THE FERTILIZER ASSOCIATION OF IRELAND

Proceedings of Spring Scientific Meeting 2011

"Maximising fertiliser efficiency under changing legislation"

8th February 2011

Horse and Jockey, Thurles, Co Tipperary

Changes to Nitrates Regulations
W. Callanan
Department of Agriculture Fisheries and Food.

Fertilizer spreading – getting the mechanics right
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The Importance of Liming and Soil pH
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Background to the Nitrates Directive

The European Economic Community was established in 1957 by the Treaty of Rome with agriculture one of the first sectors of the economy (following coal and steel) to receive the attention of EU policymakers. Article 39 of the Treaty set out the objectives for the first common agricultural policy; focusing on increasing agricultural productivity as a way to ensure a fair standard of living for the agricultural community, stabilising markets, and ensuring security of supply at affordable prices to consumers.

Price support and guaranteed markets tended to result in intensive production methods which consequently impacted negatively on the environment. In the context of nitrate pollution, intensive production resulted in increased use of chemical fertilizers (Figure 1), and more significantly large numbers of livestock being concentrated on small areas of land, particularly in the Benelux region (Table 1). In some regions intensive livestock production led to structural exceedances of the quantities of manure produced.

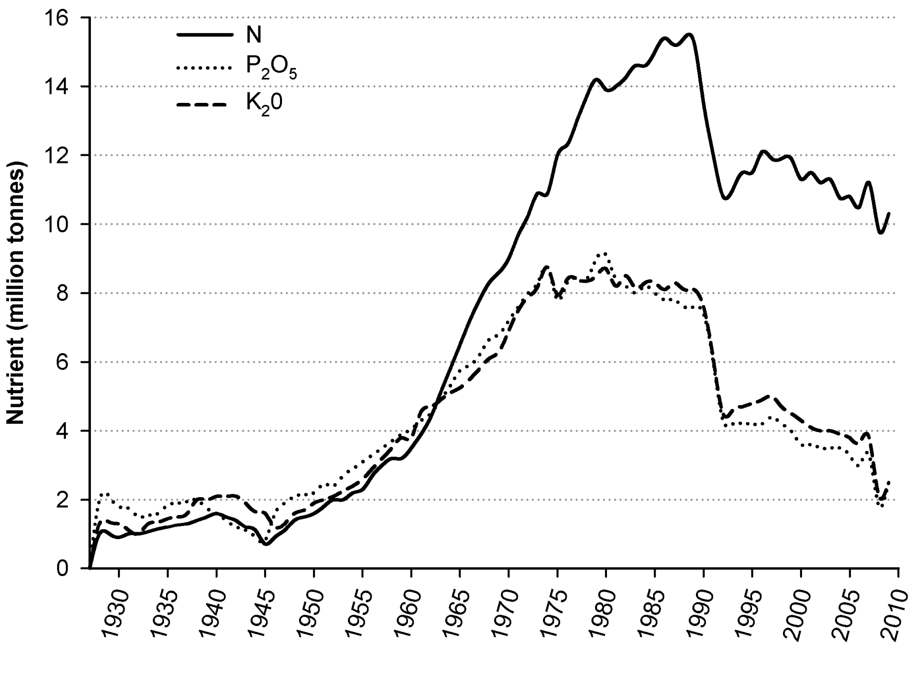

Figure 1. Fertilizer consumption in EU-27 from 1927 to 2009. (Adapted from EFMA).

Table 1. Total Pig Population in Selection of EU Countries in December ('000 head). (Source: Eurostat).

	1973	1980	1990	2000	2009
Germany	N/A	N/A	N/A	25,766.8	26,841.0
Spain	N/A	N/A	15,948.9	22,149.3	25,342.6
France	11,461.0	11,963.0	12,013.0	15,168.0	14,552.0
Poland	N/A	N/A	19,739.2	16,991.5	14,252.5
Denmark	8,364.0	9,696.0	9,282.0	12,642.0	12,873.0
Netherlands	6,889.0	10,196.0	13,788.0	12,822.0	12,108.0
Ireland	1,035.2	1,030.8	1,249.1	1,731.5	1,602.1

Within Ireland, this expansion and intensification coupled with increasing use of chemical fertilizers was also evident, albeit delayed until the after accession to the EU. (Figure 2)

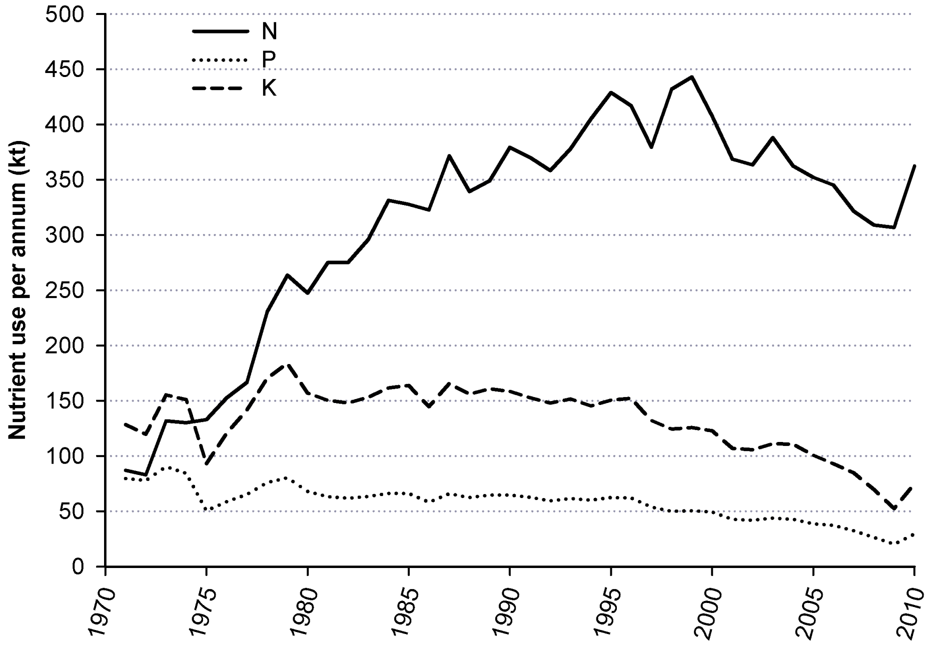

Figure 2. Fertilizer sales in Ireland from 1971 to 2010.

To address the increasing environmental pressure arising from this intensification, the *Fourth Programme of Action of the European Economic Communities on the Environment* indicated that the Commission intended to make a proposal for a Directive on the control and reduction of water pollution resulting from the spreading or discharge of livestock effluents and the excessive use of fertilizers. In

1988 the Frankfurt ministerial seminar on water reviewed the existing legislation and identified a number of improvements that could be made and gaps that could be filled. This initially resulted in the adoption by the Council of the Urban Waste Water Treatment Directive and the Nitrates Directive.

The Nitrates Directive began life as a "Proposal for a Council Directive concerning the protection of fresh, coastal and marine waters against pollution caused by nitrates from diffuse sources". An amended proposal was published in 1990 following the opinion of the European Parliament. Overall the Directive took nearly three years to negotiate and was finally concluded under the Dutch Presidency, being signed on 12/12/1991 and notified to Member States on 19/12/1991.

The objectives of the Directive are two-fold: to reduce water pollution caused or induced by nitrates from agricultural sources and; to prevent further such pollution.

