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Soil Fertility and Management on Heavy Soils Programme Farms

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Introduction

There has been a notable decline in soil fertility nationally and the impact is even more serious on farms with heavy soil types. On heavy soils, there is the potential to increase annual grass production by 30% where soil pH, phosphorus (P) and potassium (K) status is optimised. Seven dairy farms farming on ‘heavy’ soil types are participating in a monitoring and development programme and contributing key data on farm performance. The farms are deemed ‘heavy’ (i.e. predominately clay mineral soils) located in high rainfall areas of the South West of Ireland.

Heavy Soils Programme (HSP) farm profiles

There is significant variation within the HSP farms in terms of annual rainfall, clay content, topography/elevation and aspect. These greatly influence the grass growth & utilisation pattern.

Individual farms have limitations to a greater or lesser extent. However, what is common to all the farmers is that their management is always flexible and opportunistic in optimising grazed grass in their systems.

- The Doonbeg farm can become saturated very quickly but is in a lower rainfall location compared to other farms.
- The Athea farm is North facing, elevated, and is particularly vulnerable to cold NW winds and prolonged periods of dull/drizzly weather even in summer.
- The Listowel farm has 40% of paddocks with a peat soil type, is very low lying, and has lower rainfall than the average.
- The Kiskeam farm has the highest rainfall (c. 1600 mm/annum) and both Kiskeam & Castleisland have high content of very impermeable clay in the soil. Kiskeam also has some steep ground.
- The Macroom farm has high elevation with stony sub-surface.
- The Rossmore, Co Tipperary farm has heavy clay soils in lower rainfall area. The soils have lower aluminium (Al) and iron (Fe) contents than other farms in the programme.
Changes in soil fertility 2013-2016

It has been firmly established in research that soil pH must be corrected as a first step in the overall improvement of soil fertility status.

HSP farms embarked on a programme of soil fertility improvement in 2010. The low soil pH was due in part to a trend of low usage of lime nationally with higher nitrogen (N) usage masking the impact of low pH on grass growth. Fertiliser plans prepared in 2013 indicated a lime requirement of, on average, 90 tonnes of ground limestone per annum. A comprehensive soil testing programme takes place across all the heavy soils farms in December each year. The impact of these lime applications over time on the soil pH across the milking block area of the HSP farms is summarised in Table 1.

Table 1. Soil fertility status summary across the milking block on the seven farms in the Heavy Soils Programme from 2014 to 2016.

<table>
<thead>
<tr>
<th>Year</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average soil pH</td>
<td>5.8</td>
<td>6.1</td>
<td>6.3</td>
</tr>
<tr>
<td>Phosphorus (P) (mg/l)</td>
<td>7.2</td>
<td>5.9</td>
<td>5.8</td>
</tr>
<tr>
<td>Potassium (K) (mg/l)</td>
<td>123</td>
<td>102</td>
<td>102</td>
</tr>
</tbody>
</table>

Average soil pH has increased from 5.8 to 6.3. All of the seven farms showed a pH increase. The farms continued to focus on applying lime in 2016 to bring all paddocks to target pH of 6.3. No noticeable change in soil trafficability has been observed by the farmers largely due to quantities applied being limited to 2 t/acre (5 t/ha) in any one application.

Average fertiliser costs in 2015 were 3.3 c/l on the heavy soils farms, with lime accounting for 0.42 c/l of that cost. Phosphorus status increased on four farms and decreased on three farms (Kiskeam, Doonbeg and Listowel). Higher offtake issues combined with high fixation capacity remain the key factors militating against improved P status on these farms. Potassium status remained static between 2015 and 2016 with only two farms recording an improvement in K status. Higher K offtake issues will be discussed later in this paper.

Lime and loss through drainage/rainfall losses

The HSP farms are in high rainfall areas. Therefore, lime losses are estimated to be high, at up to 625 kg/ha/year. This equates to a loss through drainage alone of 1.2 t/acre over a five-year period. In addition, lime required to counteract acidity from Chemical N use and loss in milk/meat means a maintenance requirement of 2 tonnes/acre every five years is required on these farms. In effect, any lime applied in 2011-2014 was only keeping pace with the maintenance requirement and was not having an impact on lifting farm soil pH.
Timing of lime application

The experience of the HSP farms shows that lime can be applied at any time of year when ground conditions are suitable. Outside of the normal application peaks at reseeding and late Autumn, monthly lime usage statistics suggest that very little lime is applied in the Spring. April can be an ideal time to apply lime when ground is well grazed out. June/July is another suitable time after silage has been harvested or as surplus bales are taken out (stubble available) and when ground conditions are good for spreading.

Impact of lime application observed on HSP farms.

- Paddocks that were at soil pH 5.5 on HSP farms in 2013 and are now at soil pH 6.3 and grew an additional 2 t/ha of grass DM in 2016.
- Farms that are now at target pH notice a much faster response to applied fertilisers. When soil temperatures are good, paddocks are easily achieving the 21 day pre-grazing target cover of 1500 kg/ha of grass DM. This have taken 26-28 days to achieve previously. This has led to more surplus silage of high quality being harvested during the main growing season, which gives a significant boost to the winter feed supply - an invaluable resource on farms with heavy soils and longer winters!
- In 2016, the Atha farm had an average soil pH of 6.5. As well as supporting a Dairy herd stocking rate of 2.5 cows/ha, the farm also produced an additional 70 t of silage DM in the form of 390 surplus bales of silage equivalent to 10 bales/ha (almost 4 bales per cow). The farm grew 11.4 t/ha and utilised 9 t/ha of grass DM.
- Paddocks are better grazed out by the herd and palatability of grass has improved.
- Grass has a better root structure, better tillering and less open swards.
- Good progress is being made in increasing soil pH up to target. The challenge for these farms is to put a strategy in place to maintain lime status in the years ahead.
- Farmers aware of the risk of excessive lime use reducing soil trafficability have split the lime applications over time. (max. 2 tonnes per single application). This has worked well for building soil pH without negatively affecting soil structure.
- Summary financial analysis of lime application on the HSP farms is included in Appendix 1.
Building P and K status on HSP farms

Phosphorus (P)

In the past, many heavy soils would have received only low amounts of P fertilisers, at or below maintenance requirement rates. Heavy soils also tend to have high P fixation characteristics. Therefore, building soil P status on heavy clay soils can be a slow process. These soils are P hungry and have high capacity to fix applied Phosphorus. In many cases, attempts to increase the productivity of these soils must account for the fact that the P sponge/sump in the soil may effectively be empty.

The increased fixation that occurs at low soil pH is an additional complication that occurs on all mineral soils but is more easily remedied by lifting soil pH to target 6.3. The real soil P dividend that comes from being at target soil pH will only come over time when P inputs become sufficient and the P demand of the soil itself is satisfied as well as the P offtake of the grass crop (i.e. as the P reading reaches 5 to 6 mg/l, the P supply of the soil itself increases provide the pH is correct).

Building the P status on heavy clay soils is a long-term project. On the HSP farms progress is being made, but over a 5-7 year time frame. With offtakes of over 500,000 litres of milk from each farm and significant silage surpluses also being taken, it can be challenging to build P status.

Information is vital and farms should be soil tested at least every two years while building soil fertility.

Potassium (K)

Potassium status and usage has suffered due to the link with P in compound fertilisers. This combined with high rainfall has hit K status, especially on lighter soils, where K leaching can be higher than on heavier soils. Potassium is also cheaper than P so an easier problem to fix on grazing ground (ideally apply from July onwards) but needs more focus on silage ground where K offtakes are higher. Each tonne of grass dry matter harvested as surplus silage is removing 25 kg of K. Typical surpluses of six bales/ha will remove 30 kg/ha of K.

Slurry is the primary source of K on the HSP farms. However, dilute slurry may only contain 15 units/1000 gallons of K. This must be borne in mind in meeting the full K requirement of the crop. Slippage in K status continues on some farms.

The first step in building soil fertility on the HSP farms is to maximise the usage of slurry, where possible, on low Index soils. Annual soil testing provides great information on the paddocks that need additional nutrients. The slurry contribution to total nutrient supply is significant (see Table 2). Slurry supplies 12 kg/ha of P, which is 32% of the total P input. The slurry contribution of 92 kg/ha of K is the
equivalent of 66% of total K input on these farms. The K content of slurry can be highly variable, depending on dilution, and care must be taken to ensure full crop requirement is applied to avoid soil Index falling quickly and reducing production. Tools are available to establish slurry dry matter percentage.

Table 2. Slurry contribution to total available nutrient (N, P and K) supply on the HSP farms (kg/ha).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14</td>
<td>12</td>
<td>92</td>
</tr>
</tbody>
</table>

Weather conditions in the Spring of 2016 were not conducive to slurry application on heavy clay soils. After a heavy winters rainfall, these soil types were close to saturation during the spring and the risk of runoff was significant if large quantities of slurry were applied. The % of slurry applied in Spring varied from less than 20% of total slurry in the Kerry farms to over 50% in the Macroom farm. The development of low ground pressure umbilical systems is helping to get significantly more slurry spread in the Spring period. However, the HSP farms are cautious to avoid any runoff risk, particularly in steep terrain where nutrients could potentially be lost if conditions were not suitable for heavy slurry applications.

Experience with fertiliser use on HSP farms

Apply P little and often to low P Index soils

It is clear that at very low soil P status (low Index 1), P applied as either fertiliser or slurry is only available to the growing plant for a short time (i.e. less than 2 months). To counteract the impact this is having on grass production, a planned approach is required to fertiliser application on the HSP farms that ensures a steady supply of P fertiliser across the growing season.

Fertiliser application strategy on the grazing platform

In addition to targeting slurry application to the available grazing area by 1st April adequate fertiliser application is crucial to kick start grass growth.

The planned approach on the HSP farms has been to firstly apply straight nitrogen in urea form as soon as ground conditions allow. They target 60 units of N applied in two splits before 1st April with additional N in the compound fertiliser bringing total N application on the grazing area to 100 units/acre applied by 1st May.

