BALLISTIC MODELING AND PATTERN TESTING TO PREVENT SEPARATION OF NEW ZEALAND FERTILIZER PRODUCTS

M. C. E. Grafton, I. J. Yule, B. G. Robertson, S. E. Chok, M. J. Manning

ABSTRACT. *In recent years twin disc centrifugal spreaders have become larger with some manufacturers claiming to be able to spread fertilizer products as far as 60 m. To achieve wider spread widths, the fertilizer particle exit velocity off the disc has increased, as a result the ballistic qualities of the product becomes more critical. This case study uses data-mined information from Ravensdown Fertiliser Co-op Ltd, a major fertilizer supplier. This article examines and researches products used by arable and grassland farmers and studies the effect of changes in product characteristics on spread bout width from these newer spreaders.*

Ballistic modeling, based on particle density, size, and shape was used to test the distance fertilizer particles travel at various velocities. Fertilizer particle velocities were measured by high speed photometry using both common fertilizers and common spreaders found in New Zealand. Spreading equipment was pattern tested using the New Zealand Spreadmark method. Ballistic modeling of particles proved appropriate in ideal conditions. Fertilizer manufacturers believe that spreader operators often fail to take account of physical characteristics of products being spread and target the widest bout width possible. This can lead to an in-field Coefficient of Variation (CV) which is much greater than 15% and leads to sub-optimal utilization of fertilizer, where variations in particle size distribution occur. Similar situations have been experienced when spreading fertilizer blends; where blends previously spread successfully, at narrower bout widths now separate. Ballistic models could provide bout width recommendations for products and blends, for a range of applicators and reduce crop striping.

Keywords. *Ballistic modeling, Centrifugal separation, Coefficient of variation(CV), Fertilizer spreaders, Twin-disk.*

Fertilizer application is an essential practice for all farmers. In recent years complaints have been received by fertilizer suppliers from farmers and spreading contractors with regard to evidence of striping in crops and pastures. Striping is a strong indication of systematic uneven distribution of fertilizer from the spreading machinery, resulting in under and over-application of nutrients. There has been a continuing trend towards increased spread widths, placing further demands on the specification of materials spread. Greater consideration of particle characteristics such as density, size, and shape is required when trying to achieve increased spread widths. Faster particle exit speeds off the disc may be responsible for blends separating, meaning the striping is a result of less even lateral distribution of blends from the spreader, due to increased speed off the discs causing centrifugal separation.

Ballistic modeling is an established tool, which aids in the prediction of individual fertilizer, spreading distance based upon the particle characteristics along with spreader specification, such as disc diameter and spinner speeds. It is with the use of modeling that different fertilizers may be evaluated before application, allowing for an accurate indication of achievable spread widths, based upon the specification of the spreader used to apply them. Therefore, striping may be avoided through an increased awareness of which products are compatible for blending in terms of spread distance, providing more uniform spread patterns.

The work included in this article endeavors to examine and validate the fact that ballistic modeling can provide an accurate representation of genuine spread patterns from common spreading machines, providing information to reduce striping, and to determine potentially suitable fertilizer blends.

The model has successfully allowed a fertilizer company to assess the ballistic properties of their products. They

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Submitted for review in June 2014 as manuscript number MS 10828; approved for publication by the Machinery Systems Community of ASABE in March 2015.

The authors were engaged with industry to research the ballistic properties of their products; to help refine physical properties' specifications, then to recommend indicative spreading bout width distances for a range of spreaders. To provide information to prevent incompatible mixes being sold and to examine the effect of wind on bout widths in spreading from centrifugal spreaders. This work was funded by Ravensdown Fertiliser Co-op Ltd.

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then can recommend blends using dissimilar ballistic properties, not be used by their customers, having used the model and without the need for field testing.

In addition, modeling spreaders and pattern testing a spread in a cross wind, in conditions often encountered in day to day spreading was undertaken to examine another factor which may contribute to striping and lodging within crops, independent of fertilizer physical qualities.

BACKGROUND

In recent years some arable and pastoral farm applicators have been experiencing striping of crops and pastures since upgrading to spreaders capable of spreading at increased bout or swath width. This issue is more prevalent where fertilizer blends of products with dissimilar ballistic properties are sown simultaneously.

The problem is more obvious when applicators have purchased modern top of the range twin disc spreaders with the ability to spread at an acceptable spread pattern at tram lines at or greater than 30 m. These spreaders have increased tram or bout widths of spread from 20 to 24 m, to greater than 30 m thus reducing the number of tram lines, increasing output and reducing trafficking of the crop or pasture.

Spreading at a tram line of 30 m requires a total spread pattern to be around 45 m, allowing for a pattern overlap of around 50%, to achieve the desired accuracy (Chok et al., 2014). Given that the spreading discs are around 0.5 to 1.5 m above ground level, then fertilizer particles must be discharged at some considerable speed.