Requirements of the Nitrates Directive

The Nitrates Directive requires Member States to:

- Monitor water quality, applying standardised reference methods;
- Identify surface water and groundwater affected by pollution or at risk of being so, based on procedures and criteria detailed in the Directive (specifically when the concentration of nitrates in groundwater or surface water reaches 50 mg/l or when the surface water is eutrophic or is at risk of being so);
- Designate vulnerable zones, which are all known areas of land in their territories which drain into the identified waters. The Nitrates Directive provides a possibility for Member States to be exempted from the requirement to designate vulnerable zones if the action programmes are applied to the whole of their national territory;
- Establish a code of good agricultural practice to be implemented by farmers on a voluntary basis, which shall include the measures detailed in Annex II to the Directive;
- Set up compulsory action programmes to be implemented by all farmers who operate in vulnerable zones. These programmes must contain the measures listed in the good agricultural practice codes, as well as the additional measures listed in Annex III to the Directive, which aim to limit the land application of mineral and organic fertilizers, as well as land application of livestock manure;
- Report to the EU Commission every four years.

Implementation of the Nitrates Directive in Ireland

From the early 70's, Local authorities and the Environment Protection Agency (EPA) have undertaken extensive monitoring of nitrate levels in waters.

One of Irelands' actions to address nutrient losses from Agriculture was the development of 'The Code of Good Agricultural Practice' (jointly developed by the Department of the Environment and the Department of Agriculture, Food and Forestry) and which was published in July 1996 (titled *Code of Good Agricultural Practice to Protect Waters from Pollution by Nitrate*s). This booklet was widely circulated and set out guidelines aimed at reducing the loss of nutrients from Agriculture.

In July 2000, 14 groundwaters in Counties Carlow, Cork, Kerry, Louth and Waterford were identified as 'affected waters' under the Nitrates Directive.

Ireland adopted a whole territory approach in 2003 for the purposes of implementing the Directive (European Communities (Protection of Waters against Pollution from Agricultural Sources) Regulations, 2003).

A judgement of the Court of Justice of the European Union (ECJ), delivered in 2004, held that Ireland was non-compliant with the Nitrates Directive (Commission V Ireland; case C-396/01)

Regulations giving statutory effect to certain elements of Ireland's first National Action Programme were enacted in 2005 i.e. the European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2005 (S.I. No. 788 of 2005). These Regulations were subsequently replaced by S.I. No. 378 of 2006. The European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2009 ((S.I. No. 101 of 2009) revised and replaced amending legislation made in 2006 and 2007. The 2009 Regulations provided for strengthened enforcement provisions and for better farmyard management in order to comply with an ECJ judgment in relation to the Dangerous Substances Directive. They also provided the legal basis for the operation of a derogation under the Nitrates Directive granted to Ireland by the European Commission in 2007.

Highlights of Ireland's First Action Programme

In implementing the Nitrates Directive Ireland adopted a whole territory approach putting in a place a robust National Action Programme addressing both Nitrogen and Phosphorus. Highlights of this action programme include the following;

- Large investment in farm facilities (> €2 billion).
- Comprehensive Advisory and Research Programmes (DAFF, Teagasc).
- Establishment of a comprehensive Agricultural Catchments Programme.

- Reduced environmental pressure from livestock and chemical fertilizer usage.

Ireland's Second Action Programme

The Environment Protection Agency published a Progress Report on the Implementation of Ireland's 1st Action Programme in February 2010. This report did not recommend any additional measures to prevent and reduce water pollution from agricultural sources.

A comprehensive public consultation process on the proposed revisions to the Nitrates Regulations was initiated jointly by the Department of the Environment, Heritage and Local Government and the Department of Agriculture, Fisheries and Food on 11 June 2010.

The Minister for the Environment, Heritage and Local Government set up an Expert Advisory Group to assist the Departments in taking forward the review process. The terms of reference of this Group were to -

'Review the submissions received in response to the consultation paper, and having regard to these, as well as to relevant national and EU policy requirements relating to environmental protection and the development of agriculture, to determine a common position on the measures which should be included in Ireland's 2nd Nitrates Action Programme'

The Group comprised senior scientific experts from the Department of Agriculture, Fisheries and Food, the Department of the Environment, Heritage and Local Government, the EPA and Teagasc. The Expert Group operated in accordance with the following guiding principles;

- NAP2 should maintain and support the environmentally progressive outcomes achieved under NAP1.
- The developmental objectives for Irish agriculture, as set out in *Food Harvest 2020*, should be encouraged on the basis of sustainable farming practices.
- The NAP2 regime should be designed to operate as efficiently as possible.
- The review should seek incremental improvements to NAP1 and not undermine the considerable achievements of NAP1.

After a review of all submissions received (45) and discussions with the EU Commission, the revisions to the Action Programme were given effect through the European Communities (Good Agricultural Practice for the Protection of Waters) Regulations 2010 (SI No 610 of 2010), which came into effect on the 20th December 2010.

Summary of main changes in the Nitrates Regulations (SI No 610 of 2010)

Use of Pig / Poultry Manure and Spent Mushroom Compost

The facility in the Nitrates Regulations whereby the phosphorus (P) limits set out in the Regulations can be exceeded where pig or poultry manure or spent mushroom compost is being applied (in the absence of chemical P) was due to expire at the end of 2010. This facility is being extended in its present format until the end of 2012. From 2013 to 1017, a graduated facility has been put in place.

- From 1 January 2013 to the end of 2014 the limits may be exceeded by a maximum of 5 kg/ha.
- From 1 January 2015 to the end of 2016 the phosphorus limits may be exceeded by a maximum of 3 kg/ha.

From 1 January 2017, the application of spent mushroom compost and pig or poultry manures may not exceed the maximum quantities set down in the Regulations (see summary in Table 2). It is likely that many farmers presently using these fertilizers may have to reduce their usage of these materials as a result of this change. The impact of the changed rules will vary significantly from farm to farm depending on farm stocking rate, concentrate usage etc. An example is shown in Table 3 of a 40 ha dairy farm importing pig slurry and feeding 350 kg of concentrates/cow/annum (assuming soil P index 3).

Table 2. Phosphorus excess limits

Operable date	Total available phosphorus (kg/ha)
1 January 2011	No change
1 January 2013	5
1 January 2015	3
1 January 2017	0

Table 3. 40 ha grassland farm in Co. Donegal with 55 dairy cows and using 350kg concentrates/cow/annum (assuming soil P Index 3)

Operable date	Maximum amount of pig slurry that may be imported onto the farm (tonnes)
Present to 1 January 2013	506
1 January 2013 to 1 January 2015	506
1 January 2015 to 1 January 2017	436
After 1 January 2017	286

Tillage; Ploughing and Green Cover

The dates where the establishment of a green cover is required following either (1) the ploughing of arable land or (2) the application of a non-selective herbicide (e.g. products containing glyphosate) to arable land or grassland are revised. The date of 15th January has been replaced by 30th November.

This means that any land (arable or grassland) may be ploughed from the 1st December without any requirement for the subsequent establishment of green cover. Likewise non-selective herbicides may be used from 1st December without any requirement for the establishment of green cover within 6 weeks of spraying.

Tillage; Nitrogen (N) Application Limits

The maximum fertilization rates of N for an average crop of winter wheat have been increased to 210, 180, 120 and 80 kg/ha across N index 1 to 4 repsectively. This is an increase of 20 kg/ha at N index 1 (e.g. where winter wheat follows a cereal crop) and an increase of 40 kg/ha at N index 2 (e.g. where winter wheat crop follows for example short term leys) compared to previous requirements.

The maximum fertilization rates of N for an average crop of spring barley are 135, 100, 75 and 40 kg/ha across N index 1 to 4 respectively. Where proof of higher yields is available, the Regulations allow an additional 20 kg N/ha to be applied for each additional tonne above a stated reference yield. The higher yield is based on the best yield achieved in any of the three previous harvests, at 20% moisture content. The reference yield for spring barley has been reduced from 7.5 tonnes/ha to 6.5 tonnes/ha. This means that additional N can be utilised at lower yields than heretofore.

Where malting barley is grown under a contract to a purchaser of malting barley, an additional 20 kg N/ha (over an above what is set out in the previous paragraph in regard to spring barley) may be applied where it is shown on the basis of agronomic advice (by an advisor) that additional nitrogen is needed to address a proven low protein content in the grain (records of previous harvest required to show low protein content in grain).

