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IMPROVING AERIAL TOPDRESSING IN NEW ZEALAND THROUGH PARTICLE BALLISTICS MODELLING AND ACCURACY TRIALS

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Abstract

Fixed wing aircraft are utilised in New Zealand to apply dry bulk fertiliser on hill country farms. The fertiliser is most often applied manually as a blanket rate over the entire farm. Previous study indicates that this yields a field coefficient of variation (CV), which is the standard deviation over the mean application rate, of 63 – 70%. The CV decreased to 44% when the hopper door was automatically controlled using aircraft installed global positioning system (GPS) in lieu of manual intervention by the pilot. This is comparable to fertiliser application by fully GPS enabled truck spreaders. Spreadmark® specifies that the transverse overlap CV should be 15% for nitrogen-based fertilisers and 25% for all other products; however transverse overlap tested CV is considerably different to field CV. Variation in aerial topdressing is a barrier to achieving these CV. These variables include wind conditions, topography, aircraft speed and fertiliser properties.

Ravensdown Limited is upgrading their topdressing aircraft fleet with differential rate application technology (DRAT), which uses the automated hopper door and GPS to apply various application rates over specified target areas within a farm. The advantage of this system is that fertiliser can be applied to these areas with the largest potential benefit in terms of increase pasture productivity and reduced environmental impact. Two trials utilising cone shaped collectors were carried out at coastal sheep and beef farms to determine the DRAT system's accuracy when applying two application rates. Proof of release maps, which is deduced from aircraft recorded data, showed the system was able to vary rate. The CV ranged between 34% and 56%. The CV can be further improved by using a granular fertiliser ballistics model that predicts the transverse and longitudinal spread patterns based on wind conditions, fertiliser properties and aircraft operation. Validation data for this model was collected in validation trials for superphosphate, urea and di-ammonium phosphate. A validated model can provide guidelines on the optimum conditions and settings for aerial topdressing.

Introduction

The coefficient of variation (CV) is the standard deviation over the mean application rate and is a measure of precision. Grafton et al. (2012) found installing an automated hopper door linked to a global positioning system (GPS) improved field CV from 63 – 70% (conventional aerial topdressing) to 44%, which is comparable to truck spreading CV's. Spreadmark® specifies a test CV of 15% for nitrogen-based fertilisers and 25% for all other products, when determining the maximum bout width for an applicator. Field CV is unlikely to reach these levels due to variation in fertiliser properties and weather conditions.

A particle ballistic model can be used to improve the field CV. Jones et al. (2008) formulated a model that can predict a transverse spread pattern based on wind conditions, fertiliser characteristics and aircraft operation.

Ravensdown Limited is updating their fixed wing aircraft with differential rate application technology to improve aerial topdressing of granular fertiliser. The DRAT system utilises an automated hydraulic hopper door and GPS to apply different application rates depending on the area. This will allow fertiliser to be placed where it is most needed to improve pasture productivity and minimise application in to sensitive areas, such as water ways and bush areas. Murray and Yule (2010) predicted an economic benefit of using the DRAT system with a 26% increase in cash surplus per hectare under optimum pasture growth conditions.

The DRAT system records the pilot's flight path during the fertiliser application. This information is used to generate proof of release maps, which shows the farmer where fertiliser application has been completed. Recorded flight information includes GPS position, hopper door opening, aircraft speed, altitude and time. Information between each point of flight information is interpolated using kriging, a geo-statistical tool. Kriging is able to predict the application rate in areas where information wasn't recorded. It does this by predicting the spatial relationship of the data.

This paper will present proof of release maps and ground data for two accuracy trials, and initial results for the particle ballistics model.

Methodology

Accuracy trials were completed at Limestone Downs, Port Waikato (February 2014) and Longview, Waitotara (May 2015). This data set was used to determine the field CV. Fertiliser application was expected on these farms as part of annual nutrient maintenance and was therefore ideal as a trial site. Accuracy trials consisted of placing cone shaped collectors in the application zones to collect the applied fertiliser. Each collector had an area of 0.5 m^2. Collectors were positioned in a grid pattern at Limestone Downs and a nested grid sampling pattern at Longview. 136 collectors were used at Limestone Downs and 165 collectors at Longview. Superphosphate was applied at Limestone Downs at an application rate of 500 kg/ha and 250 kg/ha. At Longview a mix of superphosphate, Flexi-N, Maxi Sulphur Super and other trace elements was applied at 284 kg/ha and 162 kg/ha. Wind conditions were recorded at Longview using an anemometer but not at Limestone Downs. The average wind speed at Longview was 0.9 m/s in a north-easterly direction with a range of 0.17 – 1.97 m/s. A Pacific Aerospace Cresco 600 was used in the trial. Samples from the collectors were weighed in a laboratory.