Compound fertilisers containing N, P and K are applied from mid-March to early April in the second or third fertiliser application with a target of applying half of the annual P requirement before 1st May (e.g. if P allowance is 3 bags/acre of 18:6:12, then ensure that 1.5 bags/acre is applied to all grazing ground by 1st May. The balance of PK compound is applied in the late July/August period.
**Fertiliser response**

Overall chemical fertiliser input on the HSP farms is shown in Table 3. The farms are applying the full chemical P allowance allowed in their nutrient management plans (NMP) for nitrates regulations (average of 25 kg/ha/farm of chemical P). The HSP farms have seen huge variation in fertiliser response across their farms because of variations in soil type and fertility status within the paddocks. In spring, the heavier clay soil paddocks are colder and are slow to respond until the first P application. Indeed, at any stage these colder clay soils appear to need a continuous drip feed of P fertiliser to achieve good grass growth response. This was very noticeable in April, July and Aug/Sept in 2016. During these periods, after wet dull conditions, application of NPK compound fertiliser gave a better response than straight nitrogen applications, regardless of the P status of the paddock or extent of previous P applications. In the case of low Index soils, care must be taken to ensure that the P and K contents of compounds used are high enough to build as well as maintain fertility status.

Table 3. Average application rates of chemical fertiliser (N, P and K) on the HSP farms (kg/ha).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>234</td>
<td>25</td>
<td>47</td>
</tr>
</tbody>
</table>

Where some poaching took place in the previous grazing, the use of compound fertiliser combined with a lower pre-grazing cover (1,200 kg/ha) gave better tillering and recovery of the ryegrass in the sward.

**Table 4 Grass Production on HSP Farms in 2016.**

<table>
<thead>
<tr>
<th>Farm (location)</th>
<th>Milking block (ha)</th>
<th>Date of first measurement</th>
<th>No. of measurements</th>
<th>Total</th>
<th>1/12 to 10/4</th>
<th>11/4 to 10/8</th>
<th>11/8 to 30/11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doonbeg</td>
<td>36.8</td>
<td>13/01/16</td>
<td>36</td>
<td>12.1</td>
<td>0.2</td>
<td>8.3</td>
<td>3.6</td>
</tr>
<tr>
<td>Athea</td>
<td>39.3</td>
<td>03/02/16</td>
<td>42</td>
<td>11.4</td>
<td>0.6</td>
<td>7.3</td>
<td>3.5</td>
</tr>
<tr>
<td>Kiskeam</td>
<td>42.1</td>
<td>14/02/16</td>
<td>23</td>
<td>9.2</td>
<td>0.2</td>
<td>6.0</td>
<td>3.1</td>
</tr>
<tr>
<td>Castleisland</td>
<td>41.7</td>
<td>12/03/16</td>
<td>28</td>
<td>11.6</td>
<td>0.2</td>
<td>7.4</td>
<td>4.0</td>
</tr>
<tr>
<td>Listowel</td>
<td>31.3</td>
<td>29/01/16</td>
<td>22</td>
<td>11.1</td>
<td>0.4</td>
<td>7.5</td>
<td>3.1</td>
</tr>
<tr>
<td>Macroom</td>
<td>55.8</td>
<td>11/02/16</td>
<td>25</td>
<td>11.8</td>
<td>0.35</td>
<td>7.66</td>
<td>3.8</td>
</tr>
<tr>
<td>Rossmore</td>
<td>31.3</td>
<td>01/01/16</td>
<td>28</td>
<td>12.7</td>
<td>0.42</td>
<td>7.69</td>
<td>4.62</td>
</tr>
<tr>
<td>Average</td>
<td>39.8</td>
<td>02/02/2016</td>
<td>29</td>
<td>11.4</td>
<td>0.3</td>
<td>7.4</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Grass Production in the HSP farms (Table 4) was variable in 2016. Average growth recorded was 11.4 t/ha of grass DM, a slight increase in the 11.2 t/ha recorded in
Baseline grass growth on these farms in 2011 was 10 t/ha. The trend on average grass production on the HSP farms over time is shown in Figure 1.

Spring growth was very poor due to many soils being waterlogged until late April 2016. Overall recorded spring production was only 0.3 t/ha of grass DM compared to 0.6 t/ha recorded in spring 2015. Midseason growth was quite good across the Region with 7.4 t/ha grown up to 10th Aug. This was 0.5 t/ha higher than the corresponding period in 2015. Autumn growth at 3.7 t/ha was the same as 2015.

**Figure 1. Trend in the average annual grass DM production on HSP farms.**

**Ryegrass content**

The HSP farms (milking block area) have been scored for ryegrass ground cover for five years (Figure 2). To optimise grass production, ground cover should be 40-50% ryegrass. The HSP farms have remained at approximately 30% or below. The level of re-seeding is dependent on weather conditions. Very little re-seeding was done in 2016 and there was none in 2014. It is interesting that our new farms in Cavan and Monaghan coming into the programme have higher ryegrass scores (39% and 44%) and coincidentally also have the best soil fertility status.

**Figure 2. Percentage of perennial ryegrass grazed swards on HSP farms over time.**
Focus on maximising Mid-Season Grass Growth

The HSP Farms run a moderate stocking rate across the mid-season period (Figure 3). The target is to fully feed the herd on a grass diet and take out surpluses on a regular basis based on grass measurement data from a regular grass measurement walk.

Average grass demand during the period 25<sup>th</sup> April to 27<sup>th</sup> Sept 2016 was 46 kg/ha/day equivalent to a stocking rate of 3 cows/ha. The herd demand compared to average grass growth of 66 kg/ha/day during the 5 month period is shown in Figure 3.

![Grass Demand vs Grass Growth](image)

*Figure 3. Grass Demand (Solid line) compared with Grass Growth (dotted line) between 25<sup>th</sup> April and 27<sup>th</sup> September in 2016 on HSP Farms.*

These farms are focused on maximising grass intake so average concentrates fed during that key 5 month period averaged 1.7 kg/cow/day with July concentrate feeding restricted to 0.8 kg/cow/day.

The high grass intake is reflected in average milk protein for the period of 3.53% and milk solids averaging 1.7 kg/cow/day peaking at 2 kg/cow/day and remaining at that level for the four weeks in May 2016.

Harvesting surplus grass as high quality baled silage is a key strategy adopted by the HSP farms. This high quality feed is fed back to the herd during periods of poor grass utilisation and in the shoulders when high quality forage is required by the milking herd. However, the nutrient offtake is significantly higher when the grass crop is removed as silage.
Prioritise the paddocks within the farm that will give biggest response in terms of grass production.

Annual grass measurement has taken place on these farms since 2011 and very strong farm information has been generated. While average grass grown is an important measure for any farm, it is the knowledge of individual paddock performance over time that drives good farm investment decisions.

Each of the HSP farms has variation within their farms in key factors such as soil quality, ryegrass content, stock carrying capacity, drainage and elevation.

The first priority is to ensure that the paddocks with better soil type are quickly brought up to target pH and soil Index 3 for P & and K. On HSP farms, this strategy is bringing these paddocks quickly up to average annual production of c. 13 t/ha of grass DM. A middle group of paddocks may have a potential to grow 10 t/ha of DM and these generally have high clay content and take longer to build fertility.

Finally, all farms have poorer quality paddocks with poor grass species, poor drainage and poor soil fertility. Such paddocks are contributing 4-6 t/ha of DM each year. These paddocks require more intensive investment, which should only be undertaken when soil fertility/ryegrass content issues are corrected in the rest of the farm.

Prioritise farm spending - apply your annual P allowance

Improving soil pH by on-going lime application and applying your full chemical P allowance are both good long term investments for your farm. All aspects of the annual running cost of over €1000 per cow need to be evaluated in terms of impact on farm profitability and return on investment.

On a grassland farm where high grass production is critical to farm profitability prioritise spend on fertiliser requirement in a difficult milk price year. Apply at least maintenance P in a poor milk price year like 2016 and on heavy clay soils at least a third more.

HSP farms are focused on grass

Many Profit monitors in 2015/16 show a higher spend on purchased concentrate than on fertiliser. A feature of farms that are highly grass focused is that feed costs per litre are almost always less than fertiliser cost per litre (e.g. feed 2.5 c/l with fertiliser at 3.5 c/litre).

The silage reserve built up since 2013 is a key feature of the HSP farms system. On average the HSP farms maintain a silage reserve of 0.45 t/cow of silage DM or a 25% reserve.
Growing and using grass on HSP farms

Overall cornerstones of maximising the potential of grass in the HSP Dairy system include:

- Silage Reserve
- Compact Calving
- Flexible Approach to Grazing
- Introducing high quality silage when grazing conditions deteriorate
- Grazing infrastructure: paddock access and spur roads are vital

Seasonally, the following targets are prioritised on HSP farms:

Autumn:
- Start building grass cover from 10th Aug onwards
- Peak farm cover target – 1,000 kg/ha DM
- Start closing paddocks in late September
- Have at least 80% by 31st Oct
- Closing cover target: 650 kg/ha DM

Spring:
- Mean calving date target: 29th February
- Graze 50% of the platform before 17th March
- Graze 100% of the platform before 10th April
- Use on-off grazing to minimise soil damage
- Apply 60 units/acre of N fertiliser by 1st April (2 splits)
- Apply 100 units/acre of N fertiliser by 1st May

Summer:
- Whole milking block available for cows only
- Measure grass every 5 days
- 18 – 21 day grazing rotation
- Maintain grass DM cover at 180-200 kg/cow
- Surplus target: make 2.5 bales/cow on the milking platform
Farm financial performance on HSP farms

There has been a steady increase in the financial performance of the HSP farms as stocking rate and milk output have increased while cost structure has been maintained. The net margin per dairy hectare averaged €1377/ha in the period 2011-2015 (Figure 4), with milk price volatility largely responsible for the variation in margin from year to year. This level of profitability is in line with high performing farms on drier soil types.

![Figure 4. Net Margin per hectare on HSP farms from 2011 to 2015.](image)

However, the HSP farms are cautious of increasing overall stocking rate (Table 5) in the milking block due to the increased risk to the business. However, as grass growth production improves, gradual increases in stocking rate are occurring.