The reference to ‘any crop receiving dressings of organic fertilizer’ has been deleted from the nitrogen index for tillage crops table in the Regulations. Heretofore a crop was classified as N index 2 if for example pig slurry (or other organic fertilizer) had been applied to the land where the crop was to be sown in each of the previous two years. This no longer applies. Account need only be taken of the N (and P) contribution in the year of application; no account need be taken of the N that becomes available from the use of organic fertilizers in the years following application (see example in table 4).

Table 4. Farmer growing continuous spring barley and using 20 tonnes/ha of pig slurry every year.

	2010	From 2011
Maximum amount of chemical N that may be applied under the Regulations (kg N/ha)	100 (N Index 2) – 42 (20 x 4.2 X 0.5) = 58	135 (N Index 1) – 42 (20 x 4.2 X 0.5) = 93

Tillage; Phosphorus (P) Application Limits

Under the old Regulations the maximum amount of phosphorus that could be applied on any cereal crop was 45, 35, 25 and 0 kg P/ha for soils at P indices 1, 2, 3 and 4 respectively, regardless of yields being achieved. Under the new SI where proof of higher yields is available, an additional 3.8 kg P/ha may be applied to cereals on soils at phosphorus indices 1, 2, or 3 for each additional tonne above a reference yield of 6.5 tonnes/ha. The higher yield is based on the on the best yield achieved in any of the three previous harvests, at 20% moisture content (see example in table 5).

Table 5. Maximum fertilization rates of phosphorus (kg/ha)

Best yield achieved in any of the three previous harvests	Phosphorus index			
	1	2	3	4
Winter wheat (10 t/ha)	58.3	48.3	38.3	0
Spring barley (7.5 t/ha)	48.8	38.8	28.8	0
Spring barley (6.5 t/ha)	45	35	25	0

Nitrogen Availability

The prescribed N availability figure for spent mushroom compost (SMC) has been reduced from the previous value of 45% to 20%. This should result in an increase in the amount of SMC being used on tillage crops (see Table 6).

Table 6. Amount of SMC that may be applied on continuous spring barley (N Index 1) receiving 110 kg/ha chemical N fertilizer.

	2010	From 2011
Maximum amount of SMC (tonnes/ha) that may be applied	6.9	15.6

Nitrogen and phosphorus availability figures for pig, poultry, cattle, other livestock manure, farmyard manure and SMC are specified in the Regulations. In the case of other organic fertilizers the figures for cattle manure must be used (when estimating the contribution of nutrients from these materials) unless a different figure has been determined by the relevant Local Authority or the EPA. Nitrogen availability figures have been specified for composts (other than SMC) in the new Regulations. These vary depending on the C:N ratio of the product in question. Composts with a C:N ratio of less than 10 have a prescribed N availability value of 25% while products with a C:N ratio of greater than 20 have 0% availability value. Intermediate N availability values have also being prescribed.

Grassland: Phosphorus (P) Application Limits

The annual maximum fertilization rates of phosphorus on grassland are set out in Table 13 of the Regulations. These vary depending on grassland stocking rate and soil phosphorus index. The maximum rates have been increased by 15 kg of phosphorus per hectare at soils phosphorus indices 1, 2, or 3 for each hectare of pasture establishment undertaken (see example in Table 7).

Table 7. Annual maximum fertilization rates of phosphorus on grassland where for example grassland stocking rate is 125 kg/ha/year

	Phosphorus index			
	1	2	3	4
Reseeding of pastures (kg/ha)	50	40	30	0
Remaining grassland (kg/ha)	35	25	15	0

The Regulations require that account must be taken of the amount of P in concentrates fed to grazing livestock on the holding when calculating how much P fertilizer can be applied to grassland. Heretofore the deduction for P in concentrates related to the year in question. In order to facilitate greater certainty in regard to nutrient management in future the P contribution from concentrates fed to grazing livestock must be calculated using the previous years concentrate usage figure rather than usage in the current year.

When calculating the P contribution from concentrates fed to grazing livestock heretofore a P concentration of 0.5 kg P/100 kg of concentrate was used for all concentrates. This figure represents an average value for the range of concentrates used in Ireland (the P content of concentrate feeding stuffs varies).

In future if the feed supplier provides information on the P content of the feedstuff this information may be used when calculating the P contribution from concentrates. In the case of straights, known P values for these concentrates may be used (see examples in Table 8) In the absence of either of these the default P concentration of 0.5 kg P/100 kg of concentrate will be used.

Table 8. Phosphorus content of various feed materials (Source: Teagasc)

Feed material	P content (kg/tonne, fresh basis)
Barley	3.4
Wheat	3.6
Maize	2.4
Citrus pulp	1.0
Maize distillers grains	6.7
Soyabean meal	6.1
Rapeseed meal	9.4

Setback Distances from Waters

The setback distance for the application of chemical fertilizer to land in the vicinity of a watercourse has increased from 1.5 metres to 2 metres.

Site-specific and risk-based approach to be used in setting setback distances around drinking water abstraction points, following assessment of conditions.

Where a Local Authority has carried out a technical assessment (e.g. taking variation in soil type and subsoil conditions into account) the larger buffer distances that apply when spreading organic fertilizer or soiled water adjacent to sources of water for human consumption (200/100/25 metres) may be reduced, if circumstances permit, to a minimum of 30 metres in the case of an abstraction point supplying 10 cubic metre or more water per day or serving 50 or more people. In the case of other abstraction points supplying water for human consumption the buffer distances that apply when spreading organic fertilizer or soiled water may be reduced to a minimum of 15 metres. If however circumstances dictate (e.g. evidence of poor water quality) buffer distances may be increased by the local Authority.

Other changes of the legislation

There is a new requirement that silage bales must not be stored outside of farmyards within 20m of a surface watercourse or drinking water abstraction point in the absence of adequate facilities for the collection and storage of any effluent arising. If silage bales are stored outside of farmyards but are stored more than 20 metres from a surface watercourse or drinking water abstraction point no collection or storage facilities are required for any effluent arising.

Under the old Regulations where a holding lay partly in one county and partly in another, the storage requirement of the county with the greater requirement in regard to storage capacity for cattle manure applied. For example where a farmer's primary holding was located in Co. Meath (18 weeks) and he or she owned land in

Co. Cavan (22) weeks), he/she was required to have 22 weeks storage capacity. This has been changed and the higher manure storage requirement applies only where 20% or more of the holding lies in the county with the greater storage requirement.

Where a soil test is to be done for phosphorus or organic matter content the soil sampling procedure set out in the Regulations must be followed. The sampling area cannot exceed 4 hectare. This maximum area can be exceeded in exceptional circumstances where soil types and cropping of lands were similar during the previous five years. This latter area which was 12 hectares has been reduced to 8 hectares.

Fertilizer spreading – getting the mechanics right

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Introduction

The basic functions of a fertilizer spreader are two fold:

- To transport fertilizer to the field
- To spread fertilizer evenly in the field at the required rate

The later function is by far the most critical and complex. In one season a fertilizer spreader can spread fertilizer worth many times the value of the spreader and this can impact on the yield of hugely valuable crops. It is critical that the spreader applies fertilizer evenly to the crop to ensure efficient use of this regulated input and to allow yields and crop quality to be optimised. In this paper, the mechanical aspects of fertilizer spreading are considered. This includes brief consideration of design aspects and fuller discussion of application rate control, evenness of application and its assessment, and the cost of uneven spreading.

Machine developments

In this section, brief consideration of elements of the design of the fertilizer spreader including hopper design / spreader layout and the spreading elements is included. Design aspects of rate control are considered in later sections.

