NEW SPREADING TECHNOLOGIES FOR IMPROVED ACCURACY AND ENVIRONMENTAL COMPLIANCE

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Abstract.
There has been considerable focus on the need for accurate spreading and attempts have been made to quantify the factors responsible for creating inaccuracy. Further technological improvements in Geographical Information Systems (GIS) have made it possible to measure and model what happens in the field. The term “Field CV” was used and it was clear that factors which were not previously considered had an important impact of spreading accuracy.

Developments in spreader testing facilities have allowed some manufacturers to identify many of these factors and rapidly test equipment. This had led to an acceleration of technical development, affording farmers greater choice with the potential to improve accuracy of spread and achieve better utilisation of fertiliser.

The factors affecting spreading accuracy are identified, explained and quantified in order to give a realistic perspective of what is presently being achieved. These factors are described within three groups: Machine factors and design, there are differences and refinements in design that do make a difference to the spreaders ability to spread accurately in the field. Materials being spread and their effect on spread pattern, (blended materials for example). Environmental and field factors, field shape and slope.

The impact of new technologies such as boundary spreading; are investigated and a range of new machine developments and improvements are described. The competing demands for large machine capacity for higher work rate and achieving environmental compliance especially in the dairy sector where smaller paddock size leads to increased Field CV is also discussed.

Key words: Precision Agriculture**,** coefficient of variation of spread, CV, centrifugal disc spreaders, border spreading, headland spreading, fertiliser spreading accuracy, variable rate spreading.

Introduction.

The economic impact of poor fertiliser spreading accuracy on farm performance has been a topic for research for around 50 years, in the early sixties there was a flurry of research activity which attempted to identify the impact of uneven spreading. Jensen and Pesek, (1962a, 1962b) are examples of such work. A short review of this type of research is included in Virk *et al*, (2011). In this fifty year period we have also witnessed the development of test methods designed to measure the spread pattern from centrifugal spreaders usually with the purpose of determining an acceptable bout spreading width to spread with a predetermined coefficient of variation of spread. This is almost universally been accepted as being 15% for products containing nitrogen and 25% for other products. The test used in New Zealand comes under the Spreadmark scheme and it is similar to other schemes around the world. A review of test methods used around the world is presented in Lawrence *et al,* (2007).

In 1994 Søgaard and Kierkegaard concluded that a spatial coefficient of variation less than 20% was necessary to prevent loss of profit in agronomic crops. This will always be a function of the nutrient used and a plants response to it, the economic relationship between plant growth and fertiliser input as well as costs involved in applying the fertiliser. The early work of the sixties spawned more research activity with the objective of gaining a better understanding of the factors determining fertiliser spread patterns from spinning disc spreaders.

Theoretical models were developed by such authors as Patterson and Reece (1962) and Inns and Reece (1962), fairly crude assumption were made about the way fertiliser flowed down the vanes on a spreading disc. A number of authors contributed to the effort of understanding how machine design features influenced spreading patterns. More complex models were developed that took account of bounce off the disc for example, Olieslagers *et al,* (1996). Verifying the models has always been difficult. Grift and Hofstee (2002) developed laboratory optical measurement systems to attempt to measure what was happening from the spreading disc. More complex modelling approaches such as Discrete Element Modelling (DEM) an example being, Tijskens (2006) have been undertaken. Testing halls were also developed in Europe to allow testing of spreader in situations which were away from the influence of weather and wind. These tended to be set up so that the spreader would drive over a perpendicular (or transverse) row of trays which would collect the fertiliser. Automatic weighing was added later, but essentially these tests gave the same information as the standard test methods used out in the field.

Lawrence *et al,* (2006) was really the first to consider the “on the ground” or “in field’ pattern. He did this by considering a two dimensional spreader footprint rather than a single row of trays to catch fertiliser as in most testing methods. Using RTKDGPS it was possible to accurately track the machines position and heading. The footprint could then be superimposed on the ground and subsequent overlaps taken into account. That work really exploded the myth that we were spreading with “CV’s” of 15 and 25%. In his field experiments an “in-field” CV of 42% was estimated for spreading over a number of farms. It is clear that there are a number of further factors which diminish the accuracy of spread at work. These were not previously accounted for. That work was verified to a very large extent by Piron et al(2010). The facilities used by Lawrence were very basic and testing was extremely time consuming, the latter more comprehensive work by Piron *et al,* (2010) was carried out in a purpose built testing facility. Commissioning this advanced testing facility at CEMAGREF is one of the most significant advances over this fifty year period. The equipment and software system (CEMAGERF CEMIB) used allows a comprehensive profile of the spread footprint to be developed within seconds of testing. This highly automated facility requires less floor space than conventional testing halls and really gives machinery manufacturers the ability to rapidly test all aspects of design. Descriptions of how the system operates have been published by Piron *et al,* (2010). This improvement in testing facilities is the main reason we have observed a new generation of spreaders emerge from Europe in recent years. Although this testing system is highly significant more information on particle size distribution from spreading equipment would be useful.

