Draft Report to Fertiliser Quality Council

A review of spreading accuracy from twin disc fertiliser spreaders.

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Executive Summary

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Executive Summary

This report has been commissioned by the FQC to review the accuracy of spreading fertiliser from twin disc ground spreaders. The review includes mitigation strategies to avoid problems associated with uneven spreading and off target application.

Investigating:

1. The effect the physical properties of the fertiliser has on its ability to be spread accurately;
2. The effect that the topography of the land and climatic conditions have on spreading;
3. Mitigation practices to limit spread of fertiliser to areas where it is not wanted – e.g. water courses, across boundaries; and
4. The economic impact of inaccurate spreading.

The Spreadmark tests comprise of a spreader driving over collection trays arranged at right angles to the direction of travel, from which a spread pattern is derived. The bout width for the product is calculated from this transverse test so that the spreader pattern overlap delivers a coefficient of variation (CV) of 15% for nitrogenous fertilisers and 25% for fertilisers which do not contain nitrogen. The CV is the standard deviation of the spread rate over the mean spreading rate. Testing is undertaken on flat land in still air conditions, which are rarely the conditions spreaders operate in the field, especially in pastoral situations. The standards in terms of CV are considered the limits where visual crop differences are not visible to the human eye at these spreading accuracies (Mersmann, et al. 2013). There is evidence that significant financial loss occurs before those limits are reached.

The report finds that the physical properties of fertilisers have an impact on spread pattern and those can be reasonably predicted if the particle size distribution within the material is measured prior to spreading. As spreaders have become larger there is a tendency to want to spread wider, in order to spread wider the fertiliser must be propelled off the disc faster, wider spread patterns will tend to be less stable and more affected by environment and fertiliser physical characteristics than more conservative operation. The effects of varying particle size distribution are known and a simple sieve box test prior to spreading could give an indication of how a spreader could be set up to spread at an appropriate bout width. Providing the level of fines does not go above 15% no significant effect on bout width will occur, however if the proportion of fines increases then bout width will narrow and a peak in the distribution pattern will occur close to the centre line of the spreader in zero wind conditions.

Topography and wind also have a significant effect on spread patterns. Spread patterns are distorted in the windward direction and in the down slope direction when spreading across slopes. Rate can alter depending on the systems employed in upwards and downwards direction when travelling up and down a slope. Travelling across a slope had a dramatic effect on spread pattern, this is machine specific but we could reasonably expect all spreaders to exhibit a similar general pattern of increase spread on the downslope side of the spreader. A CV of 50% would be expected from even minor slope. Very little work has been completed on this topic.

There are a range of mitigation practices which can be employed to minimise the risk of applying fertilisers in areas where it could cause harm and other off target application situations. These range
from driving buffer zones, having individual control over disk speeds and using deflector shields or barriers to prevent application along the side of the spreader bordering the sensitive boundary. There are no test standards to decide what the cut-off is for a boundary although if the RMA were to be interpreted literally and no fertiliser is allowed to enter a water way then additional study should be made to test the reliability of the border spreader methods on offer. There would also need to be further work completed to detect the maximum range fertiliser can be propelled in order to create effective buffering and prevent accidental escape of fertiliser to waterways.

The economic impacts of inaccurate spreading are surprisingly under researched. In the nineteen sixties researchers talked about single digit CV’s having a significant effect on yield even though the effects could not be observed from the naked eye, Prummel and Datema (1962). Test standards were subsequently set at levels which were thought to be observable visually, this led to the 15% CV limit on products containing N and 25% on non-nitrogen products. Increased CV have been measured and modelled (Jensen and Pesek, 1962a; Jensen and Pesek, 1962b; Søgaard and Kierkegaard, 1994; Lawrence and Yule, 2007; Miller, et al. 2009, Grafton, et al. 2013; Mersmann, et al. 2013), but this work has only been undertaken on flat ground by combining adjacent spread patterns from real time kinematic (RTK) GPS paths in ideal conditions. It has become more accepted that “Field CV” is significantly higher than the “Test CV”, and that the current level of performance is having significant economic impact on farming through lost income due to inaccurate spreading.

The economic impact is calculated by extrapolating fertiliser response at the different application rates, it would be a matter for debate as to whether there is sufficient information to extrapolate accurate information in order to calculate the cost to New Zealand agriculture. Our best estimate is that it costs New Zealand tens of millions of dollars per annum in lost production as well as wasted fertiliser. There is a lack of either long term or comprehensive trials over multiple geographic locations, testing and trialling this type of work is very time consuming and therefore expensive. There are also the difficulties of measuring crop outputs and soil nutrient status in response to (variable) application.

All investigations have found the impact of higher CV increases cost as a result of reduced fertiliser response exponentially and that a “Field CV” of 30 -40 % will have a significant reduction in yield as well as causing harvesting difficulties in crops. If a loss of $10 per ha is predicted at a 15% CV, then the loss at 30% is likely to be $40 - $45 per ha. If the CV goes even higher to 45%, which the author do not feel is unrealistic, the loss would be $100 per ha. Clearly capturing a national figure is difficult but a national loss of productivity from inaccurate spreading of $M200 to $300 per annum does not seem unrealistic, it may very well be higher.

There is very little understanding within the farming community of the value of having fertiliser spread with a low CV. Until they do then contractors are likely to be locked in a race to the bottom where they can only compete by being the cheapest. This is what is driving contractors to spread wider and wider to achieve greater work efficiencies. They must also see benefit from the Spreadmark Scheme.
Physical Properties of Fertilisers

The physical properties of fertilisers effect spread patterns. Many of these factors are generally poorly understood which result in fertiliser being spread unevenly, however information does exist that could help spreader operators.