Transport

The transport function is not insignificant and influences the design of the fertilizer spreader. Hopper capacity is determined by the transport function. Where transport is restricted to within the farm, the hopper capacity is typically 500 litres to 3000 litres and the spreader is usually of mounted design for direct mounting on the tractor 3 point linkage or occasionally on a trailed bogey to reduce the axle load and the need for a very high lift capacity. The increase in tractor size and lift capacity has facilitated the move to larger capacity spreaders and has reduced the need for movement of fertilizers on trailers to different areas of the farm. The size and shape of the hopper opening has changed to suit big-bag loading and bulk loading via a wide front loader bucket. Fully trailed spreaders typically have a capacity of 4000 litres to 12000 litres and while they are occasionally used by large farmers for their own use, they are primarily used to transport and spread fertilizer directly from merchant's yards or sometimes in conjunction with a bulk fertilizer trailer to increase working capacity. The hopper design on these machines influences the rate control mechanism chosen as longer hopper bodies on a trailed spreader benefit from a conveyor belt transport mechanism.

The impact of heavier spreading units on soil structure cannot be ignored as heavier units are frequently used in soil conditions where compaction is likely to occur. In this regard, the timing of application of fertilizer to ploughed soils in advance of sowing can be problematic, particularly if contract spreading using bulk spreaders is deployed. Tyres large enough to work at 0.8 bar or less should be used on all equipment if working on very wet soils or ploughed ground.

Spreading mechanism developments

Developments in the spread mechanism of fertilizer spreaders has mainly been confined to twin-disc units, as spout-type spreaders have practical spread width limitations, and the older single-disc units invariably produces a one-sided pattern. Pneumatic type spreaders have all but disappeared from farm use as they are too expensive to purchase and operate compared to the improved wide-spreading twin disc machines. They still have an advantage in windy conditions and where a sharp cut-off to the spread pattern is needed. Consequently they are still in demand in specialist applications such as research farms.

The move to wider tramlines on tillage farms has seen fertilizer spreaders with ever wider spreading capabilities being developed. Broadcast fertilizer spreaders with the capability of spreading at bout widths in excess of 40m are currently available. This movement to wider spread widths over the last 20 years occurred during a period of significant independent testing of fertilizer spreaders with two series of major European tests carried out in the early and late 1990s. This produced a useful focus as manufacturers strived to achieve satisfactory spread patterns, as measured by the coefficient of variation (CV) assessment of evenness using a full tray test. Manufacturers have taken quite different approaches to the detailed design of disc spreading mechanisms to achieve satisfactory spreading at wide bout widths using variations in:

- disc size, shape, speed and rotation direction
- length, size, shape and angle of vanes
- delivery point of fertilizer to the disc

The detailed effect of the different design elements on spread patterns is beyond the scope of this paper. At the beginning of this period some manufacturers (e.g. Lely, Bredal, Bogballe) changed to discs spreading from the outside towards the centre of the spreader rather than the reverse, and this market division remains today. This design allows the spread pattern from both discs to be largely overlaid and this allows a slightly different overall spread pattern. The evaluation of spread patterns is considered later.

Applying the correct rate

There are two aspects to getting the correct amount of fertilizer distributed in the field to a position where plants can access the nutrients:

- Correct application rate onto the field / crop or perhaps onto a section of the field / crop where variable rate application is used.
- Applying the required rate evenly to the crop.

Getting the rate right

Achieving the correct application rate relies on having a known flow rate of fertilizer exiting the spreader at a known forward speed of the tractor, and that the tractor is travelling at the correct bout width. There are three basic flow control mechanisms deployed on fertilizer spreaders:

- Gravity based systems assisted by agitators which principally rely on a variable shutter opening to regulate fertilizer flow to the spreading mechanism.
- Variable speed belt delivery in conjunction with an adjustable shutter regulating flow. This is a more positive delivery system. The conveyor speed can also be proportional to forward speed.
- Seed drill type metering system with variable speed fertilizer delivery rollers or variable area delivery rollers.

The gravity system is normally used with most disc and oscillating spout type spreaders. It is simple and mechanically reliable. The feed rate, while controlled by the shutter opening, is affected by fertilizer type and condition. The distribution of particle sizes; the size/shape of particle sizes, and moisture levels, all affect fertilizer flow. The extent of this variation will be influenced by the machine design (shutter and opening design/shape and agitator type will impact on it). Consequently it is imperative that the manufacturer supplies good information on base settings for individual fertilizers and that there is a fast and easy calibration system available for users to fine-tune the settings and/or check the settings for a given fertilizer in particular conditions. This is important as the range and consistency of fertilizer varies hugely. Anecdotally, fertilizer consistency has deteriorated since the market moved from largely 50 kg bags towards 500 kg, and more particularly with bulk fertilizer, where the notion of spread quality as a factor in sales languishes behind small differences in price.

The conveyor belt type delivery mechanism is a more positive feed mechanism and consequently is less influenced by the flow characteristics of the fertilizer. This system normally uses a shutter at the end of the belt to control flow. The impact of changes or variations in forward speed on application rate can be automatically corrected by linking the belt drive to forward speed (e.g. belt drive connected to wheel). This is particularly useful with a heavy trailed spreader where it can be difficult to maintain constant forward speed in undulating conditions. While the belt delivery mechanism generally delivers a fairly constant volume of material to the spreading discs controlled by the shutter opening, the bulk density of the fertilizer will impact on application rate. It is vital therefore to know the specific weight of the material being spread.

The seed drill type metering mechanisms are normally restricted to full-width research-plot type spreaders, or pneumatic type spreaders. These are quite positive feeding systems which, particularly in the case of variable feed roller speed control, allow repeatable and consistent feed rates. However they still require calibration as fertilizer characteristics will influence feed rate to some degree.

Rate control mechanism

For most spreaders with the exception of the seed wheel delivery type, the flow rate is controlled by a shutter. With conventional manual systems once the rate is set it is fixed and the operator would leave it set at that setting for the field or a number of fields or large section of a field. Operator control in work is limited to on/off switching via manual lever or a hydraulic or electric actuator. Active rate control systems are also available which allow the flow rate to be varied during the spreading operation. There are a number of potential uses/benefits of this system:

- Allow the application rate to be kept constant when forward speed varies: requires a wheel speed or radar forward speed sensor
- Allows the rate to be kept constant even if the flow characteristics of the fertilizer vary. This requires sensitive on-board flow sensing device, usually load-cell based which continually calibrates the spreader in work.
- Allows the operator to change the application rate ‘on the go’ by a certain percentage (e.g. for visually poorer crop areas) by simple switch.
- Allows variable rate spreading to be carried out on the basis of a computer generated application map (precision agriculture practice requiring GPS position signals).
- Controlled headland operation. Allows gradual shutting off of the two independent sections of the spreader to match headland bout as an angled headland is approached (requires GPS). Also easier control of headland spreading rate

Calibration

While the level of calibration required will vary depending on the machine type, all fertilizer spreaders, perhaps with the exception of those with on-board weighing and calibration systems, require some form of calibration to ensure the correct rate of fertilizer is applied. At farm level, calibration is unfortunately a fairly rare occurrence. In many cases, farmers will monitor fertilizer application rate on a field by field basis by estimating the number of loads spread on given areas and adjusting the rate setting between fields. This can result in significant errors even though the overall rate may appear correct. A farmer spreading 40 ha in 5 fields may spread the first field at a rate 20% below what is required, the next field at 15% more than what is required, the third field at 5% more than required and the last two at the correct rate. Overall the rate appears correct but 40% of the area has been spread at rates well outside those required.

Some manufacturers provide an excellent setting guide by testing the flow characteristics of a large number of fertilizers on the Irish market and providing provisional settings. This is not the full solution as the spreading characteristics of many blended fertilizers vary each year and the shutter settings on an individual spreader may vary slightly. Manufacturers may also provide a setting system based on identifying the characteristics of the fertilizer based on simple sieving, strength and physical appearance assessments. Last year, a simple ‘flow bag’ which times the flow of fertilizer through a graduated outlet to determine the flow rate of the fertilizer was developed by one manufacturer.