**Table 5. Evolution of herd size and stocking rate from 2012 to 2015 on HSP farms.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Herd size (milking cows)</th>
<th>Stocking Rate (LU/Ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Whole Farm</td>
</tr>
<tr>
<td>2011</td>
<td>82</td>
<td>1.69</td>
</tr>
<tr>
<td>2012</td>
<td>85</td>
<td>1.71</td>
</tr>
<tr>
<td>2013</td>
<td>86</td>
<td>1.68</td>
</tr>
<tr>
<td>2014</td>
<td>90</td>
<td>1.78</td>
</tr>
<tr>
<td>2015</td>
<td>92</td>
<td>1.81</td>
</tr>
</tbody>
</table>
Summary messages from HSP experience

- Do a comprehensive soil test of all paddocks at least every two years.
- Correct lime deficiency based on lime requirement. On heavy soils limit lime application to 2 t/acre (5 t/ha) in any single application.
- As a guide, where average soil pH on the farm is below 5.8, apply 1 tonne of ground limestone per cow in the herd in year 1.
- Use your soil results to set up a fertiliser plan and know the total amount of P fertiliser you are allowed to apply. New nutrient management plans will have colour coded maps indicating the paddocks with low Indices for P and K or high lime requirements.
- The use of the low ground pressure umbilical and trailing shoe systems of slurry spreading have revolutionised the ability of HSP farms to get more slurry spread in the spring time. However, great care must be exercised to avoid runoff losses from heavy soils, especially when saturated or waterlogged.
- Apply P fertiliser on a little and often basis - split your P allowance to apply 50% in spring and remainder in the summer period.
- Prioritise lime and fertiliser spending above other lower return costs.
### Appendix 1. Lime Application on HSP farms

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil pH</td>
<td>5.5</td>
<td>5.8</td>
<td>6.3</td>
<td>6.3</td>
<td>6.3</td>
<td>6.3</td>
<td>6.3</td>
<td>6.3</td>
<td>6.3</td>
</tr>
<tr>
<td>Lime applied (t/ha)</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Extra grass DM grown (t/ha)</td>
<td>0.5</td>
<td>1.5</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cost of lime (€/ha)</td>
<td>€125</td>
<td>€125</td>
<td>€25</td>
<td>€25</td>
<td>€25</td>
<td>€25</td>
<td>€25</td>
<td>€25</td>
<td>€25</td>
</tr>
<tr>
<td>Annual financial benefit from additional grass (€/ha)*</td>
<td>€81</td>
<td>€242</td>
<td>€322</td>
<td>€322</td>
<td>€322</td>
<td>€322</td>
<td>€322</td>
<td>€322</td>
<td>€322</td>
</tr>
<tr>
<td>Cumulative Cost of Lime (€/ha)</td>
<td>€125</td>
<td>€125</td>
<td>€250</td>
<td>€275</td>
<td>€300</td>
<td>€325</td>
<td>€350</td>
<td>€375</td>
<td>€400</td>
</tr>
<tr>
<td>Cumulative value of extra grass (€/ha)</td>
<td>€81</td>
<td>€323</td>
<td>€645</td>
<td>€967</td>
<td>€1,289</td>
<td>€1,611</td>
<td>€1,933</td>
<td>€2,255</td>
<td>€2,577</td>
</tr>
<tr>
<td>€ Return per € spent on Lime</td>
<td>€0.65</td>
<td>€2.58</td>
<td>€2.58</td>
<td>€3.52</td>
<td>€4.30</td>
<td>€4.96</td>
<td>€5.52</td>
<td>€6.01</td>
<td>€6.44</td>
</tr>
</tbody>
</table>

*assumes each additional t of DM is worth €161

### Appendix 2. Rainfall and Evapotranspiration (ETP) Statistics for HSP Farms in 2016 and compared to long-term average (LTA)

<table>
<thead>
<tr>
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Introduction

Fertilizer nitrogen (N) is one of the largest input costs for cereal production in Ireland. Hence, from an economic viewpoint, it is imperative that it is used as efficiently as possible. However, within the soil/crop system nitrogen is essentially a ‘leaky’ nutrient that is subject to several loss processes that can have negative environmental consequences. Nitrogen can be lost from the soil/crop system in many forms including nitrous oxide, a potent greenhouse gas, nitrate, which can cause issues in ground and estuarine waters and ammonia. This ‘leaky’ nature of nitrogen makes the process of achieving high efficiency of use of fertilizer N challenging, but essential if the environment is to be protected.

Efficient use of fertilizer N entails achieving good recovery of the applied N by the crop from the soil and subsequently achieving high crop productivity, in terms of grain yield, per unit of recovered N. While these processes can be affected by a range of soil and environmental factors the key decisions at farm level that will impact on these processes are the quantity and timing of N that is applied to the crop as well as the form of nitrogen applied.

Theoretical considerations

A key requirement of an efficient fertilizer N strategy is to ensure that there is sufficient available N present in the soil to satisfy the crops requirements through the season and that large excesses of available N are avoided. Therefore, a knowledge of the uptake pattern of cereals is an important prerequisite for determining fertilizer strategies. A typical pattern of N uptake by a crop is presented in Figure 1 (green line). Cereals have low requirements for nitrogen during the very early stages of growth since the amount of green area being produced, the main driver of N requirement, is relatively small. The rate of N uptake increases very considerably once the crop enters the stem elongation phase because of a large increase in the rate of green leaf area production. Typically, up to 75% of total N accumulated in the crop at harvest will be accumulated after GS30. Therefore, it is essential that sufficient N is available to the crop during this period.
Figure 1. Diagrammatic illustration of the seasonal pattern of total N uptake (green line) and N acquired from soil (red line) by a cereal crop. Dashed lines indicate the variation that can occur in both total N uptake and soil N supply. Blue lines indicate the effect of this variation on the amount of N that must be supplied by fertilizer.

The total amount of N (from both soil and fertilizer) that a crop will accumulate over its lifetime will be influenced by the yield level and the N content (protein content) of that yield. Both are variable although there tends to be an inverse relationship between the two i.e. as yield goes up N content of the grain (protein content) tends to decrease due to a dilution effect. A key problem is that there is often not a well-defined relationship between yield level and total accumulated N i.e. for a given yield the total amount of N accumulated is not constant. For example, a wheat crop with a grain yield of 10 t/ha that has a protein content of 12% (2.1% N) would have a total N content in the grain of 210 kg/ha whereas if the same crop had a protein content of 8% (1.4% N) the total N content of the grain would only be 140 kg/ha. This indicates that using yield to determine the crop N requirement has limitations. However, as will be shown later, while yield is not a necessarily a good indicator of the total amount of N that a crop will accumulate it can be used to adjust the economic optimum fertilizer N rate for crops. Obviously as well as the N that is in the grain there will be N in the straw also. The amount of N in the straw tends to be relatively constant relative to what is in the grain. Typically, at harvest, there is 25 kg/ha of N in the straw for every 75 kg/ha of N in the grain.

Not all N in the crop originates from fertilizer N; crops acquire a proportion of their nitrogen from the soil. Generally during the very early stages of growth the soil will supply sufficient N to meet the crops needs, which will be low, and often there will be little effect of applied fertilizers visible in the crop. The length of this
period will depend on how much N is in the soil and how quickly the crop is growing. For an autumn sown cereal crop, which will be growing relatively slowly and will not enter the nitrogen demanding stem elongation phase until spring, there is normally sufficient available N in the soil, either residual fertilizer N from the previous crop or N mineralized from soil organic N, to meet the crops demands over the winter period. Hence autumn sown cereals rarely respond to autumn applied fertilizer N, in terms of grain yield, and such applications are not recommended. For spring sown cereals, the duration of the period that the crops’ N needs will be satisfied by soil N is much shorter. Available soil N in the spring in the upper soil layer, which the young cereal plant will be exploiting, under Irish conditions is likely to be nearly always much lower than in autumn due to downwards movement of the available N over the winter period in drainage water. In addition, the spring crop will be emerging at a time when day length, radiation intensity and temperature are increasing and hence the crop will enter the period of rapid growth at a much younger age than a winter crop. Therefore, spring crops can respond to N applied at or before sowing in some cases, and in any case, will require fertilizer N application soon after emergence if N has not already been applied at sowing.

Soil N supply will be affected by a large range of factors including previous cropping history, organic matter content, soil type and overwinter rainfall as well as soil conditions that affect N mineralization (temperature and moisture). Thus, soil N supply is very variable between fields and even within fields. Currently the soil N Index is used to alter fertilizer N advice based on the potential of the soil to supply N but this is a relatively crude system and doesn’t take many factors that can affect soil N supply into account. In other European countries, mineral N content in the soil to a depth of 90 cm measured in spring before significant crop growth is sometimes used to indicate the potential of soils at different sites to supply N. This has shown some promise in improving estimates of soil N supply under our conditions. However, this is a laborious and potentially expensive measurement and is unlikely to gain widespread commercial acceptance. More precise estimates of soil N supply have the potential to considerably improve the accuracy of fertilizer N recommendations but considerably more research is required to identify suitable methods under our conditions.

The total amount of N that a crop must acquire from fertilizer is the difference between the amount that the crop requires and the amount that the soil can supply. However, as is illustrated in Figure 1, there can be considerable variability in both the total amount of N that a crop will accumulate and the soil N supply. This variability can occur between different sites within a season, between the same site in different seasons and even for a single site in a single season. Kindred et al. (2015), working in the UK, found that within a single field the crop demand for N and soil N supply could vary by over 100 kg/ha which resulted in variation in the optimum fertilizer N rate for different parts of that field of over 100 kg/ha. This
illustrates the difficulty in determining accurate estimates of how much N a crop must recover from applied fertilizer N. Even if we knew exactly how much N a crop needed to recover from applied fertilizer N we still would not know exactly how much fertilizer N to apply. This is because fertilizer N is not recovered with 100% efficiency by cereal crops. Recovery of fertilizer by cereal crops can typically range from 40-70% although in practice many crops will have recovery rates in the range 50-60% i.e. for every 100 kg/ha of N applied as fertilizer a crop will recover 50-60 kg/ha of that N. This can have a significant effect on the amount of fertilizer N required to meet crop demand. For example, where a crop needs to accumulate 100 kg/ha of N from applied fertilizer N a recovery rate of 70% would mean that 143 kg/ha of fertilizer N needs to be applied so that the crop will accumulate 100 kg/ha of N (143 x 0.7) into its tissues. However, if the recovery rate is only 40% the fertilizer N requirement would be 250 kg/ha of N. Many factors affect how efficiently a crop recovers N. Any factor that negatively affects rooting will tend to reduce N uptake so factors such as compaction and root disease will reduce fertilizer recovery. There is little evidence to date to suggest that this value can be predicted with any degree of certainty under our climatic conditions.