Fertilizer customer representatives have often recommended product blends to reduce the number of fertilizer applications and deliver a proprietary nutrient mix or blend for their customers. Some of their arable customers have continued to purchase these mixes. When spread at the correct settings to achieve a 30 m tramline they have experienced striping which did not occur using the previous narrower tram lines. Striping is a real economic issue as it is only visible at in-field coefficient of variation (CV) of around 40%, giving a yield reduction of at least 20%, (Miller et al., 2009; Mersmann et al., 2013; Grafton, et al., 2013; Yule and Grafton, 2013). This reduction in yield and economic impact on the fertilizer end user has resulted in farmers' concern in many parts of the world (Miller, 1996; Miserque and Pirard, 2004; Miserque et al., 2008; Virk et al., 2013). The fertilizer blends that are spread have not changed. The only change being the spreader used and the bout width distances the products are being spread. In addition, some pastoral applicators using truck spreaders; claim that the bout widths they are achieving are reduced as the physical quality of single superphosphate (9% P, 11% S, 20% Ca) has reduced, in terms of particle strength, as the amount of fines material has increased markedly. Applicators suggest that the striping is due to changes in fertilizer physical specifications. Whereas, importers and manufacturers of fertilizers claim their products have not materially changed and that striping results from poor spreading practices.

There have been a number of case studies undertaken which demonstrate splitting of fertilizer blends through ballistic differences in particles, which have resulted in uneven spread. Miserque et al. (2008) and Yule and Grafton (2013) identified the elements which lead to separation, they are: particle size, particle density or specific density, and particle shape in order of importance. Virk et al. (2013), Yule and Pemberton (2009), and Miserque and Pirard (2004) have undertaken field experiments which have demonstrated that blends separate and nutrient application varies greatly from the targeted application rate. Virk et al. (2013) found that the resultant application of blended fertilizers was significantly different from the targeted application using variable rate technology. It is intended to shed some light on these experimental findings by predicting the ballistic properties of various fertilizers and measuring their performance when spread in the field.

Spreader operators are required to undertake a bulk density test and establish mean particle size by using a sieve box prior to setting the equipment for the correct bout width as specified in the manufacturers' tables. Miller (1996) and Miserque et al. (2008) found that proprietary mixes and blended fertilizers often produce a bulk density and mean particle size, which will often differ from the ideal settings of the products mixed if they have different particle sizes and specific densities, These mixes may separate by percolation of smaller particles through larger ones and by centrifugal separation by particle size and mass.

This article uses ballistic modeling to identify fertilizer ballistic characteristics, so that spreading distances and bout widths can be predicted for products and subsequently validated. Spreadmark tests and the Australian spread test ACCUSpread are both based on ISO 5690-2. Both New Zealand Spreadmark and ACCUSpread provide test results and total spread width and bout distances were compared by Chok et al. (2014). Bout widths are approximately 67% of total lateral spread for centrifugal spreaders which passed the spread test. Product mixes which may result in blends separating are then identified, by modeling different products over a range of particle sizes. The model is partially validated by field testing and undertaking a spread test. In addition, a superphosphate with high fines content is compared to one with a low proportion of fines content in a spread test.

MATERIALS AND METHODS

SINGLE SUPERPHOSPHATE

The materials chosen for the exercise were two superphosphate samples with different levels of fines (<1.0 mm), which were chosen after sampling17 supplier warehouses and two manufacturing plants owned by New Zealand's two largest suppliers, Ballance Agri-Nutrients Ltd. and Ravensdown Fertiliser Co-op Ltd. Approximately 15 kg of superphosphate (SSP) was taken from each site and sieve tested at Massey University. The sieve sizes used were 200 mm diameter, with mesh sizes of: 4.75 mm, 3.55 mm, 2.36 mm, 1.70 mm, 1.18 mm, and pan. The shaker was an Electrolab electromagnetic sieve shaker, approximately 0.5 kg of material was sieved according to BS 410-2. The samples chosen from two Ravensdown stores one (Feilding) contained 17.5% fines from with a mean particle size of 2.1 mm, and the other sample (Wanganui) contained 0.3% fines with a mean particle size of 3.2 mm. Fines were measured as percentage pan sample weight over total sample weight.

An analysis was undertaken by Yule (2011) on the effect of fines fractions on spread patterns for single superphosphate spreaders using data from an earlier paper from, Yule and Pemberton (2009). Although a desktop project, the paper is based on spread pattern testing undertaken during previous research activities using 1100 (0.5 × 0.5 m) square collectors, randomly distributed in a field experiment covering some 80ha, to establish the in-field CV of spreading accuracy on New Zealand dairy pastures Lawrence and Yule (2007). It was found that spread patterns would be robust, around a mean particle size (typically 2.0 to 3.5 mm) unless a fines fraction greater than 15% was present.