All manufacturers provide static calibration procedures whereby the flow rate of fertilizer is calculated by weighing the collected output of fertilizer from a timed run of the spreader mechanism with the agitator running. On many machines this requires the spreading disc (or spout) to be removed and/or a collector to be installed and may not always be a convenient operation. The fertilizer is collected and weighed. The easier the calibration system is to operate, the more likely it is to be used. The second part of a calibration procedure is to ensure the forward speed of the tractor at a standard pto speed is known. This may involve calibrating the tractor’s own speedometer or verifying a speed chart based on engine speed and gear selected. With 4wd tractors, relying on wheel speed sensors for forward speed, wheel-slip can give a significant forward speed error (10-20%) particularly if the tractor is spreading on ploughed or cultivated ground. Radar speed sensors are generally more accurate.

Manual field calibration can also be used where the quantity of fertilizer spread over a known area is assessed. This can be quite difficult however as fertilizer is more frequently handled in 500kg bags or as bulk. Large areas may have to be measured if a 500kg bag is used for calibration. Frequently, operators use a particular known field size or paddock to calibrate, however it is often impossible to accurately assess how much fertilizer is left in a hopper when the known area is fully spread.

The most convenient calibration techniques are those facilitated by on-board weighing systems on the spreader. The spreader is fitted with one or more weigh cells which allow the calibration to be easily and quickly carried out in the field with the weighing system able to check the actual application rate against the area covered. These calibration routines are simple and accurate provided the weighing system itself is occasionally calibrated and an accurate forward speed sensor is used.

Pneumatic type fertilizer spreaders with seed drill type or force feed delivery systems are usually easy to calibrate and come complete with calibration buckets and either powered or manually operated calibration drive mechanisms.

Accurate bout marking is essential for correct application. GPS tracking systems avoid the huge errors that can occur if you rely on guessing the right distance in a grass field. Manual marking of the field can be accurate but operators should measure their stepped distances to get markers down at the correct width. Tramlines can be out by 5%.

Spreading evenly

Getting the right quantity of fertilizer onto the crop is only the beginning of the task of good spreading. The most difficult challenge is to achieve uniform spreading both in the direction of travel and laterally across the width of spread. There are many elements to this:

- Machine design: The detailed design of the spreading elements particularly the disc and vanes and delivery point of fertilizer to the disc have a profound effect on distribution.
- Machine setting: The correct setting /adjustment of the various elements of the spread mechanism and also height over the crop and angle of the hopper
- Absence of wear on the spreading components: Disc, vane and fertilizer delivery mechanism wear will impact on spreading evenness
- Fertilizer characteristics: The physical nature of the fertilizer impacts on its spreadability.

Fertilizer characteristics

The effect of fertilizer characteristics, specifically granule size, shape, density and strength, on spreading performance has been the subject of considerable research and was considered in some detail by Fortune (1995). Particle characteristics affect the fertilizers movement on the disc, throw-off from the vanes, and movement through the air. Particle size distributions with the majority of particles (80%) in the 2-4 mm range, coupled with rounded smooth particles, usually allow the spread pattern to be optimised giving broadly triangular patterns compared to angular material of variable size or very small grained fertilizers. Where the different components of an NPK fertilizer are provided as different constituents (blend rather than compound) it is important that all constituents have broadly similar physical characteristics (mean particle diameter within 10% of mean) to avoid segregation and uneven spreading of the constituent elements. There is an interaction between fertilizer quality and spreader type as manufacturers try to cope with the range of materials to be spread. Some spreaders' spread patterns are reasonably accommodating of variations in particle type and size whereas others require very careful setting and adjustment. Wider bout widths present a particular challenge for fertilizers with poor physical quality, causing the spread patterns of all spreaders to be compromised, although there can be significant differences in this drop off in performance depending on spreader model.

Evenness testing

The challenge with modern wide-spreading fertilizer spreaders is immense. Spreading fertilizer accurately and evenly over such a distance is a tremendous achievement. Accurate assessment of performance is essential. While most of the emphasis is correctly on lateral distribution with granular fertilizer spreaders, evenness of distribution in the direction of travel cannot be ignored and manufacturers must ensure that the flow rate to the spreading mechanism remains constant and that at normal spreading forward speeds, the spread pattern does not break down to give variation in the direction of travel.

The evenness of fertilizer spreading is assessed by collecting spread material in a series of trays and producing a spread pattern from the resulting weighed material. For complete spread analysis a full set of 0.25m or 0.5m wide trays for a total width of between two and three times the expected bout width is usually required. The degree of unevenness is typically expressed by quoting the coefficient of variation (CV), a mathematical expression of variation about the mean of the individual test tray weights. Lower CV values indicate better spreading evenness. While values of 15% or less were considered good in the past, today spreaders would need to have CV values of less than 10% under test conditions to be considered good. Many spreaders can achieve CVs of between 4% and 7% in tests with good quality fertilizer.

While the CV value is a useful single figure which describes the evenness of spread at a particular bout width, it does not indicate how likely it is to achieve that CV in practice with a range of fertilizers in a range of field conditions. The shape of the spread pattern can give an indication of the likely robustness of the CV value. Good and poor spread patterns are illustrated graphically in Figures 1 and 2 respectively. The CV values of 9% and 16% apply to the good and poor patterns respectively. The shaded section is the basic spread pattern, while the continuous line indicates the overlapped pattern. The triangular shape in Figure 1 indicates a pattern that should prove robust and easy to work with whereas the shouldered pattern in Figure 2 would be more typical of a spreader that requires careful setting and that may be susceptible to poor spreading with variable quality fertilizer.

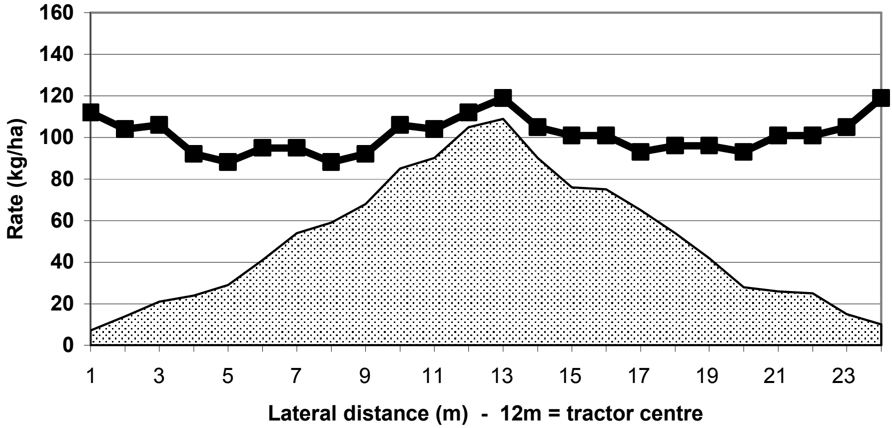

Figure1. Basic (shaded area) and overlapped (line) spread pattern: Good.

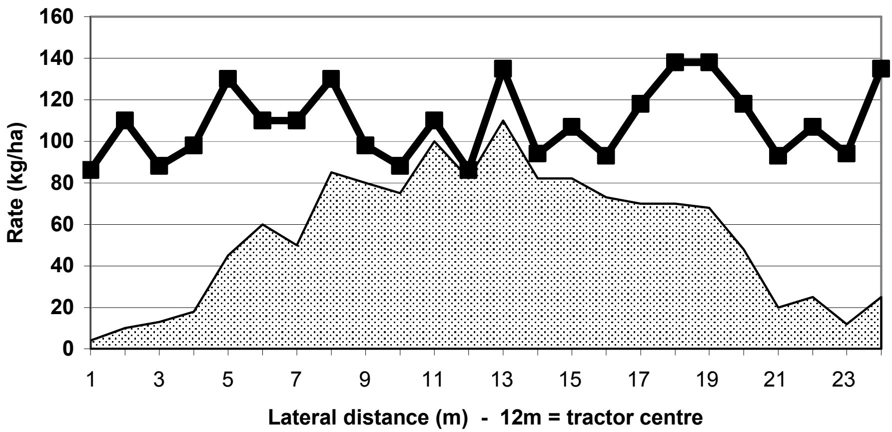

Figure 2. Basic (shaded area) and overlapped (line) spread pattern: Poor.