The recorded data from the aircraft was converted before a proof of release map could be generated. Beverloo's equation (equation 1) was used to correlate the recorded hopper door openings to the intended application rate. The equation is valid for free flowing bulk material through an orifice. The mass flow rate (M) is calculated from the fertiliser bulk density (ρ), hopper door opening (B) and mean particle diameter ($\bar{d}$).

$$M = LK\rho g^{\frac{1}{2}}(B - k\bar{d})^{\frac{3}{2}} \tag{1}$$

L is the length of the hopper door, K is an aircraft constant, k is a fertiliser constant and g is acceleration due to gravity. The mass flow rate (kg/s), along with aircraft speed and area, is used to calculate application rate. The application rate can then be kriged.

Kriging is a geo-statistical interpolation method. It can transform discrete data sets in to a continuous layer. Kriging generates intermediary points by considering the surrounding data. The closest data points are given more weight than those further away. To ensure that an appropriate level of variation is included, the data points are fitted to a mathematical model. Mathematical models, which best represent the spatial variability, were selected depending on the data's fit to the semi-variogram function. The penta-spherical model was the most appropriate for the aircraft calculated application rate for both trials (figure 1 and 2). ArcGIS 10.1 geo-statistical analyst was used to create the proof of release maps in this paper. The tool allows for semi-variograms to be created.

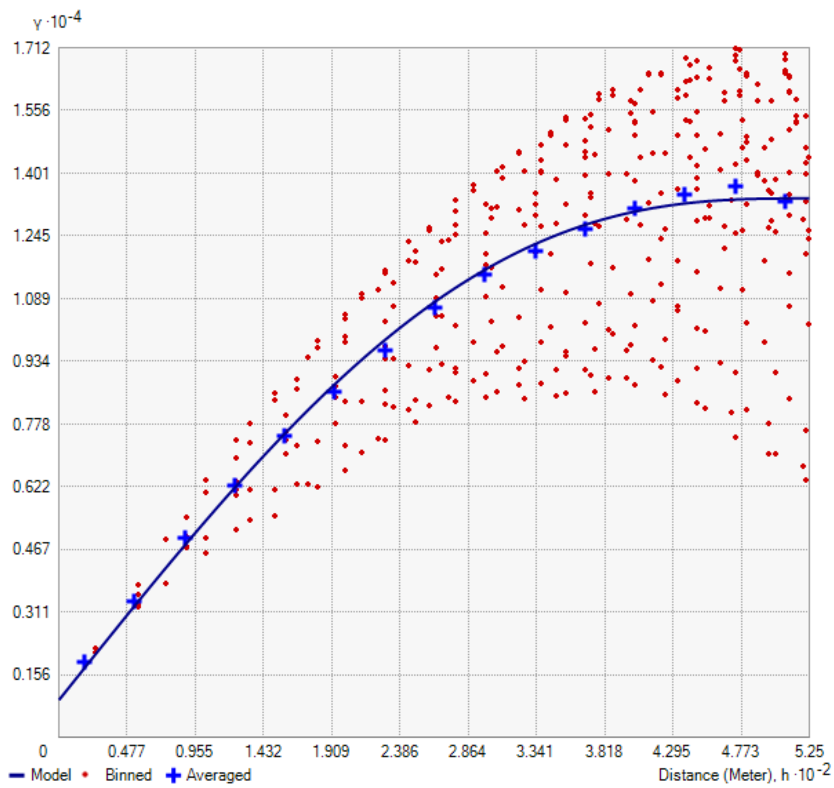

Figure 1: Limestone Downs penta-spherical semi-variogram.