Method

The research completed can be divided in three categories: considering, 1) the machine design, 2) the materials spread and 3) the environment within which the materials are spread. For the purposes of this paper machine design and materials spread are considered.

Machine design.

Machine design factors have previously been reviewed at this workshop Yule (2009). However the importance of one, the "drop on point", to the disc has received much more attention in recent years. The drop on point is important for a number of reasons. It does determine the spread pattern, if it changes, then so does the spread pattern. Many spreaders have poor stability between rates, as demonstrated in figure ,this is important in terms of testing spread patterns and also in relation to variable rate applications where significant on-the-go changes in application may be required.

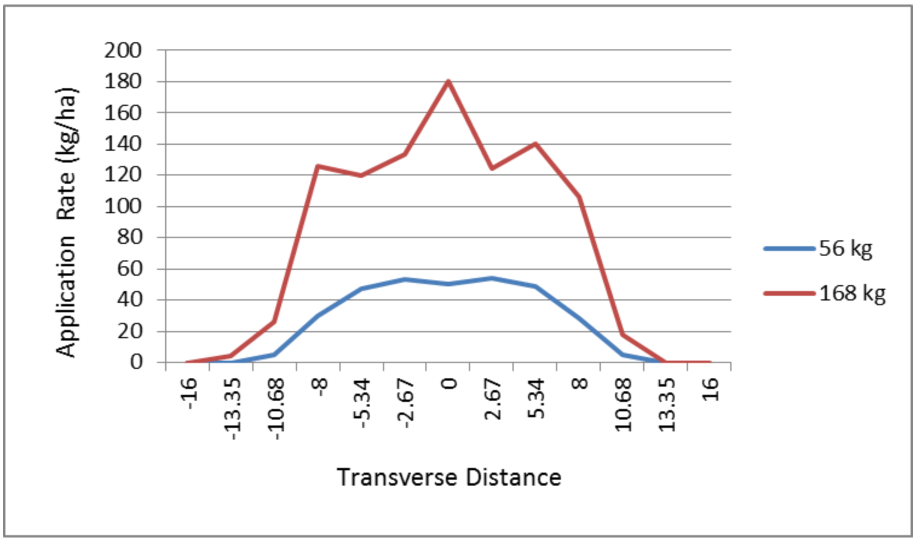


Figure 1. The spread pattern has gone from a slight "M" pattern at an application rate of 56 (kg/ha) to a "W" pattern at 168 (kg/ha). From Fulton *et al* (2001)

Stability of spread pattern is also important in terms of slope; all spreader testing is completed on flat level sites. Side slope can have a very large effect. Very little work has been published on this, again it is extremely time consuming and results are particular to each machine and product. Yilidrim (2008) demonstrated that relatively small changes in slope can have a large effect on spreading pattern. A plus or minus 5 degree side slope led to a peak application rate of 600kg/ha, compared to the desired application rate of 325 kg/ha. The +/- 10 degree side slope, increased peak application to between 800 and 900 kg/ha. Clearly each spreader will have a different ability to cope with slope but it is somewhat alarming to find the level of changes that can occur on fairly moderate slope that would be felt suitable for groundspread operation in New Zealand, 20% of the land area of New Zealand is classified as being between 5 and 10 degrees of slope.