For comparative purposes testing is normally carried out under controlled conditions in large clear-span test halls. While essential for valid comparison, results from these perfect wind-free conditions can give an erroneous impression of spread capability in the field, particularly at wider bout widths.

The importance of independent testing cannot be over-emphasised as it allows users compare spreaders and also influences manufacturer's objectives. While manufacturers will produce test results, they are not as useful as the comparative standard tests such as those carried out under the ENTAM (European network for testing agricultural machinery) testing body. In the 'golden age' of independent fertilizer spreading in the late 1990s, the majority of fertilizer spreaders from the main European manufacturers were able to achieve CV values of less than 15%, and most less than 10%, at their designated bout widths with a number of fertilizers. The spread mechanisms on most of today's spreaders are very similar to those tested in this period. During these tests a number of different fertilizer types are tested; usually nitrogen; an NPK blend; and granular urea.

New developments in testing

With modern wide spreading spreaders which also throw fertilizer quite a distance to the rear of the spreader, the cost of huge clear span test halls needed to accommodate them has become prohibitive. In the last 5 years a move towards measuring one radial section of the spread pattern in detail as the spreader rotates around a pivot allows all the information required to be collected to generate both lateral and longitudinal spread patterns. The system depends on the availability of a complex dynamic tray weighing system needed to put accurate time tags on the weigh data which is essential to allow processing into spread patterns. This system has reduced the requirement for enormous clear test halls and has speeded up the testing process dramatically (Piron, 2005). It is now being used by some manufacturers.

Field performance

While the availability of independently tested CVs is extremely useful and a good starting point for assessment of a fertilizer spreader, there can be a considerable 'gap' between test performance and field performance. What is also certain is that fertilizer spreaders which may achieve the same or similar CV under controlled indoor test conditions may achieve quite different CVs from one another under similarly challenging field conditions. Performance in the field can be affected by a number of factors compared to controlled test conditions:

- Variation in fertilizer physical quality.
- Variation in disc speed caused by engine loading due to slopes, wheel sinkage, etc., or by inaccurate speed sensors.
- Difference in angle of disc to the crop caused by:
    - Uneven link arm setting / excess movement.
    - Ground surface variation beneath the tractor wheels.
    - Ground/crop surface variation within the spread distance of the spreader.
    - Incorrect top-link adjustment.

  - Varying load of emptying hopper causing front/rear attitude to change due to sinkage, tyre loading, stability and strain response of linkage components.
  - Dynamic acceleration (bumps) exacerbating all of the above.

- Insufficient or incorrect height from crop to disc.
- Slopes and dynamic acceleration interfering with fertilizer delivery point to disc.
- Incorrect setting for fertilizer type and conditions.
- Wear in all spreading components.
- Weather conditions, especially wind.

Spread pattern and field performance

Output from independent tests other than the CV can give an indication of the susceptibility of a spreader spread pattern to some of the field factors outlined above.

To illustrate this, the spread patterns of two different fertilizer spreaders (A and B) tested in the same test hall are presented (Figures 3, 4 and 5). Both machines were set to spread nitrogen at an 18 m bout width. While the CVs achieved are both excellent at 4.4% and 6.2% respectively for the targeted 18 m setting, there is a substantial difference in the shape of the basic spread pattern. Spreader A has a very wide basic spread with gently tapering sides and the last fertilizer granules reaching about 24m out from the centre of the tractor at each side. This pattern is likely to be very forgiving in practice as evidenced by the consistent CV achieved over a range of widths as highlighted in Figure 5. A CV of 5% or better is achieved from 6 m to about 21 m. Spreader B in contrast has a much more flat-topped pattern with relatively steeply sloped slides and an overall spreading distance of just 17 m to each side of the tractor. Matching bout widths with this type of spread pattern is very important and this model achieves a low CV at 18 to 20 m bout width, but moving 2 m to either side of that range causes the CV to rise to 15%, with 30% a possibility with a little more movement. While bout width should not vary much in practice, difference in these two basic spread patterns indicates that anything which might affect the basic spread pattern (machine angle and height, fertilizer and wind factors) is likely to have a much more harmful effect on machine B rather than machine A, as small changes in the shape of the sides or top of the basic pattern of spreader B could have a serious impact on the overlapped pattern at a set bout width. Spreader B is reliant on careful adjustment to optimise the CV at a particular bout width and is consequently prone to small changes in field conditions having a potential large effect on the spread pattern. Spreader A requires little adjustment to achieve a good pattern and its spread pattern is relatively robust.

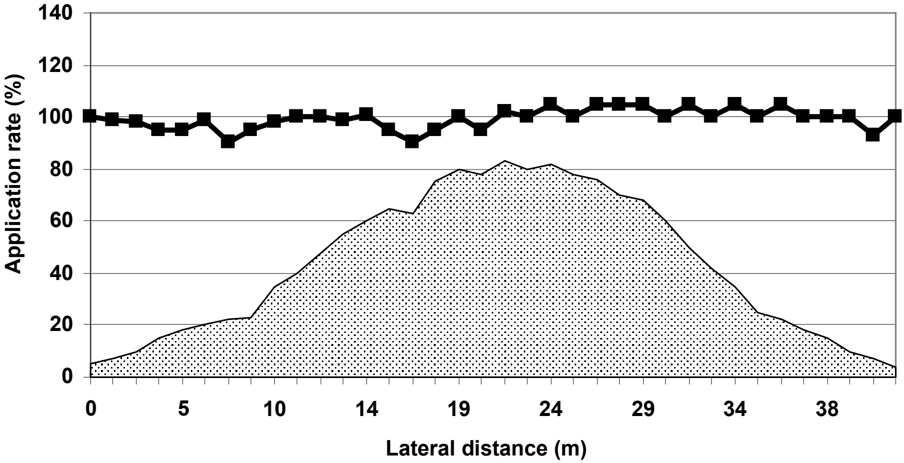

Figure 3. Basic (shaded area) and overlapped (line) spread pattern at 18 m: Spreader A.

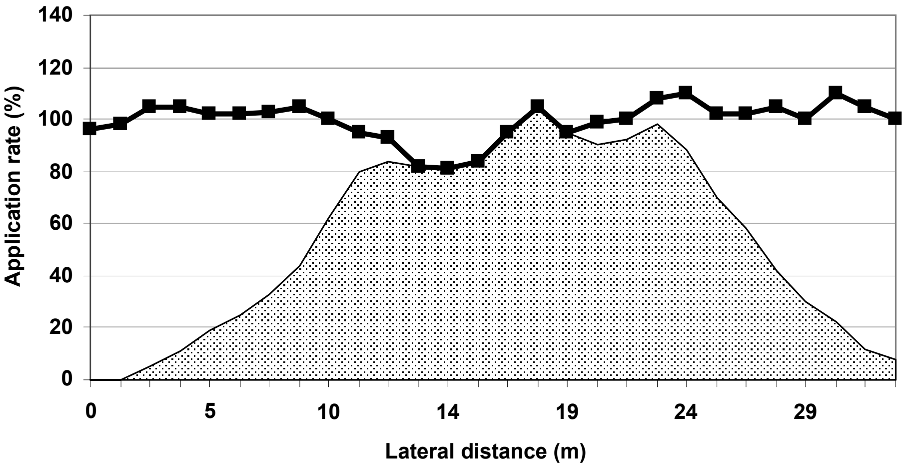

Figure 4: Basic (shaded area) and overlapped (line) spread pattern at 18 m: Spreader B