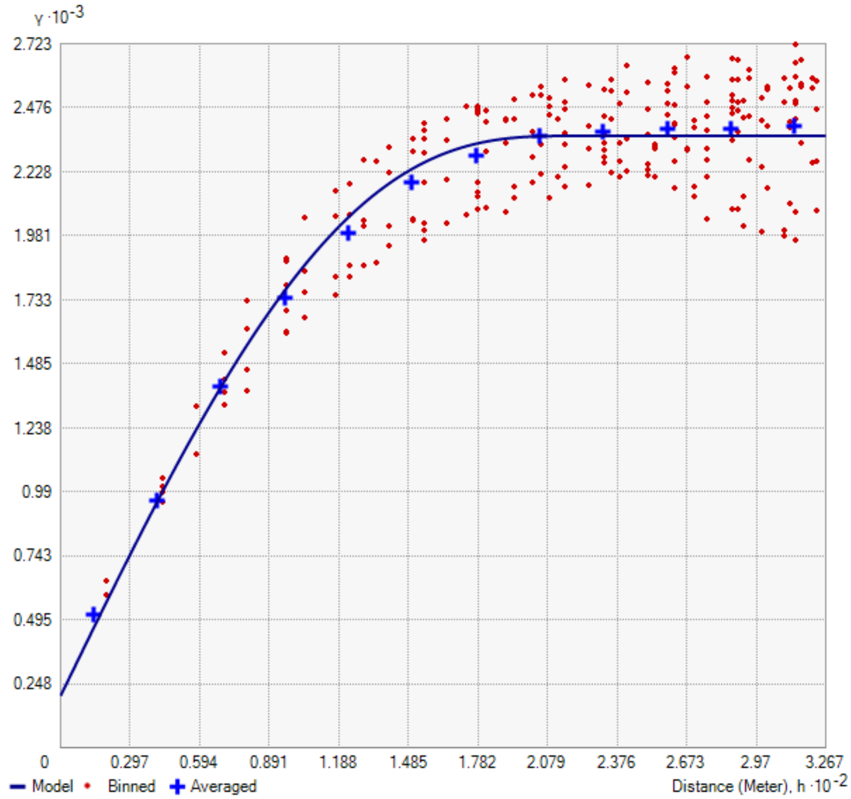

Figure 2: Longview penta-spherical semi-variogram.

The ballistics model was validated at Longview, Waitotara (May 2014). Collectors were positioned in nine rows with each row 20 m a part. There were 19 collectors in a row placed 3 m a part (figure 3). A wind anemometer measured the wind direction and speed every 30 seconds. The transverse spread patterns of superphosphate, urea and di-ammonium phosphate (DAP) were collected on the day. A Cresco 600 plane flew in a west-east direction perpendicular to the centre of the rows in a single pass. The collected samples were weighed in a laboratory. The particle size distribution of each fertiliser type was found by sieving a sample collected at Longview's fertiliser storage shed.

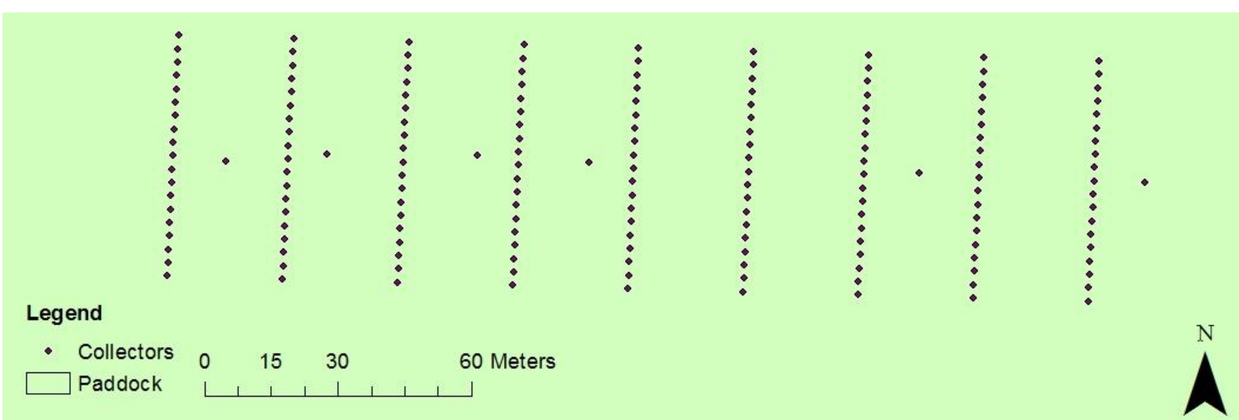

Figure 3: Validation trial set-up at Longview, Waitotara in May 2014.