Variability of product

Factors associated with the physical characteristics of materials being spread:

- Variability of product being spread (especially single superphosphate and agricultural crushed limestone)
- Chemically reactive blends (especially urea single superphosphate mixes)
- Layered and mixed loads (degree of separation and percolation longitudinal separation when spread changing concentration of mix along spreading track)
- Incompatible mixes different ballistic properties (when centrifugally spread separate laterally, changes concentration of mix on either side of spreading track)

Products can vary in terms of mean particle size and particle size distribution. Some products such as single superphosphate (SSP) have a wide range of particle size. SSP is very important in New Zealand as it is the most widely used fertiliser product in the country and is manufactured by the country’s two largest fertiliser distribution companies. The method of manufacture and granulation using a simple drum granulator leads to a large particle size distribution from less than 0.5mm to 7.0mm in diameter (Chok, et al. 2014). Whereas other products such as di-ammonium phosphate (DAP) tend to have a narrow particle size range (Miller, 1996; Grafton, et al. 2014; Grafton, et al. 2015a) and the particles all have similar ballistic properties.

When products are heterogeneous, that is; have a range of particles sizes such as SSP then there is a similar range of particle ballistic properties. It is the variability in particle size distribution which has led to discussions on product variation having an impact on spreading accuracy (Grafton, et al. 2015b). Because SSP is brittle particles are prone to degradation forming fines (particles less than 0.5mm in diameter) which have poor ballistic qualities. Fines have a very high drag coefficient and cannot be spread a lateral distance any greater than 2-3 metres from the spinning disk. They tend to land directly behind the spreading truck. However, if spread in windy conditions, fines may be distributed some distance away, by the prevailing wind.

Yule (2011) calculated that 15% fines would have little impact on the CV of twin disk applied SSP. From the quality assurance data provided from both New Zealand manufacturers of SSP that for 95% of the product dispatched there would be negligible effect on truck spread patterns. Chok, et al. (2014) found that SSP in bulk stores could comprise up to 40% fine particles from samples collected from stores throughout the North Island. This is indicative of a problem with handling the product, after the product is dispatched. Fine particles can be produced through movement or mixing of SSP particles due to their brittle nature. Rough handling with front end loaders and piling of SSP in stores to achieve bulk storage at angles higher than the normal angle of repose for the bulk solid can create a high percentage of fines. In addition SSP, which is hygroscopic, can form clumps which are problematic to spread if it has not been stored in damp free conditions (Chok, et al. 2014). Chok, et al. (2014) found very little difference (less than 0.5m in certified bout width) in spread pattern
performance, in terms of overlap distance when undertaking field tests in ideal conditions with product with 0.3% fines and product with 17.1% fines.

Although SSP has a large variation in particle size distributions it is quite robust in spread patterns that comply with Spreadmark certification. This is because SSP contains no nitrogen and a CV of 25% is permissible so a less accurate spread is acceptable.

Grafton et al. (2015a) calculated some spreading distances from two twin disk spreaders, one with a long and a short vane on each disk attached by a three point linkage to a tractor, the other a truckspreader with an Ace bin. The tractor mounted spreader uses vanes of different lengths to broaden the spread pattern of products with a narrow range of particle sizes. If the vanes were the same length this produces what is known as a hollow pattern as all the particles would land a similar distance from the spreader in very narrow band. By broadening the spread pattern a more even spread is achieved.

The ACE bin has four vanes on each disk of equal length. This type of spreader is suited to spreading heterogeneous products like SSP, which naturally have a broad pattern. Both spreaders deliver fertiliser at 15° above the horizontal to achieve parabolic flight of the products being spread, to achieve a wider spread. Particle ballistics in terms of increased distance travelled in order of importance: size, particle density and particle shape.

Table 1 shows the calculated distances for representative samples of Nitrophoska 12-10-10, DAP spread, using a Kuhn Axis spreader and SSP spread from a truck based spreader using an ACE bin. The particle sizes (property diameter) represent the 5%, 50% and 95%, percentile of cumulative size distribution for 12-10-10 and DAP and quartile distribution for a sample of SSP.

Field testing that validated these calculations was undertaken using the Spreadmark test method in ideal and cross wind conditions, where the modelled distribution is skewed in the windward direction, validation was undertaken (Chok, et al. 2014, Grafton, et al. 2014, Grafton, et al. 2015a). The data showed that the distortion to the distribution pattern could be predicted from the model.

Variation in fertiliser particle physical properties does impact spreading. For products such as SSP that vary considerably in particle size distributions this will mean that the bout width calculated at the time of Spreadmark Certification may need to be revised. This would apply to other products where a variation in product size distribution is apparent, the use of a Spreadmark sieve box would help spreaders keep track of particle size distributions by using the size guide number and uniform
index for products as outlined in the driver training programme, (Pers. Comm. Ron Smith, Director R and R Spreading, August 2015).

In summary when the physical properties of the fertiliser being spread is different in terms of mean particle size and particle size distribution, from the product that the spreader was certified with then the bout width needs to be adjusted. As the mean particle size of fertiliser reduces then the distance the fertiliser will be spread also reduces. Data mining of Spreadmark tests by (Chok, et al. 2014; Grafton, et al. 2015a) found that the certified bout width from a Spreadmark test is invariably between 65 – 70% of the total spread distance, e.g.SSP with a mean particle size of 2.1mm spread from an ACE bin will spread around 47.5m (see Table 1), 23.7m from each disk, which will achieve a certified bout width of around 32m.

The consistency of Urea products was placed under closer scrutiny in the UK in the 1990’s, two aspects were examined, the ability to be consistently metered (flow characteristics) and the ability to maintain a consistent spread pattern(spread characteristics). Miller(1996) noted the limitations of that system, including the use of reference materials to assess the flowability of products. He reported the limitations as being:

1) The determination of the longitudinal distribution pattern as a measure of the flow characteristics of the material involving an outdoor test on a reference bumpy test track which was weather dependent;
2) The defined procedure is comparative and any test with a candidate material must be conducted as part of a series of tests that included reference materials;
3) The tests were based on a commercial design of spreader which may give some bias to the results and:
4) There was a need to improve the precision with which such spreading performance characteristics could be determined.