The chosen samples were spread tested using the same truck spreader with an ACE™ bin at the same farm, each over three sets of 80 collectors and the tray samples weighed as per the New Zealand Spreadmark method (New Zealand Fertiliser Quality Council, 2013), using version 17 of the spread software (Chok et al., 2014). A CV of 25% for a transverse pattern test is required for fertilizers with no nitrogen. Spread pattern tests were carried out to find the maximum bout widths that would achieve this standard for both fertilizers.

Ballistic Modeling

A ballistic model was developed to estimate spreading distances for a range of fertilizers from a variety of spreaders. Samples of commonly applied store fertilizers were collected in addition to single superphosphate from Ravensdown's Feilding warehouse and sieve tested as per BS-410-2 for this project. The sieve tests were undertaken to compare the samples with physical attributes of fertilizer samples as tested from received shipments over the previous 10 years. All samples were within specification and materially the same as the received shipments, in respect of physical characteristics.

The ballistic model was used to predict the spreading distances of the fertilizers collected and four 500 kg bags of fertilizers were provided for testing. A bag each of the two superphosphate samples and a bag of di-ammonium phosphate (DAP), and also of Nitrophoska 12-10-10. The fertilizer was supplied to provide some validation to the model. The model was run to suggest bout widths for the fertilizers, based on the 5 percentile, mean, and 95 percentile of each products' particle sizes found from the cumulative particle size distribution, (Grafton et al., 2014). The DAP and Nitrophoska products were then spread tested using the Spreadmark method (NZ Fertiliser Quality Council, 2013) with a tractor-mounted Kuhn Axis spreader in still and cross wind conditions to validate the modeling, in addition to the superphosphate samples. DAP and Nitrophoska 12-10-10 both contain nitrogen and must pass a transverse pattern test with a bout width which achieves a maximum CV of 15% to meet the Spreadmark standard.

Model

This information is required for ballistic modeling. The drag force on a particle is:

$$Fd = \frac{1}{2}\rho v^2 cdA \tag{1}$$

where

ρ = 1.2 kgm^{-3}, the density of air at 0 velocity, at standard temperature and pressure,
v = the velocity of the particle,
cd = the drag coefficient of the particle,
A = the cross sectional area of the particle,
v_f = the final velocity,
v_i = the initial velocity,
M = the mass of the particle.

By dividing the force imparted on the particle by the particle mass, which was calculated by the mean particle volume, divided by the specific or particle density, determined by immersion testing in methanol, the acceleration a of the particle is determined. Through differentiation and integration the distance D a particle will travel can be determined as set out below:

$$a = \frac{1}{2}\rho v^2 cdAM^{-1} \tag{2}$$

$$K = \frac{1}{2}\rho cdAM^{-1} \tag{3}$$

$$\Delta a = 2vKt \tag{4}$$

$$v_f = (v_i - Kv_i^2)dt \tag{5}$$

By taking small increments of time the distance travelled in each increment is given by:

$$D \approx v_i - (Kv_i^2 \Delta t)dt \quad \lim_{0-t} v_i > 0 \tag{6}$$

The acceleration "a" is merely the drag force divided by the particle mass.

K is a term to simplify the mathematics, it is merely a temporary constant for the terms that do not change for each particle being modeled.

The distance measured in the lateral plane is DCosØ, which, for this model, is when Ø is 90° and therefore the CosØ term is 1. The simple model is used merely to calculate total travel distance for a range of typical fertilizer particles to examine which ones will separate if blended and produce incompatible spread patterns, which are likely to lead to lodging and striping. The model also examines and compares the effect of cross winds on spreading accuracy so as to measure the effect of environmental factors. Then environmental and fertilizer physical properties' effects on spread patterns can be measured.

Integrating the velocity time function reveals the distance travelled horizontally. However, as the result is an exponential function both in terms of velocity and time, then the result is only accurate when changes in time are extremely small. This requires calculating the time a particle will travel, which is a function of the height and gravity and undertaking iterative calculations at short time intervals. As particles in the vertical plane start from rest and the height of the spreading disks above ground for this test is 0.75 m, then the time particles travelled can be approximated with the assumption of drag force in this plane being close to zero as the drag in the vertical plane as the particles gain height is almost equal to that in the opposite direction as they descend. There is an assumption independent of the delivery angle that there is a distance between the spreading disk and the ground which in this case is 0.75 m where no drag coefficient for air is assumed. As the particles are starting from 0 ms^{-1} in this plane, and the time effect between no drag force and drag force is very small, it does not affect the calculated horizontal distance of spread.