Results and Discussion

Figure 4 and 5 shows the proof of release map for Limestone Downs and Longview, respectively. The map for Limestone Downs is based on over 4000 recorded GPS points and Longview's is based on 2500 points. The figures illustrate the capability of the DRAT system to recognise the treatment separation boundary and adjust the application rate accordingly.

Figure 6 and 7 are plots of the predicted kriged values against the aircraft application rate values. There are two distinct zones, which represent the low and high application zones. Most points are well predicted as they lie on the 1:1 line. The points that deviate from a 1:1 relationship are where the predicted values are close to the treatment separation boundary. The kriged maps for Longview experienced greater deviation of prediction values near the treatment separation boundary because the boundaries were irregular.

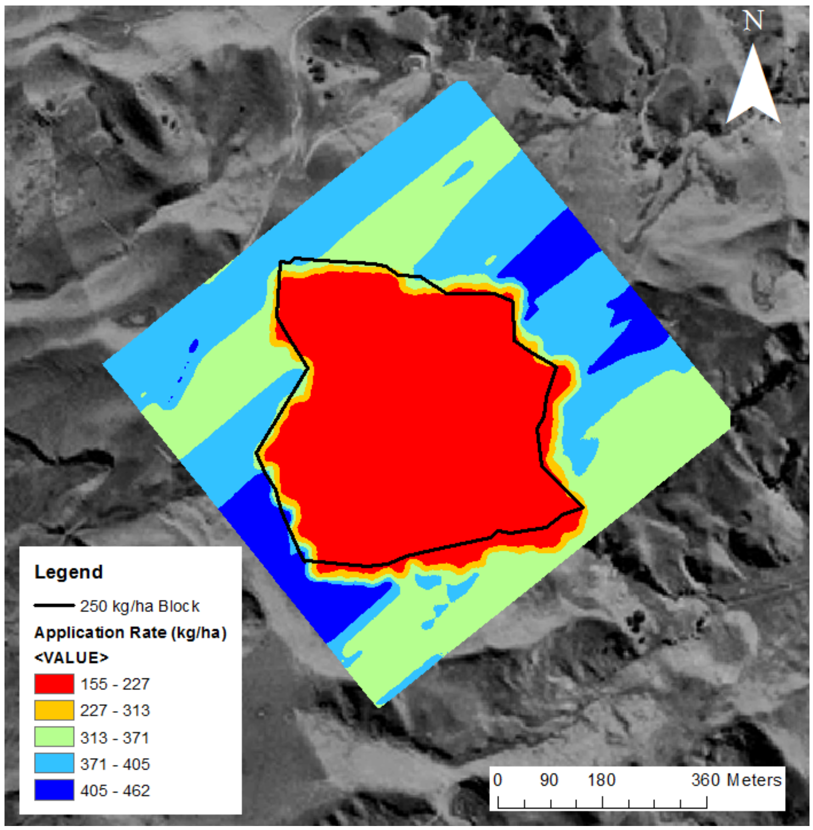

Figure 4: Proof of release map for Limestone Downs (February 2014) produced through kriging.