The SP Spread Pattern was successful during the period when fertiliser quality was a major issue in the UK (early 1990’s to 2000). It helped to differentiate fertiliser quality in the marketplace but the companies using the ‘top rating’ (SP5) also had brand recognition and their own stewardship programmes which eventually reduced the demand for a national scheme and gradually the uptake slowed. It was finally decided that companies who had historically achieved the SP5 quality mark, would be entitled to do so, if they wished, providing that they could demonstrate, if questioned, that their quality standards were at least maintained or improved. The fertiliser industry found that there was a poor appetite for adopting the lower ratings (SP1, SP2, SP3,SP4) on packaging.

Blended and Mixed Products

Blended products have been extensively studied, and to be spread successfully they must have complimentary physical properties. Miserque et al (2008) demonstrated the agents that cause segregation and these are basically consistent with ballistic properties. A number of guides have been published which show compatible and incompatible products. There are a number of guides that can be used to indicate which products should not be mixed as well as describing those that can be spread successfully with a blend. The following link is a guide published by Fertilizers Europe on GUIDANCE FOR COMPATIBILITY OF FERTILIZER BLENDING MATERIALS.
Compatibility is judged on physical and chemical suitability. Some caution should be observed regarding physical compatibility due to the trend for increased spreading bout width, it has been observed in New Zealand that some products which were previously spread with reasonable results can separate across the bout width when used with a wider spread.

Chemically reactive blends
The most problematic blends in New Zealand are blends of urea and SSP. Although, blends of reactive phosphate rock (RPR) and elemental sulphur have been problematic in aerial spreading (Pers. Comm. A. Beck, Director Beck Helicopters August 2011). RPR sulphur mixes have ignited in fertiliser bins and a helicopter spreading bucket. These incidents occurred despite there being a maximum allowable percentage of elemental sulphur of 30% in a fertiliser mix being applied by an aircraft, Civil Aviation Authority (CAA) (CAA Rule 19.103). Sulphur fortified superphosphate is much safer as molten sulphur is injected in the granule and therefore is unable to percolate through and achieve a concentration that will allow sulphur to ignite. Although the incidents which have occurred have been during aerial application, sulphur fires would also be problematic in ground-spread operations.

Urea and SSP mixtures are problematic as they chemically react, which causes calcium sulphate to precipitate out and coat all the surfaces of the spreader, adversely affecting the disk performance. The mixture also changes texture from a mixture of two granules, to a sticky mixture which does not flow readily.

Although chemically reactive blends are really not part of the brief, chemically reactive blends do change the physical characteristics of the products being blended. Both major fertiliser companies produce a coated urea which prevents the urea reacting with SSP, thus mitigating the risk of the products reacting, these coated urea products should always be used when being mixed with SSP.

Layered and mixed loads
Layered and mixed loads combine two or more fertilisers and spread them together. Mixed loads are prepared in mixing plants with the intention of preparing a proprietary mix or a bespoke blend to deliver the recommended nutrients at the same time rather than spread products separately. These mixes are prone to separation by percolation when smaller particles pass between larger ones, which lead to longitudinal separation. That is the fertilisers with small particles apply first at a higher rate than desired and larger particles are applied last so the application rate of the fertilisers varies as the ground-spread truck moves along (Miserque and Perard, 2004; Miserque, et al. 2008; Yule and Pemberton, 2009; Virk, et al. 2013).

Twin disk spreaders are essentially centrifugal spreaders. If blended fertilisers have particles which have different sizes, density and shape then the blends will separate laterally as the larger denser particles will travel the furthest distance, with a blend of homogenous fertilisers the application rate of each will vary on either side of the spreader (Grift, et al. 1997; Bradley and Farnish, 2005; Yule, 2011; Yule and Grafton, 2013; Grafton, et al. 2014; Grafton, et al. 2015a).
Since the introduction of the twin disk spreader in 1955, spreaders have gradually increased in size (Mersmann, et al. 2013). Larger spreaders provide increased spreading distances, which increase the degree of centrifugal separation of dissimilar particles (Antille, et al. 2015; Grafton, et al. 2014; Grafton, et al. 2015). Grafton et al. 2014 calculated the spreading distances for the average particles of some fertilisers taken as a representative sample from a fertiliser store (Ravensdown, Wanganui) if they were propelled horizontally at a height of 1.5 m at a range of speeds, see Table 2. As disc discharge speeds increase the likelihood of mixed fertiliser blends separating increases.

Table 2 shows the distance some representative fertiliser particles would travel if discharged at a range of velocities horizontally from a height of 1.5m from Grafton et al. (2014).