To achieve an accurate calculation of the distance fertilizer particles will travel at an initial velocity, the distance was calculated by integrating and accumulating the distance travelled through 20 iterations. The time for the particles to travel before landing, (in this exercise is a little over half a second on which the iterations were based), that is, distance over time. Many twin disk spreaders deliver fertilizers in a parabolic flight path, which contains a vertical, as well as a horizontal component. The vertical component is approximately Sin 15° of the exit velocity, which is a little over 25% of the horizontal component. The vertical component is also subject to a drag force. The drag in the upwards direction is opposite and almost equal to the drag in the downwards component of flight, so at the speeds and time period of fertilizer delivery from this spreader a drag force of 0 can be assumed. Therefore gravity as the only acceleration in this plane is a valid approximation.

Thus the time to the parabolic apex is the exit velocity in the vertical plane divided by acceleration of g:

$$t \approx \Delta v_h \,/\, g \tag{7}$$

The distance to the apex is the area under the velocity time graph and total time of flight includes the time of descent which requires the apex height to be known.

$$d \approx \frac{\Delta v_h}{2} t \tag{8}$$

$$t \approx \sqrt{\frac{2h}{g}} \tag{9}$$

Particle samples were measured in both planes and cross-sectional area measured in addition. Particle mass was calculated by dividing particle density by particle volume.

The drag coefficient was estimated from known shape drag coefficients, acknowledging that it changes little at these speeds through the medium of air and requires field measurement to establish exactly. Spherical particles were estimated to have a drag coefficient between 0.55 and 0.6, whilst trapezoid particles 0.8. Mass and particle density have the most influence in ballistic modeling, whereas shape is the least important factor, therefore an estimate of the coefficient of friction makes little difference (Miserque et al., 2008).

The speed and dimensions of the equipment used was measured. The Kuhn Axis spreader that was used for spreading DAP and Nitrophaska 12-10-10 is designed to spread products with homogenous particle sizes. It has two vanes of different sizes (0.285 and 0.215 m) which deliver fertilizer different distances. This increases the spatial variation of the distribution and prevents all the particles arriving at a similar radius of the spinner, which would deliver what is known as a hollow spread pattern. The spinner speed was read from the tractor consul and confirmed using high speed photometry (figs. 1 and 2). The use of high speed photometry was necessary to confirm if the disc imparted spin to the fertilizer particles, as spin would have either increased the distance travelled if top spin was imposed, or reduced the distance if back spin was imposed by the disks.

The single superphosphate (SSP) was spread from an ACE™ bin mounted on a truck, this is a general spreader, designed to spread a wide range of material and is of a type used to spread products with heterogeneous particle sizes (fig. 3).

RESULTS

The dimensions and calculations of the ballistic properties imparted by the spreader on the particles are shown in table 1.

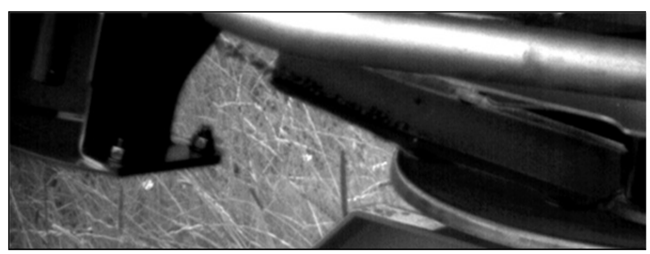

Figure 1. Long vane spinner of the Kuhn Axis 0.285 m spreading Nitrophoska 12-10-10 at 1083 rpm, a still photograph from high speed photometry.

Figure 2. Short vane spinner of the Kuhn Axis 0.215 m spreading Nitrophoska 12-10-10 at 1083 rpm, a still photograph from high speed photometry.

Figure 3. The ACE bin and spreader used to sow SSP.

Table 1. The properties of the spreaders that impart ballistic properties on particles.

Properties	Kuhn Axis	ACE
Vane long (m)	0.285	0.3
Vane short (m)	0.215	
ω rotational velocity (rads^{-1})	18.05	17.5
Exit velocity large vane (ms^{-1})	32.5	33.2
Exit velocity short vane (ms^{-1})	24.5	
Elevation angle of delivery (°)	15	15
Horizontal initial velocity long vane (ms^{-1})	31.4	32.0
Vertical initial velocity long vane (ms^{-1})	8.4	8.8
Horizontal initial velocity short vane (ms^{-1})	23.7	
Vertical initial velocity short vane (ms^{-1})	6.3	
Height of disks above ground level (m)	0.7	0.91
Apex long vane (m)	4.3	4.7
Apex short vane (m)		
Time long vane (s)	1.79	1.85
Time short vane (s)	1.4	
Height of apex long vane (m)	4.3	4.7
Height of apex short vane (m)	2.75	

The particle results of the sieve tests are displayed as cumulative distribution curves in figures 4(a-d).