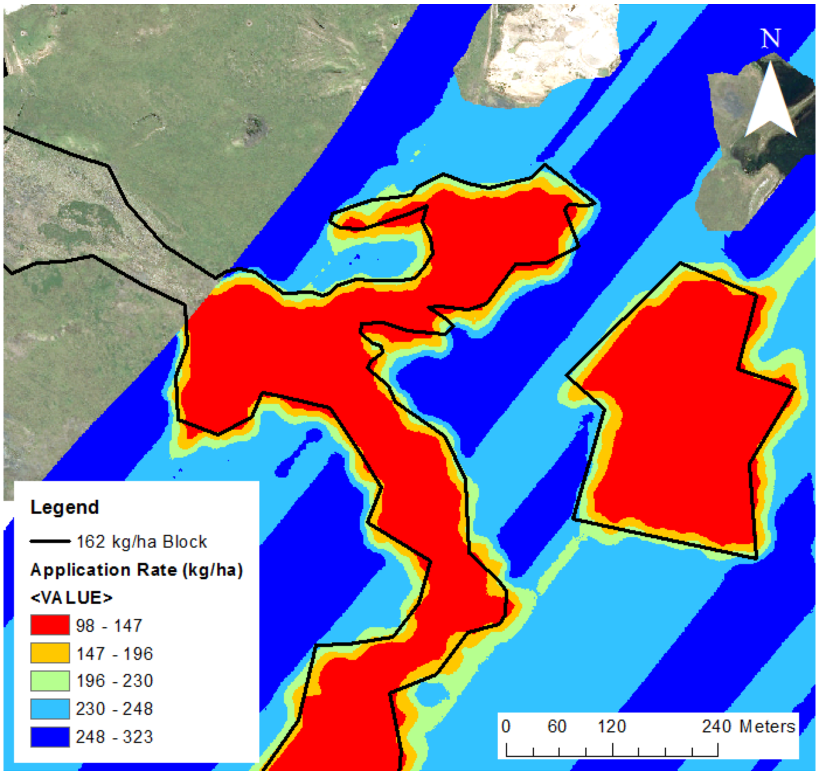

Figure 5: Proof of release map for Longview (May 2015).

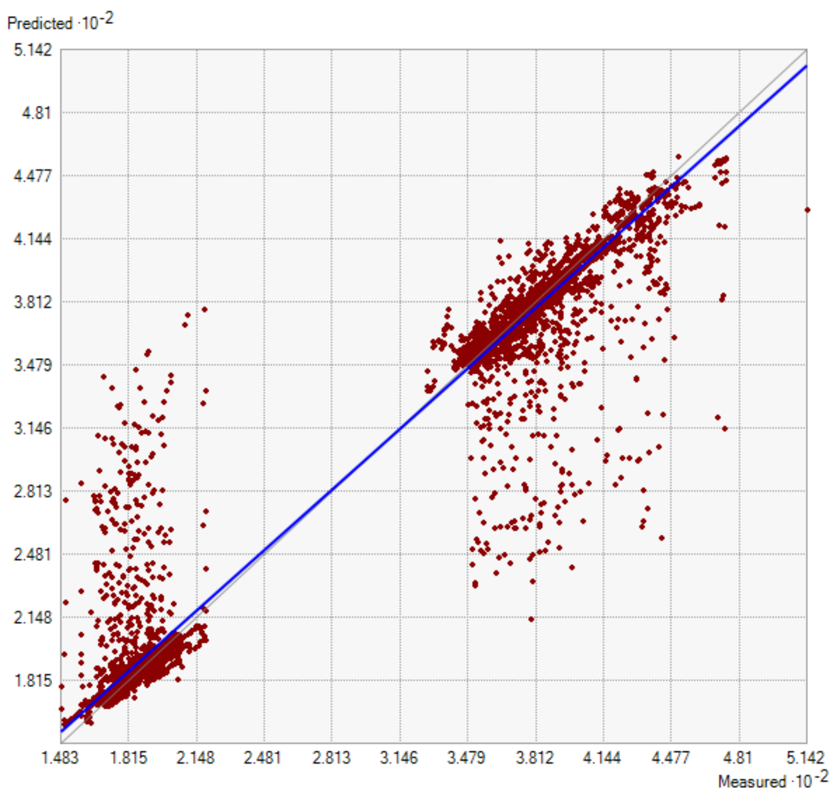

Figure 6: Comparison of predicted and measured aircraft application rate for Limestone Downs.