<table>
<thead>
<tr>
<th>Horizontal velocity (m/s)</th>
<th>Ammonium Sulphate (m)</th>
<th>KCl (m)</th>
<th>MAP (m)</th>
<th>DAP (m)</th>
<th>Urea (m)</th>
<th>SSP 1.0mm (m)</th>
<th>SSP 2.9mm (m)</th>
<th>SSP 4.7mm (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>17.0</td>
<td>21.8</td>
<td>18.8</td>
<td>17.9</td>
<td>23.6</td>
<td>17.9</td>
<td>24.0</td>
<td>25.2</td>
</tr>
<tr>
<td>50</td>
<td>15.3</td>
<td>18.6</td>
<td>16.6</td>
<td>16.0</td>
<td>19.8</td>
<td>16.0</td>
<td>20.0</td>
<td>20.9</td>
</tr>
<tr>
<td>40</td>
<td>13.1</td>
<td>15.1</td>
<td>13.8</td>
<td>13.5</td>
<td>15.8</td>
<td>13.5</td>
<td>16.0</td>
<td>16.5</td>
</tr>
<tr>
<td>30</td>
<td>10.2</td>
<td>11.3</td>
<td>10.6</td>
<td>10.4</td>
<td>11.7</td>
<td>10.5</td>
<td>11.7</td>
<td>12.0</td>
</tr>
<tr>
<td>20</td>
<td>6.9</td>
<td>7.3</td>
<td>7.0</td>
<td>6.9</td>
<td>7.4</td>
<td>7.0</td>
<td>7.5</td>
<td>7.6</td>
</tr>
<tr>
<td>10</td>
<td>3.1</td>
<td>3.2</td>
<td>3.2</td>
<td>3.1</td>
<td>3.2</td>
<td>3.1</td>
<td>3.2</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Spread pattern modelling of fertiliser spread from twin disk spreaders has been undertaken, some examples are (Inns and Reece, 1962; Olieslagers, et al. 1996; Aphale, et al. 2003; Reumers et al. 2003; Dintwa et al. 2004; Antille et al. 2015). However, the modelling has always been undertaken assuming there is no wind and the spreader is operating on flat ground, almost laboratory conditions. Although modelled conditions differ significantly from field conditions the models do demonstrate which fertilisers will separate due to their ballistic differences. Similarly some manufacturers are using the testing hall pivot table developed at the Laboratory for Agro-machinery and Processing with the assistance of the K.U. Leuven Research Fund (Dintwa et al. 2004) and described by (Piron et al. 2010). Cemagref built a state of the art facility in Montoldre, Clermont-Ferrand, which has been used by many groups and companies and is described by Piron. It uses computer algorithms to model spread patterns in 3 dimensions in one pass in a few minutes allowing hundreds of tests to be completed in a day. Although these tests have been pivotal in understanding spreading behaviour and allow rapid testing of the effects of changes in machine design as well as product spreading characteristics, these spread patterns are not measured under field conditions but a still air hall.

When considering fertiliser blends it is important that the particle sizes are similar to avoid percolation which will lead to longitudinal separation. Also it is important to avoid products with dissimilar ballistic properties as these will separate laterally, the degree of separation will increase at wider bout widths. Mixed loads have more consistent flow and spreading properties than layered loads, so stores which have mixing plants produce better mixed products than stores without plants (Yule and Pemberton, 2009).
The effect that the topography of the land and climatic conditions have on spreading

Most ground-spread spreader testing and modelling has been undertaken assuming little or no wind and no incline or slope. Testing of spread patterns by collection in trays based on ISO 5690 or in testing halls using the testing hall pivot table (Piron et al. 2010) are undertaken on the flat in still wind conditions. Although manufacturers are beginning to introduce wind adjusted spread patterns, little research has been undertaken on the effects of wind (Mersmann et al. 2013; Grafton et al. 2014; Grafton et al. 2015a; Izquierdo Acebes et al. 2015). Likewise the effects of slope have some manufacturers designing mitigation strategies such as fixed disk drop point (Kvernland, 2015) see Figure 1. Little research has been published about the effects of slope on spread patterns (Yildirim, 2008; under laboratory conditions, whereas Grafton et al. 2015c; Izquierdo Acebes et al. 2015), completed work which included field testing.

![Figure 1: Shows a fixed drop point on disk (Kvernland) top as compared to a fixed release point bottom.](image)

Effects of topography

In New Zealand, spreaders have tended to have increased in size with larger capacity bins and a desire to spread wider in order to reduce operating costs and increase work rate, this applies to truck spreaders, tractor towed spreaders and tractor mounted spreaders. For ground-spread application on pasture many truck spreaders use trucks with four wheel drive and dual tyres. These trucks have been increasingly applying fertiliser on hillsides with inclines up to 20°, which twenty years ago would have required fertiliser delivery by aircraft. This has also led to several fatal accidents over recent years as trucks have been involved in dynamic roll over occurrences, see Figure 2. The accident rate appears to have been increasing in recent years. The dramatic effect of slope on spread pattern has not been extensively researched but work by Grafton et al (2015) and Izquierdo Acebes et al (2015) indicates that performance on slope is poor.
Izquierdo Acebes et al. (2015) undertook 78 spread tests on slope and in wind, using the Spreadmark test method with three different spreaders and three different fertilisers to measure the effect on spread pattern results. The results were similar to those obtained by Yildirim (2008) who undertook 20 spread tests (each test had 3 replicates) using two fertilisers on 0°, ± 5°, and ±10° inclines, see figure 3. An example of the effect of slope on spread pattern measured in the field is illustrated in figure 4. A side slope of as little as 5° appears to make a very big difference. Results will be specific to machine as machine design factors will come into play when dealing with lateral spread stability.

![Fatal rollover accident Northern Southland NZ](image)

Figure 2: Fatal rollover accident Northern Southland NZ, with what appears to be a well equipped truck with dual tyres. Barry Harcourt/ Fairfax NZ

Spreading across a slope has a marked effect on the spread pattern and evenness of spread. Much more is spread on the downhill section of slope, from around 50% on each side as found on the flat to 63% to 37% on a 12° slope (Izquierdo Acebes, et al. 2015), Figure 4, (page 12).

When spreading uphill and downhill the spread pattern was also affected. In general there was a greater rate applied whilst sowing uphill, around 50% more than sowing downhill with the same settings.
Figure 3: shows spread patterns from applications of triple superphosphate on transverse slopes, the lines represent the mean of 3 replicates, from Yildirim (2008). The tractor drove between trays 26 and 27.