The particle sizes for modeling were selected from the cumulative distributions measured and the mean particle sizes of both superphosphate samples were run through the ballistic model and predicted spreading distances calculated. These are displayed in table 2.

Figure 4(a) shows a heterogeneous superphosphate sample with a low fines count as there is an insignificant amount of product in the pan, that is particles which will percolate through the smallest mesh. In contrast, figure 4(b) shows a heterogeneous product where 15% of the product has percolated through the smallest mesh into the pan, hence the cumulative distribution curve begins above the abscissa. Heterogeneous products produce a wide flat cumulative distribution curve as a high percentage of particles are represented in each sieve. These products are best spread by general purpose spreaders (fig. 3) as they are not sensitive to particle size distribution and particle density to operate effectively.

Figures 4(c) and (d) show homogeneous products, this results in a steep cumulative distribution curve as most particles are found within a narrow particle size distribution. These products can be accurately spread by specialist centrifugal spreaders, such as the Kuhn Axis, which can be set up to spread at set distances, based on the median particle size and product bulk density.

Spread testing was undertaken using 500 kg samples of all four products and transverse pattern tested over three sets of 80 trays of dimension (0.5 × 0.5m) as per the New Zealand Spreadmark method (NZ Fertiliser Quality Council) and tray weights fed into version 17 of the Spreadmark software. The pattern test results and bout width calculation analysis for the four products are displayed in figures 5(a-d).

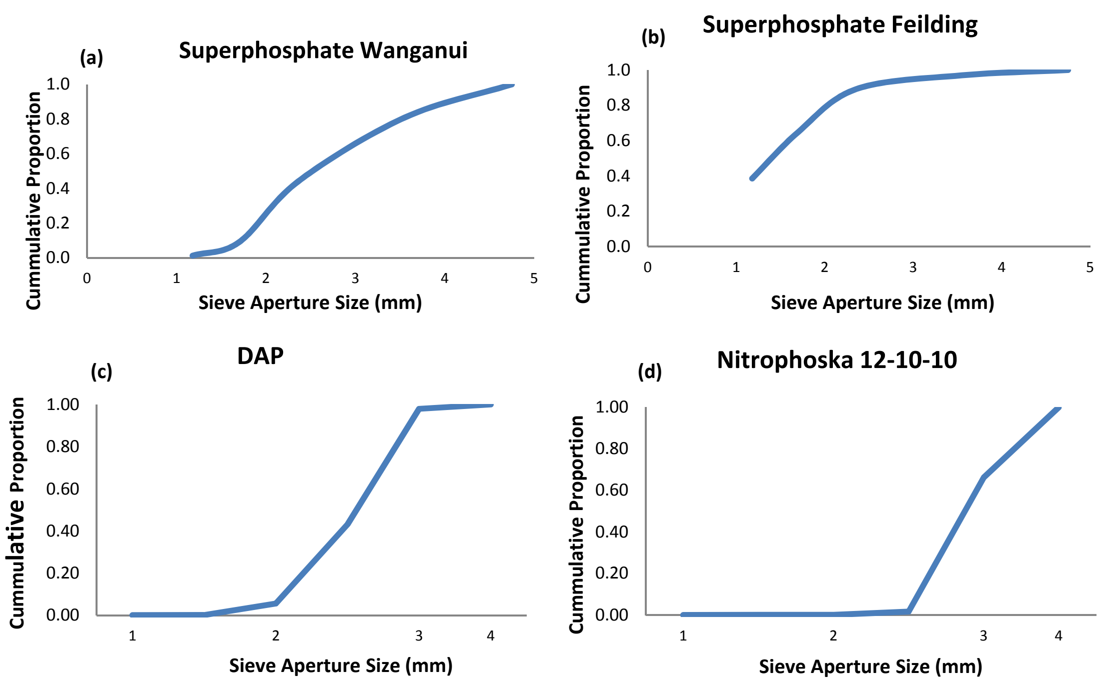

Figure 4. Cumulative particle size distributions of fertilizers (a) superphosphate from Wanganui, (b) superphosphate from Feilding, (c) DAP, and (d) Nitrophoska 12-10-10.