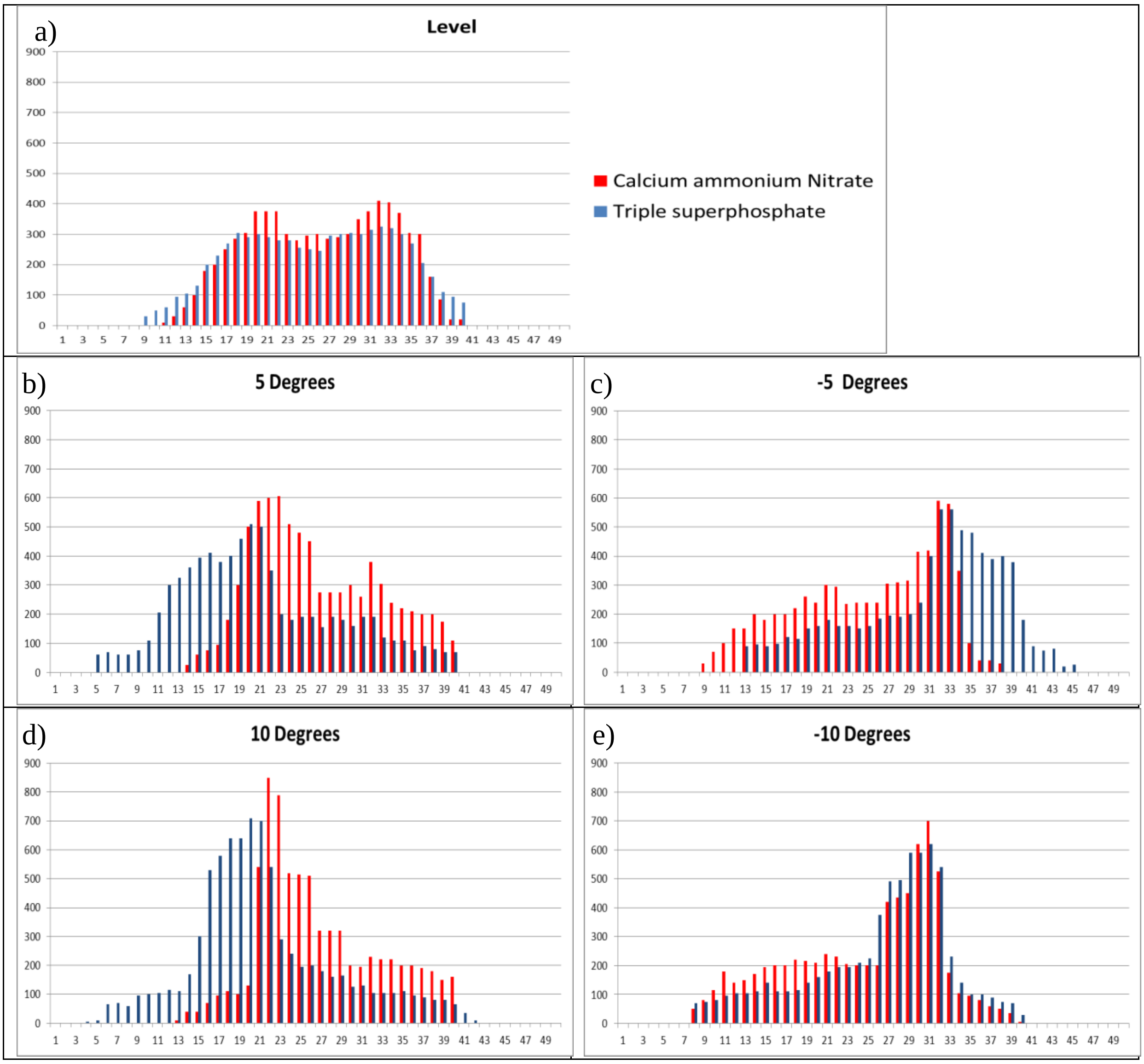


Figure 2 Adapted from Yilidrim (2008) a) indicate spreader performance (kg Spread per ha) on level surface. b and c), 5 and -5 degree of slope.d and e) 10 and -10 degrees of slope.

Product Characteristics.

At the most basic level we understand that very small particles will not be thrown far off the centreline of a spreader, whereas larger, spherical, denser particles will fly much further. However how a machine responses to changes in product is very dependent upon individual machine design elements. The main characteristics of interest are particle density, particle size (mean and distribution) and particle shape. Based on field experiments using one particular spreader Yule (2011) calculated that as long as material less than 0.5mm in diameter comprised no more than 15% of material by mass, a situation which occurs on most occasions aside from, a handful of occasions per year, the effect on CV is less than 5%.