Figure 4: Example of the effect of a 12° slope on a Spreadmark test using a Kuhn-Axis mounted spreader spreading Nitrophoska blue (78 Kg/ha) with yield settings, showing the dispersion curve at BW=24m from Izquiero Acebes et al. (2015).
**Effects of wind**

The effects of wind, like slope are as expected, more product is delivered to the leeward side of the spreader than upwind of the spreader. The effects of wind in moderate conditions are much less than were measured for slope (Izquierdo Acebes, *et al.* 2015; Grafton, *et al.* 2015a; Grafton, *et al.* 2014), see table 3.

Table 3 Shows effect of adding cross wind component to the ballistic model from Grafton, *et al.* (2014)

<table>
<thead>
<tr>
<th></th>
<th>12-10-1-0</th>
<th>DAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance long vane large particle size (m)</td>
<td>16.6</td>
<td>15.6</td>
</tr>
<tr>
<td>Distance short vane large particle size (m)</td>
<td>9.0</td>
<td>8.7</td>
</tr>
<tr>
<td>Distance long vane mean particle size (m)</td>
<td>14.7</td>
<td>15.0</td>
</tr>
<tr>
<td>Distance short vane mean particle size (m)</td>
<td>8.5</td>
<td>8.6</td>
</tr>
<tr>
<td>Distance long vane small particle size (m)</td>
<td>12.2</td>
<td>14.1</td>
</tr>
<tr>
<td>Distance short vane small particle size (m)</td>
<td>7.8</td>
<td>8.3</td>
</tr>
</tbody>
</table>

With 6ms⁻¹ tail wind

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance long vane large particle size (m)</td>
<td>22.8</td>
<td>24.4</td>
</tr>
<tr>
<td>Distance short vane large particle size (m)</td>
<td>18.1</td>
<td>17.1</td>
</tr>
<tr>
<td>Distance long vane mean particle size (m)</td>
<td>22.2</td>
<td>22.9</td>
</tr>
<tr>
<td>Distance short vane mean particle size (m)</td>
<td>16.2</td>
<td>16.5</td>
</tr>
<tr>
<td>Distance long vane small particle size (m)</td>
<td>15.6</td>
<td>20.6</td>
</tr>
<tr>
<td>Distance short vane small particle size (m)</td>
<td>13.7</td>
<td>15.6</td>
</tr>
</tbody>
</table>

The distances spread in table 3 were modelled (Grafton, *et al.* 2014), these distances were then compared to those tested by the Spreadmark method by the spreader in the modelled conditions, see Figure 5, (Page 14)

The measured results supported the predicted results that the spread pattern was distorted. However, if a correction track offset is not driven the bout width driven to achieve the permissible spread accuracy should reduce significantly, from 22m to 14m for Nitrophoska 12-10-10 using the Kuhn spreader tested (Grafton, *et al.* 2014).
Figure 5: Spread pattern test in 6ms\(^{-1}\) cross wind, Nitrophoska 12-10-10. Top figure represents spread pattern, bottom figure is calculated bout width showing both to and fro and round and round patterns, which reduce from 22m in still air (not included in figure) to 14m in the crosswind; (included) from Grafton, et al. (2014). (Pink line to and fro spreading, blue round and round)

Although it is possible to mitigate the effect of wind by driving an offset, this is not done in practice. The use of small anemometers and some tables may be all that is required to improve spread in the wind.
Mitigation Strategies.

Many of the manufacturers of equipment have undertaken a number of changes to machinery design in order to improve field performance. There has been an acceptance of the notion of “Field CV” is around double “Test CV”. Machine manufacturers accept that there are physical limits to how far products can be propelled off a disk. Machine functionality to improve field performance appears to be the main driver for change in the last ten years. Efforts to control bout width (through variable disc speed), border spreading, headland control and auto-calibration are all features to have been introduced to modern machinery. Application rate can be adjusted to ensure accuracy by using on-board weighing to work out the mass of material used over the area already spread. This has been proven to be a considerable benefit to contractors and farmers as it reduces the chances of having excess fertiliser left at the end of a paddock, or running out before the paddock is finished.

There are a number of different methods used to create border spreading. Border spreading allows a much sharper cut—off of spread pattern, allowing the desired application rate to applied close to the paddock boundary and reducing the area where low application is applied. With normal operation the overlap between run can be considerable and the machine will either put fertiliser over the boundary or have a large zone around the outside of a paddock with reduced application rate as the driver has attempted to avoid putting fertiliser over the boundary.

Table 4 shows features available from major suppliers of spreading equipment available to arable farmers from Yule and Grafton (2013) amended to include the automatic measurement of the spread pattern.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Amazone</th>
<th>Bogballe</th>
<th>Bredal</th>
<th>Kuhn</th>
<th>Kverneland-Vicon</th>
<th>Sulky</th>
<th>Transspread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Border/ Headland Control</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hydraulic</td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
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<tr>
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<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
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</tr>
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<td>✓</td>
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<td>X</td>
<td></td>
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<td>Auto start/ stop</td>
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<tr>
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<td>✓</td>
<td></td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
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<td>Varying drop point</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stationary drop point</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
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<tr>
<td>Mechanical deflector for headland</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
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</tr>
</tbody>
</table>

✓ Possesses feature; X does not have feature

The most recent additional feature has been the measurement of the spread pattern through measuring fertiliser particles travelling off the disc. The Amazone Argus system uses a video camera to track the trajectory of particles off the disc. These types of techniques were discussed by Villette et al (2006) and it has now been possible to process the information on particle speed and trajectory in near real time to adjust the setting of the spreader. Earlier attempts to measure the trajectory off the disc included the use of ultrasonics, Hofstee (1994) and optical means, Grift and Hofstee(1997). Cointault and Vangeyte(2005) attempted to use photographic imaging while Villette et al (2005, 2006) published further modelling work for particle motion off a spinning disc.
While many of the innovations have been developed by European manufacturers their spreaders are often unsuitable for spreading the complete range of products required by New Zealand farmers, notably lime and superphosphate. In most other countries this is completed by using different spreaders for those products. The New Zealand built Transspread manufacturer would appear to have most of the features required for better field performance and have followed a somewhat similar development pathway to European manufacturers over recent years.