Table 2. **Ballistic properties of spread width tested samples and calculated spread from each vane.**

Property Diameter	12-10-10 2.2 mm	12-10-10 3.0 mm	12-10-10 4.0 mm	DAP 2.0 mm	DAP 2.5 mm	DAP 3.0 mm	SSP 1.0 mm	SSP 2.1 mm	SSP 3.2 mm	SSP 4.7 mm
cd	0.55	0.55	0.55	0.6	0.6	0.6	0.6	0.6	0.6	0.6
P (kgm^{-3})	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
A (m^2)	3.8×10^{-6}	7.1×10^{-6}	1.3×10^{-5}	3.1×10^{-6}	4.9×10^{-6}	7.0×10^{-6}	3.9×10^{-7}	1.7×10^{-6}	4.0×10^{-6}	8.7×10^{-6}
M (Kg)	9.6×10^{-6}	2.44×10^{-5}	5.8×10^{-5}	6.6×10^{-6}	1.3×10^{-5}	2.2×10^{-5}	1.2×10^{-6}	1.1×10^{-5}	3.8×10^{-5}	1.2×10^{-4}
K	0.15	0.10	0.07	0.17	0.14	0.12	0.12	0.07	0.04	0.03
P_s(kgm^{-3})	1,723	1,723	1,723	1,587	1,587	1,587	2,200	2,200	2,200	2,200
Spread										
Long vane (m)	14.4	18.7	21.9	17.7	19.2	20.1				
Short vane (m)	10.9	12.4	12.9	12.1	12.6	13.5				
Ace (m)							20.7	23.7	24.6	25.2

As the DAP spread test was undertaken in cross wind conditions of about 6 ms^{-1}, these conditions were incorporated in the model by adding 6 ms^{-1} and deducting 6 ms^{-1} to the delivery velocity's horizontal component and compared to the spread test, see table 3. Although the calculated bout width was greatly reduced by the wind, the shape of the pattern remained relatively intact, although distorted toward the wind direction.

Figures 5 (a-d) are taken directly from the output of the Spreadmark v17 software supplied by Spreadmark. The histogram represents the weight of material in each tray. Trays are removed to allow the truck to pass through them without damaging them. These gaps in the tray line are measured by interpolation. The S curve represents the CV, which is the standard deviation over the mean weight at various bout widths. In New Zealand Spreadmark certification, products containing nitrogen should be applied at a bout width which delivers a CV over the trays of 15%, the bottom horizontal line. However, fertilizers with no nitrogen may be applied at a bout width which delivers a 25% CV over the trays, the top horizontal line. Where the S curve penetrates the required horizontal line will be the certified bout width.

Discussion

There was very little difference in bout width settings between the superphosphate samples to achieve the Spreadmark pattern test standard of a transverse CV of less than 25%. The Wanganui SSP sample with a mean particle size diameter of 3.2 mm and 0.3% pan fines did achieve the wider bout width of 34.25 m. The Feilding SSP sample with 17% fines and a mean particle size diameter of 2.1 mm achieved a bout width of 33.75 m. Both spread tests showed that the required CV is achieved at around 67% of the total spread width. The ballistic modeling predicted spreading distances well and supports the findings of Yule, (2011) that the spread patterns of SSP will remain robust over a range of particle size distributions and be largely unaffected in still conditions with fine

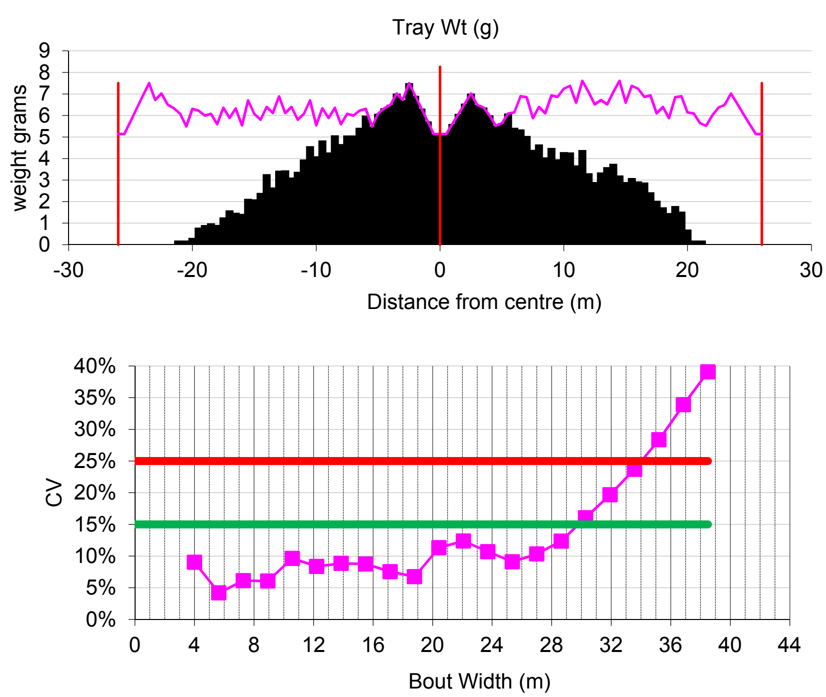

Figure 5a. Superphosphate from Wanganui sown from ACE™ spreader in still conditions. Spread pattern top, calculated bout width for 25% CV where top line is intersected 34.25 m.