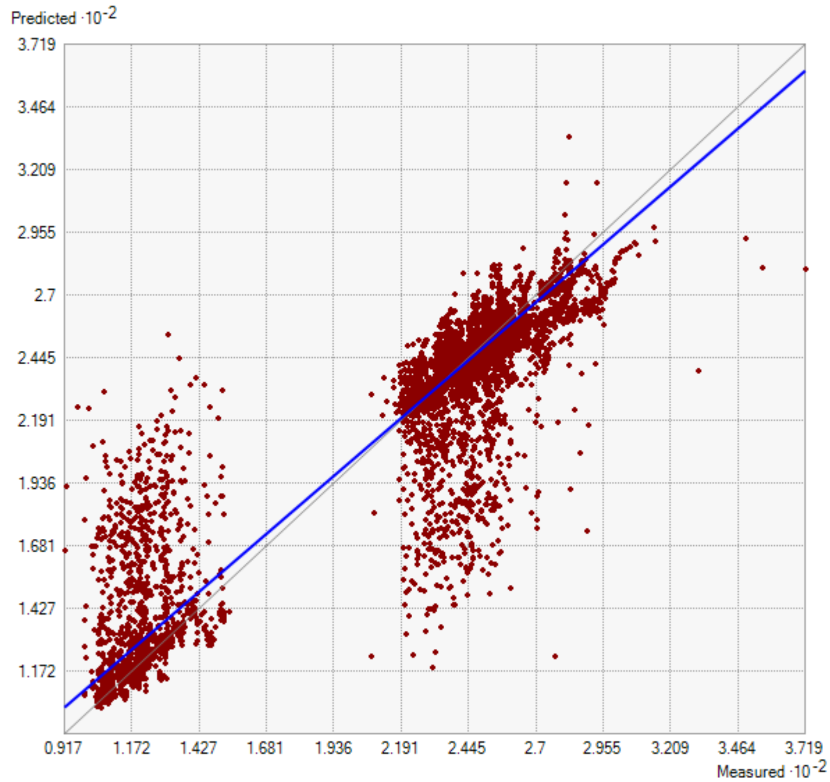

Figure 7: Comparison of predicted and measured aircraft application rate for Longview.

The ground data collected at the Limestone Downs and Longview trials showed that the average application rate found in the collectors was lower than the target application rate (Table 1). The field CV calculated was lower than if the hopper door was pilot operated.

Table 1: Summary statistics for Limestone Downs and Longview.

Farm	**Limestone Downs**		**Longview**	
Target application rate (kg/ha)	500	250	284	162
Average measured application rate (kg/ha)	308.0	203.4	198.4	120.3
Standard deviation (kg/ha)	174.4	103.0	68.8	63.8
Coefficient of variation (%)	56.6	50.6	34.7	53.0

The ballistics particle model formulated by Jones et al. (2008) could be used to account for the variability found in aerial topdressing. The results of the validation trial at Longview were modelled. There was good overlap between the model and trial results for the three fertiliser types (figure 8 – 10). Any differences between the model and trial distributions are due to poor characterisation of initial conditions.

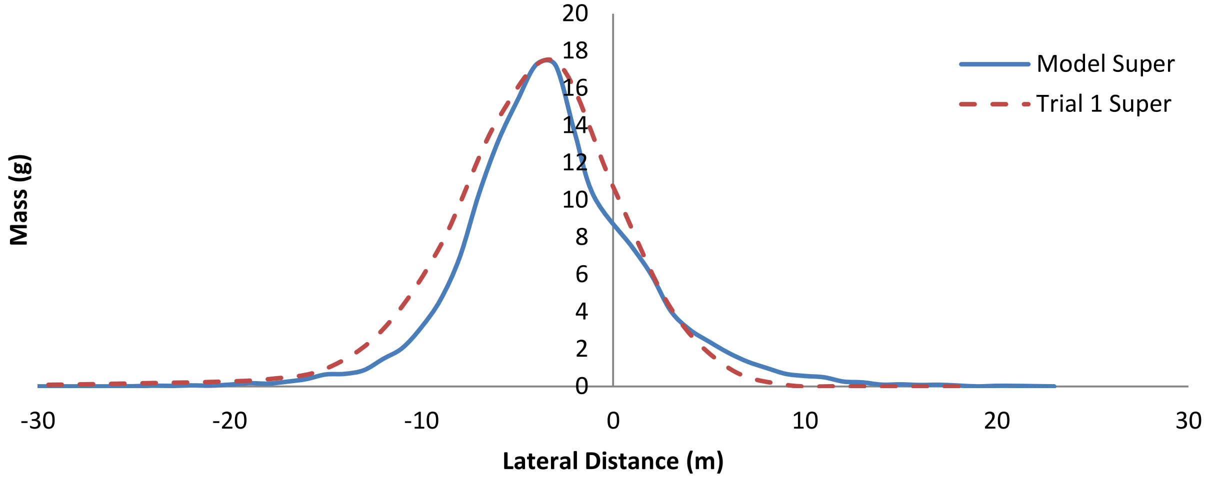

Figure 8: Comparison of trial and model transverse spread patterns for superphosphate.