**Variability in optimum N**

It can be seen from the preceding paragraphs why the biggest challenge with N management in crops is to accurately estimate the amount of fertilizer N that will maximize the return on investment in fertilizer N for the grower, the economic optimum N rate ($N_{opt}$), for any crop at the time of fertilizer application. This is because $N_{opt}$ can vary considerably even on sites that might be expected to have similar responses to N. An example of the level of variation in $N_{opt}$ that can occur between sites can be seen in Figure 2 which presents data on the response of spring barley to fertilizer N at a range of sites where the supply of N to the crop from the soil would be expected to be low (Index 1) and which might be expected to have a similar response to N. While some of this variation can be explained by differences in yield and soil N supply between sites, a significant proportion of the variation remains unexplained. As mentioned earlier as well as there being considerable variation in optimum N between sites with similar characteristics there is a growing body of work that suggests that the optimum rate of fertilizer N varies quite substantially even within fields (Kindred *et al.* 2015).
Figure 2. Fertilizer nitrogen response curves for spring barley for a range of site-seasons between 2011 and 2014. Diamonds indicate the economic optimum N rate (N_{opt}) for each site-season. The dashed line represents the increase in N_{opt} as yield level increases.

Therefore, for many countries, including Ireland, the method of estimating the N_{opt} relies on carrying out several nitrogen response trials at a range of sites typical of the sites used for production of that crop and determining N_{opt} for each site. An average N_{opt} is then calculated which can be adjusted to account for factors known to affect N_{opt}, such as yield level and soil N supply. As an example, in Ireland fertilizer N recommendations are adjusted upwards by 20 kg/ha of N for each additional 1 t/ha of yield. Recommended rates of fertilizer N for cereals in Ireland are outlined in the Teagasc ‘Green Book’ (Wall and Plunkett, 2016).

**Timing of N**

Nitrogen is applied to most cereal crops in either two or three applications. The main objective of applying nitrogen in more than one application is to ensure that there is sufficient N present to meet the crops requirement during its growth without having excess N present for long periods which could be subject to loss. Where the risk of loss is low, there is often no difference between applying all a crop’s N allocation in one application compared to using a number of splits. For example, recent work in southern Germany found no difference in grain yield between winter wheat crops that received all their N in one dose at GS27-31 compared to where N was applied in two or three splits. However, rainfall in that region during the growing season is much lower than in Ireland and applying all N
in one dose under Irish conditions, particularly where more than 100 kg N is to be applied, could expose the N to a high risk of loss because of high rainfall after application.

Since, as indicated in Figure 1, the highest rates of uptake occur during stem extension the largest doses will be applied during the early stages of stem extension to ensure sufficient amounts of N are available to the crop during this period. Research has shown that there is considerable flexibility in the timing and splitting of fertilizer N for cereal crops as will be outlined in the following sections.

**Winter wheat**

Nitrogen is normally applied in two or three splits to winter wheat. While the first application of N is often made to winter wheat in early March research has shown that the first N can be delayed on winter wheat until the crop is near GS30, which often occurs in the latter half of March for mid-October sown crops, without affecting yield (Figure 3). This means that there is some flexibility for growers if soil conditions are poor early in the season. However, where other nutrients, particularly phosphorus, are being applied with the nitrogen the first application should be made as soon as land is trafficable in late February/early March. Since growth rates, and hence nitrogen requirement, are relatively low at this time typically no more than 25-30 % of the total N needs to be applied at this stage.

![Figure 3](image-url)

**Figure 3.** Effect of timing of the first split of N to winter wheat. The first of two splits were applied at late tillering, GS30, GS31 or GS32 with the second split applied approximately 15-20 days later but not before GS 31. (Efretuei et al, 2016)
The main split of N will be applied between GS30 and GS31, to ensure that there is sufficient N present to feed the rapid period of leaf area formation that begins around GS31. There is often no yield benefit associated with using three splits compared to using two splits provided at least about 75 % of the total N is applied by GS31. This is demonstrated for three site-seasons in Figure 4 where yield differences between a three-split regime and two two-split regimes were generally small and not statistically significant. This experiment was repeated over eight site-seasons in total and significant differences between the splitting regimes were detected on only two occasions and in those cases the differences were modest. However, retaining some of the fertilizer until the crop is at the flag leaf stage, particularly where rates in excess of 150 kg/ha of N are used, can reduce the risk of N losses as a result of unfavourable weather after application of a large main split. Use of third splits can also facilitate the use of various crop reflectance sensors to guide the final application and allow more precise estimation of the amount of N required.

![Figure 4](image_url)

**Figure 4. Effect of splitting regime on grain yield of winter wheat at three sites.** Bars are means of four N rates (150, 190, 230 and 270 kg/ha of N). Bars with the same letter within a site are not significantly different. The first split was applied at or before GS30, the second split at around GS31 and the third split at GS37.

**Winter barley**

The acreage of winter barley has increased substantially in recent years but there has been relatively little research regarding the timing and amount of fertilizer N inputs to the crop since the ‘80’s. Recent research into nitrogen fertilization of winter barley in the UK has indicated that a greater proportion of the total N fertilizer should be applied earlier in the growing season than was previously
recommended. Research at Oak Park set out to determine if similar recommendations should be made for Irish conditions. The results of this work have indicated that there is some flexibility in terms of timing of the first application of N to winter barley, but ideally it should be applied at GS30 at the latest. A comparison of the grain yield of crops that received their first application of fertilizer N in late February/early March with crops that received the first N in mid-March, shortly before GS30, revealed little difference between the two treatments (Figure 5). Indeed, even where the first N was delayed until early April, when the crops were approaching GS31, grain yield was often unaffected compared to where the first N was applied earlier although delaying until this late is not recommended due to the risk of stimulating late maturing tillers at harvest. Regarding the proportion of N applied in the first application, there was no advantage, and in some cases a slight reduction in yield, from increasing the percentage of the total N applied in the first application above 30%. The work also indicated that there was usually no advantage in terms of yield to using three applications compared to two applications. However, where unfavourable conditions occur after application, particularly of the main split, retaining some of the nitrogen for a third split may be advantageous. Third splits should also be considered where total annual rates above 150 kg/ha of N are being used. Third splits, which should be applied between GS32 and GS37 should comprise no more than 30% of the total N allocation.

Work comparing different variety types (two-row, six-row and six-row hybrid) in terms of their response to N suggested that variety type had no influence on the response to fertilizer N. Any differences in N requirements between variety types are due to differences in yield rather than due to whether the variety is a two-row or six-row variety or a hybrid.

**Figure 5.** Effect of timing and size of the first N application (30-70 % of total N) to winter barley (cv. Cassia). Total N was applied in two (solid bars) or three (hatched bars) applications in late February/early March (early), mid-March (mid) or late March/early April (late). Bars with the same letter are not significantly different (P<0.05).
Spring barley

Spring barley is the arable crop with the greatest area in Ireland. While principally grown as a source of animal feed a growing proportion is being grown for malting. While fertiliser N management is important for all spring barley it is particularly important for malting barley where protein content of the grain is an important criterion for acceptance of grain by maltsters.

A considerable amount of work has been carried out at Oak Park in recent years regarding the timing and splitting of fertiliser N in terms of both yield and protein content. The key message from this work is that fertilizer N rate has the largest effect on grain yield and particularly grain protein content rather than timing or number of splits used. As for other cereal crops, there is large variation in the optimum N rate for spring barley between sites and seasons and this will be influenced by yield level and soil N supply.

![Figure 6. Effect of timing of the first N application (at sowing or at emergence) and size (30, 60 or 90 of a total of 150 kg/ha of N) on grain yield and protein content of spring barley. Data are averaged over 17 site-seasons. The remaining N was applied at mid-tillering for all treatments.](image)

While the first dose of nitrogen is normally applied to spring barley at or just before sowing research has indicated little consistent difference, in either grain yield or protein content, between applying the first N at sowing compared to applying the first N as the crop emerges (Figure 6). This is of particular relevance to growers who are planting barley very early (February) as they can avoid applying N at sowing and thus reduce the risk of N loss if wet weather conditions...
occur between sowing and emergence. Applying a greater proportion of the total N at sowing had little effect on either grain yield or protein content.

A comparison of using two splits compared to three splits to apply the total N allocation to spring barley showed that, on average, there were no significant differences in grain yield between treatments that received all the N in two splits compared to where a proportion of the total was retained and applied as a third split (Figure 7). There was a small increase in protein content where some of the N was retained for a third split and that third split was applied at GS37 or later. However, for more typical timings of a third split, GS31-GS32, differences in protein content compared to using a two split programme, where all the N was applied by mid-tillering, were very small.

**Forms of N**

Calcium ammonium nitrogen (CAN) is the predominant form of ‘straight’ nitrogen fertilizer used on arable crops in Ireland. It supplies ammonium and nitrate, the readily plant available forms of nitrogen. It has been widely used and gives consistent results. In recent years, there has been considerable interest in urea as a nitrogen source for cereals principally due to its lower cost per unit of N relative to
CAN. Additionally, urea is a more concentrated form of N (46 % N vs 27 % N) with consequent handling and transport advantages. However, urea has two potential disadvantages compared to CAN which need to be considered by growers. Firstly, urea has a lower bulk density than CAN, its bulk density typically being 75-80 % that of CAN. This makes it more difficult to spread evenly with spinning disc type spreaders, particularly at wider bout widths and its spread pattern is more susceptible to disruption by wind. Most spreaders are not capable of spreading urea evenly at as wide a tramline width as CAN. Where spreaders are technically capable of reaching the required tramline width using urea, careful setting of the spread components (discs, vanes, drop point angle etc.), as well as consideration of weather conditions on the day of spreading, is required to ensure even spread across the full bout width. A particular problem can occur where fertilizers with a greater bulk density are blended with urea e.g. where ammonium sulphate (21 % N) is blended with urea (46 % N). In this case the spreader can be set up to give an even distribution of granules across a particular bout width but separation of the two fertilizers in the blend can occur across the bout width, with the fertilizer with the greater bulk density concentrated towards the outer regions of the bout width and the urea more concentrated towards the centre of the spread pattern. Where the two fertilizers have different concentrations of nitrogen this will lead to uneven distribution of nitrogen even though there was an even distribution of granules. Some spreaders may spread both blend components more evenly than others. This problem can be mitigated by careful selection of granule size of the two fertilizers before blending; growers should check with suppliers that their product’s spreading capability has been validated for the particular spreader and bout width being used.