The authors have not tested the full range of spreaders described in Table 4. It would be worth considering test methods that would allow these control mechanisms to be tested in a systematic and statistically valid way. Most of these improvements have not been subjected to independent testing. This may be important when it comes to working out their effectiveness in achieving border spreading for example where placing fertiliser in waterways must be avoided.

**Border Control**

Is designed to achieve the desired spread application rate much closer to the edge of the paddock or area being spread. This is achieved by a number of means, a deflector shield can be dropped into the path of the fertiliser as it flows off the disc. The fertiliser is diverted to reduce the overall width of the spread but maintain application rate for a distance before achieving a rapid drop off.

Other manufacturers have attempted to achieve the same thing by either reversing, slowing down or stopping the outside disc. Clearly the feed mechanism needs to be altered to achieve this.

The authors have experience of using and testing this, it was found that although the shielding system could work well it did require to be set up for every product and that different products will produce different results. The setup for urea for example, was not easily transferable to other products such as DAP.

**Disc Drive Systems Variable Width Spreading**

A number of systems are used in order to achieve different disc speeds in order to spread different products or alter spread width. Essential components are that the disc speed of rotation can be accurately monitored and feedback given to the automation system and operator. The authors have seen no published material of how well these are achieved in independent tests. The feed-rate onto the disc also needs to be altered to adjust for the reduced spreading width, again no evidence of independent testing.

**Auto Start /Stop**

The idea of this facility is to make sure the spread is either switched on or switched off at the optimum time in order to reduce excess overlap or misses. A two part test would have to be developed which first measured the transverse spread pattern and then measured the longitudinal displacement of the spread was also measured. This may be more practically possible at the type testing level rather than the spreadmark testing level.

**Self Calibrating**

This is designed to allow for differences in bulk density or flow properties of a material so that the appropriate application rate can be achieved. Evidence of this working well has been observed but the authors found no evidence of independent testing. The automatic measurement of spread pattern is very new and so far no independent test results have been published.
**Variable Rate Application Systems.**

A further mitigation strategy which may be considered is variable rate application. This is where the rate of application can be changed as the spreader moves across a paddock either in response to a pre-ordained plan or as a result of sensor readings which are mounted on the vehicle and allow the application rate to be changed in response to an algorithm contained within the control system. There are a number of sensors available which tend to measure the amount and chlorophyll content of the crop or pasture. The most common nutrient to use this approach is for nitrogen where the use of N can be changed by measuring the growing crop. This sensing technology has not been adopted by farmers. The main reasons suggested are an unproven financial benefit, addition time and effort.

For other nutrients soil sampling is usually used and either a more intensive grid sampling scheme or zonal sampling scheme is employed. There is an additional cost to doing this but it had been demonstrated to be worthwhile by being able to apply a more appropriate rate over different parts of the paddock or between paddocks on a dairy farm. This system has been successfully used in dairying where the smaller paddocks are treated as the smallest unit and soil sampling dedicated to each paddock gives a required nutrient application. This has been proved to save farmers money in many instances as well as eliminate over application with examples illustrating considerable savings. There are similar findings in other parts of the world and this technology is being widely adopted by farmers.
Economic loss from inaccurate spreading.

Assessment of economic loss from sub optimal spreading has always been difficult to achieve on an experimental basis, also the costs are hidden and to large extent unknown and because there was little visual evidence then there was little appreciation that the problem was real. Prummel and Datema (1962) however, stated that economic loss occurs before there is any sign of the crop being uneven. Horrell et al (2001) cited a number of studies carried out in the 1960’s and 80’s, a study by Holmes (1968) suggested that losses of 1 to 2% of gross margin was unacceptable and suggested that fertiliser should be spread at a CV of 10% or better on more valuable crops and a maximum of 15% on cereals and grassland. Again there would be no visible sign of uneven growth. Richards (1985) is quoted as calculating a yield loss of 3% from a CV of 20%. He also stated that in the 1980’s this was a loss of 10 to 20 million pounds to the annual wheat crop in the UK. In the 1990’s Miller(1992) stated that £56 million was lost to British agriculture through inaccurate spreading.

Yule and Crooks(1996) collated a number of yield response functions for arable crops in the UK as well as pasture to estimate loss of yield potential from poor spreading. The purpose of the paper was to demonstrate that the cost of having a spreader properly calibrated and checked was financially worthwhile. A number of the response curves used were derived from crop experiments prior to the mid 1980’s in the UK, England (1986) England and Audsley(1987) Kling (1986), pasture was also included through the work of Morrison et al (1980). Yields were generally much lower in that period (25 to 30 years ago) but for a farm of 400ha with a typical arable rotation, the loss in productivity was estimated at approximately £6000, (£15 per ha). This equates to NZ$33 per ha, for production levels achieved 30 years ago in non-irrigated circumstances, wheat yields under irrigation in New Zealand are currently at least 50% to 100% higher than those studied.

When the consequences of uneven spread are visible to the eye, significant economic loss has occurred. In arable cropping situations lodging of crops starts occurring when spreading CV is greater than 30% with a similar loss in yield (Søgaard and Kierkegaard, 1994; Miller, et al. 2009; Mersmann, et al. 2013), similar percentage losses occur in pasture production at similar CV (Lawrence and Yule, 2007; Grafton, et al. 2013; Yule and Grafton,2013). The visible effects of striping are more common with nitrogenous fertilisers than with fertilisers that do not contain nitrogen.