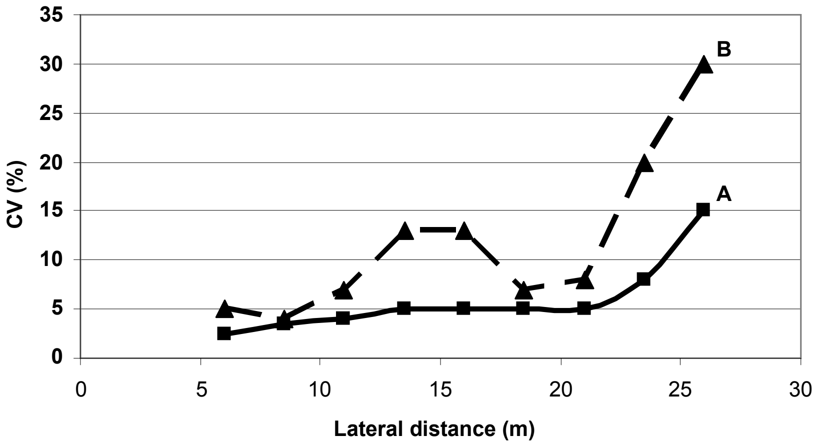

Figure 5. CV and bout width for spreaders A and B.

In the example shown, the discs on spreader B spread outwards from the centre while the discs on spreader A rotate towards the centre. While this is by no means the only factor in determining the spread pattern, a well designed unit with the latter type tends to produce a more robust pattern, which may be less affected by wind or fertilizer and is usually easier to set. However, because the pattern of each disc overlaps the other to a large extent, there is less scope to balance the spread pattern by turning off one side of the spread pattern when approaching an angled headland. The outward turning disc type (B) generally needs more careful adjustment to achieve even spreading with different fertilizers or in different conditions. Manufacturers of this type of spreader generally supply a lot of setting information to help the user set the spreader. Developments in this type of spreader include the development of sensors on the spreader which measure the trajectory of the fertilizer as it leaves the spreader to determine if the setting is appropriate.

While there is no doubt that the field CV of both machines will always be poorer than that measured in the test hall, the shape of the basic pattern is likely to impact on the level of change that occurs.

Regardless of spreader type, very wide bout widths are extremely prone to wind impacting on the spread pattern. The relatively high density fertilizer particles depart wide-spreading discs at tremendous speeds, carrying a lot of momentum relative to their size to be accurately thrown 24 m from the spreader. This is required to achieve a satisfactorily overlapped spread pattern, and is a tremendous challenge.

The cost of uneven spreading

It is difficult to quantify the cost of uneven spreading. Two factors contribute:

- The quality of spreading at farm level
- Calculation of the cost of uneven spreading.

Spreading quality at farm level is influenced by: machine type; its condition; correct setting of the machine; fertilizer quality and weather conditions on the day of spreading. A machine with an indoor test CV of <10% may give quite a different figure in farm use under real and imperfect spreading conditions. A design that produces a broad triangular shaped spread pattern with little requirement for adjustment of the spreader settings for different bout widths or fertilizer types is likely to be less influenced by fertilizer quality, lower levels of wind and/or imperfect angle of the fertilizer spreader.

The impact of uneven fertilizer spreading on yield and financial loss has been researched previously (Dilz et al 1985; Sogaard and Kierkegaard, 1994; Ernst and Heymann,1992, Miller et al, 2009). In most of these studies the effect is mainly modelled rather than actually measured and there are potential flaws in this approach. The most significant impact on yield is likely to result from nitrogen application. Millar et al (2009) studied a series of possible spread patterns based on possible deviations from the characteristic spread patterns commonly found on broadcast spreaders. The effect on coefficient of variation was calculated and the effect on the yield and financial value of a winter wheat crop was extrapolated using N response curves.

Table 1. The effect of modelled spreader errors on CV and resulting winter wheat crop margin loss (adapted from Millar et al 2009).

	Good CV*	Problem modelled	Resulting range of CVs (%)	Range of Costs (€/ha)
Pneumatic	5.6	Skewed side distribution	5.6 – 20.6	1.04 – 13.80
Twin Disc	4.6	In-correct width - displaced	4.6 – 27.1	0.69 – 22.54
Twin Disc	4.6	Asymmetric pattern	4.6 – 50.1	0.69 – 73.53
Twin Disc	7.4	Quadratic spline - displaced	7.4 – 57.2	1.78 – 134.55
Twin Disc	7.4	Twin spline – displaced	7.4 – 55.1	1.78 – 74.59
Twin Disc	8.4	Twin spline – asymmetric	8.4 – 40.8	2.32 – 47.23

*CV expected with a good spread pattern (data 'noise' level 2 from Millar et al 2009)

Combining all of this data resulted in a clear relationship between the CV and financial loss for winter wheat based on a dried wheat price of €127 per tonne of the form:

$$\textit{Financial loss (€/ha)} = 0.0345 \times (CV)^2$$

This general relationship is illustrated in Figure 6. While this assumes that all patterns with similar CVs have a similar effect on yield, in practice, this may not be the case.

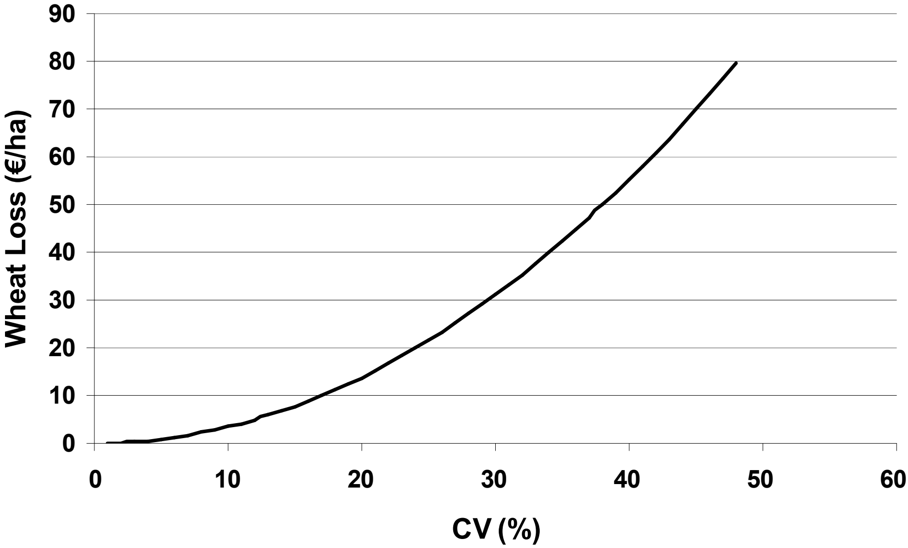

Figure 6. The relationship between CV and financial loss in winter wheat (adapted from Miller et al, 2009).

The value of this loss in any other crop would depend on the yield response curve and the value of the crop. Other cereals are likely to be less responsive to N application than wheat and grazed grass is of a lower value.

The unknown in estimating financial loss is the size and extent of poor spreading in the field. While it is unlikely that there are many spreaders operating with CV values in excess of 40%, it is likely that poor spreading in field situations will result in CVs of more than 25% as it would generally require variations of this level to give clear visual differences in the field. This gives a likely range of potential loss from 'bad' spreading of this magnitude of from €22/ha at 25% CV to €55/ha at 40% CV in winter wheat. If field performance of a good fertilizer spreader achieves field CVs of between 5% and 10% then the loss compared to perfectly uniform spreading is as low as from €1 and €3/ha with winter wheat. As these are modelled values based on a specific wheat response curve, there is need to establish the performance of fertilizer spreaders in typical field conditions. Also the emphasis in spreader design should firmly be on producing patterns which are robust in the field and not on trying to drop another 1% unit drop in CV under test hall conditions.