The second disadvantage of urea compared to CAN is that a portion of the nitrogen applied as urea can be lost to the atmosphere as ammonia gas in the process known as volatilization. The amount of N that is lost through this process is variable and very much dependent on soil and weather conditions around the time of application. High soil pH will increase the risk of volatilization; therefore urea should not be spread on recently limed land. Similarly, drying conditions after application of urea increase the risk of loss so application of urea on moist soils or just before light rain can minimise losses. Many experiments comparing CAN and urea as a nitrogen source for cereals have been carried out both in Ireland and abroad over the last 40-50 years. These experiments have shown that urea can give similar results to CAN in the majority of occasions but in some instances urea will give inferior results particularly where conditions favour nitrogen loss as ammonia. This risk, albeit a relatively small risk, has militated against the widespread use of urea on cereal crops in Ireland.
Figure 8. Effect of N fertilizer type on spring barley grain yield at two sites at Oak Park in 2015. Total N was surface applied in two equal applications after emergence.

More recently urea that has been treated with N-(n-butyl) thiophosphoric triamide (NBPT), a urease inhibitor, which slows down the conversion of urea to ammonium, and hence reduces the risk of nitrogen loss as ammonia, have become commercially available in Ireland. These stabilized urea products give similar levels of efficacy to CAN even in conditions where yield losses would occur as a result of using ‘normal’ urea. An example of this from experiments carried out at Oak Park is presented in Figure 8. In EXP 1 where ‘normal’ urea (not treated with NBPT) was used as the N source grain yield was lower than that achieved with CAN. However, where stabilized urea (urea + NBPT) was used there was no difference in grain yield compared to CAN. In the more typical situation, represented by EXP 2 in Figure 8, there was no difference in grain yield between CAN, ‘normal’ urea and stabilized urea. Similar experiments, over three years, with spring barley at another Irish site found no difference between ‘normal’ urea and CAN in terms of grain yield in all three years (Roche et al., 2016). Therefore, in situations where yield loss can occur as a result of using urea use of stabilized urea products can mitigate against this loss. However, the price differential between these stabilized products and CAN is less than the price differential between ‘normal’ urea and CAN and so the economic incentive to use stabilized urea instead of CAN is reduced.

Future perspectives

There several potential routes for improving the efficiency of fertilizer N use in the coming years including more nitrogen efficient varieties, new fertilizers and the use of precision agriculture techniques to guide fertilizer inputs.

The genetic makeup of crops can have a significant impact on how efficiently crops recover N from the soil and how efficiently they use that N to produce yield. In the past, there has been relatively little attention paid to directly selecting for nitrogen efficiency in the majority of cereal breeding programs producing varieties that have been used in Ireland. Varieties of many crops are selected in ‘high input’
environments where increased N efficiency, particularly recovery efficiency is unlikely to be selected for. Thus, while crop yields have increased there has also been a gradual increase in the amount to fertilizer N required by some cereal crops over the years (Foulkes et al 1998). An exception to this has been shown to occur in barley breeding programs, where achieving malting specification is an objective, since the varieties are often evaluated with lower levels of fertilizer N addition than, for example, in wheat breeding programs. Work in the UK indicated that spring barley yields were increased as newer varieties became available but this increase in yield was not associated with a corresponding increase in fertilizer N requirement (Sylvester-Bradley and Kindred, 2009).

The availability of variable rate technology on modern fertilizer spreading units offers the potential to modify fertilizer application rates on-the-go even within fields. For such technology to be useful for fertiliser N applications a sound rationale for determining the amount of N to apply to any particular area of the field is required. A range of sensors, which can be mounted on tractors, aircraft, drones or satellites as well as being handheld, have been developed which can detect the nitrogen status of crops at high spatial resolution. This offers the opportunity to refine fertilizer application rates based on growth characteristics of the actual crop rather than using crop independent information, such as historic yield levels, as is currently the case. However, while many of these systems can redistribute a particular pre-determined rate of fertilizer N between areas that have a higher or lower nutrient status, many do not give any indication of how much should be applied and so are subject to any error associated with a grower’s estimation of nitrogen requirement. Determining the optimum rate of N to apply based on sensed characteristics remains a challenge.

More precise and site-specific estimation of soil N supply (SNS) would contribute substantially towards more refined fertiliser N recommendations for cereals. Despite much work in this area worldwide progress has been modest. Recent work at Oak Park has indicated that as a means of estimating SNS the current soil N Index system, which relies on previous crop as an indicator of SNS, is limited. The system could potentially be improved by including more variables to improve estimation of SNS, with soil mineral N measurements in spring showing some promise. The use of other sensing technologies such as near-infra red spectroscopy (NIRS) may also have a role to play but again considerable research would be needed before any such system could be recommended at farm level. Monitoring of unfertilized areas within crops during the growing season, with for example reflectance sensors, has the potential to give good estimations of variations in soil N supply between sites and seasons, and could allow adjustment of fertilizer N inputs. Such a system, which would be of particular use for guiding late season N inputs, is already in limited use in parts of Sweden (Delin et al. 2015).
There is also potential for new fertilizer formulations to improve nitrogen use efficiency either by reducing the risk of loss or improving the efficiency with which the crop uses N. A range of inhibitors and coatings, that either slow down the conversion of nitrogen from one form to another or that slow down the rate at which the nitrogen is released into the bulk soil have been developed and tested (Thapa et al., 2016). Some of these have already been evaluated and shown promise under Irish conditions, as described earlier in the case of stabilized urea. However, before being used any new fertilizer formulations need to be comprehensively evaluated to ensure that they offer enhanced efficacy to the Irish grower.

References


Introduction

Since the publication of the 1st Programme for Economic Expansion in the 1958 the importance of grassland farming “…future agricultural expansion will depend mainly on a dynamic policy of grassland development” coupled with good soil fertility “first and basic essential is the presence in the soil of a satisfactory level of lime and nutrients” has been recognised as being closely linked with Irish economic development (Whitaker 1958). Current government policy is still closely aligned with these concepts and the recent FoodWise 2025 (DAFM 2015) strategies for the development of the agricultural and food sector reinforce these aims. A major responsibility of the research staff at Johnstown Castle (An Foras Taluntais and currently Teagasc) has been to support the development and dissemination of good soil fertility advice through the publication of leaflets, booklets and manuals providing nutrient and trace element advice for grassland and crops (Coulter, 2002). This paper discusses the challenges faced by farmers and the agricultural sector in relation to soil fertility, increased productivity and environmental sustainability. It also outlines the recent developments in fertiliser advice detailed in the Teagasc Green Book “Major and Micro Nutrient Advice for Productive Agricultural Crops (Wall and Plunkett, 2016).

Sustainable intensification of agricultural production

Food Wise 2025 represents the national policy vision for the Irish agri-food sector (DAFM, 2015). It envisages a 65% increase in the value of farm gate output to almost €10bn in the next ten years. It also sets a target for an additional 23,000 jobs in the sector, with an 85% increase in food exports from their 2012 level to €19bn. It recognises that achieving economic competitiveness and environmental sustainability are equal pillars in the delivery of this vision. Ireland has an advantage over most countries in terms of our water quality (and quantity), but there is a danger that our ability to maintain satisfactory water quality and improve our unsatisfactory water quality could constrain our ability to increase farming outputs.

The effect of FW 2025 has been examined based on the Strategic Environmental Assessment (SEA) for FW 2025 and scenario modelling. Expansion in the agriculture sector must comply with a range of environmental legislation such as the Nitrates Directive and thus there are constraints to this expansion. Overall, the FW 2025 scenario projects an increase in milk production, stable beef production and a relatively stable total cattle population. Increased milk production has and
will be achieved through a slight increase in cow numbers, increased milk per cow associated with an increase in the Economic Breeding Index. The increased numbers of dairy cows will be offset by a reduced number of beef cows, leading to a relatively stable overall number of bovines. This projection is supported by evidence of the evolution of dairy cow numbers and milk production from 1990: compared to the 1990 baseline year, in 2015 milk production and milk fat/protein has increased by 24 and 39%, respectively while dairy cow numbers are 5.5% lower. The result of changes in the national herd composition will result in a small (+2.9%) increase in national bovine manure N excretion between 2005-07 and 2030, but it is projected to still be 2.4% lower than the peak year in 1998. FoodWise 2025 is expected to result in changes to our national inorganic fertiliser use. Currently only 11% of soil samples have the optimum mix of soil pH, P & K. Changes in fertiliser use nationally must comply with the Good Agricultural Practice regulations under the Nitrates Directive. A small increase in inorganic nitrogen fertiliser use is projected to occur between 2005-07 and 2030 (an increase of 8.8% however, this is still lower than the average used in the period 1990 to 2000. National P fertiliser use is more difficult to predict. Any additional use of inorganic P fertiliser requires a farmer to demonstrate a requirement for P on their farm based on soil testing. Any increases in P use must take other non-fertiliser P imports into account e.g. feed and/or imported manures. Over the last decade, the percentage of soils that are suboptimal for P (Index 1 and 2) has increased from 40% in 2007 to 61% in 2015 (Plunkett and Wall, 2016). At the same time, excessive soil P (index 4) decreased by 43% between 2007 and 2015. This suggests that the production potential of our grassland soils is being slowly eroded and to increase production nationally there will need to be increased use of P fertiliser on the suboptimal index 1 and 2 soils. So how can Irish agriculture expect to grow output and income within the potential confines of environmental constraint as we look towards the future?