The means of propelling the fertiliser from the disc and the distance it has to travel will also be affected by the ballistic qualities of the material. Some general purpose spreaders which are required to spread a wider range of products over a narrower bout width create the momentum for spreading through impact of the vanes on the fertiliser rather than fertiliser running down the vanes and being slung off the vane. A high speed video of this will be demonstrated within the presentation. The required exit speed of a particle off the disc required to travel 30 to 40m, is clearly greater than a particle which is required to travel 0 to 5m.

There has not been a lot of significant research into looking at the particle size distribution off spinning discs and analysing where particles of different size end up, most work has simply concentrated on overall spread pattern. This is again due to the time consuming nature and therefore expense of the work when trying to separate out the different sized particles. Recently one of two European spreader manufacturers has published user information which indicates the effect of changes of size guide number (SGN) on operating width. More independent research work has been completed on identifying when blended products will segregate. Some work has been completed in New Zealand, Yule and Pemberton (2009), in Europe Miserique has been a major contributor to the research effort, Miserique and Pirard (2004), Miserique *et al*, (2008) and in the USA, Virk *et al* (2011) have recently completed work which investigates the product separation and stability of spread within a variable rate application environment.

Ground-spread manufacturers have made improvements to machine design in order to address a number of issues around field performance. This has been completed in a hierarchical sequence to decrease field CV. Some of these improvements have been made possible by automated recording and measuring systems which allow for rapid evaluation of spreading systems and self-calibration.

It is likely that computer based modelling and decision support system software used in agriculture to provide fertiliser delivery advice and recording that assumes a perfect spread contributes to the lack of awareness of the issue and impetus to address the problem.

Identifying Elements of “Field CV”

Lawrence (2007), Lawrence and Yule (2007a and b) identified a means of measuring field CV from ground-spread vehicles and identified the major factors contributing to the variation in spread. Grafton *et al*, (2011) and Yule (2011) quantified the contributing factors to field CV on near flat paddocks. Lawrence and Yule (2007a) established that the use of differential global positioning (DGPS) systems could improve the CV of a ground-spread vehicle by at least 13% as it improves driving accuracy significantly over that of a GPS without a differential corrections system. Grafton *et al* (2011) using the same techniques estimated the effects of using automatic shut off to prevent multiple applications on the same area and variable rate control, which adjusts the rate applied to compensate changes in vehicle speed, these are summarised in Table 2.

Table 2 Sources of variability and mitigation strategies for in-field CV, Grafton *et al* (2011)

Source of Variability	***Mitigation available***	***Effect of the Technology on reducing the field CV***
Track spacing being inaccurate driven	Guide the spreader with GPS (+- 8 meters)	Nil
Track spacing being inaccurate driven	Guide the spreader with GPS corrected signal (+-0.2 meters)	9 – 17%
Variability in application rate when the spreader speed varies	Flow value control linked to spreader speed.	10%
Inaccurate vehicle repositioning post the vehicle stopping and recommencing	Vehicle repositioning GPS with corrected signal	10%
Small irregular shaped paddocks	Remove fences to form large regular shaped paddocks	8%
Variability in fertiliser particles (provided the variability does not exceed >15% <0.5 mm and the product is stored properly	Increase the cost of domestically manufactured fertiliser significantly to enable the product to be dried and cooled	5%
Application rates outside the certified 30% tolerance	Certify spreaders at a range of application rates as per the Australian test methods	*Unknown*

Financial Implications

The effect of adoption of the spreading technologies has been to reduce the CV on flat dairy and arable situations from around 50% Lawrence (2006) to levels as low as 20%. Lawrence and Yule (2007a) established that as the relationship between CV and cost was exponential, that losses when applying urea were significant at levels of CV greater than 30%.

The financial impact of the improvement in CV whilst sowing urea, using these technologies is summarised in Table 3.

Table 3: Economic loss and improvement with change in CV, Grafton *et al* (2011)

CV%	**Economic loss ($)ha^{-1}**	**Economic Improvement ($)ha^{-1} 2005 -2010**
37	**21.06**	**-**
28	**8.51**	**12.55**
23	**4.60**	**16.46**
20	**3.04**	**18.02**

The situation with ground-spread is similar to aerial application in that the costs of inaccurate spread are greater than the application cost, however by introducing new technologies as described the economic improvement can also be greater than the application cost.