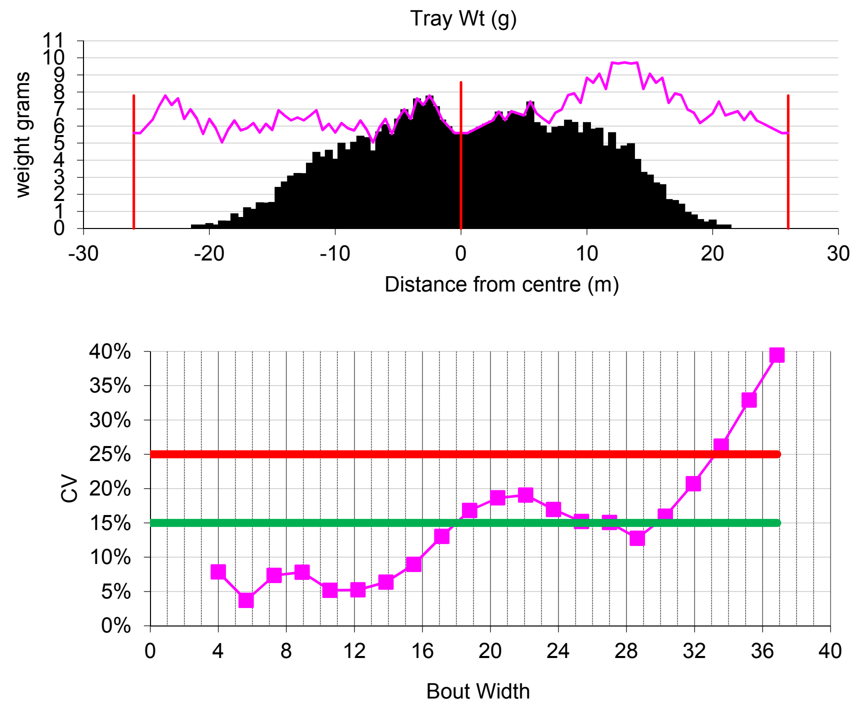

Figure 5b. Superphosphate from Feilding sown in still conditions. Spread pattern top, calculated bout width for 25% CV 33.75 m.

particles content up to 15%. This is because a 25% CV over the trays allows for considerable variation in tray weights, plus or minus 25% of the mean.

The homogenous fertilizers (DAP and Nitrophoska 12-10-10) spread by the Kuhn Axis also fitted the ballistic modeling well. To achieve a 15% CV the Nitrophoska 12-10-10 required a bout width of approximately 50% of total spread from the longer vane and 85% of the spreading distance of the short vane.

Wind had a real impact on the bout width. However the actual pattern test remained robust. The cross wind reduced the acceptable bout width from around 21m to 13m. This demonstrates that factors such as cross wind can have far greater impacts on spread patterns than fertilizer physical properties. However, being able to predict which fertilizers have incompatible ballistic properties and the effects of environmental conditions is possible and should reduce problems of striping and lodging associated with blend separation and uneven spread. A driver offset may be

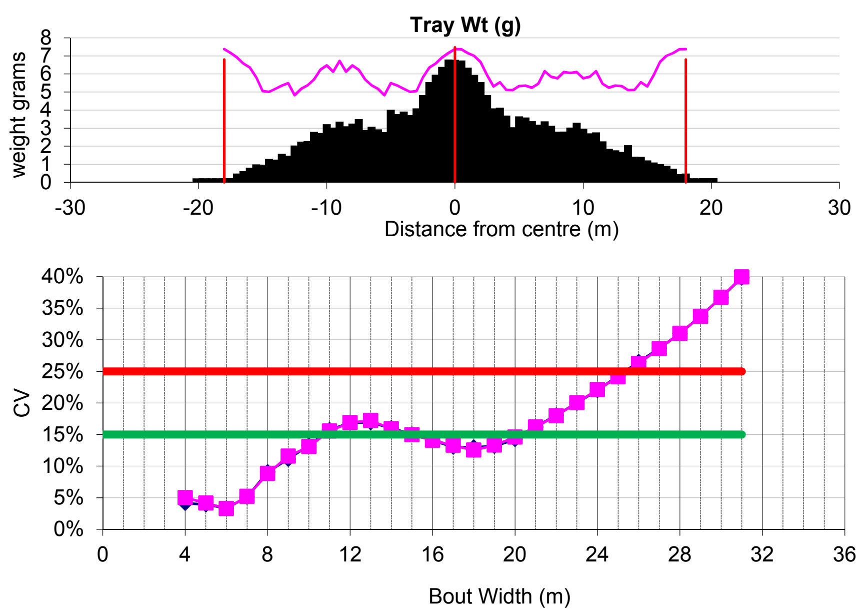

Figure 5c. Spread pattern test results, pattern top and below bout width calculator for N fertilizer (bottom line) and other fertilizers top line, test using Nitrophoska 12-10-10 in still conditions, bout width 21 m to achieve 15% CV.