**Good agricultural practices for the protection of the environment**

In order to maximise the efficiency of nutrient use on farmland and to minimise environmental impacts, application of nutrients should follow a code of good agricultural practice. The major environmental risks from nutrients are (a) leaching of nitrate from the soil to groundwater which can result in the nitrate levels in water supplies being unacceptably high; (b) surface loss or runoff of soluble P from soils or manure, or movement of P enriched clay to drainage channels, ditches or streams increasing the risk of eutrophication of rivers and lakes and (c) losses of ammonia or nitrogen oxides from chemical or organic fertilizers to the atmosphere with possible adverse effects on the upper atmosphere. Good agricultural practice requires that nutrient supply be matched to crop demand, both in terms of the quantity applied and the time of application relative to the crop yield, soil and climatic conditions.
On the 1st February 2006, the government transposed the EU Nitrates Directive – National Action Programme (NAP) (Anon, 2006) into Irish law. The original legal instrument (SI 378 of 2006), called the Good Agricultural Practice for Protection of Waters Regulations has undergone 3 revisions (SI 101 of 2009, SI 610 of 2010 and SI 31 of 2014) and will be reviewed and update again in 2017. This legally binding statutory instrument deals with the protection of waters from pollution caused by nitrates and phosphates from agricultural sources and is now part of Irish law. Under the single farm payment scheme there are 13 Statutory Management Requirements (SMRs) of which compliance with the Nitrates Directive is one. Thus, Irish farming must comply with the NAP regulations to meet cross compliance requirements.

Under the NAP there is a cap on stocking rate of 170 kg Organic N loading /ha which equates to 2 LU (dairy cows)/ha. However, since 2006 Ireland has successfully negotiated derogation from these limits for farmers who wish to farm more intensively up to a stocking rate of 250 kg organic N loading/ha (2.9 LU/ha). The current NAP and nitrates derogation are up for review by the EU Commission during 2017 and the new programme will run from 2018 to 2021. In recent Nitrates Directive reviews, other member states, for example Denmark and Germany, have had difficulty securing their derogation to farm more intensively as they were not able to satisfy the EU Commission that water quality was being adequately protected. Similarly, Ireland will be required to provide evidence of good agricultural practice and cross compliance on farms in addition to improved nutrient fertility and reduced risk to water quality to secure a new Nitrates derogation up until 2021.

Reducing risk to water from agriculture – evidence from the monitoring and research

Phosphorus loss is considered the main risk to water from farming in Ireland. Since well-drained soils generally pose a relatively low risk of phosphorus loss, intensification of agricultural production on these soils is unlikely to substantially increase risk to water quality. It is likely that the greater part of the expected increased production (particularly dairy) in the mid-west, south east and the southwest will be concentrated on well drained soils given their suitability for this purpose. Thus, intensification will mainly occur in areas where the soils potential for natural attenuation of P is greatest. Substantial efforts have been made by the farming community to implement the Good Agricultural Practice (GAP) measures under the Nitrates Action programme since their introduction in 2006. Evidence of the implementation and its efficacy has been gathered through a range of studies and on-going research and monitoring programmes are summarised as follows.
National water quality monitoring

While the Water Framework Directive (WFD) 2000/60/EC monitoring programme in Ireland (EPA 2016a) has noted a general decrease in levels of phosphorus in Irish waters and evidence of this decrease has emerged from a number of sources, including agriculture. A recently published study, on the intensively farmed Suir catchment, improved fertiliser usage and good timing of nutrient applications was linked to reduced nutrient loadings in the estuary. Here, P and water column chlorophyll concentrations improved while N remained stable.

Agricultural Catchments Programme (ACP)

Research from the ACP shows that good nutrient management practices can reduce P source pressure while maintaining high production levels (Murphy et al., 2015). Over a three-year study period the proportion of soils with excessive P concentrations (i.e. Index 4) decreased from 32 to 24%. Over the same period, P concentrations in shallow groundwater decreased. As well as targeting slurry and fertiliser applications to their low fertility field’s, the farmers have changed the timing of slurry spreading with more slurry going out in the spring and early summer reflecting national trends. This better matching of the application of nutrients to the peak growing season is a big factor in improving the uptake of the nutrients thus reducing the risk of nutrient loss to water.

A further study in a Co. Monaghan catchment that is vulnerable to P runoff from surrounding poorly drained drumlin soils looked at changes in P levels in lake water. Sediment records showed that while agriculture intensified in the area between 2000 and 2010 (i.e. 8 to 17 kg/ha in organic livestock P loading) there was a decline in P enrichment of the lake. Phosphorus mitigation measures from rural environmental protection schemes, group water scheme initiatives and the GAP regulations were indicated as the key drivers of the lake’s recovery.

On-farm water quality monitoring

Evidence from farm scale research also points to positive impacts from careful management of nutrient sources including manures and soiled water. Nitrogen (N) and P concentrations in water leaving these farms have been reduced (Fenton et al. in press). These concentrations are below water quality thresholds and on a downward trajectory. Similar outcomes have been shown from work in the Heavy Soils Programme where data from five commercial farms across the south west shows that water quality in open drains, in-field drains and groundwater are below the maximum admissible concentrations for N (Teagasc, 2012).
National fertiliser use and soil fertility

Use of chemical P has roughly halved in Ireland over the past 30 years with the result that soil P levels have dropped dramatically. Currently less than 15% of samples analysed through Teagasc, have P in excess of the optimum (P Index 4) and this has declined from 30% in 2007, just after the introduction of the GAP measures. The risk of P loss to water has been shown to increase where surplus P to crop requirement is present (i.e. Index 4), thus the reduction in the area of farmland at Index 4 has significantly reduced the potential for P loss to water nationally. However, this reduction in fertiliser use has also negatively impacted on national soil fertility and in 2016 over 60% of samples analysed from commercial farms had low or deficient status for P (Index 1 and 2). Additionally, the low soil pH and K status of the majority of soils tested indicates that overall N and P fertiliser use efficiency is being compromised due to lack of correct nutrient balance (pH, P and K) across Irish farms

Overall farm production efficiency increases

The overall thrust of Irish research and knowledge transfer is focused on increasing the efficiency of production i.e. producing the same or more from a fixed or reduced level of inputs. Any improvement in efficiency contributes to better use of inputs, including nutrient inputs, leading to more nutrient exports in product and less nutrient available for loss to the environment. Many metrics of increasing efficiency of grass-based production are being used to focus farmers’ attention and efforts on efficiency gains, particularly in dairying. Substantial strides have been and will continue to be made in improving efficiency. To succeed, this practice adoption based approach ‘will require improved knowledge exchange among farmers, knowledge providers and policy makers. This knowledge exchange will have to be facilitated through a range of existing and new structures and policy instruments (EPA, 2016b).

To date, improvements in nutrient use efficiency have been found at national level stemming from reduced levels of nutrient inputs and a consequent reduction in nutrient available for loss to water. A study of 150 specialist dairy farms between 2006 and 2012 showed declines in farm-gate N and P surpluses and increases in N and P use efficiencies since the introduction of GAP regulations, (Buckley et al., 2016a, 2016b). Similar results were reported in a survey of 21 dairy farms in the south-east of Ireland, (Mihăilescu et al., 2014, 2015). Another study reported notable shifts in farm practice aligned with utilizing organic manures according to their nutrient value (e.g. spring applications) citing the change to the “positive impact of GAP regulations”, (Hennessy et al., 2011).
National Nutrient Management Advice

National nutrient advice is being constantly developed and refined as we gain new knowledge of soil-plant nutrient dynamics and changes in crop varieties and impact of climate. Prior to now the latest nutrient advice for grassland and tillage crops was available in 3rd edition of the Teagasc Green Book (Coulter and Lalor, 2008). In 2016 a full revision and update of nutrient advice was conducted incorporating the latest scientific research and knowledge to produce the present volume (4th edition) published by Wall and Plunkett (2016). New sections soil types and nutrient cycling, fertilizer ingredients, adaptive nutrient management planning and nutrients for energy crops have been added. Additionally, new information and updates based on the latest scientific findings have been made to soil acidity and liming, organic manures, grassland, and crops sections. Many of the chapters have been reorganised to make them easier to consult and the advice and tables have been redesigned to reflect the latest knowledge, which is supported by recent research.

A major objective in this revision was to ensure that it was comprehensive and that it contained sufficient information to allow agricultural and farm advisors and consultants to recommend optimum levels of major and micro nutrients for the most important agricultural and field horticultural crops. The Teagasc Green Book sets out to minimise conflicts between the need to ensure an economic return from grassland and tillage farming on the one hand, and concerns about losses of nutrients to water or gaseous emissions to the atmosphere on the other.

Many of the changes in this 4th Edition were made necessary by legally binding requirements of the NAP Regulations. This NAP has major implication for use of N and P in farming, both for the farmer and for organisations and advisers recommending levels of nutrient use for agriculture. It has been the intention of Teagasc that fertilizer advice, if followed carefully, should have the desirable effect of optimising yield, protecting the environment, as well as saving money for the farmer. In revising this document, this policy has been continued, where appropriate, within the constraints of the current NAP particularly when dealing with the environmental consequences of N and P use.

Fertilizer rates for optimum yield may sometimes exceed the maximum currently allowed under the NAP. For example, N fertilizer rates for high yielding crops require that proof of historic yields are available, although, historic yields are not necessarily a good predictor of expected yields. Nutrient advice tends to be self-correcting when accompanied by frequent soil testing. Thus, if soil variation or sampling errors cause nutrient applications to be higher than necessary, this will tend to be corrected following the next soil test. Since soil nutrient levels change slowly under most cropping systems, it is usually safe to base fertilizer advice on soil tests for four to five years from the date of sampling. Where soil analysis suggests that no nutrient applications are needed, or with very light soils which
have limited buffering capacity, it is prudent to have soil analysis carried out more frequently to monitor soil fertility statues for example every three years.

**Teagasc Green Book, 4th Edition Summary of Changes**

**New Sections**

- **Soil Types and Nutrient Cycling:** Information on the major soil types in Ireland and their influence on nutrient cycling and management, including links to further information of Irish soils
- **Fertiliser Ingredients:** Definitions and information on the main fertiliser ingredients available in Ireland
- **Adaptive Nutrient Management Planning; NMP–online:** Information on the new nutrient management system “NMP-online” and how it can be used to facilitate better nutrient management planning and sustainable outcomes for farmers into the future
- **Nutrients for Energy Crops:** New information and nutrient recommendations for energy crop production

**Revised Sections**

- **Soil Acidity and Liming:** Improved information on importance of soil pH correction and new information on lime and lime products has been included
- **Nutrients in Organic Manures:** Updated the fertiliser replacement values for slurries and provide new information nutrient constituents in a range of organic manure and biosolid types. Information on tools to measure slurry variability and how to maximise slurry efficiency
- **Grassland:** New N advice for beef and sheep systems and suggested application timings for fertilisers
- **Cereals:** New advice on N application timings for cereal crops
- **Potatoes:** New N advice for potatoes, which considers production system and haulm longevity
- **Oilseed Rape:** New advice on N timing based on density of the crop and leaf area index
- **Vegetable Crops:** Updated of N, P and K advice for vegetable crops based on best available information has been included.