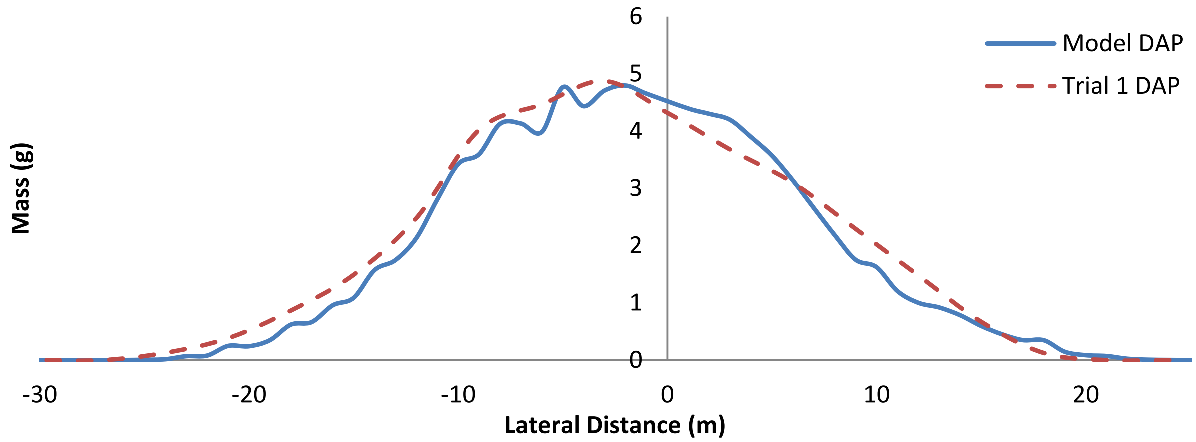

Figure 9: Comparison of trial and model transverse spread patterns for DAP. A Transland 11 duct spreader was used.

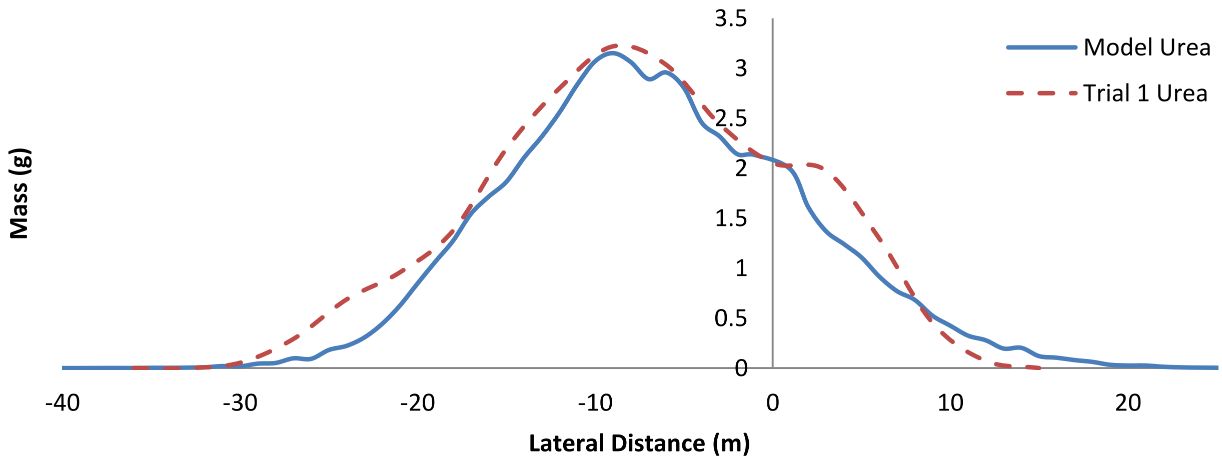

Figure 10: Comparison of trial and model transverse spread patterns urea. A Transland 11 duct spreader was used.

The ballistics model was also validated longitudinally. Particles were found to land 35 – 48 m ahead of where the aircraft hopper door closed. The ballistics model was able to predict similar distances.

Conclusion

Differential rate application technology can decrease the field CV of aerial spreading in New Zealand. The system is able to detect a treatment separation boundary and change the aircraft's hopper door opening when entering a different application rate area. However the field CV can be further improved if there was greater understanding of the variability in aerial spreading. Some variations can be attributed to wind conditions and aircraft speed. To account for these variations, a ballistics model was validated for superphosphate, urea and DAP.

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