributed at the rear of the spreader, while a trapezoidal curve will be obtained if it is distributed “all around” the disc. Overlapping between successive curves is also more important for triangular configurations, while it’s less important in trapezoidal configuration. The extreme configuration is the absolute rectangle (such as with a sprayer) which doesn’t necessitate any overlapping, but is very sensitive to, and dependent upon, the accuracy of the tramline widths.
Figure 6. Specific analysis of the 3D measured spread pattern: angular and radial distribution around the disc axis. Experimental values are extracted, as well as the best Gaussian fit (mean and standard deviations).

Regarding the spreader manufacturer, technologies used to set and obtain the correct working configuration are variable, but there are common factors that determine if the fertilizer is spread in the correct place. These include the fertilizer drop zone, disc angular velocity, vane position, and spreader angle.

Take for example a divergent twin-disc spreader. By varying the angular drop zone, the optimum working width can be easily adjusted just by changing the 3D spread pattern, as shown on Figure 7. The 3D spread pattern is identical in all cases, but angularly positioned progressively more on one the side of the run. Curves become more and more trapezoidal and working widths increase gradually from 26 m to 40 m. As a consequence, the robustness decreases, and gives spread patterns which are increasingly sensitive to the accuracy of the tramline width.
Figure 7. Using the same fertilizer and spreader, the working width can be adjusted by changing the angular position of the 3D spread pattern. Transverse curves become more trapezoidal resulting in a less robust configuration.

As another consequence, for a given mean projection distance value, many different spreading configurations can be obtained, from the triangular curve to the trapezoidal curve, as shown in Figure 8.

Figure 8. Effect of working width and projection distance on the spreading pattern.
The same working width can be obtained with different mean projection distance values, but with important consequences on the curve shape and robustness. The greater the working width required, the greater the projection distance must be.

For example, Figure 9 shows a comparison between two different spreading configurations with a fertilizer spread at a mean projection distance of 18 m (fertilizer 1), and a second spread at a distance of 16.5 m (fertilizer 2). The two graphs below the transverse curves (b and c) show the setting points which must be applied on the spreader in order to obtain the best configuration for all the working widths between 2 and 50 m. Even if the CV value is identical for a 28m working width (less than 4%), fertilizer (1) is better from the spreading point of view than fertilizer (2) due to its distribution at a greater projection distance.

Figure 9. Comparison of two different spreading performances. The colour of the points represent the CV value for each configuration (green for CV < 5%, blue for CV between 5 and 10%, orange for CV > 15%).

Fertiliser (1): blue curve; CV=3.9% (at 28m)
Fertiliser (2): red curve; CV=2.4% (at 28m)
Projection distance variability and determinant

Many parameters influence the projection distance which can be measured on a spread pattern. Some of them are completely dynamic (initial velocity and vertical angle at the output of the disc) while others are directly linked to the physical characteristics of the fertilizer.

Using high velocities, for example by having high speed discs and long vanes, results in greater projection distances provided granules can withstand the acceleration exerted by the centrifugal device. Increasing the vertical ejection angle (vane inclination on the disc, or spreader positive tilt) also produces a greater projection distance. As an example, Figure 10(a) shows how different types of granules with equal vertical projection angle can respond differently in projection distance values when disc velocity increases from 700 to 1100 rpm. The same graph also shows the importance of granule characteristics and limitations. This graph presents a real classification of the products from a ballistics point of view. Some particles, such as the slug pellets tested, will never be able to reach the minimum distance of other fertilizers.

Figure 10. Product ballistic performances (a), relation with granule physical properties (b) and consequences on their spreadability (c).

Figure 10(c) presents, for 10 different slug-pellets, the spreading performances which can be obtained regarding the required working width. The CV values are represented with the same scale as in Figure 9. The relationship between the
spreadability of the granules and the projection aptitude is very well identified. Figure 10(b) brings new information as it shows, for slug-pellets, the direct link between particle diameter and projection distance. Spreadability of the slug-pellets can also be explained by their size: the higher the mean diameter (low number of granules per kg), the higher the working width can be due to the increased ability to reach higher projection distances.

For fertilizers, the link is the same but less easy to understand because of highly variable nature of fertilizer granules. Indeed, for slug-pellets, shapes are very often the same (cylindrical for all of the granules analyzed in Figure 10), and their real density are very similar (flour base of the bait). If the granules are hard enough (we don’t analyze this parameter here since we look only for particles of the spread pattern which where correctly accelerated, so the particles which were broken were not taken into account), the only parameter which remains variable is the mean diameter.

Modern mineral fertilizers can generally be classified according to the three principal production processes: granulation, compaction, and prilling. Granulated fertilizers are produced by repeatedly coating a ‘seed’ particle which picks up further layers of nutrient ‘slurry’ material until it reaches a desired size range. Compacted fertilizers are formed by binding small nutrient particles together using either physical compaction, a cementing agent or a chemical bond. Prilled fertilizers are manufactured by producing a controlled stream of droplets of molten fertilizer material from a height which then solidify into small particles. All three types have several different physical characteristics which greatly affect their ballistic properties. The size, shape and density of the particles are very important since all three have an impact on all aspects of the centrifugal spreading process (Figure 11(b)):

- Angular particles reach a lower velocity at the output of the disc, so their total initial velocity and vertical ejection angle are lower than spherical particles.
- They also have a higher Cx value (aerodynamic resistance during flight), although relatively little work has been published on this topic and the Cx measurement has not been definitively defined at present.