Teagasc fertilizer advice is not static but is reviewed constantly in the light of new national and international research findings, changes in farm practices, nutrient regulations and the onset of new grass and crop varieties with different nutrient
requirements. Some of these updates in the new Green Book are summarised as follows

**Soil types and Nutrient cycling**

Plant production and nutrient cycling are two of the key functions that farmed soils must perform. Nutrient cycling is the capacity of soil to provide nutrition for food, fuel and fibre crops that are grown across the landscape. ‘Cycling’ stands for a movement of matter without getting lost out of an imaginary circle and that is exactly how we want essential plant nutrients to behave (Schroder & Wall *et al.*, 2016). The quality of agricultural soils is deemed to play a role in the cycling of nutrients in residues, indirectly by governing the productivity and harvest ability of crops and thus the effective capture of nutrients from soils, and more directly by its impact on the capacity to accommodate the reception of nutrients in residues and convert these nutrients in forms that can be utilized by crops.

Farmers regularly manage the fertility of the soils on their farms by applying fertilizers and organic manures to build-up or maintain the supply of nutrients required for the grass or crop types they produce. However, experienced farmers will know that not all soils (or fields) have the same production potential (or suitability for certain crop types) or respond in terms of their soil fertility status to the nutrients that are applied. While several factors will determine production potential and fertility status, one major denominator is soil type and most farms will have at least two different soil types, if not more, dispersed within the farm boundary. Given the nature of the Irish landscape and its origins (glaciation) there is often large variability in soils over relatively small spatial areas, even within towns-lands or farms. This poses a challenge for individual farmers and their advisors when planning nutrient and fertilizer management strategies for their farms. A blanket approach, where all fields, even with similar soil test results, receive and “are perceived to respond” to similar nutrient application rates may not happen in reality. This is because different soil types possess different characteristics and qualities. Some of the main characteristics related to soil fertility and nutrient cycling include parent material (rock type, glacial till or mineral deposit) that soil is derived from and its nutrient composition, soil texture (i.e. proportions of sand, silt & clay present), soil organic matter level, water holding capacity and drainage class (i.e. free draining vs. poorly draining) etc.

**Soil test phosphorus**

Low soil P levels, especially P Index 1, will not achieve optimum sward productivity throughout the year without additional P fertilizer above the rate required for soil P maintenance. Soil P levels at Index 2 may restrict grass growth in spring. Where grass demand is low early in the season P index 2 soils may achieve sufficient dry matter (DM) yields, but the herbage P concentration may not
meet the dietary requirements of some grazing animals. In general, soil P levels at
Index 3 are advised to ensure that the grass sward will achieve optimum DM yield,
encourage growth of clover and early grass, and contain a P concentration that is
adequate to meet the dietary requirements of grazing animals.

A recent study of Irish soil types showed that aluminium (Al) in soil had a strong
influence on the soil’s ability to supply available P for plant uptake (Daly et al.,
2015). At high Al to P ratios, P fixation occurred and soils had difficulty supplying
P. For these soils the critical range of Morgan’s P at which P was plant available
fell between 5.9 and 8.7 mg/l. The current grassland P Index 3 range (5.1 – 8.0
mg/l Morgan’s extractable P) may not capture all these high P fixing soils.
Therefore, soils within the current Index 3 and Index 4 categories may show
additional P responses beyond the generalised recommended rates of P fertilizers.

In addition, the Morgan’s soil test may overestimate the available soil P on
calcareous soils and those with high soil pH (>7.0) as it was developed for
naturally acidic soils where a large proportion of P is bonded to Al, Iron and
Manganese in the mineral matter. These high pH soils may require additional P
fertilizer, even at optimum soil test P levels, for intensive grassland production to
maintain an adequate P supply throughout the growing season.

Management of organic manures

There are many forms of organic fertilizer that can be land spread to supply
nutrients to crops. The most common of these are animal manures, with over 40
million tonnes available nationally. Another organic fertilizer is spent mushroom
compost which is often used to provide N, P and K. Organic materials from
industrial and municipal sources may also be considered, under certain
circumstances, as these can have a valuable nutrient contribution when applied to
land. The aim when land spreading organic fertilizer is to optimise nutrient uptake
by the crop and to minimise losses to water and air resources. Understanding the
manure composition and timing of application are critical to achieving these
objectives.

Fertilizer replacement value

In addition to the variation that exists between manures regarding the total nutrient
content, the proportion of the total nutrient content that is actually available for
plant uptake is also variable due to timing and method of application. In the season
of application, the fertilizer replacement value of N, P and K is lower than the total
quantities applied and farmers may need to adopt strategies that improve the
nutrient uptake from organic fertilizers as a result.

Animal slurries account for approximately 80% of organic fertilizers used in
Ireland. Land application of slurry and manure is also susceptible to ammonia loss.
Exposure of slurry or manure to warm, windy and sunny conditions at the time of application promotes high ammonia losses. Therefore, applying manure or slurry in a manner that minimises ammonia losses will maximise the N fertilizer replacement value. Adherence to the following guidelines will help to maximise the N fertilizer replacement value.

1. **Timing of application:**

   - Apply at a time when crop demand is high in spring. Where soil conditions allow, aim to have 70% applied by the end of April. Opportunity for spring application on heavy soils may be increased by using application methods that reduce soil compaction, e.g. umbilical system.

   - Application in dull, cool, overcast or misty conditions will result in lower ammonia losses compared to application in warm, dry, sunny weather.

2. **Slurry management to reduce N losses:**

   - Slurry dry matter: slurries with lower dry matter contents will percolate and wash into the soil more quickly than material with higher dry matter, thus reducing the duration of exposure to the air. Dilution of slurry with soiled water increases the volume to be managed; however, a 1% decrease in slurry DM% will decrease ammonia losses by approximately 5 - 8%.

   - Slurry application method: ‘low emission’ application methods, have been shown to increase the N fertilizer replacement value of slurry under Irish conditions (Lalor et al., 2010). Methods such as band spreading and trailing shoe, place the slurry in bands or lines rather than on the entire surface of the soil or crop as with the conventional splashplate method. Slurry applied with a low emission method has reduced ammonia losses compared to splashplate applied slurry. For example, ≥25% reduction in ammonia losses for a trailing shoe technique compared to splashplate under Irish grassland conditions.

   - Speed of incorporation: where organic fertilizers are applied to tillage land prior to or during the cultivation process, incorporation is beneficial for reducing ammonia losses, as this will reduce the length of time for which the manure is exposed to the air. Immediate incorporation (or at least within 3 - 6 hours of application) is recommended.
Table 1: Nitrogen fertilizer replacement values (NFRV)\(^1\) in cattle slurry with differing to application timings and methods.

<table>
<thead>
<tr>
<th>Timing</th>
<th>Method</th>
<th>NFRV (%)(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>Splashplate</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Trailing shoe</td>
<td>40</td>
</tr>
<tr>
<td>Summer</td>
<td>Splashplate</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Trailing shoe</td>
<td>25</td>
</tr>
</tbody>
</table>

\(^1\) Nitrogen fertilizer replacement values (NFRV) is the plant availability of the total slurry N relative to N in chemical fertiliser (Lalor et al., 2014).

\(^2\) Refers to the total NFRV in the year of application, and is the sum of the short term NFRV after slurry application and the residual NFRV over the remainder of the year.

Determining slurry nutrient content

Knowing the nutrient content of slurry is important as it helps to ensure that crops receive the targeted levels of N, P and K to maximise crop growth. The nutrient content of cattle slurry varies on farms depending on animal type and diet, and especially with the dilution effect of water i.e. how watery the slurry is (dry matter content).

Research has shown that the nutrient content of slurry increases as the dry matter content of the slurry increases (Berry \textit{et al.}, 2013). Laboratory analysis of slurry can be used to get a direct estimate of the nutrient values for different slurries on farms. However, in practice this is rarely done due to the time and cost of the analysis. A more practical approach may be to estimate the slurry dry matter on-farm using a slurry hydrometer and then use the conversion Table 9-8, which illustrates the typical amounts of available N, P and K applied in both cattle and pig slurry depending on the slurry dry matter content and slurry application rate. The slurry hydrometer is a relatively quick, cheap and easy on farm tool to use.

Selecting N fertiliser types

Urea may be used as a source of N and in the majority of instances with similar agronomic performance to that of CAN at a lower cost per kilogram of N. However, under certain conditions a portion of N applied as urea can be lost to the atmosphere through the process of ammonia volatilisation which can lead to inferior yields from urea relative to CAN. Protected urea [urea treated with N-(n-butyl) thiophosphoric triamide (NBPT)] is an alternative source of N to CAN, with reduced risk of N loss compared to urea.

Recent research has shown that CAN, urea and protected urea [urea treated with N-(n-butyl) thiophosphoric triamide (NBPT)] are good sources of N for Irish grassland from a yield perspective (Antille \textit{et al.}, 2015; Harty \textit{et al.}, 2016). However, the efficiency of unprotected urea tends to decline with increasing N rate.
(Forrestal et al., 2016). Urea protected with NBPT has lower ammonia loss, comparable to CAN, and thus is consistently as good as CAN in terms of yield and efficiency (Forrestal et al., 2016). Urea protected with NBPT also has significantly lower losses of the greenhouse gas nitrous oxide compared with CAN (Harty et al., 2016).

On spring barley protected urea reduced ammonia losses compared to urea and consistently produced similar grain yields to CAN, with slightly higher N uptake (Roche et al., 2016). Using protected urea also reduced N\textsubscript{2}O emissions. On soils where conditions are conducive to ammonia volatilisation, which include high pH and drying conditions after application, protected urea can be used to minimise N loss risk.

**Nitrogen Advice for grazing systems**

Nitrogen fertilizer requirements for all grazing systems are related to the demand for grazed grass over the growing season. The N requirements for dairy grazing is generally highest while sheep grazing requirements are generally lower than for dairy cows or cattle.