The value of improved CV to the New Zealand dairy industry is based on the exponential equation developed by Lawrence and Yule (2007a), to express economic loss as CV increases, see equation 1.This equation was based on a dry matter value of $0.20Kg^{-1} from Horrell *et al*, (1999) and is based on N response from Ball and Field (1982) using urea (46% N) applied at 80Kgha^{-1} on optimal fertility dairy farms. (x is the CV expressed as a decimal rather than a percent, eg.(x = 0.3 means CV 30%)

$$Y = 286.78x^3 - 49.374x^2 + 5.4683x \qquad (1)$$

Current valuation based upon dairy farm conversion ratios value a kilogram of dry matter at NZ$0.40 based on a pay out of $6.08Kg^{-1} of milk solids dairy pay out and a conversion ratio of 15 - 1 (CR), the same as that assumed by Lawrence and Yule (2007a) which allows the loss to be calculated at current prices. This conversion ratio is well within the range of 7.7 – 25 kg dry matter per kilogram of milk solids found on New Zealand dairy farms (Anon, 2010). There are 4.82 million cows and heifers in New Zealand, farmed on about 1.66 million hectares (Anon, 2012). The estimated sales mix of fertilisers for all dairy farms in New Zealand (Pers Comm., Dr. Miles Grafton, Ravensdown, 2013) is shown in Table 4**.** Although estimated the results are in line with MPI statistics, Anon (2011).

Table 4 Sales mix of fertiliser sales in New Zealand by tones, value, hectare and cow

Fertiliser	**Tonnes (000)**	**Value NZ($) (million)**	**Value Cow^{-1} ($)**	**Value Ha^{-1} ($)**
Superphosphate products	603	223	46.31	134.29
Potassium products	106	69	14.35	41.62
Ammonium phosphate (s)	138	124	25.70	74.52
Urea	604	449	93.21	270.30
Magnesium	9	6	1.16	3.35
Total	1,460	871	180.72	524.08

The amount spent on urea represents applications of urea which total 360Kgha^{-1}. This would need to be applied in several applications and for the purposes of this paper is represented as 4 applications at 90Kgha^{-1}. This is not unreasonable and is close enough to 80kgha^{-1} to allow for the equation developed by Lawrence and Yule (2007a) to be valid. Spreadmark testing has found that the swath pattern of a truck does not change markedly ± 30% of the tested rate. Urea is the only product which has been tested for CV economic cost analysis and using this product. The economic benefit of CV improvement in moving from a CV of 40% to 20% is shown in Table 5.

Table 5 Value to NZ Dairy farmers in improving CV of urea spread from 40% to 20%.

Dairy pay Out ($)	**Economic Loss CV 40% ($)**	**Economic Loss CV 20% ($)**	**Improvement ($)**	**Total Benefit 4 Applications**	**Total Benefit Over 1.66 million ha Million ($)**
5.50	23.18	2.59	20.59	82.34	137
6.00	25.28	2.83	22.46	89.83	149
6.50	27.39	3.06	24.33	97.31	162
7.00	29.50	3.30	26.20	104.8	174

Results

Further Improvements in Spreading Technologies

Traditionally most research was geared towards finding better explanations of what was happening on the spreading disc in order to explain spread patterns. Now the research focus has changed and many of the improvements being made are to do with the spatial pattern in the field and as a result there is a need to produce a variable but controlled pattern from the disc.

Disc Drop on point.

The disc drop on point can either be restrained to achieve more consistent spread in variable circumstances or deliberately manipulated in order to produce changes in spread pattern. The reason for this is that in most spreaders is that as the spreader pitches and rolls; the drop point on the spreading discs moves; which distorts the spreading pattern, or changes in flow rate onto the disc also create a change on drop on point, see Figure 5.

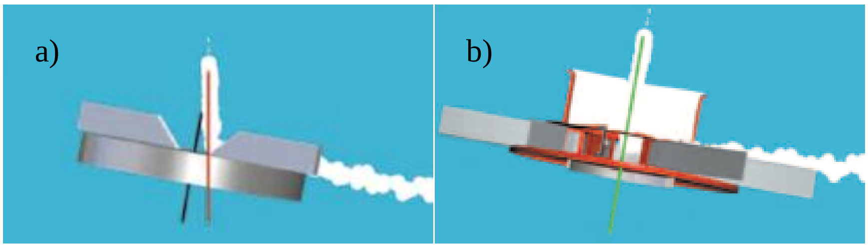


Figure 1: A schematic of a) change in drop point on a spreading disc, or: b) a static drop point on a spreading disc from www.Kverneland.com on 2, January 2013

The impact of changes in transverse and longitudinal spreading patterns with slope has not been modelled in the field to the authors' knowledge. However, the effects will be to increase CV significantly on spreaders in which the drop point moves on the disc as the vehicle moves from the horizontal. There are spreaders which are designed to overcome this problem, for example Kverneland produce spreaders where the drop point remains in the centre of the disc, which they claim reduces the distortion to the spreading, see Figure 5. Other manufacturers have developed alternative ways to reduce spread distortion on slope.