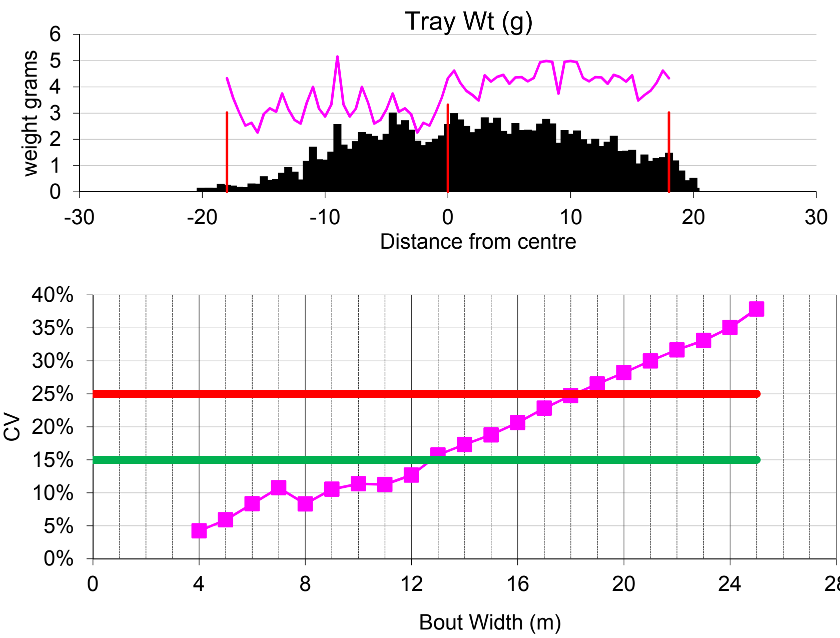

Figure 5d. Spread pattern test using DAP, in a 6ms^{-1} cross wind, bout width calculated at 13 m for 15% CV.

calculated to mitigate the effects of wind. However, this would not be possible in tram line spreading.

Conclusions

The ballistic modeling of spreading distances of fertilizers is possible and is being used to prevent fertilizer mixes with incompatible ballistic properties from being mixed or spread together. It has also led to a tightening of physical specifications in respect of particle size ranges for fertilizer products being sold.

Modeling could also be used to help establish tram line spacing for farmers spreading several fertilizers to prevent ballistic separation at wider bout widths. This would mean setting a tram spacing at the narrowest acceptable spreading distance, rather than at the most extended. Ballistic separation increases exponentially with particle speed and this should be a consideration in setting tram line spacing and supplying or purchasing proprietary fertilizer mixes and blends.

More consideration should be given to the risks and impacts of striping and lodging if in field application of fertilizers is not accurate. The benefits of reduced spreading charges by spreading a mix of products may and are likely to be less than the cost of yield loss and extra processing charges associated through striping, uneven ripening and crop lodging.

The environmental conditions at the time of application, especially wind, have a considerable effect on spread, if the direction is 90° to the direction of travel. The wind conditions in which the spread test was undertaken and modeled for DAP would be encountered on some spreading jobs, especially during peak seasonal demand and would have more impact on spreading accuracy than would differences in particle physical properties.

The issue of fertilizer blend separation and a reduction in crop lodging and striping could be achieved by:

- Soil testing early and establishing crop nutrient requirements.
- Direct drilling fertilizers or broadcasting fertilizers at or close to time of sowing.
- Setting a tramline for one fertilizer product such as urea or ammonium sulfate which will be side dressed as the crop establishes.
- Not applying fertilizer by broadcast spreaders during unsuitable conditions.

This work could be built upon to benefit farmers by reducing yield loss, through crop striping, reduce the cost of the farm input of the fertilizer spread and improve incomes through increased production.

Table 3. The calculated effect of adding cross wind component to the ballistic model.

	12-10-1-0	DAP
Into 6 ms^{-1} head wind		
Distance long vane large particle size (m)	16.6	15.6
Distance short vane large particle size (m)	9.0	8.7
Distance long vane mean particle size (m)	14.7	15.0
Distance short vane mean particle size (m)	8.5	8.6
Distance long vane small particle size (m)	12.2	14.1
Distance short vane small particle size (m)	7.8	8.3
With 6 ms^{-1} tail wind		
Distance long vane large particle size (m)	22.8	24.4
Distance short vane large particle size (m)	18.1	17.1
Distance long vane mean particle size (m)	22.2	22.9
Distance short vane mean particle size (m)	16.2	16.5
Distance long vane small particle size (m)	15.6	20.6
Distance short vane small particle size (m)	13.7	15.6

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