![Grass demand for different beef systems](image)

**Figure 1. Grass demand for different beef systems at a stocking rate of 2 LU/ha over the grazing season.**

New advice for beef and sheep grazing systems has been included in the 4\textsuperscript{th} edition of the green book. Research has quantified the demand for grass across the different beef production systems according to the length of the grazing season and grazing intensity. Additionally, grass demand will depend on a number of
management factors for the beef production system (e.g. calving/turnout dates, silage harvest strategy, animal finishing system, housing dates, etc). A generalised depiction of grass demand for different spring calving beef systems is shown in Figure 1. New N advice for grazed swards is now provided for the 3 main beef production systems; suckler calf to weaning, suckler calf to beef and calf to beef.

**Nitrogen Advice for potatoes**

Potato cultivars differ in their N requirement and there is no correct standard rate of N for all cultivars. Deep rooting varieties with very long haulm longevity such as Kerr’s Pink and Markies are effective nitrogen scavengers and may require lower application rates in certain circumstances compared to those with medium or long haulm longevity. Varieties can be divided into four distinct groups according to the haulm longevity (Table 2).

**Table 2: Classification of varieties according to haulm longevity\(^1\) or maturity.**

<table>
<thead>
<tr>
<th>Haulm Longevity Group</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determinate varieties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short haulm longevity(^1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partially determinate varieties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium haulm longevity(^1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermediate varieties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long haulm longevity(^1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very long haulm longevity(^1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variety</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Première</td>
<td>British Queen</td>
<td>Rooster</td>
<td>Markies</td>
<td></td>
</tr>
<tr>
<td>Home Guard</td>
<td>Lady Rosetta</td>
<td>Maris Piper</td>
<td>Kerr’s Pink</td>
<td></td>
</tr>
<tr>
<td>Lady Claire</td>
<td>Golden Wonder</td>
<td>Record</td>
<td>Cara</td>
<td></td>
</tr>
<tr>
<td>Nectar, Maris Peer</td>
<td>Electra</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charlotte</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Haulm longevity assessed from 50% emergence to haulm death.

The main effect of N is to increase canopy size and prolong its duration. Yield increases from higher nitrogen rates will only result if harvest is delayed to take advantage of the extended canopy duration and consequent solar interception. However, this is more likely up to September as yield increases are small from mid-September onwards due to reduced solar radiation intensity. Also, harvesting prior to canopy maturity may result in reduced dry matter/specific gravity and after cooking blackening in some cultivars. Where sowing date is delayed, nitrogen rates should be reduced accordingly. Thus, where tuber quality is important it is essential not to use high amounts of N in the event of a restricted growing season. The recommended available N rates are shown in Table 3. For most crops apply the nitrogen to the seedbed prior to planting. However, where the risks of leaching are high (light or shallow soils) a top dressing of no more than one third of the total can be considered but should be applied well before canopy closure.
Table 3. Example - Main Crop Rooster planted into long term tillage land (Index 1).

<table>
<thead>
<tr>
<th>Length of growing season</th>
<th>Variety determinacy group</th>
<th>Index 1</th>
<th>Available N (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;120 days Main crop</td>
<td>3</td>
<td>1</td>
<td>170 kg/ha(^1)</td>
</tr>
</tbody>
</table>

\(^1\) Recommended maximum N rate – for Rooster which has high soil N utilisation is not recommended to apply more than 170 kg/ha N.

For early, second early and late maturing cultivars high N delays maturity therefore it is important to avoid over-use. The recommendations below take into account the length of growing period from planting to burn off. Where planting is delayed or early burn off is predicted to meet early market demands N use should be reduced accordingly.

**Timing of fertiliser applications for cereal crop production**

**Nitrogen for winter and spring barley**

The latest advice for winter and spring barley is that N should not be applied to winter barley at sowing. For winter barley, the first application should be made at the onset of significant growth between late February and mid-March when the crop is at the late tillering stage, before GS 30. Generally, 25-30% of the total should be applied at this timing. The second application should be made at around GS 31, which will typically be in late March/early April. In general, a third application will not be required.

For spring barley, the initial fertilizer N can be applied at sowing, either broadcast before sowing or combine drilled, or alternatively, particularly for early drilled crops (i.e. February sown crops), the initial N application can be made as soon as the crop has emerged. Research has shown little difference between applying the first N at sowing compared to applying the first N at emergence to spring barley. Since the crop demand is very low in the early stages of growth approximately 25-30% of the total planned N application is sufficient at the first application. The second application should be made during tillering (GS22-25). At this stage the remainder of the fertilizer N can be applied, or, particularly if there is a risk of high rainfall after application, a portion of the total N to be applied (typically <20%) can be retained and applied as a third application at GS 31.

**Phosphorus**

With regards to P applications on cereal crops recent research has investigated P application methods for spring barley across various soil types. For spring sown cereals on low P soils (P Index 1 and 2) it is advisable that fertilizer P be incorporated at or before sowing. Research has shown a consistent benefit of
placing P with the seed (combine drilling) for spring crops at Index 1 and 2 (Wall et al., 2013) soils. While benefits to placing P with the seed can be obtained at Index 3 the benefits are likely to be smaller and less consistent than at lower soil P indices. For early sown spring cereals placement of P fertilizers may be more critical where soil and weather conditions are less than optimal.

Research with winter wheat crops has indicated no consistent yield benefit, even where soil P levels are very low, of autumn applied P, compared to broadcast applications in the spring. While there is some evidence of increased seedling survival where P is placed with the seed at sowing time, this maybe more pertinent to winter barley crops grown on low P supply sites where yield formation is more dependent on tiller number development and survival compared to winter wheat. Since fertilizer P application after mid-September is prohibited, spring applications of P are normally advised for winter cereal crops and these applications should be made in February/early March before the onset of significant growth in the spring.

Restricted periods for fertilizer application as set out in the NAP regulations must be observed.

**Nitrogen management for oilseed rape**

Oilseed rape is a crop that has increased in popularity in the last decade and better advice was required by farmers and agronomists to manage N fertiliser inputs for this crop more precisely and depending on the levels of growth over the winter period. While some farmers will follow the green area index approach as a basis for prescribing N fertiliser application rates and splits a more general and practical guide to making decision on N fertiliser was included in the Green Book as follows;

For backward crops or crops grazed extensively by pigeons a light dressing (30kg N/ha) should be applied at the onset of spring growth (late Feb to early March), a third of the remainder should be applied 10 days later and the final dressing in early April.

On moderate crops, one third of the N should be applied in mid-March with the rest applied in early April.

On large crops with lots of leaf area post winter, early N will encourage excessive vegetative growth and applications should be delayed with the first third of the total applied in late March/early April and the remainder applied as late as possible whilst still allowing a uniform spread pattern between the tramlines (before the crop gets too tall).

This approach can be further refined by assessing the extent of green or leaf area development post winter using image analysis (mobile phone apps). A green area index (GAI) of 0.5 or less can be considered ‘backward’ or grazed. An LAI of 0.5
to 1.5 would be normal, while anything above 1.5 at the end of February would be considered large.

For spring oilseed rape some nitrogen will normally be applied to the seedbed, but no more than 50 kg/ha N should be applied to reduce the risk of poor establishment. The remainder of the nitrogen will be applied between the two-true leaf stage and the early stem extension stage.

**Facilitating Better Nutrient Advice**

Over the last decade, since the introduction of environmental legislation on farms, nutrient planning has changed from being a relatively straightforward field by field process to being a complex whole farm nutrient balance based system. To deal with the new complexity a variety of nutrient planning tools have been prepared to aid farmers in meeting statutory requirements. However, the complexity of the statutory requirement provided plans which were not suitable for guiding farmers to apply chemical and organic fertilizers.

Teagasc undertook a process of consultation with farmers. The outcome of this process was a request for a divergence in output within a nutrient management planning system with tabulation based outputs for regulators but a much more visual output for farmers integrating mapping and graphical outputs that support the day to day actions at farm level. In developing NMP On-line Teagasc had three main objectives:

- To improve nutrient management at farm level in support of more efficient, competitive and profitable farming systems
- To improve the efficiency and quality of plans produced to meet the statutory requirements
- To improve environmental outcomes, particularly in relation to water quality and gaseous emissions

NMP On-line is available to all advisers and consultants working in Ireland. It facilitates the efficient production of high quality nutrient management plans and provides a basis for improving soil fertility management on Irish farms.

NMP On-line utilises a data-set of farm information to allow a consultant to work with a farmer to create a nutrient management plan. Much of the required data is available from other sources and the system integrates with many databases to speed up the planning process. Connected databases include Department of Agriculture Food and the Marine (DAFM) land parcel data, DAFM livestock information, and soil analysis results.

The NMP On-line planning system is based on two main rule sets. The first is the European Union - National Action Programme (NAP) (Good Agricultural Practice for Protection of Waters) regulations. This provides the regulatory rules which set
the limits for fertilizer use at farm level. The Teagasc Green Book (Major and Micro Nutrient Advice for Productive Agricultural Crops) provides the basis for the recommendation for field by field application of organic and chemical nutrient based on crop and animal requirements.

Figure 3. Conceptual framework of the Teagasc NMP Online system.
A nutrient management plan needs to satisfy two basic requirements:

1. To provide a plan to the farmer in a comprehensible format that will act as a guide to the application of organic and chemical fertilizer and which will support the achievement of a good soil fertility status and targeted crop output on the farm
2. To provide a plan to show compliance with regulation and to be in a format required by the statutory authorities

Conclusions

Fertilizer advice from Johnstown Castle has always been based on a combination of agronomic and economic factors. In recent decades, environmental sustainability which has been given increased prominence and is advocated by adherence with codes of good agricultural practice (Anonymous, 2001), by taking account of nutrients in organic manures, and by applying no more nutrients than were necessary to achieve optimum yields of crops. As more scientific studies are conducted with the aim of increasing the technical and environmental efficiency of Irish farm production systems, new advice must be developed and effectively disseminated to achieve practice adoption by advisors and farmers. The new Green Book of nutrient advice is an example of this process and aims to provide the agricultural industry with the latest knowledge to manage our most important resource “our soils” for the future.

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References