Whilst manufacturers such as Transpread; mitigate transverse slopes by having a divider which can be fitted between the discs, so that each disc continues to receive an equal amount of fertiliser. This, combined with individual spinner control may reduce the pattern distortion. These systems do not prevent the drop point changing on the disc as slopes are encountered. Very little research work has been completed on the effect of slope on spreader performance.

Headland / Border spreading

Headland and border spreading are areas where spread patterns do not overlap. Border spreading methods reduce the width of fertiliser spread pattern that is delivered on the side of the spreader that is adjacent to a boundary or that borders a sensitive area such as watercourse. The spread pattern has a much sharper cut off. Headlands are the areas where patterns do not overlap usually because the paddock or area being spread is an irregular shape. Generally this requires the spreader to reduce its spreading bout width as it completes spreading in these areas to prevent a double or out of zone application.

Border and headland spreaders use several mechanisms to achieve spread pattern control. Some manufacturers such as Amazone and Kverneland use a deflector vane plate to prevent fertiliser being spread on one side of the spreader, these can be controlled electronically or put in place manually see, Figure 6.

Exact Line

Spreading to the border from the outside tramline with the Exact Line system available for the Exacta CL, CL EW, HL, TL and TL GEOspread models. Adjustable vanes ensure application right up to the field borders.

The Exact Line is operated hydraulically (1 s.a. valve required).

Indicator work or transport position

Figure 6: Kveneland spreading system showing deflector vanes for border spreading, downloaded from www.Kveneland.com on 2, January 2013

Bredal and Transpread use individual spinner control to stop or slow one spinner to reduce the spread bout width on one or both discs to achieve a border or headland spread, see Figure 7.

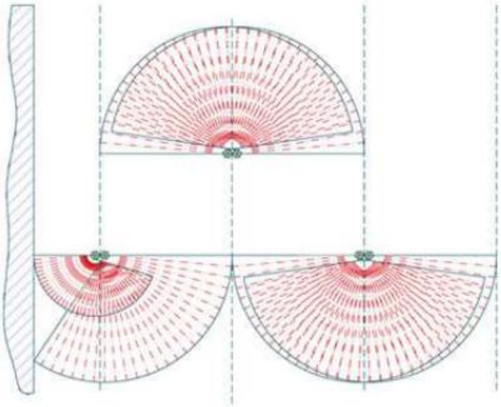


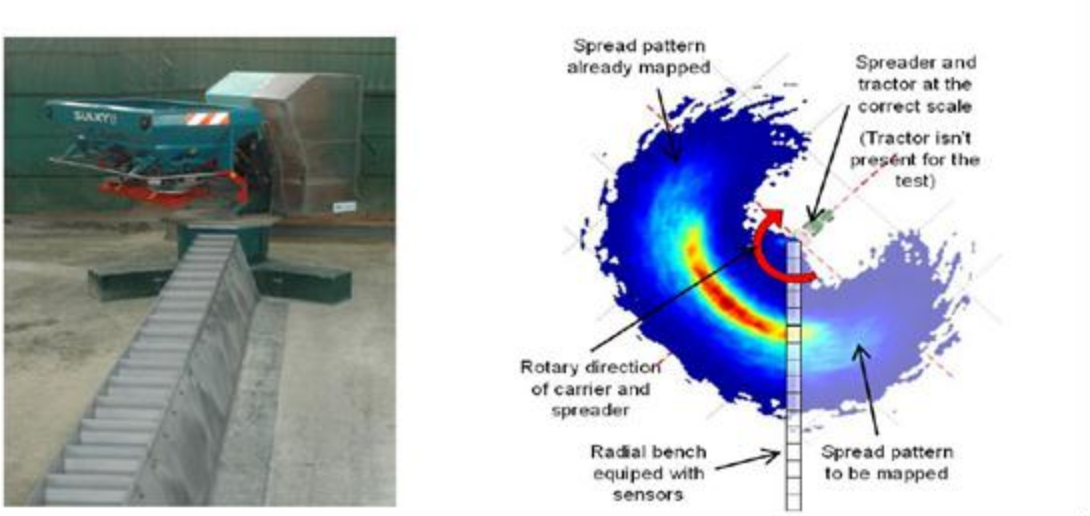
Figure 7: Bredal overlapping spread pattern in normal and headland operation, downloaded from: www.Bredal.co.nz on 4, January 2013