Angular particles have significantly lower projection distances than spherical particles. This is because they will have lower disc exit velocity and a lower vertical angle of ejection. They will also have increased drag forces during flight. The real density (mass of the granule volume without the immediately surrounding air) is also an important parameter since it influences the global drag force acting on the granule by the projected area acting against its displacement. High density particles are therefore projected farther than low density particles (Figure 11(a)). Finally the particle diameter is critical, since the global drag force acting on the
particle depends on the ratio between its projected surface and its mass (volume dependent). All parameters identical, larger particles are projected farther than smaller diameter particles (Figure 11(a)).

Figure 11. Influence of fertilizer physical properties on the projection distance. Aerodynamic distance during flight (Cx), density and diameter are the variable parameters while all the others are constant: initial velocity = 35 m s\(^{-1}\), initial vertical projection angle = 7°, initial height of the disc = 0.7 m, air density = 1.21 kg m\(^{-3}\). On figure (b), particles are classified by increasing order from the more aerodynamic (Cx=0.44) to the less aerodynamic shape (Cx=2.05). In the same order, corresponding shapes are: Sphere, vertical cube, reverse cube, cylinder, vertical prism and reverse prism. (Colin, 1997).

To illustrate the effect of the different parameters on the ballistic flight, take a fixed typical value for each parameter. For example if the particle diameter is 3 mm, with a density of 1500 kg m\(^{-3}\) and a Cx value of 0.44. If only parameter is changed successively to increase the spreading distance from 12 m to 14 m: the diameter would need to increase from 2.57 mm to 3.47 mm; the density would need to increase from 1260 to 1740 kg m\(^{-3}\); or the Cx would need to increase from 0.325 to 0.54. While the variations required in diameters or densities are high, the Cx has the greatest influence in terms of variation required.

The standard deviation around the mean diameter also has an impact on the spreading properties of the fertilizer, with a tendency to increase both mean and standard deviation values of the projection distance when the variability (measured by the standard deviation) around the mean particle size increases (Figure 12). Variations remain small, but do exist, and nevertheless, a narrow size distribution around the mean diameter will lead to difficulties in setting up the spreader since the covered area on the ground becomes localised with high fertilizer density distribution on a restricted area. So a narrow range of particle diameters isn’t conducive to accurate spreading at wide bout widths.
Figure 12. Influence of particle size standard deviation on the induced projection distribution (obtained simulation).

Absolute fertilizer spreading characteristics can be effectively and easily evaluated using the projection distance criteria only if the centrifugal spreader is always set the same way, with identical disc, speed, height, etc. For this restrictive reason, the team at Irstea developed a novel test centrifugal spreader, the results of which are easily and directly comparable to those obtained on a real spreader. Using the CEMIB patented method developed at Irstea (Figure 13), the specific signature (behaviour on the disc, in the air etc.) of a fertilizer can be assessed. Calibration using commercial spreaders can be checked with ease afterwards using the same technique. Parameters such as angular drop zone or disc angular velocity can be accounted for using specifically designed software which is available at Irstea in order to evaluate, with a limited number of tests, optimum settings and associated performances.
Figure 13. CEMIB test bench photo and working principle. The centrifugal spreader to be tested is positioned on a pivot and rotates on itself during the test (around 3°/s). The registered data coming from the 72 load cells allow an accurate fertilizer distribution chart to be generated, which represents the 3D spread pattern. Total test duration is between 30 seconds and 3 minutes depending on the flow rate selected.

Conclusions

Much work has been done in the past in order to evaluate the optimum desired physical properties for fertilizer granules. They were all carried out using the traditional transverse measurement device and the associated transverse curve it provides. Unfortunately, this device “integrates” the spreader displacement and thus masks the physical effects. It explains why transverse shape curves were never correctly explained.

However, CEMIB technology which is able to produce 3D distribution charts offers improved accuracy and speed and therefore offers exciting new opportunities for scientific investigation into the many different questions and problems that have arisen such as physical parameters for the particles; evaluation of fertilizer spreading limits; and fertilizer and spreader improvements. Specific studies must be performed with a pragmatic approach but with the right tool to balance between scientific and experimental approaches.

Using this new technology and knowledge, the preparation of spreader settings data for new fertilizers is easier and faster and will allow rapid testing for many spreader types, and fast evaluation of many fertilizer types for a newly developed spreader. At present, each fertilizer must be checked on the test bench in order to
edit the setting table of each spreader. Irstea’s specific centrifugal test spreader is a tool to reach this objective.

In a similar direction and already initiated at Irstea during 2012, some specific questions and issues around properties and limitations of blended fertilizers are able to be investigated. It is hoped that both vane properties and particle flight behaviour can be further investigated with the eventual establishment of some newly adapted recommendations or definition of limitations of different blend types.

References