In earlier studies there was an assumption around low “CV” which was used because field practice was not taken into account and perfect spreading was assumed. It should be remember that because we are already starting from a point where a CV of 15 to 25% is the best possible outcome due to the transverse tests being used to decide maximum bout width to comply with the standard. However we know from field practice that this is not possible. It has always been extremely difficult to either measure or simulate what is going on in the field. There are a number of factors which will have an effect, the main ones being field shape and size. The main purpose of this infield analysis is to gain a better idea of the actual distribution of application rates achieved in the field. Two methods are described, 1) where a spreader is tracked through accurate GPS and the output simulated over every square meter of paddocks, or, 2) rather than assume the average application rate is achieved simulate the distribution through a software tool such as @Risk which can simulate the distribution within the application from known CV’s.
In 2006 Lawrence et al. (2006) presented work which indicated that around that time; on farms where the infield performance of spreading was measured, the calculated annual losses were anywhere between $52 and $72 per hectare on pasture in New Zealand conditions. This is production not achieved because the optimum application rate was not achieved from the modelled nitrogen response equation. The average field CV’s achieved over the 4 farms in the study ranged from 36 to 43 % individual paddocks were even more variable. This was from a typical annual N use of 185kg ha\(^{-1}\) per annum, completed in 5 split applications. The cost of each application was $10.24 per ha, therefore the annual loss of production was higher than the actual cost of application.

Prior to Lawrence et al. (2006) no work had been completed where the actual distribution on the field had been accounted for, this was done through using a simulation of spread pattern from a tracked vehicle going over a paddock. A further possible way to take account of the increasingly wide distribution of spot application rates is to simulate the variable distribution as taking a simple average has no real effect as the average doesn’t change. Spreading distribution was simulated through applying a statistical package called “@Risk” version 6.3 (Palisade Corporation, NY). The software runs Monte Carlo simulations to produce a distribution of outputs based on either discrete or continuous distributions with a number of iterations based on the user’s preference; in this case a continuous output was required with 5,000 iterations. The application rate had a normal distribution fitted which was given a standard deviation based on the coefficient of variation of the spreading performance. That is; an application rate of 140Kg N ha\(^{-1}\) spreading at a CV of 15%, would have a normal distribution fitted, with a mean of 140 and a standard deviation of 21. This was used to estimate the economic loss from spreading.

The spreading benefit was derived by assigning an output which varied with the spreading rate being simulated, using the yield curve for wheat response to nitrogen application for example:

\[
y = 11.45 - 7e^{(-0.0196x)} - 0.00293x
\]

from Miller et al. (2009). Where x is the N application rate. The maximum yield in this case was 10.7 tha\(^{-1}\). The simulated financial loss is calculated in table 5, at three levels of field CV, The wheat is valued at $300 per tonne.

Table 5: Simulated loss of productivity in wheat from uneven spreading using three levels of field CV.

<table>
<thead>
<tr>
<th>Field CV %</th>
<th>Nitrogen Application Rate kg ha(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40</td>
</tr>
<tr>
<td>15</td>
<td>6.67</td>
</tr>
<tr>
<td>30</td>
<td>20.22</td>
</tr>
<tr>
<td>45</td>
<td>34.65</td>
</tr>
</tbody>
</table>

The 15% level assumes perfect spreading as the bout width is calculated from the transverse test used to calculate bout width. We consider the 30% Field CV realistic, we have seen evidence of Field CV’s up to and beyond 45% in the presence of minor slopes or wind for example.

For hill country in New Zealand there is limited data available, a simulation was developed using models produced from the work of Gillingham et al. (2007). They are based on 3 hill country East Coast farms that had fertiliser trials undertaken on them. This is the data table from this trial. For the
N and P calculations Wairoa was used as an example for developing a response curve as it is the middle of the other two but separate simulation could be developed. The response is a diminishing return KgDM per Kg elemental N.

Table 6 : Diminishing return fertiliser plot trials dry matter Kg per Kg elemental Nitrogen applied

<table>
<thead>
<tr>
<th>Area</th>
<th>N application rate kg ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-30</td>
</tr>
<tr>
<td>Wairoa DM</td>
<td>24.1</td>
</tr>
<tr>
<td>Puketapu DM</td>
<td>29.3</td>
</tr>
<tr>
<td>Waipawa DM</td>
<td>17.5</td>
</tr>
</tbody>
</table>

Work completed by Morton *et al.* (1998) to develop response data from the South Island in a longer term trial was also used to simulate an economic response. They looked at Triple Superphosphate (14% P) no S. Applying Sulphur on its own and applying single superphosphate 9.1%P and 14%S. The best response was single superphosphate. Again this is KgDM per Kg elemental P see Table 7.

Table 7: Diminishing return fertiliser plot trials dry matter Kg per Kg P applied as single superphosphate.

<table>
<thead>
<tr>
<th>Kg elemental P in SSP</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>40</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>S &amp; P 50% each DM Resp.</td>
<td>0.0</td>
<td>101.2</td>
<td>77.6</td>
<td>45.3</td>
<td></td>
</tr>
</tbody>
</table>

Dry matter was valued at $0.28 per KgDM and a cost and response model was developed to calculate the cost of deteriorating CV using the methodology utilising the Monte Carlo simulation of @Risk. The model was based on 11SUha⁻¹ sheep farm balance with good fertility. This happens to be what the value of DM is at $4.15 on the modal dairy farm too.

There is a means of converting a diminishing return curve to a cost benefit analysis. In this case a dry matter production average was obtained, in which about 33,000 Kg DM converted to 7,216 Kg meat. Assuming a dairy conversion of 15KgDM to 1 Kg milk solids (MS) which is within the 7 – 25 suggested for seasonal adjustment by Dairy NZ, the value of dry matter if meat is valued $5Kg⁻¹ carcass weight and milk solids at $4.15 comes to $0.28 per Kg DM.