Manufacturers such as Sulky use different length spreading vanes to vary the spread from each disc. Long vanes are used to spread further and shorter vanes for reduced spread. Electronic and mechanical vein deflectors may be added to these systems for border spreading, as illustrated in figure 8.

Figure 8: Shows Sulky Triboid border spreading vane. Downloaded from www.Sulky-Burel.com 3, January 2013

In New Zealand assessing the impact these various systems have on border and headland spreading is extremely time consuming, as the country is reliant on transverse spreading over collectors and weighing the contents to establish fertiliser distribution.

Whereas, in Europe facilities with automatic testing, of fertiliser delivery and computerised measuring of spreading devices exist which; produce a spread pattern within a few seconds. Facilities such as these are able to pattern test spreaders in a wide range of conditions so that comparisons can be made between them, see Figure 9.



Figures 9, The CEMAGREF CEMIB device (left). Figure 11, (right), diagram illustrating the general principle of operation. Reproduced from Piron *et al* (2010).

The facilities such as the Cemagref Cemib are also able to produce spread patterns in a wide range of configurations as in Figure 10. A summary of features available in major European spreaders may be compared in Table 4.

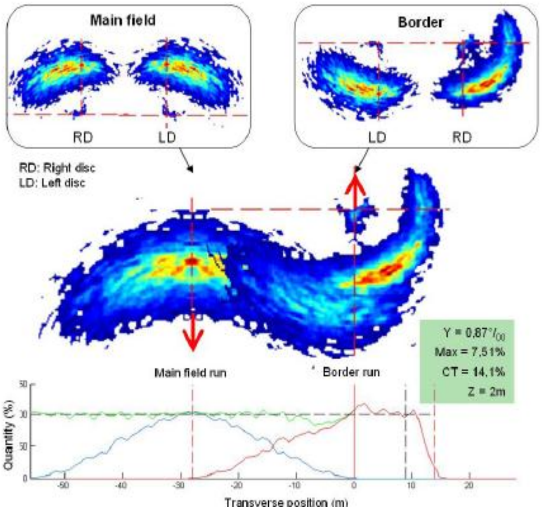


Figure 10: Shows a spreader test in main and border mode using the CEMAGREF CEMIB device.Piron *et al* (2010)

Automated devices such as the Cemagref Cemib will be required in New Zealand if spreaders are to be thoroughly tested and compared and the best suited used for the range of conditions found.

Table 4: A summary of headland and border control features used by major manufacturers

	Amazone	Bogballe	Bredal	Kuhn	Kverneland-Vicon	Sulky	Transpread
Border/ Headland Control	✓	✓	✓	✓	✓	✓	✓
Hydraulic							✓
Electric	✓	✓	✓	✓		✓	
Mechanical					✓		
Upload GIS	✓	✓	✓	✓	✓	✓	✓
Changing swath on the move	✓	✓	✓	✓	✓	X	✓
Auto start/ stop	✓	✓	✓	X	✓	✓	✓
Self Calibrating	✓	✓	✓	X	✓	X	✓
Varying drop point	✓	✓	✓	✓		✓	✓
Stationary drop point					✓		
Mechanical deflector for headland							
Manual				✓		✓	
Automatic					✓		

✓ Possesses feature; X does not posses feature

Conclusion

Over the last twenty years there has been a great deal of work undertaken in improving ground-spreading technology. Technolgies such as GPS have allowed the field performance of spreading to be analysed and the true level of performance identified. This has occurred in conjunction with improvements in GIS measurement and modelling.

It is now possible to measure the effects of spread patterns on field CV. Ground-spreader manufacturers have improved their technology in a hierarchical manner to address the sources of in-field CV in order of their contributing importance and this has led to considerable improvements in spreading accuracy. These improvements have a direct economic benefit to farmers.

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