Uneven spreading can also impact on crop quality. Protein content in cereal crops can be reduced by uneven spreading, while grass digestibility at silage harvesting stage could also be adversely affected due to induced variation in crop maturity at the critical grass heading stage.

An impact on yield and quality, significantly beyond what would be expected due to a nutrient yield response, can occur if a cereal crop lodges. In a season where soil nitrogen supply is plentiful, an uneven spread pattern can result in significant lodging. Depending on the extent and time of lodging, significant yield, quality and financial loss can occur.

Practical considerations for users

- The most critical factor when purchasing a fertilizer spreader is to select a model that is capable of even spreading, at the bout width which you require. This is determined by its basic spread pattern and CV values. Always ask for the results of an independent test report. Look for a broad gently sloping pattern which may prove more robust in the field.
- Secondary but important considerations include selecting the specification that is required or justified such as hopper capacity, headland spreading facility, control systems, weigh system etc. Ensure you have a facility to calibrate the application rate.
- Select fertilizer that has good spreading characteristics with 80% of the granules in the 2-4 mm size range and preferably smooth round shapes.
- Use all the manufacturer’s resources such as instruction manuals, and internet-based material, to ensure the fertilizer spreader is accurately set for the fertilizer and spread conditions in your situation. Be aware of all the setting/adjustment components.
- Calibrate the fertilizer spreader for new or unknown fertilizers
- Check all the spreading components for wear frequently. Any wear on the vanes in particular can easily result in poorer spreading evenness. Clean after every working day and protect from corrosion.

Conclusions

Finally while there has been considerable research into factors which affect spreader performance from a design perspective, and we know a lot about spreader operation and test-hall spread patterns, there are two clear areas where more research is needed:

- The impact of uneven fertilizer spreading on yield of our crops grown in our conditions as determined by field trials rather than modelling

- The relationship between test-hall performance and field performance of a range of fertilizer spreader types producing different characteristic spread patterns

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The Importance of Liming and Soil pH

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Introduction - Consider pH early

The amendment of soil by the application of lime is without doubt one of the oldest ways of improving a soil, second only to spreading FYM on a field. However this simple task is often over looked in favour of more expensive, complicated treatments, which would in many cases be unnecessary if lime had been applied. The pH or calcium status of any soil will have a huge influence on what crops will grow and how well they will grow. In short, the pH or calcium level will play a large part in how profitable a farm is.

Soil pH and fertilizer availability

It is commonly accepted that a pH range of 6.5-7.0 would be the ideal to grow most commercial crops. With the exception of potatoes that should be grown at around pH of 6.0. The conventional way of displaying this is with a graph showing the availability of the soil elements at different pH levels. This is a great teaching aid used in every agricultural college in the world. However it does not have the impact value that a % chart showing the effect on availability caused by different pH has on the major elements, as shown in Table 1.

Table 1. Effect of soil pH on the availability (%) of N, P and K (Source: MEAC).

	pH 4.5	pH 5.0	pH 5.5	pH 6.0	pH 7.0
Nitrogen	30%	43%	77%	89%	100%
Phosphorus	23%	31%	48%	52%	100%
Potassium	33%	52%	77%	100%	100%

This is because we can easily convert these percentage figures into Euros that the grower is spending on fertilizer, but not getting a return from and to present the cost of not maintaining a suitable pH level on a farm. It is now possible to present a Euro loss figure per/ha for different crops at a range of pH levels (Table 2).

Table 2. Effect of low soil pH on the losses of the money spent on fertilizer for different crops

Crop	% loss of annual fertilizer costs at soil pH 5.0-6.0
Wheat	58% - 13%
Grazing	57% - 12%
2 cut silage	58% - 13%

Liming products and particle size

Materials sold as agricultural liming products must meet the regulatory requirements regarding moisture content, particle size and total neutralising value (TNV%) (Table 3).

Table 3. Requirements standards for Agricultural Liming Products

Criteria	Requirement
Moisture Content	$\leq 3\%$
Particle size	100% < 3.35 mm
	35% < 0.15 mm
TNV	$\geq 90\%$ (relative to $CaCO_3$)

Trial work from around the world over many years has reported that the size of the lime particle is very important. In other countries there is a far greater importance applied to the size spectrum of any given lime material, with the recognition that as the particle becomes smaller, the greater its effectiveness in changing the pH of the soil it is applied to.

A number of scales of effectiveness have been developed in different countries and become part of legislation governing the quality of Agricultural Lime. The work by Scott et al. (1992) is among the most recent resulting in a scale of effectiveness of particles (Table 4).

Table 4. Effect of lime particle size on physical effectiveness. (Scott et al., 1992)

Particle size (mm)	< 0.075	0.075 - 0.15	0.15 - 0.25	0.25 - 0.5	0.5 - 1.0	1.0 - 2.0
Physical effectiveness	100 %	58 %	52 %	47 %	34 %	9 %

When lime is applied to the soil, the lime particles interact with the soil acidity, with the outer layers peeling away as the acid penetrates them. The amount of penetration will depend on the intensity of the soil acid solution and the physical structure of the lime particle being penetrated.

However for application rate guidelines, these effectiveness levels shown in Table 4 can be very useful. The core of a particle larger than 0.075mm will be left as an inert particle in the soil having very little if any further impact on the pH of the soil. This process will take place as soon as the lime is applied to the soil and be completed within 3-6 months (Figure 1).

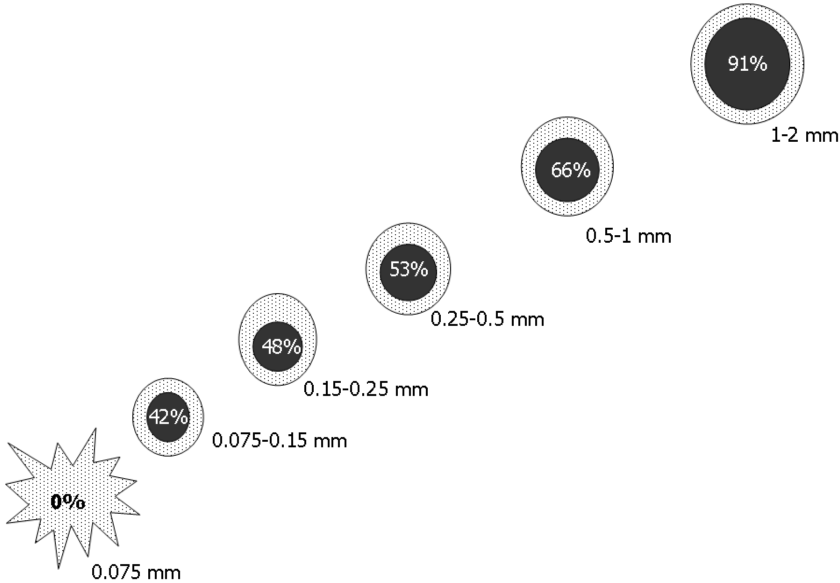

Figure 1. Effect of lime particle size on the % of the lime particle that does not react with the soil after 3-6 months following lime application.

It is important to understand that the rate of pH decline is controlled by climate and farming practice .Therefore the speed of soil pH decline after an application of lime is not related to the size of the lime particle applied, but what the soil is used for, how it is treated, and by the level of rainfall.

Conclusions

The quality of lime applied is a very important consideration and should be optimised as much as possible. Lime can be shown to be a very important input for profitable farming and should not be overlooked. It can greatly help with the utilisation of chemical and organic fertilizers as sources of cost effective plant nutrients.

The use of lime should be the primary consideration in maintaining and managing soil fertility levels in Ireland. Low soil pH through under utilisation of lime will result in inefficient use of fertilizers, and restrict the soils capacity to deliver its production potential.

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