Whereas the cost of applying Phosphate using SSP was estimated at $4.17Kg⁻¹P and urea at $1.74Kg⁻¹N. Urea assumes 4 applications to SSP having 1 application. The cost of poor application is seen as an exponential function where losses remain low at lower application rate but ramp up at higher rates, also achieving a very low CV (considered to be 15% in the field) would achieve a very high utilisation of the fertiliser, the difference between a cv of 15% and 30% is a four and a half fold increase, 15% to 45% which has been observed is ten-fold increase in financial loss. A further increase in CV would lead to a 1.7 times increase between a CV of 45% and 60% for P and a doubling of financial loss for N.
If all of the nation’s P applied to pasture was applied with a CV of 45% then that would lead to a loss to farming of $43.5M, and if the same performance was repeated for N the loss would be approximately $28M.

Some attempts have been made to assess the financial effect of varying physical attributes of Nitrogen fertiliser, notably the SP rating system used in the UK. One paper by Millar (1996) did present data on the modelled financial effect of poorer quality fertiliser by comparing the return from wheat in the UK and using Spreading Rated SP5 (the highest rating) SP3 and SP1, the poorest rating. The difference was a loss of £6 per ha using the SP3 and £11 (NZ$13 to 23) when using the SP1. Although this is less than other factors it still has a negative impact.
Conclusions

There is a considerable body of research work from around the world which describes the behaviour of centrifugal disc spreaders, that work appears to be reasonably consistent but it is often characterised by testing which took place in ideal or perfect test conditions rather than field conditions that an operator might experience. There is acceptance that the “Field CV” achieved in the field is much higher than the “Tested CV” achieved from a transverse test and this is due mainly to the spreader being out of ideal position while spreading or the field is not perfectly matched for the spread pattern or footprint of the spreader. A number of manufacturers have developed considerable improvements to their spreading equipment in order to improve the accuracy of field operation. Indeed this was recognised as a significant problem over a decade ago and considerable progress has been made with the adoption of new technology as outlined in table 4. So far however many of these technologies remain untested from an independent perspective.

There has been little work completed on the effect of variable field parameters such as slope and wind, this is expensive to carry out because of its very time consuming nature unless a specialised testing hall can be utilised. Spreader testing and modelling has with a very few exceptions taken place on the flat in near ideal spreading conditions. In the last decade the majority of the work has taken place in specially equipped halls which have allowed manufacturers to rapidly test and retest spreaders. Twin disc spreaders have been becoming larger and truck spreaders have been developing to be able to operate on a greater variety of terrain using features such as low ratio all-wheel drive, differential lock and twin wheels to apply fertiliser on increasingly steeper slopes in pastoral situations. Spreading on slope has a very pronounced effect of spread pattern and application rate achieved whether spreading across or up and down a slope. New Zealand is a windy country which lies in the roaring forties as a result of there being little land mass at these latitudes, wind also has a significant effect on the operation accuracy of twin disc spreaders.

There is very little understanding within the farming community of the value of having a good quality, “low CV”, spread, this is perhaps something the FQC could undertake to improve. Until farmers understand there is value in having fertiliser applied accurately and evenly then the contracting industry is likely to be locked into a race to the bottom, where the only way they can compete is through cheaper and cheaper application. In most cases where spreading occurs the value of production lost through indifferent spreading is greater than the price charged for applying the product. It is difficult and expensive to obtain credible data to allow realistic figures to be generated. The figures used in this report do contain a lot of assumption but these assumptions are at least based on experience, some measurement and judgement.

The need to operate businesses profitably and for farmers to have their fertiliser applied means that fertiliser is spread in less than ideal conditions. The effect of slope on spread is very significant and even at reasonably low gradients between 5 - 12°, the spread pattern and application rate is greatly affected. The certified spread pattern and bout widths measured in test conditions do not apply on slopes and we would expect to experience CV’s of over 50%. Farmers should be aware that truck spreading on slopes will not achieve an even spread.

Spreading in wind also has a significant but lesser effect than spreading on slopes. Unlike spreading on slopes, spreading in wind can be mitigated with driver offsets, however, such offsets need to be calculated and a means of informing the driver of what these are needs to be established.
Many of the new developments in spreading technology are designed to reduce the “Field CV”, however most remain untested through any independent testing and the range of products that the manufacturers have used during testing is unclear. One attribute of most immediate concern is border spreading used to avoid fertiliser application to water ways. This technology needs to be assessed as regional authorities look more and more to enforce buffered spreading regimes. These must be properly informed and manufacturer’s claims must be tested. The possible escape of very small amounts of fertiliser must also be balanced against lost production from excessively large buffered zones.

It would not be practical to include these many improvements or attributes into the Spreadmark testing scheme however it may be possible to use type testing to establish the performance characteristics of spreaders, especially the border control. Type testing to include slope stability or accepted design to avoid the worst excesses may be also worth considering.

Investment in NZ infrastructure to deliver high quality product to farms and have that product stored correctly once delivered is also required. Codes of practice are in place but there does appear to be a lack of investment. It is also clear that some stores consistently deliver good quality product while others do not. The level and nature of handling the product receives does appear to make a significant difference. Product physical specification does appear to be a constant running sore between manufacturers and the spreading contractors. Although what happens in the field has the largest effect in terms of spreading performance, inconsistent product does create problems for spreaders. The information referring to how to set up particular machines to achieve certifiable spread when the physical characteristic of the product changes does exist and can be utilised by the spreading contractors, however if excessive fines are present this will lead to a narrower bout width.

This creates a problem for the spreading contractors as many are under financial pressure to offer low cost jobs, especially in the current economic climate. Farmers simply do not appear to accept or have sufficient evidence in front of them that even spreading is financially advantageous and would allow them to improve their own performance. This is an area which FQC could take a further look at not only in the context of more efficient use of nutrients to produce more grass but in possibly lowering emissions by making fertiliser application more accurate and efficient.
References


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